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## 1 Basic

### 1.1 Run

```
1 #use -> sh run.sh {name}
2 g++ -O2 -std=c++14 -Wall -Wextra -Wshadow -o $1 $1.cpp
3 ./ $1 < t.in > t.out
```

### 1.2 Default

```
1 #include <bits/stdc++.h>
2 using namespace std;
3 using LL = long long;
4 #define IOS ios_base::sync_with_stdio(0); cin.tie(0);
5 #define pb push_back
6 #define eb emplace_back
7 const int INF = 1e9;
8 const int MOD = 1e9 + 7;
9 const double EPS = 1e-6;
10 const int MAXN = 0;
11
12 int main() {
13
14 }
```

### 1.3 Black Magic

```
1 #include <bits/stdc++.h>
2 #include <ext/pb_ds/assoc_container.hpp>
3 #include <ext/pb_ds/tree_policy.hpp>
4 #include <ext/pb_ds/priority_queue.hpp>
5 using namespace std;
6 using namespace __gnu_pbds;
7 using set_t =
8     tree<int, null_type, less<int>, rb_tree_tag,
9         tree_order_statistics_node_update>;
10 using map_t =
11     tree<int, int, less<int>, rb_tree_tag,
12         tree_order_statistics_node_update>;
13 using heap_t =
14     __gnu_pbds::priority_queue<int>;
15 using ht_t =
16     gp_hash_table<int, int>;
17 int main() {
18     //set-----
19     set_t st;
20     st.insert(5); st.insert(6);
21     st.insert(3); st.insert(1);
22
23     // the smallest is (0), biggest is (n-1), kth small
24     // is (k-1)
25     int num = *st.find_by_order(0);
26     cout << num << '\n'; // print 1
27
28     num = *st.find_by_order(st.size() - 1);
29     cout << num << '\n'; // print 6
30
31     // find the index
32     int index = st.order_of_key(6);
33     cout << index << '\n'; // print 3
34
35     // check if there exists x
36     int x = 5;
37     int check = st.erase(x);
38     if (check == 0) printf("st not contain 5\n");
39     else if (check == 1) printf("st contain 5\n");
40
41     //tree policy like set
42     st.insert(5); st.insert(5);
43     cout << st.size() << '\n'; // print 4
44
45     //map-----
46     map_t mp;
47     mp[1] = 2;
48     cout << mp[1] << '\n';
49     auto tmp = *mp.find_by_order(0); // pair
50     cout << tmp.first << " " << tmp.second << '\n';
51
52     //heap-----
53     heap_t h1, h2;
54     h1.push(1); h1.push(3);
55     h2.push(2); h2.push(4);
56     h1.join(h2);
57     cout << h1.size() << h2.size() << h1.top() << '\n';
58     // 404
59
60     //hash-table-----
61     ht_t ht;
62     ht[85] = 5;
63     ht[89975] = 234;
64     for (auto i : ht) {
65         cout << i.first << " " << i.second << '\n';
66     }
```

### 1.4 Binary Search

```
1 lower_bound(a, a + n, k); //最左邊 ≥ k 的位置
2 upper_bound(a, a + n, k); //最左邊 > k 的位置
3 upper_bound(a, a + n, k) - 1; //最右邊 ≤ k 的位置
```

```

4 lower_bound(a, a + n, k) - 1; //最右邊 < k 的位置
5 [lower_bound, upper_bound) //等於 k 的範圍
6 equal_range(a, a + n, k);

```

## 2 Data Structure

### 2.1 Disjoint Set

```

1 // 0-base
2 const int MAXN = 1000;
3 int boss[MAXN];
4 void init(int n) {
5     for (int i = 0; i < n; i++) {
6         boss[i] = -1;
7     }
8 }
9 int find(int x) {
10     if (boss[x] < 0) {
11         return x;
12     }
13     return boss[x] = find(boss[x]);
14 }
15 bool uni(int a, int b) {
16     a = find(a);
17     b = find(b);
18     if (a == b) {
19         return false;
20     }
21     if (boss[a] > boss[b]) {
22         swap(a, b);
23     }
24     boss[a] += boss[b];
25     boss[b] = a;
26     return true;
27 }

```

### 2.2 BIT RARSQ

```

1 // 1-base
2 #define lowbit(k) (k & -k)
3
4 int n;
5 vector<int> B1, B2;
6
7 void add(vector<int> &tr, int id, int val) {
8     for (; id <= n; id += lowbit(id)) {
9         tr[id] += val;
10    }
11 }
12 void range_add(int l, int r, int val) {
13     add(B1, l, val);
14     add(B1, r + 1, -val);
15     add(B2, l, val * (1 - 1));
16     add(B2, r + 1, -val * r);
17 }
18 int sum(vector<int> &tr, int id) {
19     int ret = 0;
20     for (; id >= 1; id -= lowbit(id)) {
21         ret += tr[id];
22     }
23     return ret;
24 }
25 int prefix_sum(int id) {
26     return sum(B1, id) * id - sum(B2, id);
27 }
28 int range_sum(int l, int r) {
29     return prefix_sum(r) - prefix_sum(l - 1);
30 }

