

ICPC MX 2025 Reference (Date 2 version)

Falsificamos el INE de Wicho

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1 C++ Functions

1.1 Common STL Algorithms

Sorting Algorithms

Function	Parameters	Description
sort	begin, end, [comp]	Standard unstable sort ($O(n \log n)$)
stable_sort	begin, end, [comp]	Stable sort preserves element order
is_sorted	begin, end, [comp]	Checks if range is sorted (returns bool)
nth_element	begin, nth, end, [comp]	Partitions around nth element

Searching Functions

Function	Parameters	Description
lower_bound	begin, end, val, [comp]	First element \leq value
upper_bound	begin, end, val, [comp]	First element $>$ value
binary_search	begin, end, val, [comp]	Existence check in sorted range
find	begin, end, val	Linear search for value
find_if	begin, end, pred	Find first matching predicate

Sequence Operations

Function	Parameters	Description
reverse	begin, end	Reverse elements in-place
rotate	begin, mid, end	Rotate elements left
next_permutation	begin, end	Generate next permutation
unique	begin, end, [pred]	Remove consecutive duplicates
remove	begin, end, val	Remove elements equal to value

Numerical Functions

Function	Parameters	Description
accumulate	begin, end, init, [op]	Sum/accumulate elements
partial_sum	begin, end, dest, [op]	Compute prefix sums
_gcd	a, b	Greatest common divisor (C++17)
lcm	a, b	Least common multiple (C++17)
iota	begin, end, val	Fill with consecutive values

Memory/Array Operations

Function	Parameters	Description
memset	ptr, value, count	Fill memory with byte value
fill	begin, end, value	Fill range with value
fill_n	begin, count, value	Fill N elements with value
copy	src_b, src_e, dest	Copy range to destination
copy_if	src_b, src_e, dest, pred	Copy elements matching predicate

Utility Functions

Function	Parameters	Description
swap	a, b	Swap two values
max_element	begin, end, [comp]	Find maximum element
min_element	begin, end, [comp]	Find minimum element
count	begin, end, val	Count element occurrences
all_of	begin, end, pred	Check all elements satisfy condition

2 Binary search in the answer

```

1 // Standard binary search (iterative)
2 int binary_search(vector<int>& arr, int target) {
3     int left = 0, right = arr.size() - 1;
4     while (left <= right) {
5         int mid = left + (right - left) / 2;
6         if (arr[mid] == target) return mid;
7         if (arr[mid] < target) left = mid + 1;
8         else right = mid - 1;
9     }
10    return -1;
11 }
12
13 // Lower bound (first element >= target)
14 int lower_bound(vector<int>& arr, int target) {
15     int left = 0, right = arr.size();
16     while (left < right) {
17         int mid = left + (right - left) / 2;
18         arr[mid] < target ? left = mid + 1
19                          : right = mid;
20     }
21    return left;
22 }
23
24 // Upper bound (first element > target)
25 int upper_bound(vector<int>& arr, int target) {

```

```

26     int left = 0, right = arr.size();
27     while (left < right) {
28         int mid = left + (right - left) / 2;
29         arr[mid] <= target ? left = mid + 1
30                             : right = mid;
31     }
32     return left;
33 }
34
35 // Binary search on real numbers (e.g. sqrt)
36 double sqrt_precision(double n, double eps=1e-6) {
37     double left = 0, right = n;
38     for (int i = 0; i < 100; ++i) { // or while (right-left >
39                                     eps)
39         double mid = (left + right) / 2;
40         if (mid*mid < n) left = mid;
41         else right = mid;
42     }
43     return left;
44 }
45
46 // Binary search on answer space (monotonic condition)
47 int find_min_valid(vector<int>& nums, int k) {
48     auto is_valid = [&](int x) {
49         /* condition check */
50     };
51
52     int left = 0, right = 1e9; // adjust bounds
53     while (left < right) {
54         int mid = left + (right - left) / 2;
55         is_valid(mid) ? right = mid
56                       : left = mid + 1;
57     }
58     return left;
59 }z

```

3 Data Structures

3.1 Fenwick Tree

```

1 struct FenwickTree {
2     vector<int> bit; // binary indexed tree
3     int n;
4
5     FenwickTree(int n) {
6         this->n = n;
7         bit.assign(n, 0);
8     }

```

```

9
10 FenwickTree(vector<int> const &a) : FenwickTree(a.size()){
11     for (int i = 0; i < n; i++) {
12         bit[i] += a[i];
13         int r = i | (i + 1);
14         if (r < n) bit[r] += bit[i];
15     }
16 }
17
18 FenwickTree(vector<int> const &a) : FenwickTree(a.size()) {
19     for (size_t i = 0; i < a.size(); i++)
20         add(i, a[i]);
21 }
22
23 int sum(int r) {
24     int ret = 0;
25     for (; r >= 0; r = (r & (r + 1)) - 1)
26         ret += bit[r];
27     return ret;
28 }
29
30 int sum(int l, int r) {
31     return sum(r) - sum(l - 1);
32 }
33
34 void add(int idx, int delta) {
35     for (; idx < n; idx = idx | (idx + 1))
36         bit[idx] += delta;
37 }
38 };

```

3.2 Fenwick Minimum

```

1 struct FenwickTreeMin {
2     vector<int> bit;
3     int n;
4     const int INF = (int)1e9;
5
6     FenwickTreeMin(int n) {
7         this->n = n;
8         bit.assign(n, INF);
9     }
10
11     FenwickTreeMin(vector<int> a) : FenwickTreeMin(a.size()) {
12         for (size_t i = 0; i < a.size(); i++)
13             update(i, a[i]);
14     }
15
16     int getmin(int r) {

```

```

17     int ret = INF;
18     for (; r >= 0; r = (r & (r + 1)) - 1)
19         ret = min(ret, bit[r]);
20     return ret;
21 }
22
23 void update(int idx, int val) {
24     for (; idx < n; idx = idx | (idx + 1))
25         bit[idx] = min(bit[idx], val);
26 }
27 };

```

3.3 1-Indexed Fenwick Tree

```

1 struct FenwickTreeOneBasedIndexing {
2     vector<int> bit; // binary indexed tree
3     int n;
4
5     FenwickTreeOneBasedIndexing(int n) {
6         this->n = n + 1;
7         bit.assign(n + 1, 0);
8     }
9
10    FenwickTreeOneBasedIndexing(vector<int> a)
11        : FenwickTreeOneBasedIndexing(a.size()) {
12        for (size_t i = 0; i < a.size(); i++)
13            add(i, a[i]);
14    }
15
16    int sum(int idx) {
17        int ret = 0;
18        for (++idx; idx > 0; idx -= idx & -idx)
19            ret += bit[idx];
20        return ret;
21    }
22
23    int sum(int l, int r) {
24        return sum(r) - sum(l - 1);
25    }
26
27    void add(int idx, int delta) {
28        for (++idx; idx < n; idx += idx & -idx)
29            bit[idx] += delta;
30    }
31 };