```

### 2.3 zkw RMQ

```

1 // 0-base
2 const int INF = 1e9;
3 const int MAXN = ;
4
5 int n;
6 int a[MAXN], tr[MAXN << 1];
7
8 // !!! remember to call this function
9 void build() {
10     for (int i = 0; i < n; i++) {
11         tr[i + n] = a[i];
12     }
13     for (int i = n - 1; i > 0; i--) {
14         tr[i] = max(tr[i << 1], tr[i << 1 | 1]);
15     }
16 }
17 void update(int id, int val) {
18     for (tr[id += n] = val; id > 1; id >>= 1) {
19         tr[id >> 1] = max(tr[id], tr[id ^ 1]);
20     }
21 }
22 int query(int l, int r) { // [l, r)
23     int ret = -INF;
24     for (l += n, r += n; l < r; l >>= 1, r >>= 1) {
25         if (l & 1) {
26             ret = max(ret, tr[l++]);
27         }
28         if (r & 1) {
29             ret = max(ret, tr[--r]);
30         }
31     }
32     return ret;
33 }

```

## 3 Graph

### 3.1 Dijkstra

```

1 // 0-base
2 const LL INF = 1e18;
3 const int MAXN = ;
4 struct Edge {
5     int to;
6     LL cost;
7     Edge(int v, LL c) : to(v), cost(c) {}
8     bool operator < (const Edge &other) const {
9         return cost > other.cost;
10    }
11 };
12
13 int n;
14 LL dis[MAXN];
15 vector<Edge> G[MAXN];
16
17 void init() {
18     for (int i = 0; i < n; i++) {
19         G[i].clear();
20         dis[i] = INF;
21     }
22 }
23 void Dijkstra(int st, int ed = -1) {
24     priority_queue<Edge> pq;
25     pq.emplace(st, 0);
26     dis[st] = 0;
27     while (!pq.empty()) {
28         auto now = pq.top();
29         pq.pop();
30         if (now.to == ed) {
31             return;
32         }
33         if (now.cost > dis[now.to]) {
34             continue;
35         }
36     }
37 }

```

```

35     }
36     for (auto &e : G[now.to]) {
37         if (dis[e.to] > now.cost + e.cost) {
38             dis[e.to] = now.cost + e.cost;
39             pq.emplace(e.to, dis[e.to]);
40         }
41     }
42 }
43 }

```

### 3.2 SPFA(negative cycle)

```

1 // 0-base
2 const LL INF = 1e18;
3 const int MAXN = ;
4 struct Edge {
5     int to;
6     LL cost;
7     Edge(int v, LL c) : to(v), cost(c) {}
8 };
9
10 int n;
11 LL dis[MAXN];
12 vector<Edge> G[MAXN];
13
14 void init() {
15     for (int i = 0; i < n; i++) {
16         G[i].clear();
17         dis[i] = INF;
18     }
19 }
20 bool SPFA(int st) {
21     vector<int> cnt(n, 0);
22     vector<bool> inq(n, false);
23     queue<int> q;
24
25     q.push(st);
26     dis[st] = 0;
27     inq[st] = true;
28     while (!q.empty()) {
29         int now = q.front();
30         q.pop();
31         inq[now] = false;
32         for (auto &e : G[now]) {
33             if (dis[e.to] > dis[now] + e.cost) {
34                 dis[e.to] = dis[now] + e.cost;
35                 if (!inq[e.to]) {
36                     cnt[e.to]++;
37                     if (cnt[e.to] > n) {
38                         // negative cycle
39                         return false;
40                     }
41                     inq[e.to] = true;
42                     q.push(e.to);
43                 }
44             }
45         }
46     }
47     return true;
48 }

```

### 3.3 Floyd Warshall

```

1 // 0-base
2 // G[i][i] < 0 -> negative cycle
3 const LL INF = 1e18;
4 const int MAXN = ;
5
6 int n;
7 LL G[MAXN][MAXN];
8
9 void init() {
10     for (int i = 0; i < n; i++) {

```

```

11         for (int j = 0; j < n; j++) {
12             G[i][j] = INF;
13         }
14         G[i][i] = 0;
15     }
16 }
17 void floyd() {
18     for (int k = 0; k < n; k++) {
19         for (int i = 0; i < n; i++) {
20             for (int j = 0; j < n; j++) {
21                 if (G[i][k] != INF && G[k][j] != INF) {
22                     G[i][j] = min(G[i][j], G[i][k] + G[k][j]);
23                 }
24             }
25         }
26     }
27 }

```

### 3.4 Topological Sort

```

1 // 0-base
2 // if ret.size < n -> cycle
3 int n;
4 vector<vector<int>> G;
5
6 vector<int> topoSort() {
7     vector<int> indeg(n), ret;
8     for (auto &li : G) {
9         for (int x : li) {
10             ++indeg[x];
11         }
12     }
13     // use priority queue for lexic. largest ans
14     queue<int> q;
15     for (int i = 0; i < n; i++) {
16         if (!indeg[i]) {
17             q.push(i);
18         }
19     }
20     while (!q.empty()) {
21         int u = q.front();
22         q.pop();
23         ret.pb(u);
24         for (int v : G[u]) {
25             if (--indeg[v] == 0) {
26                 q.push(v);
27             }
28         }
29     }
30     return ret;
31 }

```

### 3.5 Kosaraju SCC

```

1 // 0-base
2 int n;
3 vector<vector<int>> G, G2; // G2 = G rev
4 vector<bool> vis;
5 vector<int> s, color;
6 int sccCnt;
7 void dfs1(int u) {
8     vis[u] = true;
9     for (int v : G[u]) {
10         if (!vis[v]) {
11             dfs1(v);
12         }
13     }
14     s.pb(u);
15 }
16 void dfs2(int u) {
17     color[u] = sccCnt;
18     for (int v : G2[u]) {
19         if (!color[v]) {

```

```

20     dfs2(v);
21 }
22 }
23 }
24 void Kosaraju() {
25     sccCnt = 0;
26     for (int i = 0; i < n; i++) {
27         if (!vis[i]) {
28             dfs1(i);
29         }
30     }
31     for (int i = n - 1; i >= 0; i--) {
32         if (!color[s[i]]) {
33             ++sccCnt;
34             dfs2(s[i]);
35         }
36     }
37 }

```

### 3.6 Tree Diameter

```

1 // 0-base;
2 const int MAXN = ;
3
4 struct Edge {
5     int to;
6     int cost;
7     Edge(int v, int c) : to(v), cost(c) {}
8 };
9
10 int n, d = 0;
11 int d1[MAXN], d2[MAXN];
12 vector<Edge> G[MAXN];
13 // dfs(0, -1);
14 void dfs(int u, int from) {
15     d1[u] = d2[u] = 0;
16     for (auto e : G[u]) {
17         if (e.to == from) {
18             continue;
19         }
20         dfs(e.to, u);
21         int t = d1[e.to] + e.cost;
22         if (t > d1[u]) {
23             d2[u] = d1[u];
24             d1[u] = t;
25         } else if (t > d2[u]) {
26             d2[u] = t;
27         }
28     }
29     d = max(d, d1[u] + d2[u]);
30 }

```

### 3.7 Directed MST

```

1 // 0-base
2 const LL INF = 1e18;
3 const int MAXN = ;
4
5 struct Edge {
6     int from;
7     int to;
8     LL cost;
9     Edge(int u, int v, LL c) : from(u), to(v), cost(c) {}
10 };
11
12 struct DMST {
13     int n;
14     int vis[MAXN], pre[MAXN], id[MAXN];
15     LL in[MAXN];
16     vector<Edge> edges;
17     void init(int _n) {
18         n = _n;

```

```

19     edges.clear();
20 }
21 void add_edge(int from, int to, LL cost) {
22     edges.eb(from, to, cost);
23 }
24 LL run(int root) {
25     LL ret = 0;
26     while (true) {
27         for (int i = 0; i < n; i++) {
28             in[i] = INF;
29         }
30
31         // find in edge
32         for (auto &e : edges) {
33             if (e.cost < in[e.to] && e.from != e.to) {
34                 pre[e.to] = e.from;
35                 in[e.to] = e.cost;
36             }
37         }
38
39         // check in edge
40         for (int i = 0; i < n; i++) {
41             if (i == root) {
42                 continue;
43             }
44             if (in[i] == INF) {
45                 return -1;
46             }
47         }
48
49         int nodedum = 0;
50         memset(id, -1, sizeof(id));
51         memset(vis, -1, sizeof(vis));
52         in[root] = 0;
53
54         // find cycles
55         for (int i = 0; i < n; i++) {
56             ret += in[i];
57             int v = i;
58             while (vis[v] != i && id[v] == -1 && v != root) {
59                 vis[v] = i;
60                 v = pre[v];
61             }
62             if (id[v] == -1 && v != root) {
63                 for (int j = pre[v]; j != v; j = pre[j]) {
64                     id[j] = nodedum;
65                 }
66                 id[v] = nodedum++;
67             }
68         }
69
70         // no cycle
71         if (nodedum == 0) {
72             break;
73         }
74
75         for (int i = 0; i < n; i++) {
76             if (id[i] == -1) {
77                 id[i] = nodedum++;
78             }
79         }
80
81         // grouping the vertices
82         for (auto &e : edges) {
83             int to = e.to;
84             e.from = id[e.from];
85             e.to = id[e.to];
86             if (e.from != e.to) {
87                 e.cost -= in[to]; //!!!
88             }
89         }
90
91         n = nodedum;
92         root = id[root];
93     }
94     return ret;