```

3.4 Fenwick 2D (Sum query)

```

1 struct Fenwick2D {
2     vector<vector<int>> tree;
3     int rows, cols;
4
5     Fenwick2D(int r, int c) : rows(r), cols(c),
6         tree(r + 1, vector<int>(c + 1)) {}
7
8     // Update: add delta to (x, y) (1-based)
9     void update(int x, int y, int delta) {
10         for(int i = x; i <= rows; i += lsb(i))
11             for(int j = y; j <= cols; j += lsb(j))
12                 tree[i][j] += delta;
13     }
14
15     // Query sum from (1,1) to (x,y)
16     int query(int x, int y) {
17         int sum = 0;
18         for(int i = x; i > 0; i -= lsb(i))
19             for(int j = y; j > 0; j -= lsb(j))
20                 sum += tree[i][j];
21         return sum;
22     }
23
24     // Range sum from (x1,y1) to (x2,y2)
25     int range_query(int x1, int y1, int x2, int y2) {
26         return query(x2, y2) - query(x1-1, y2)
27             - query(x2, y1-1) + query(x1-1, y1-1);
28     }
29
30     int lsb(int i) { return i & -i; }
31 };

```

3.5 Fenwick 2D (Counting in range)

```

1 struct Fenwick2DPerType {
2     int rows, cols;
3     unordered_map<int, Fenwick2D> trees; // Map from type to 2D
4                                         Fenwick Tree
5
6     Fenwick2DPerType(int r, int c) : rows(r), cols(c) {}
7
8     // Update: add 'delta' objects of type 't' at position (x, y)
9     void update(int t, int x, int y, int delta) {
10         if (trees.find(t) == trees.end()) {
11             trees[t] = Fenwick2D(rows, cols);
12         }
13         trees[t].update(x, y, delta);
14     }
15 };

```

```

15 // Query: count of type 't' in rectangle [x1,y1] to [x2,y2]
16 int query(int t, int x1, int y1, int x2, int y2) {
17     if (trees.find(t) == trees.end()) return 0;
18     return trees[t].range_query(x1, y1, x2, y2);
19 }
20 };
21
22 // Requires the base Fenwick2D implementation from previous answer
23 struct Fenwick2D {
24     vector<vector<int>> tree;
25     int rows, cols;
26
27     Fenwick2D(int r, int c) : rows(r), cols(c),
28         tree(r + 1, vector<int>(c + 1)) {}
29
30     void update(int x, int y, int delta) { /* same as before */ }
31
32     int query(int x, int y) { /* same as before */ }
33
34     int range_query(int x1, int y1, int x2, int y2) { /* same as
35         before */ }
36
37     int lsb(int i) { return i & -i; }
38 };

```

3.6 Fenwick Tree Range Update - Point Query

```

1 // Range Update - Point Query (1-based indexing)
2 struct FenwickRUQ {
3     int n;
4     std::vector<int> bit;
5
6     FenwickRUQ(int size) : n(size + 1), bit(size + 2) {}
7
8     // Add val to range [l, r] (1-based)
9     void range_add(int l, int r, int val) {
10         add(l, val);
11         add(r + 1, -val);
12     }
13
14     // Get value at position idx (1-based)
15     int point_query(int idx) {
16         int res = 0;
17         for(; idx > 0; idx -= idx & -idx)
18             res += bit[idx];
19         return res;
20     }
21
22 private:

```

```

23 void add(int idx, int val) {
24     for(; idx < n; idx += idx & -idx)
25         bit[idx] += val;
26 }
27 };

```

3.7 Fenwick Tree - Range update and query

```

1 // Range Update - Range Query (1-based indexing)
2 struct FenwickRURQ {
3     int n;
4     std::vector<int> B1, B2;
5
6     FenwickRURQ(int size) : n(size + 1), B1(size + 2), B2(size +
7         2) {}
8
9     // Add val to range [l, r] (1-based)
10    void range_add(int l, int r, int val) {
11        add(B1, l, val);
12        add(B1, r + 1, -val);
13        add(B2, l, val * (l - 1));
14        add(B2, r + 1, -val * r);
15    }
16
17    // Get sum of range [l, r] (1-based)
18    int range_sum(int l, int r) {
19        return prefix_sum(r) - prefix_sum(l - 1);
20    }
21
22 private:
23    void add(std::vector<int>& b, int idx, int val) {
24        for(; idx < n; idx += idx & -idx)
25            b[idx] += val;
26    }
27
28    int sum(const std::vector<int>& b, int idx) {
29        int total = 0;
30        for(; idx > 0; idx -= idx & -idx)
31            total += b[idx];
32        return total;
33    }
34
35    int prefix_sum(int idx) {
36        return sum(B1, idx) * idx - sum(B2, idx);
37    }
38 };

```


3.8 Segment Tree (Sum query)

```

1 ll t[4*MAX];
2
3 // Shout-out to CP algo for the SegTree implementation: https://cp
  -algorithms.com/data_structures/segment_tree.html#memory-
  efficient-implementation
4
5 void buildSegTree(vector<ll> &a, int v, int tl, int tr) {
6     if (tl == tr) {
7         t[v] = a[tl];
8     } else {
9         int tm = (tl + tr) / 2;
10        buildSegTree(a, v*2, tl, tm);
11        buildSegTree(a, v*2+1, tm+1, tr);
12        t[v] = t[v*2] + t[v*2+1];
13    }
14 }
15
16
17 ll sum(int v, int tl, int tr, int l, int r) {
18     if (l > r)
19         return 0;
20     if (l == tl && r == tr) {
21         return t[v];
22     }
23     int tm = (tl + tr) / 2;
24     return sum(v*2, tl, tm, l, min(r, tm))
25            + sum(v*2+1, tm+1, tr, max(l, tm+1), r);
26 }
27
28 void update(int v, int tl, int tr, int pos, ll new_val) {
29     if (tl == tr) {
30         t[v] = new_val;
31     } else {
32         int tm = (tl + tr) / 2;
33         if (pos <= tm)
34             update(v*2, tl, tm, pos, new_val);
35         else
36             update(v*2+1, tm+1, tr, pos, new_val);
37         t[v] = t[v*2] + t[v*2+1];
38     }
39 }

```

3.9 Segment Tree (Minimum query)

```

1 ll t[4*MAX];
2

```

```

3 // Shout-out to CP algo for the SegTree implementation: https://cp
  -algorithms.com/data_structures/segment_tree.html#memory-
  efficient-implementation
4
5 void buildSegTree(vector<ll> &a, int v, int tl, int tr) {
6     if (tl == tr) {
7         t[v] = a[tl];
8     } else {
9         int tm = (tl + tr) / 2;
10        buildSegTree(a, v*2, tl, tm);
11        buildSegTree(a, v*2+1, tm+1, tr);
12        t[v] = min(t[v*2], t[v*2+1]); // Change to minimum
13    }
14 }
15
16
17 ll query(int v, int tl, int tr, int l, int r) {
18     if (l > r)
19         return LLONG_MAX; // Return maximum possible value for
20                             empty range
21     if (l == tl && r == tr) {
22         return t[v];
23     }
24     int tm = (tl + tr) / 2;
25     return min(query(v*2, tl, tm, l, min(r, tm)),
26               query(v*2+1, tm+1, tr, max(l, tm+1), r));
27 }
28
29 void update(int v, int tl, int tr, int pos, ll new_val) {
30     if (tl == tr) {
31         t[v] = new_val;
32     } else {
33         int tm = (tl + tr) / 2;
34         if (pos <= tm)
35             update(v*2, tl, tm, pos, new_val);
36         else
37             update(v*2+1, tm+1, tr, pos, new_val);
38         t[v] = min(t[v*2], t[v*2+1]); // Change to minimum
39     }
40 }