```

```
95 }
96 };
```

## 4 Flow & Matching

### 4.1 Relation

```
1 | 1. 一般圖
2 | |最大匹配| + |最小邊覆蓋| = |V|
3 | |最大獨立集| + |最小點覆蓋| = |V|
4 | |最大圖| = |補圖的最大獨立集|
5 | 2. 二分圖
6 | |最大匹配| = |最小點覆蓋|
7 | |最大獨立集| = |最小邊覆蓋|
8 | |最大獨立集| = |V| - |最大匹配|
9 | |最大圖| = |補圖的最大獨立集|
```

### 4.2 Bipartite Matching

```
1 // 0-base
2 const int MAXN = ;
3 int n;
4 vector<int> G[MAXN];
5 int vy[MAXN], my[MAXN];
6
7 bool match(int u) {
8     for (int v : G[u]) {
9         if (vy[v]) {
10             continue;
11         }
12         vy[v] = true;
13         if (my[v] == -1 || match(my[v])) {
14             my[v] = u;
15             return true;
16         }
17     }
18     return false;
19 }
20 int sol() {
21     int cnt = 0;
22     memset(my, -1, sizeof(my));
23     for (int i = 0; i < n; i++) {
24         memset(vy, 0, sizeof(vy));
25         if (match(i)) {
26             cnt++;
27         }
28     }
29     return cnt;
30 }
```

### 4.3 KM

```
1 const int INF = 1e9;
2 const int MAXN = ;
3 struct KM { //1-base
4     int n, G[MAXN][MAXN];
5     int lx[MAXN], ly[MAXN], my[MAXN];
6     bool vx[MAXN], vy[MAXN];
7     void init(int _n) {
8         n = _n;
9         for (int i = 1; i <= n; i++) {
10             for (int j = 1; j <= n; j++) {
11                 G[i][j] = 0;
12             }
13         }
14     }
15     bool match(int i) {
16         vx[i] = true;
17         for (int j = 1; j <= n; j++) {
```

```
18         if (lx[i] + ly[j] == G[i][j] && !vy[j]) {
19             vy[j] = true;
20             if (!my[j] || match(my[j])) {
21                 my[j] = i;
22                 return true;
23             }
24         }
25     }
26     return false;
27 }
28 void update() {
29     int delta = INF;
30     for (int i = 1; i <= n; i++) {
31         if (vx[i]) {
32             for (int j = 1; j <= n; j++) {
33                 if (!vy[j]) {
34                     delta = min(delta, lx[i] + ly[j] -
35                                 G[i][j]);
36                 }
37             }
38         }
39     }
40     for (int i = 1; i <= n; i++) {
41         if (vx[i]) {
42             lx[i] -= delta;
43         }
44         if (vy[i]) {
45             ly[i] += delta;
46         }
47     }
48 }
49 int run() {
50     for (int i = 1; i <= n; i++) {
51         lx[i] = ly[i] = my[i] = 0;
52         for (int j = 1; j <= n; j++) {
53             lx[i] = max(lx[i], G[i][j]);
54         }
55     }
56     for (int i = 1; i <= n; i++) {
57         while (true) {
58             for (int i = 1; i <= n; i++) {
59                 vx[i] = vy[i] = 0;
60             }
61             if (match(i)) {
62                 break;
63             } else {
64                 update();
65             }
66         }
67     }
68     int ans = 0;
69     for (int i = 1; i <= n; i++) {
70         ans += lx[i] + ly[i];
71     }
72     return ans;
73 };
```

### 4.4 Dinic

```
1 #define eb emplace_back
2 const LL INF = 1e18;
3 const int MAXN = ;
4 struct Edge {
5     int to;
6     LL cap;
7     int rev;
8     Edge(int v, LL c, int r) : to(v), cap(c), rev(r) {}
9 };
10 struct Dinic {
11     int n;
12     int level[MAXN], now[MAXN];
13     vector<Edge> G[MAXN];
14     void init(int _n) {
15         n = _n;
16         for (int i = 0; i <= n; i++) {
```

```

17     G[i].clear();
18 }
19 }
20 void add_edge(int u, int v, LL c) {
21     G[u].eb(v, c, G[v].size());
22     // directed graph
23     G[v].eb(u, 0, G[u].size() - 1);
24     // undirected graph
25     // G[v].eb(u, c, G[u].size() - 1);
26 }
27 bool bfs(int st, int ed) {
28     fill(level, level + n + 1, -1);
29     queue<int> q;
30     q.push(st);
31     level[st] = 0;
32     while (!q.empty()) {
33         int u = q.front();
34         q.pop();
35         for (const auto &e : G[u]) {
36             if (e.cap > 0 && level[e.to] == -1) {
37                 level[e.to] = level[u] + 1;
38                 q.push(e.to);
39             }
40         }
41     }
42     return level[ed] != -1;
43 }
44 LL dfs(int u, int ed, LL limit) {
45     if (u == ed) {
46         return limit;
47     }
48     LL ret = 0;
49     for (int &i = now[u]; i < G[u].size(); i++) {
50         auto &e = G[u][i];
51         if (e.cap > 0 && level[e.to] == level[u] + 1) {
52             LL f = dfs(e.to, ed, min(limit, e.cap));
53             ret += f;
54             limit -= f;
55             e.cap -= f;
56             G[e.to][e.rev].cap += f;
57             if (!limit) {
58                 return ret;
59             }
60         }
61     }
62     if (!ret) {
63         level[u] = -1;
64     }
65     return ret;
66 }
67 LL flow(int st, int ed) {
68     LL ret = 0;
69     while (bfs(st, ed)) {
70         fill(now, now + n + 1, 0);
71         ret += dfs(st, ed, INF);
72     }
73     return ret;
74 }
75 };

```

## 4.5 MCMF

```

1 // 0-base
2 const LL INF = 1e18;
3 const int MAXN = ;
4 struct Edge {
5     int u, v;
6     LL cost;
7     LL cap;
8     Edge(int _u, int _v, LL _c, LL _cap) : u(_u),
9         v(_v), cost(_c), cap(_cap) {}
10 };
11 struct MCMF { // inq times
12     int n, pre[MAXN], cnt[MAXN];
13     LL ans_flow, ans_cost, dis[MAXN];
14     bool inq[MAXN];

```

```

14     vector<int> G[MAXN];
15     vector<Edge> edges;
16     void init(int _n) {
17         n = _n;
18         edges.clear();
19         for (int i = 0; i < n; i++) {
20             G[i].clear();
21         }
22     }
23     void add_edge(int u, int v, LL c, LL cap) {
24         // directed
25         G[u].pb(edges.size());
26         edges.eb(u, v, c, cap);
27         G[v].pb(edges.size());
28         edges.eb(v, u, -c, 0);
29     }
30     bool SPFA(int st, int ed) {
31         for (int i = 0; i < n; i++) {
32             pre[i] = -1;
33             dis[i] = INF;
34             cnt[i] = 0;
35             inq[i] = false;
36         }
37         queue<int> q;
38         bool negcycle = false;
39
40         dis[st] = 0;
41         cnt[st] = 1;
42         inq[st] = true;
43         q.push(st);
44
45         while (!q.empty() && !negcycle) {
46             int u = q.front();
47             q.pop();
48             inq[u] = false;
49             for (int i : G[u]) {
50                 int v = edges[i].v;
51                 LL cost = edges[i].cost;
52                 LL cap = edges[i].cap;
53
54                 if (dis[v] > dis[u] + cost && cap > 0) {
55                     dis[v] = dis[u] + cost;
56                     pre[v] = i;
57                     if (!inq[v]) {
58                         q.push(v);
59                         cnt[v]++;
60                         inq[v] = true;
61
62                         if (cnt[v] == n + 2) {
63                             negcycle = true;
64                             break;
65                         }
66                     }
67                 }
68             }
69         }
70
71         return dis[ed] != INF;
72     }
73     LL sendFlow(int v, LL curFlow) {
74         if (pre[v] == -1) {
75             return curFlow;
76         }
77         int i = pre[v];
78         int u = edges[i].u;
79         LL cost = edges[i].cost;
80
81         LL f = sendFlow(u, min(curFlow, edges[i].cap));
82
83         ans_cost += f * cost;
84         edges[i].cap -= f;
85         edges[i ^ 1].cap += f;
86         return f;
87     }
88     pair<LL, LL> run(int st, int ed) {
89         ans_flow = ans_cost = 0;
90         while (SPFA(st, ed)) {

```

```

91     ans_flow += sendFlow(ed, INF);
92 }
93 return make_pair(ans_flow, ans_cost);
94 }
95 };