```

3.10 Segment Tree Lazy Propagation

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 typedef vector<pair<int,int>> vpii;
4 const ll mod=1e9+7;
5 const int MAX=1e5+3;
6 const int limit=2e5+3;

```

```

7  const int TAM=2e5+1;
8  ll t[4*TAM];
9  ll op[4*TAM];
10 int type[4*TAM];
11 //ascii https://elcodigoascii.com.ar/
12
13 void propagate(int root,int l,int r)
14 {
15     if(type[root]==1)
16     {
17         t[root]+=op[root]*(r+1-l);
18         if(l!=r){
19             op[2*root]+=op[root];
20             op[2*root+1]+=op[root];
21             type[2*root+1]=max(1,type[2*root+1]);
22             type[2*root]=max(1,type[2*root]);
23         }
24     }
25     else
26     {
27         if(type[root]==2){
28             t[root]=op[root]*(r+1-l);
29             if(l!=r){
30                 op[2*root]=op[root];
31                 op[2*root+1]=op[root];
32                 type[2*root+1]=2;
33                 type[2*root]=2;
34             }
35         }
36     }
37     op[root]=0;
38     type[root]=0;
39 }
40
41 void build(int root,int l,int r,vector<ll> &arr)
42 {
43     if(l==r)
44     {
45         t[root]=arr[l];
46         op[root]=0;
47         type[root]=0;
48         return;
49     }
50     int mid=(l+r)/2;
51     build(2*root,l,mid,arr);
52     build(2*root+1,mid+1,r,arr);
53     t[root]=t[2*root]+t[2*root+1];
54     op[root]=0;
55     type[root]=0;
56 }
57

```

```

58 void sum(int root,int l,int r,int a,int b,ll val)
59 {
60     propagate(root,l,r);
61     if(a>b) return;
62     if(l==a && r==b)
63     {
64         op[root]=val;
65         type[root]=1;
66         propagate(root,l,r);
67         return;
68     }
69     int mid=(l+r)/2;
70     sum(2*root,l,mid,a,min(b,mid),val);
71     sum(2*root+1,mid+1,r,max(mid+1,a),b,val);
72     t[root]=t[2*root]+t[2*root+1];
73 }
74
75 void setR(int root,int l,int r,int a,int b,ll val)
76 {
77     propagate(root,l,r);
78     if(a>b) return;
79     if(l==a && r==b)
80     {
81         op[root]=val;
82         type[root]=2;
83         propagate(root,l,r);
84         return;
85     }
86     int mid=(l+r)/2;
87     setR(2*root,l,mid,a,min(b,mid),val);
88     setR(2*root+1,mid+1,r,max(mid+1,a),b,val);
89     t[root]=t[2*root]+t[2*root+1];
90 }
91
92 ll consult(int root,int l,int r, int a,int b)
93 {
94     propagate(root,l,r);
95     if(a>b) return 0;
96     if(l==a && r==b){
97         return t[root];
98     }
99     int mid=(l+r)/2;
100     return consult(2*root,l,mid,a,min(b,mid))+
101     consult(2*root+1,mid+1,r,max(mid+1,a),b);
102 }

```

3.11 Segment Tree 2D

```

1  typedef long long ll;

```

```

2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 const int TAM=1e3+1;
5 //ascii https://elcodigoascii.com.ar/
6 vector<vector<int>> forest(TAM,vector<int> (TAM));
7 ll t[4*TAM][4*TAM];
8 int n;
9
10 void buildNode(int root,int l,int r,int node,vector<int> &arr){
11     if(l==r)
12     {
13         t[node][root]=arr[l];
14         return;
15     }
16     int mid=(l+r)/2;
17     buildNode(2*root,l,mid,node,arr);
18     buildNode(2*root+1,mid+1,r,node,arr);
19     t[node][root]=t[node][2*root]+t[node][2*root+1];
20 }
21
22 void build(int root,int l,int r,vector<vector<int>> &arr)
23 {
24     if(l==r)
25     {
26         buildNode(1,0,n-1,root,arr[l]);
27         return;
28     }
29     int mid=(l+r)/2;
30     build(2*root,l,mid,arr);
31     build(2*root+1,mid+1,r,arr);
32     FO(i,4*TAM) t[root][i]=t[2*root][i]+t[2*root+1][i];
33 }
34
35
36 void updateNode(int root,int l,int r,int y,int node,int val)
37 {
38     if(l==r)
39     {
40         t[node][root]=val;
41         return;
42     }
43     int mid=(l+r)/2;
44     if(y>mid)
45     {
46         updateNode(2*root+1,mid+1,r,y,node,val);
47     }
48     else{
49         updateNode(2*root,l,mid,y,node,val);
50     }
51     t[node][root]=t[node][2*root]+t[node][2*root+1];
52 }

```

```

53
54 void update(int root,int l,int r,int x,int y,int val)
55 {
56     if(l==r)
57     {
58         updateNode(1,0,n-1,y,root,val);
59         return;
60     }
61     int mid=(l+r)/2;
62     if(x>mid)
63     {
64         update(2*root+1,mid+1,r,x,y,val);
65     }
66     else{
67         update(2*root,l,mid,x,y,val);
68     }
69     int i=0,j=n-1,Ndt=1,mid_aux;
70     while(i!=j)
71     {
72         mid_aux=(i+j)/2;
73         t[root][Ndt]=t[2*root][Ndt]+t[2*root+1][Ndt];
74         if(y>mid_aux){
75             i=mid_aux+1;
76             Ndt=2*Ndt+1;
77         }
78         else{
79             j=mid_aux;
80             Ndt*=2;
81         }
82     }
83     t[root][Ndt]=t[2*root][Ndt]+t[2*root+1][Ndt];
84 }
85
86 ll consultNode(int root,int l,int r,int node,int y1,int y2)
87 {
88     if(y1>y2) return 0;
89     if(l==y1 && r==y2) return t[node][root];
90     int mid=(l+r)/2;
91     return consultNode(2*root,l,mid,node,y1,min(y2,mid))+
92     consultNode(2*root+1,mid+1,r,node,max(mid+1,y1),y2);
93 }
94
95 ll consult(int root,int l,int r, int x1,int x2,int y1,int y2)
96 {
97     if(x1>x2) return 0;
98     if(l==x1 && r==x2) return consultNode(1,0,n-1,root,y1,y2);
99     int mid=(l+r)/2;
100     return consult(2*root,l,mid,x1,min(x2,mid),y1,y2)+
101     consult(2*root+1,mid+1,r,max(mid+1,x1),x2,y1,y2);
102 }

```

3.12 Segment tree with Index Compression

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 typedef vector<pair<int,int>> vpai;
4 const ll mod=1e9+7;
5 const int MAX=4e5+3;
6 const int limit=2e5+3;
7 const int TAM=2e5+1;
8 ll t[4*MAX];
9 //ascii https://elcodigoascii.com.ar/
10
11 void update(int root,int l,int r,int pos,int val)
12 {
13     if(l==r)
14     {
15         t[root]+=val;
16         return;
17     }
18     int mid=(l+r)/2;
19     if(pos>mid)
20     {
21         update(2*root+1,mid+1,r,pos,val);
22     }
23     else{
24         update(2*root,l,mid,pos,val);
25     }
26     t[root]=t[2*root]+t[2*root+1];
27 }
28
29 ll consult(int root,int l,int r, int a,int b)
30 {
31     if(a>b) return 0;
32     if(l==a && r==b) return t[root];
33     int mid=(l+r)/2;
34     return consult(2*root,l,mid,a,min(b,mid))+
35     consult(2*root+1,mid+1,r,max(mid+1,a),b);
36 }
37
38 inline void solve()
39 {
40     int n,m,index;
41     cin>>n>>m;
42     vector<ll> arr(n);
43     vector<tuple<char,ll,ll>> queries(m);
44     set<ll> salary;
45     memset(t,0,sizeof(t));
46     FO(i,n){
47         ll aux; cin>>aux;
48         arr[i]=aux;
49

```

```

50         salary.insert(aux);
51     }
52     FO(i,m)
53     {
54         char a;
55         ll b,c;
56         cin>>a>>b>>c;
57         queries[i]=make_tuple(a,b,c);
58         if(a=='!') salary.insert(c);
59     }
60
61     vector<ll> coord(all(salary));
62     int tn=coord.size();
63     //FO(i,tn) cout<<coord[i]<<" ";
64     //cout<<endl;
65     FO(i,n)
66     {
67         index=lower_bound(all(coord),arr[i])-coord.begin();
68         update(1,0,tn-1,index,1);
69     }
70     FO(i,m)
71     {
72         char a=get<0>(queries[i]);
73         ll b=get<1>(queries[i]);
74         ll c=get<2>(queries[i]);
75         if(a=='?'){
76             b=lower_bound(all(coord),b)-coord.begin();
77             c=(upper_bound(all(coord),c)-coord.begin())-1;
78             if(b==tn || c==tn){
79                 cout<<0<<endl;
80             }
81             else cout<<consult(1,0,tn-1,b,c)<<endl;
82         }
83         else{
84             index=lower_bound(all(coord),arr[b-1])-coord.begin();
85             update(1,0,tn-1,index,-1);
86             arr[b-1]=c;
87             index=lower_bound(all(coord),arr[b-1])-coord.begin();
88             update(1,0,tn-1,index,1);
89         }
90     }
91 }
92
93 }

```

3.13 Segment Tree Prefix-Suffix-Biggest

```

1 typedef long long ll;
2 typedef vector<int> vec;

```

```

3 typedef vector<pair<int,int>> vpai;
4 const ll mod=1e9+7;
5 const int MAX=1e5+3;
6 const int limit=2e5+3;
7 const int TAM=2e5+1;
8 ll t[4*TAM];
9 ll prefix[4*TAM], suffix[4*TAM], biggest[4*TAM];
10 //ascii https://elcodigoascii.com.ar/
11 ll cero=0;
12 void build(int root,int l,int r,vector<ll> &arr)
13 {
14     if(l==r)
15     {
16         t[root]=arr[l];
17         suffix[root]=max(t[root],cero);
18         prefix[root]=max(t[root],cero);
19         biggest[root]=max(t[root],cero);
20         return;
21     }
22     int mid=(l+r)/2;
23     build(2*root,l,mid,arr);
24     build(2*root+1,mid+1,r,arr);
25     t[root]=t[2*root]+t[2*root+1];
26     biggest[root]=max(biggest[2*root],
27 max(biggest[2*root+1], suffix[2*root]+prefix[2*root+1]));
28     prefix[root]=max(prefix[2*root], t[2*root]+prefix[2*root+1]);
29     suffix[root]=max(suffix[2*root+1], t[2*root+1]+suffix[2*root]);
30 }
31
32 void update(int root,int l,int r,int pos,ll val)
33 {
34     if(l==r)
35     {
36         t[root]=val;
37         suffix[root]=max(cero,t[root]);
38         prefix[root]=max(cero,t[root]);
39         biggest[root]=max(t[root],cero);
40         return;
41     }
42     int mid=(l+r)/2;
43     if(pos>mid)
44     {
45         update(2*root+1,mid+1,r,pos,val);
46     }
47     else{
48         update(2*root,l,mid,pos,val);
49     }
50     t[root]=t[2*root]+t[2*root+1];
51     biggest[root]=max(biggest[2*root],
52 max(biggest[2*root+1], suffix[2*root]+prefix[2*root+1]));
53 }

```

```

54     prefix[root]=max(prefix[2*root], t[2*root]+prefix[2*root+1]);
55     suffix[root]=max(suffix[2*root+1], t[2*root+1]+suffix[2*root]);
56 }
57
58 ll consult(int root,int l,int r, int a,int b)
59 {
60     if(a>b) return 0;
61     if(l==a && r==b) return t[root];
62     int mid=(l+r)/2;
63     return consult(2*root,l,mid,a,min(b,mid))+
64     consult(2*root+1,mid+1,r,max(mid+1,a),b);
65 }

```

3.14 Persistent Array

```

1 vector<pair<int, int>> arr[100001]; // The persistent array
2
3 int get_item(int index, int time) {
4     // Gets the array item at a given index and time
5     auto ub =
6         upper_bound(arr[index].begin(), arr[index].end(),
7             make_pair(time, INT_MAX));
8     return prev(ub)->second;
9 }
10
11 void update_item(int index, int value, int time) {
12     // Updates the array item at a given index and time
13     // Note that this only works if the time is later than all
14     // previous
15     // update times
16     assert(arr[index].back().first < time);
17     arr[index].push_back({time, value});
18 }
19
20 void init_arr(int n, int *init) {
21     // Initializes the persistent array, given an input array
22     for (int i = 0; i < n; i++) arr[i].push_back({0, init[i]});
23 }

```

3.15 Path Copying - Persistent Array

```

1 struct Node {
2     int val;
3     Node *l, *r;
4
5     Node(ll x) : val(x), l(nullptr), r(nullptr) {}
6     Node(Node *ll, Node *rr) : val(0), l(ll), r(rr) {}
7 };

```

```

8
9 int n, a[100001]; // The initial array and its size
10 Node *roots[100001]; // The persistent array's roots
11
12 Node *build(int l = 0, int r = n - 1) {
13     if (l == r) return new Node(a[l]);
14     int mid = (l + r) / 2;
15     return new Node(build(l, mid), build(mid + 1, r));
16 }
17
18 Node *update(Node *node, int val, int pos, int l = 0, int r = n -
19     1) {
20     if (l == r) return new Node(val);
21     int mid = (l + r) / 2;
22     if (pos > mid) return new Node(node->l, update(node->r, val,
23         pos, mid + 1, r));
24     else return new Node(update(node->l, val, pos, l, mid), node->
25         r);
26 }
27
28 int query(Node *node, int pos, int l = 0, int r = n - 1) {
29     if (l == r) return node->val;
30     int mid = (l + r) / 2;
31     if (pos > mid) return query(node->r, pos, mid + 1, r);
32     return query(node->l, pos, l, mid);
33 }
34
35 int get_item(int index, int time) {
36     // Gets the array item at a given index and time
37     return query(roots[time], index);
38 }
39
40 void update_item(int index, int value, int prev_time, int
41     curr_time) {
42     // Updates the array item at a given index and time
43     roots[curr_time] = update(roots[prev_time], index, value);
44 }
45
46 void init_arr(int nn, int *init) {
47     // Initializes the persistent array, given an input array
48     n = nn;
49     for (int i = 0; i < n; i++) a[i] = init[i];
50     roots[0] = build();
51 }