```

## 5 String

### 5.1 Manacher

```

1 int p[2 * MAXN];
2 int Manacher(const string &s) {
3     string st = "@#";
4     for (char c : s) {
5         st += c;
6         st += '#';
7     }
8     st += '$';
9     int id = 0, mx = 0, ans = 0;
10    for (int i = 1; i < st.length() - 1; i++) {
11        p[i] = (mx > i ? min(p[2 * id - i], mx - i) : 1);
12        for (; st[i - p[i]] == st[i + p[i]]; p[i]++);
13        if (mx < i + p[i]) {
14            mx = i + p[i];
15            id = i;
16        }
17        ans = max(ans, p[i] - 1);
18    }
19    return ans;
20 }

```

### 5.2 Trie

```

1 const int MAXL = ;
2 const int MAXC = ;
3 struct Trie {
4     int nex[MAXL][MAXC];
5     int len[MAXL];
6     int sz;
7     void init() {
8         memset(nex, 0, sizeof(nex));
9         memset(len, 0, sizeof(len));
10        sz = 0;
11    }
12    void insert(const string &str) {
13        int p = 0;
14        for (char c : str) {
15            int id = c - 'a';
16            if (!nex[p][id]) {
17                nex[p][id] = ++sz;
18            }
19            p = nex[p][id];
20        }
21        len[p] = str.length();
22    }
23    vector<int> find(const string &str, int i) {
24        int p = 0;
25        vector<int> ans;
26        for (; i < str.length(); i++) {
27            int id = str[i] - 'a';
28            if (!nex[p][id]) {
29                return ans;
30            }
31            p = nex[p][id];
32            if (len[p]) {
33                ans.pb(len[p]);
34            }
35        }
36        return ans;
37    }
38 };

```

### 5.3 Z-value

```

1 // 0-base
2 // 對於個長度為 n 的字串 s
3 // 定義函數 z[i] 表示 s 和 s[i, n - 1]
4 // (即以 s[i] 開頭的後綴) 的最長公共前綴 (LCP) 的長度
5 // z[0] = 0
6 vector<int> z_function(string s) {
7     int n = (int)s.length();
8     vector<int> z(n);
9     for (int i = 1, l = 0, r = 0; i < n; ++i) {
10        if (i <= r && z[i - l] < r - i + 1) {
11            z[i] = z[i - l];
12        } else {
13            z[i] = max(0, r - i + 1);
14            while (i + z[i] < n && s[z[i]] == s[i + z[i]])
15                ++z[i];
16            if (i + z[i] - 1 > r) l = i, r = i + z[i] - 1;
17        }
18    }
19    return z;
20 }

```

## 6 DP

### 6.1 LIS

```

1 int LIS(vector<int> &a) {
2     vector<int> s;
3     for (int i = 0; i < a.size(); i++) {
4         if (s.empty() || s.back() < a[i]) {
5             s.push_back(a[i]);
6         } else {
7             *lower_bound(s.begin(), s.end(), a[i],
8                 [](int x, int y) {return x < y;}) = a[i];
9         }
10    }
11    return s.size();
12 }

```

### 6.2 LCS

```

1 int LCS(string s1, string s2) {
2     int n1 = s1.size(), n2 = s2.size();
3     vector<vector<int>> dp(n1 + 1, vector<int>(n2 + 1,
4         0));
5     for (int i = 1; i <= n1; i++) {
6         for (int j = 1; j <= n2; j++) {
7             if (s1[i - 1] == s2[j - 1]) {
8                 dp[i][j] = dp[i - 1][j - 1] + 1;
9             } else {
10                dp[i][j] = max(dp[i - 1][j], dp[i][j - 1]);
11            }
12        }
13    }
14    return dp[n1][n2];
15 }

```

## 7 Math

### 7.1 Extended GCD

```

1 // ax + by = c
2 int extgcd(int a, int b, int c, int &x, int &y) {
3     if (b == 0) {
4         x = c / a;
5         y = 0;
6         return a;
7     }
8 }

```

```

7   }
8   int d = extgcd(b, a % b, c, y, x);
9   y -= (a / b) * x;
10  return d;
11 }

```

## 7.2 Gaussian Elimination

```

1  const double EPS = 1e-6;
2  double Gauss(vector<vector<double>> &d) {
3      int n = d.size(), m = d[0].size();
4      double det = 1;
5      for (int i = 0; i < m; i++) {
6          int p = -1;
7          for (int j = i; j < n; j++) {
8              if (fabs(d[j][i]) < EPS) {
9                  continue;
10             }
11             if (p == -1 || fabs(d[j][i]) > fabs(d[p][i])) {
12                 p = j;
13             }
14         }
15         if (p == -1) {
16             continue;
17         }
18         if (p != i) {
19             det *= -1;
20         }
21         for (int j = 0; j < m; j++) {
22             swap(d[p][j], d[i][j]);
23         }
24         for (int j = 0; j < n; j++) {
25             if (i == j) {
26                 continue;
27             }
28             double z = d[j][i] / d[i][i];
29             for (int k = 0; k < m; k++) {
30                 d[j][k] -= z * d[i][k];
31             }
32         }
33     }
34     for (int i = 0; i < n; i++) {
35         det *= d[i][i];
36     }
37     return det;
38 }