```

3.16 Persistent Segment Tree

```

1 using ll = long long;
2

```

```

3 class PersistentSegtree {
4     private:
5         struct Node {
6             ll sum = 0;
7             int l = 0, r = 0;
8         };
9
10        const int n;
11        vector<Node> tree;
12        int timer = 1;
13
14        Node join(int l, int r) { return Node{tree[l].sum + tree[r].
15            sum, l, r}; }
16
17        int build(int tl, int tr, const vector<int> &arr) {
18            if (tl == tr) {
19                tree[timer] = {arr[tl], 0, 0};
20                return timer++;
21            }
22
23            int mid = (tl + tr) / 2;
24            tree[timer] = join(build(tl, mid, arr), build(mid + 1, tr,
25                arr));
26
27            return timer++;
28        }
29
30        int set(int v, int pos, int val, int tl, int tr) {
31            if (tl == tr) {
32                tree[timer] = {val, 0, 0};
33                return timer++;
34            }
35
36            int mid = (tl + tr) / 2;
37            if (pos <= mid) {
38                tree[timer] = join(set(tree[v].l, pos, val, tl, mid),
39                    tree[v].r);
40            } else {
41                tree[timer] = join(tree[v].l, set(tree[v].r, pos, val,
42                    mid + 1, tr));
43            }
44
45            return timer++;
46        }
47
48        ll range_sum(int v, int ql, int qr, int tl, int tr) {
49            if (qr < tl || tr < ql) { return 0ll; }
50            if (ql <= tl && tr <= qr) { return tree[v].sum; }
51
52            int mid = (tl + tr) / 2;
53            return range_sum(tree[v].l, ql, qr, tl, mid) +

```

```

50         range_sum(tree[v].r, ql, qr, mid + 1, tr);
51     }
52
53     public:
54     PersistentSegtree(int n, int MX_NODES) : n(n), tree(MX_NODES)
55     {}
56
57     int build(const vector<int> &arr) { return build(0, n - 1, arr
58 ); }
59
60     int set(int root, int pos, int val) { return set(root, pos,
61 val, 0, n - 1); }
62
63     ll range_sum(int root, int l, int r) { return range_sum(root,
64 l, r, 0, n - 1); }
65
66     int add_copy(int root) {
67         tree[timer] = tree[root];
68         return timer++;
69     }
70 };

```

3.17 Policy Ordered Set

```

1 #include <ext/pb_ds/assoc_container.hpp> // Common file
2 #include <ext/pb_ds/tree_policy.hpp>
3 #include <functional> // for less
4 using namespace __gnu_pbds;
5
6 // To allow repetitions
7 typedef tree<int, null_type, less<int>, rb_tree_tag,
8 tree_order_statistics_node_update>
9 ordered_set;
10
11 // To not allow repetitions
12 typedef tree<pair<int, int>, null_type,
13 less<pair<int, int>>, rb_tree_tag,
14 tree_order_statistics_node_update>
15 ordered_multiset;
16
17 ordered_set pt; // Definition
18
19 pt.order_of_key(x); // Number of items strictly smaller than x
20 pt.find_by_order(k); // Iterator to the kth element

```

3.18 Disjoint Set Union

```

1 // Shout-out to Usaco Guide for DSU implementation: https://usaco.
2 guide/gold/dsu?lang=cpp
3
4 class DisjointSets{
5     private:
6         vector<int> parents;
7         vector<int> sizes;
8         int components;
9     public:
10     DisjointSets(int size) : parents(size), sizes(size,1),
11 components(size){
12         for(int i=0; i<size; i++){parents[i] = i;}
13     }
14
15     int find(int x) {return parents[x] == x ? x : (parents[x]
16 = find(parents[x]));}
17
18     bool unite(int x, int y){
19         int x_root = find(x);
20         int y_root = find(y);
21
22         if(x_root == y_root) {return false;}
23
24         if(sizes[x_root] < sizes[y_root]) {swap(x_root,y_root)
25 };
26         sizes[x_root] += sizes[y_root];
27         parents[y_root] = x_root;
28         components--;
29         return true;
30     }
31
32     vector<int> getAllComponentSizes(){
33         map<int, int> component_sizes;
34         for (int i = 0; i < parents.size(); ++i){
35             int root = find(i);
36             if (component_sizes.find(root) == component_sizes.
37 end()){
38                 component_sizes[root] = sizes[root];
39             }
40         }
41
42         vector<int> result;
43         for (auto& [root, size] : component_sizes) {
44             result.push_back(size);
45         }
46
47         return result;
48     }
49
50     bool connected(int x, int y) { return find(x) == find(y);}

```

```

47     int getSize(int x) {return sizes[find(x)];}
48     int getComponents() const {return components;}
49 };

```

3.19 DSU to detect cycles

```

1 class CycleDetectionDSU {
2     vector<int> parent;
3     vector<int> size;
4
5 public:
6     CycleDetectionDSU(int n) : parent(n), size(n, 1) {
7         iota(parent.begin(), parent.end(), 0);
8     }
9
10    int find(int x) {
11        return parent[x] == x ? x : parent[x] = find(parent[x]);
12    }
13
14    // Returns true if adding edge u-v creates a cycle
15    bool add_edge(int u, int v) {
16        int u_root = find(u);
17        int v_root = find(v);
18        if (u_root == v_root) return true;
19
20        if (size[u_root] < size[v_root]) swap(u_root, v_root);
21        parent[v_root] = u_root;
22        size[u_root] += size[v_root];
23        return false;
24    }
25 };

```

3.20 DSU to check online bipartiteness

```

1 class BipartiteDSU {
2     vector<int> parent;
3     vector<int> size;
4
5 public:
6     BipartiteDSU(int n) : parent(2*n), size(2*n, 1) {
7         iota(parent.begin(), parent.end(), 0);
8     }
9
10    int find(int x) {
11        return parent[x] == x ? x : parent[x] = find(parent[x]);
12    }
13
14    // Returns true if graph remains bipartite after adding u-v

```

```

15    bool add_edge(int u, int v) {
16        int u_orig = 2*u;      // Original node
17        int u_mirror = 2*u+1;  // Mirror node
18        int v_orig = 2*v;
19        int v_mirror = 2*v+1;
20
21        // Union u_orig <-> v_mirror and v_orig <-> u_mirror
22        for(int i = 0; i < 2; i++) {
23            int x = i ? v_orig : u_orig;
24            int y = i ? u_mirror : v_mirror;
25
26            int x_root = find(x);
27            int y_root = find(y);
28            if (x_root != y_root) {
29                if (size[x_root] < size[y_root]) swap(x_root,
30                y_root);
31                parent[y_root] = x_root;
32                size[x_root] += size[y_root];
33            }
34
35            // Check if u is in both partitions
36            return find(u_orig) != find(u_mirror);
37        }
38    };
39
40    // -- Other implementation --
41
42    void make_set(int v) {
43        parent[v] = make_pair(v, 0);
44        rank[v] = 0;
45        bipartite[v] = true;
46    }
47
48    pair<int, int> find_set(int v) {
49        if (v != parent[v].first) {
50            int parity = parent[v].second;
51            parent[v] = find_set(parent[v].first);
52            parent[v].second ^= parity;
53        }
54        return parent[v];
55    }
56
57    void add_edge(int a, int b) {
58        pair<int, int> pa = find_set(a);
59        a = pa.first;
60        int x = pa.second;
61
62        pair<int, int> pb = find_set(b);
63        b = pb.first;

```



```

65     int y = pb.second;
66
67     if (a == b) {
68         if (x == y)
69             bipartite[a] = false;
70     } else {
71         if (rank[a] < rank[b])
72             swap (a, b);
73         parent[b] = make_pair(a, x^y^1);
74         bipartite[a] ^= bipartite[b];
75         if (rank[a] == rank[b])
76             ++rank[a];
77     }
78 }
79
80 bool is_bipartite(int v) {
81     return bipartite[find_set(v).first];
82 }

```

3.21 DSU with rollback

```

1 class DSU {
2     private:
3         vector<int> p, sz;
4         // stores previous unites
5         vector<pair<int &, int>> history;
6
7     public:
8         DSU(int n) : p(n), sz(n, 1) { iota(p.begin(), p.end(), 0); }
9
10        int get(int x) { return x == p[x] ? x : get(p[x]); }
11
12        void unite(int a, int b) {
13            a = get(a);
14            b = get(b);
15            if (a == b) { return; }
16            if (sz[a] < sz[b]) { swap(a, b); }
17
18            // save this unite operation
19            history.push_back({sz[a], sz[a]});
20            history.push_back({p[b], p[b]});
21
22            p[b] = a;
23            sz[a] += sz[b];
24        }
25
26        int snapshot() { return history.size(); }
27
28        void rollback(int until) {

```

```

29            while (snapshot() > until) {
30                history.back().first = history.back().second;
31                history.pop_back();
32            }
33        }
34    };

```

3.22 Dynamic connectivity

```

1 struct dsu_save {
2     int v, rnk, u, rnku;
3
4     dsu_save() {}
5
6     dsu_save(int _v, int _rnkv, int _u, int _rnku)
7         : v(_v), rnk(_rnkv), u(_u), rnku(_rnku) {}
8 };
9
10 struct dsu_with_rollback {
11     vector<int> p, rnk;
12     int comps;
13     stack<dsu_save> op;
14
15     dsu_with_rollback() {}
16
17     dsu_with_rollback(int n) {
18         p.resize(n);
19         rnk.resize(n);
20         for (int i = 0; i < n; i++) {
21             p[i] = i;
22             rnk[i] = 0;
23         }
24         comps = n;
25     }
26
27     int find_set(int v) {
28         return (v == p[v]) ? v : find_set(p[v]);
29     }
30
31     bool unite(int v, int u) {
32         v = find_set(v);
33         u = find_set(u);
34         if (v == u)
35             return false;
36         comps--;
37         if (rnk[v] > rnk[u])
38             swap(v, u);
39         op.push(dsu_save(v, rnk[v], u, rnk[u]));
40         p[v] = u;

```

```

41     if (rnk[u] == rnk[v])
42         rnk[u]++;
43     return true;
44 }
45
46 void rollback() {
47     if (op.empty())
48         return;
49     dsu_save x = op.top();
50     op.pop();
51     comps++;
52     p[x.v] = x.v;
53     rnk[x.v] = x.rnk;
54     p[x.u] = x.u;
55     rnk[x.u] = x.rnk;
56 }
57 };
58
59 struct query {
60     int v, u;
61     bool united;
62     query(int _v, int _u) : v(_v), u(_u) {}
63 }
64 };
65
66 struct QueryTree {
67     vector<vector<query>> t;
68     dsu_with_rollbacks dsu;
69     int T;
70
71     QueryTree() {}
72
73     QueryTree(int _T, int n) : T(_T) {
74         dsu = dsu_with_rollbacks(n);
75         t.resize(4 * T + 4);
76     }
77
78     void add_to_tree(int v, int l, int r, int ul, int ur, query& q)
79     {
80         if (ul > ur)
81             return;
82         if (l == ul && r == ur) {
83             t[v].push_back(q);
84             return;
85         }
86         int mid = (l + r) / 2;
87         add_to_tree(2 * v, l, mid, ul, min(ur, mid), q);
88         add_to_tree(2 * v + 1, mid + 1, r, max(ul, mid + 1), ur, q);
89     }

```

```

90 void add_query(query q, int l, int r) {
91     add_to_tree(1, 0, T - 1, l, r, q);
92 }
93
94 void dfs(int v, int l, int r, vector<int>& ans) {
95     for (query& q : t[v]) {
96         q.united = dsu.unite(q.v, q.u);
97     }
98     if (l == r)
99         ans[l] = dsu.comps;
100     else {
101         int mid = (l + r) / 2;
102         dfs(2 * v, l, mid, ans);
103         dfs(2 * v + 1, mid + 1, r, ans);
104     }
105     for (query q : t[v]) {
106         if (q.united)
107             dsu.rollback();
108     }
109 }
110
111 vector<int> solve() {
112     vector<int> ans(T);
113     dfs(1, 0, T - 1, ans);
114     return ans;
115 }
116 }

```

3.23 Trie

```

1 class TrieNode
2 {
3     public:
4         // Array for children nodes of each node
5         TrieNode *children[26];
6
7         // for end of word
8         bool isLeaf;
9
10        TrieNode()
11        {
12            isLeaf = false;
13            for (int i = 0; i < 26; i++)
14            {
15                children[i] = nullptr;
16            }
17        }
18
19 };

```

```

20 // Method to insert a key into the Trie
21 void insert(TrieNode *root, const string &key)
22 {
23
24     // Initialize the curr pointer with the root node
25     TrieNode *curr = root;
26
27     // Iterate across the length of the string
28     for (char c : key)
29     {
30
31         // Check if the node exists for the
32         // current character in the Trie
33         if (curr->children[c - 'a'] == nullptr)
34         {
35
36             // If node for current character does
37             // not exist then make a new node
38             TrieNode *newNode = new TrieNode();
39
40             // Keep the reference for the newly
41             // created node
42             curr->children[c - 'a'] = newNode;
43         }
44
45         // Move the curr pointer to the
46         // newly created node
47         curr = curr->children[c - 'a'];
48     }
49
50     // Mark the end of the word
51     curr->isLeaf = true;
52 }
53
54 // Method to search a key in the Trie
55 bool search(TrieNode *root, const string &key)
56 {
57
58     if (root == nullptr)
59     {
60         return false;
61     }
62
63     // Initialize the curr pointer with the root node
64     TrieNode *curr = root;
65
66     // Iterate across the length of the string
67     for (char c : key)
68     {
69
70         // Check if the node exists for the