```

## 7.3 Prime Table

```

1  vector<int> p;
2  bitset<MAXN> is_notp;
3  void PrimeTable(int n) {
4      is_notp.reset();
5      is_notp[0] = is_notp[1] = 1;
6      for (int i = 2; i <= n; ++i) {
7          if (!is_notp[i]) {
8              p.push_back(i);
9          }
10         for (int j = 0; j < (int)p.size(); ++j) {
11             if (i * p[j] > n) {
12                 break;
13             }
14             is_notp[i * p[j]] = 1;
15             if (i % p[j] == 0) {
16                 break;
17             }
18         }
19     }
20 }

```

## 7.4 Phi Table

• 歐拉函數計算對於一個整數  $N$ ，小於等於  $N$  的正整數中，有幾個和  $N$  互質

• 如果  $\gcd(p, q) = 1, \Phi(p) \cdot \Phi(q) = \Phi(p \cdot q)$

•  $\Phi(p^k) = p^{k-1} \times (p - 1)$

```

1  void phi_table(int n) {
2      phi[1] = 1;
3      for (int i = 2; i <= n; i++) {
4          if (phi[i]) {
5              continue;
6          }
7          for (int j = i; j < n; j += i) {
8              if (!phi[j]) {
9                  phi[j] = j;
10             }
11             phi[j] = phi[j] / i * (i - 1);
12         }
13     }
14 }

```

## 7.5 Chinese Remainder Thm

```

1  //参数可为负数的扩展欧几里德定理
2  void exOJLD(int a, int b, int& x, int& y) {
3      //根据欧几里德定理
4      if (b == 0) { //任意数与0的最大公约数为其本身。
5          x = 1;
6          y = 0;
7      } else {
8          int x1, y1;
9          exOJLD(b, a % b, x1, y1);
10         if (a * b < 0) { //异号取反
11             x = -x1;
12             y = a / b * y1 - x1;
13         } else { //同号
14             x = y1;
15             y = x1 - a / b * y1;
16         }
17     }
18 }

```

//剩余定理

```

19 int calSYDL(int a[], int m[], int k) {
20     int N[k]; //这个可以删除
21     int mm = 1; //最小公倍数
22     int result = 0;
23     for (int i = 0; i < k; i++) {
24         mm *= m[i];
25     }
26     for (int j = 0; j < k; j++) {
27         int L, J;
28         exOJLD(mm / m[j], -m[j], L, J);
29         N[j] = m[j] * J + 1; // 1
30         N[j] = mm / m[j] * L; // 2
31         //1和2这两个值应该是相等的。
32         result += N[j] * a[j];
33     }
34     return (result % mm + mm) % mm;
35     //落在(0,
36     //mm)之间，这么写是为了防止result初始为负数，本例中不可能为
37     //写成：return result%mm;即可。
38 }

```

```

39 int main() {
40     int a[3] = {2, 3, 6}; // a[i]=n%m[i]
41     int m[3] = {3, 5, 7};
42     cout << calSYDL(a, m, 3) << endl;
43     //輸出為滿足兩條陣列的最小n,第3參數為陣列長度
44     //所有滿足答案的數字集合為n+gcd(m0,m1,m2...)*k,
45     //k為正數
46     return 0;
47 }

```



## 7.6 Josephus

```
1 int josephus(int n, int k) { //
    有n個人圍成一圈,每k個一次
2     return n > 1 ? (josephus(n - 1, k) + k) % n : 0;
3 } // 回傳最後一人的編號, 0 index
```

## 8 Geometry

### 8.1 Point

```
1 // notice point type!!!
2 using dvt = int;
3 const double EPS = 1e-6;
4 const double PI = acos(-1);
5
6 struct Pt {
7     dvt x;
8     dvt y;
9 };
10 bool operator < (const Pt &a, const Pt &b) {
11     return a.x == b.x ? a.y < b.y : a.x < b.x;
12 }
13 bool operator == (const Pt &a, const Pt &b) {
14     return a.x == b.x && a.y == b.y;
15 }
16 Pt operator + (const Pt &a, const Pt &b) {
17     return {a.x + b.x, a.y + b.y};
18 }
19 Pt operator - (const Pt &a, const Pt &b) {
20     return {a.x - b.x, a.y - b.y};
21 }
22 // multiply constant
23 Pt operator * (const Pt &a, const dvt c) {
24     return {a.x * c, a.y * c};
25 }
26 Pt operator / (const Pt &a, const dvt c) {
27     return {a.x / c, a.y / c};
28 }
29 // |a| x |b| x cos(x)
30 dvt iproduct(const Pt &a, const Pt &b) {
31     return a.x * b.x + a.y * b.y;
32 }
33 // |a| x |b| x sin(x)
34 dvt cross(const Pt &a, const Pt &b) {
35     return a.x * b.y - a.y * b.x;
36 }
37 dvt dis_pp(const Pt &a, const Pt &b) {
38     dvt dx = a.x - b.x;
39     dvt dy = a.y - b.y;
40     return sqrt(dx * dx + dy * dy);
41 }
```

### 8.2 Line

```
1 struct Line {
2     Pt st;
3     Pt ed;
4 };
5 // return point side
6 // left, on line, right -> 1, 0, -1
7 int side(Line l, Pt a) {
8     dvt cross_val = cross(a - l.st, l.ed - l.st);
9     if (cross_val > EPS) {
10         return 1;
11     } else if (cross_val < -EPS) {
12         return -1;
13     } else {
14         return 0;
15     }
16 }
```

```
17 // AB infinity, CD segment
18 bool has_intersection(Line AB, Line CD) {
19     int c = side(AB, CD.st);
20     int d = side(AB, CD.ed);
21     if (c == 0 || d == 0) {
22         return true;
23     } else {
24         // different side
25         return c == -d;
26     }
27 }
28 // find intersection point, two line, not seg
29 pair<int, Pt> intersection(Line a, Line b) {
30     Pt A = a.ed - a.st;
31     Pt B = b.ed - b.st;
32     Pt C = b.st - a.st;
33     dvt mom = cross(A, B);
34     dvt son = cross(C, B);
35     if (std::abs(mom) <= EPS) {
36         if (std::abs(son) <= EPS) {
37             return {1, {}}; // same line
38         } else {
39             return {2, {}}; // parallel
40         }
41     } else {
42         // ok
43         return {0, a.st + A * (son / mom)};
44     }
45 // line to point distance
46 dvt dis_lp(Line l, Pt a) {
47     return area3x2(l.st, l.ed, a) / dis_pp(l.st, l.ed);
48 }
```

$$d(P, L) = \frac{|ax_0 + by_0 + c|}{\sqrt{a^2 + b^2}}$$

### 8.3 Area

```
1 // triangle
2 dvt area3(Pt a, Pt b, Pt c) {
3     return std::abs(cross(b - a, c - a) / 2);
4 }
5 dvt area3x2(Pt a, Pt b, Pt c) { // for integer
6     return std::abs(cross(b - a, c - a));
7 }
8 // simple convex area(can in)
9 dvt area(vector<Pt> &a) {
10     dvt ret = 0;
11     for (int i = 0, sz = a.size(); i < sz; i++) {
12         ret += cross(a[i], a[(i + 1) % sz]);
13     }
14     return std::abs(ret) / 2;
15 }
16 // check point in/out a convex
17 int io_convex(vector<Pt> convex, Pt q) {
18     // convex is Counterclockwise
19     for (int i = 0, sz = convex.size(); i < sz; i++) {
20         Pt cur = convex[i] - q;
21         Pt nex = convex[(i + 1) % sz] - q;
22         dvt cross_val = cross(cur, nex);
23         if (std::abs(cross_val) <= EPS) {
24             return 0; // on edge
25         }
26         if (cross_val < 0) {
27             return -1; // outside
28         }
29     }
30     return 1; // inside
31 }
```

### 8.4 Convex Hull

```
1 vector<Pt> convex_hull(vector<Pt> &a) {
2     sort(a.begin(), a.end());
```

```
3 | a.erase(unique(a.begin(), a.end()), a.end());
4 | int sz = a.size(), m = 0;
5 | vector<Pt> ret(sz + 5); // safe 1 up
6 | for (int i = 0; i < sz; i++) {
7 |     while (m > 1 &&
8 |         cross(ret[m - 1] - ret[m - 2], a[i] - ret[m -
9 |             2]) <= EPS) {
10 |         m--;
11 |     }
12 |     ret[m++] = a[i];
13 | }
14 | int k = m;
15 | for (int i = sz - 2; i >= 0; i--) {
16 |     while (m > k &&
17 |         cross(ret[m - 1] - ret[m - 2], a[i] - ret[m -
18 |             2]) <= EPS) {
19 |         m--;
20 |     }
21 |     ret[m++] = a[i];
22 | }
23 | if (sz > 1) {
24 |     m--;
25 | }
26 | ret.resize(m);
27 | return ret;
28 | }
```