```

```

71         // current character in the Trie
72         if (curr->children[c - 'a'] == nullptr)
73             return false;
74
75         // Move the curr pointer to the
76         // already existing node for the
77         // current character
78         curr = curr->children[c - 'a'];
79     }
80
81     // Return true if the word exists
82     // and is marked as ending
83     return curr->isLeaf;
84 }
85
86 // Method to check if a prefix exists in the Trie
87 bool isPrefix(TrieNode *root, const string &prefix)
88 {
89     // Initialize the curr pointer with the root node
90     TrieNode *curr = root;
91
92     // Iterate across the length of the prefix string
93     for (char c : prefix)
94     {
95         // Check if the node exists for the current character in
96         // the Trie
97         if (curr->children[c - 'a'] == nullptr)
98             return false;
99
100        // Move the curr pointer to the already existing node
101        // for the current character
102        curr = curr->children[c - 'a'];
103    }
104
105    // If we reach here, the prefix exists in the Trie
106    return true;
107 }

```

3.24 Palindromic Tree

```

1 const int MAXN = 105000;
2
3 struct node {
4     int next[26];
5     int len;
6     int sufflink;
7     int num;
8 };
9

```

```

10 int len;
11 char s[MAXN];
12 node tree[MAXN];
13 int num;           // node 1 - root with len -1, node 2 - root
14   with len 0
15 int suff;         // max suffix palindrome
16 long long ans;
17 bool addLetter(int pos) {
18     int cur = suff, curlen = 0;
19     int let = s[pos] - 'a';
20
21     while (true) {
22         curlen = tree[cur].len;
23         if (pos - 1 - curlen >= 0 && s[pos - 1 - curlen] == s[pos])
24             break;
25         cur = tree[cur].sufflink;
26     }
27     if (tree[cur].next[let]) {
28         suff = tree[cur].next[let];
29         return false;
30     }
31
32     num++;
33     suff = num;
34     tree[num].len = tree[cur].len + 2;
35     tree[cur].next[let] = num;
36
37     if (tree[num].len == 1) {
38         tree[num].sufflink = 2;
39         tree[num].num = 1;
40         return true;
41     }
42
43     while (true) {
44         cur = tree[cur].sufflink;
45         curlen = tree[cur].len;
46         if (pos - 1 - curlen >= 0 && s[pos - 1 - curlen] == s[pos]) {
47             tree[num].sufflink = tree[cur].next[let];
48             break;
49         }
50     }
51
52     tree[num].num = 1 + tree[tree[num].sufflink].num;
53
54     return true;
55 }
56
57 void initTree() {

```

```

58     num = 2; suff = 2;
59     tree[1].len = -1; tree[1].sufflink = 1;
60     tree[2].len = 0; tree[2].sufflink = 1;
61 }
62
63 // -- Other implementation --
64
65 const int maxn = 1e5, sigma = 26;
66
67 int s[maxn], len[maxn], link[maxn], to[maxn][sigma];
68
69 int n, last, sz;
70
71 void init()
72 {
73     s[n++] = -1;
74     link[0] = 1;
75     len[1] = -1;
76     sz = 2;
77 }
78
79 int get_link(int v)
80 {
81     while(s[n - len[v] - 2] != s[n - 1]) v = link[v];
82     return v;
83 }
84
85 void add_letter(int c)
86 {
87     s[n++] = c;
88     last = get_link(last);
89     if(!to[last][c])
90     {
91         len[sz] = len[last] + 2;
92         link[sz] = to[get_link(link[last])][c];
93         to[last][c] = sz++;
94     }
95     last = to[last][c];
96 }

```

3.25 Treap

```

1 typedef struct item * pitem;
2 struct item {
3     int prior, value, cnt;
4     bool rev;
5     pitem l, r;
6 };
7

```

```

8 int cnt (pitem it) {
9     return it ? it->cnt : 0;
10 }
11
12 void upd_cnt (pitem it) {
13     if (it)
14         it->cnt = cnt(it->l) + cnt(it->r) + 1;
15 }
16
17 void push (pitem it) {
18     if (it && it->rev) {
19         it->rev = false;
20         swap (it->l, it->r);
21         if (it->l) it->l->rev ^= true;
22         if (it->r) it->r->rev ^= true;
23     }
24 }
25
26 void merge (pitem & t, pitem l, pitem r) {
27     push (l);
28     push (r);
29     if (!l || !r)
30         t = l ? l : r;
31     else if (l->prior > r->prior)
32         merge (l->r, l->r, r), t = l;
33     else
34         merge (r->l, l, r->l), t = r;
35     upd_cnt (t);
36 }
37
38 void split (pitem t, pitem & l, pitem & r, int key, int add = 0) {
39     if (!t)
40         return void( l = r = 0 );
41     push (t);
42     int cur_key = add + cnt(t->l);
43     if (key <= cur_key)
44         split (t->l, l, t->l, key, add), r = t;
45     else
46         split (t->r, t->r, r, key, add + 1 + cnt(t->l)), l = t;
47     upd_cnt (t);
48 }
49
50 void reverse (pitem t, int l, int r) {
51     pitem t1, t2, t3;
52     split (t, t1, t2, l);
53     split (t2, t2, t3, r-l+1);
54     t2->rev ^= true;
55     merge (t, t1, t2);
56     merge (t, t, t3);
57 }
58

```

```

59 void output (pitem t) {
60     if (!t) return;
61     push (t);
62     output (t->l);
63     printf ("%d ", t->value);
64     output (t->r);
65 }

```

4 Graph Theory

4.1 Bipartite Check BFS

```

1 bool bfs(int s){
2     queue<int> q;
3     q.push(s);
4     color[s] = 1; // Assign the initial color
5
6     while(!q.empty()){
7         int u = q.front();
8         q.pop();
9
10        // Check all adjacent vertices of u
11        for(auto v : adj[u]){
12            // If v is not colored yet
13            if(color[v] == 0){
14                color[v] = (color[u] == 1) ? 2 : 1;
15                q.push(v);
16            }
17            else if (color[v] == color[u]){
18                return false;
19            }
20        }
21    }
22    return true;
23 }

```

4.2 Cycle Detection DFS

```

1 // Thanks CP-Algo for Cycle finding implementation: https://cp-
  algorithms.com/graph/finding-cycle.html
2
3 bool dfs(int v, int par) { // passing vertex and its parent vertex
4     visited[v] = true;
5     for (int u : adj[v]) {
6         if(u == par) continue; // skipping edge to parent vertex
7         if (visited[u]) {
8             cycle_end = v;

```

```

9         cycle_start = u;
10        return true;
11    }
12    parent[u] = v;
13    if (dfs(u, parent[u]))
14        return true;
15 }
16 return false;
17 }
18
19 void find_cycle() {
20     visited.assign(n+1, false);
21     parent.assign(n+1, -1);
22     cycle_start = -1;
23
24     for (int v = 0; v < n; v++) {
25         if (!visited[v] && dfs(v, parent[v]))
26             break;
27     }
28
29     if (cycle_start == -1) {
30         cout << "IMPOSSIBLE" << endl;
31     } else {
32         vector<int> cycle;
33         cycle.push_back(cycle_start);
34         for (int v = cycle_end; v != cycle_start; v = parent[v])
35             cycle.push_back(v);
36         cycle.push_back(cycle_start);
37
38         cout << cycle.size() << endl;
39         for (int v : cycle)
40             cout << v << " ";
41         cout << endl;
42     }
43 }

```

4.3 Topological Sort

```

1 vector<int> ans;
2
3 void dfs(int v) {
4     visited[v] = true;
5     for (int u : adj[v]) {
6         if (!visited[u])
7             dfs(u);
8     }
9     ans.push_back(v);
10 }
11

```

```

12 void topological_sort() {
13     visited.assign(n+1, false);
14     ans.clear();
15     for (int i = 1; i <= n; ++i) {
16         if (!visited[i]) {
17             dfs(i);
18         }
19     }
20     reverse(ans.begin(), ans.end());
21 }

```

4.4 Kahn's Algorithm

```

1 def kahnTopoSort(self, adj: List[List[int]]) -> List[int]:
2     #print(adj)
3     in_deg = [0] * len(adj)
4     for i in range(len(adj)):
5         for u in adj[i]:
6             in_deg[u] += 1
7
8     q = []
9     for i in range(len(in_deg)):
10        if in_deg[i] == 0:
11            q.append(i)
12
13    arns = []
14    while len(q) > 0:
15        u = q[0]
16        q.pop(0)
17        arns.append(u)
18
19        for v in adj[u]:
20            in_deg[v] -= 1
21            if in_deg[v] == 0:
22                q.append(v)
23
24    print(str(len(arns)) + " " + str(len(adj)))
25    if (len(arns) != len(adj)):
26        return []
27
28    return arns

```

4.5 Lexicographically Min. TopoSort

```

1 int n;
2 vector<vector<int>> adj(MAX);
3 vector<int> in_degree(MAX);
4 vector<int> group_ids(MAX);

```

```

5 vector<int> ans;
6
7 //topological sort implementation: https://cp-algorithms.com/graph
  /topological-sort.html
8
9 void topological_sort() {
10     priority_queue<pair<int, int>, vector<pair<int, int>>, greater
      <pair<int, int>>> pq;
11
12     for(int i = 1; i <= n; i++) {
13         if(in_degree[i] == 0) {
14             pq.emplace(group_ids[i], i);
15         }
16     }
17
18     while(!pq.empty()) {
19         int u = pq.top().second;
20         pq.pop();
21         ans.push_back(u);
22
23         for(int v : adj[u]) {
24             in_degree[v]--;
25             if(in_degree[v] == 0) {
26                 pq.emplace(group_ids[v], v);
27             }
28         }
29     }
30 }
31 }

```

4.6 BFS Flood Fill

```

1 bool validate(int x, int y){
2     if(vis[x][y]) return false;
3     if(maze[x][y] == '#') return false;
4     if(x<0 or x>=n or y<0 or y>=m) return false;
5     return true;
6 }
7
8 bool solveMaze(int x, int y){
9     queue<pii> q;
10    q.push(mp(x,y));
11    vis[x][y] = true;
12
13    int dx[] = {1, -1, 0, 0};
14    int dy[] = {0, 0, 1, -1};
15    char move_dir[] = {'D', 'U', 'R', 'L'};
16
17    while(!q.empty()){

```

```

18    int u = q.front().fs;
19    int v = q.front().sc;
20    q.pop();
21
22    if(maze[u][v] == 'B'){
23        while(true){
24            res.push_back(path[u][v]);
25
26            if(res.back() == 'U' && u + 1 < n) u++;
27            if(res.back() == 'D' && u - 1 >= 0) u--;
28            if(res.back() == 'L' && v + 1 < m) v++;
29            if(res.back() == 'R' && v - 1 >= 0) v--;
30
31            if(u == x and v == y) break;
32        }
33        return true;
34    }
35
36    for (int i = 0; i < 4; ++i) {
37        int new_u = u + dx[i];
38        int new_v = v + dy[i];
39        if (validate(new_u, new_v)) {
40            path[new_u][new_v] = move_dir[i];
41            vis[new_u][new_v] = true;
42            q.push(mp(new_u, new_v));
43        }
44    }
45    return false;
46 }

```

4.7 BFS Iterative Flood Fill

```

1 void floodFill(int x, int y, char color ,int r, int c) {
2     if (maze[x][y] == color) return;
3     queue<pii> q;
4     q.push(pii(x, y));
5     while (!q.empty()) {
6         pii currentCoor = q.front();
7         q.pop();
8         x = currentCoor.fi;
9         y = currentCoor.sc;
10        if (x >= 0 && x < r && y >= 0 && y < c && maze[x][y] !=
            color) {
11            maze[x][y] = color;
12            q.push(pii(x + 1, y));
13            q.push(pii(x - 1, y));
14            q.push(pii(x, y + 1));
15            q.push(pii(x, y - 1));
16        }

```

```

17     }
18 }

```

4.8 DFS Flood Fill

```

1 void floodFill(int x, int y, char color, vector<vector<char>>&
   board){
2     if(x<0 or y<0 or x>=board.size() or y>=board[x].size() or
       board[x][y] != '0') return;
3     board[x][y] = color;
4     floodFill(x+1,y,color,board);
5     floodFill(x-1,y,color,board);
6     floodFill(x,y+1,color,board);
7     floodFill(x,y-1,color,board);
8 }

```

4.9 Lava Flow (Multi-source BFS)

```

1 struct Cell{
2     int x,y,t;
3 };
4
5 const int MAX = 1005;
6 int n,m;
7
8 char maze[MAX][MAX];
9 int vis[MAX][MAX];
10 int player[MAX][MAX];
11 char path[MAX][MAX];
12 set<pii> isExit;
13 queue<Cell> q;
14 string res;
15
16 bool isValid(int x, int y){
17     if(x < 0 || x >= n || y < 0 || y >= m) return false;
18     if(maze[x][y] == '#') return false;
19     return true;
20 }
21
22 bool isSafe(int x, int y, int u, int v){
23     return player[x][y] == -1 and maze[x][y] != 'M' and (vis[x][y]
        == -1 or player[u][v] + 1 < vis[x][y]);
24 }
25
26
27 void restorePath(int u, int v, int x, int y){
28     while (x != u || y != v) {
29         res.push_back(path[u][v]);

```

```

30
31     if (res.back() == 'U') u++;
32     if (res.back() == 'D') u--;
33     if (res.back() == 'L') v++;
34     if (res.back() == 'R') v--;
35 }
36 }
37
38 bool lavaFlow(int x,int y){
39     q.push({x,y,1});
40     player[x][y] = 0;
41
42     while(!q.empty()){
43         int u = q.front().x;
44         int v = q.front().y;
45         int t = q.front().t;
46
47         q.pop();
48
49         vector<pii> dir = {{1, 0}, {-1, 0}, {0, 1}, {0, -1}};
50
51         for(auto it: dir){
52             int i = u+it.fs;
53             int j = v+it.sc;
54
55             if(isValid(i,j)){
56                 if(t == 0){
57                     if(vis[i][j] == -1){
58                         vis[i][j] = vis[u][v]+1;
59                         q.push(Cell{i,j,0});
60                     }
61                 }else{
62                     if(isSafe(i,j,u,v)){
63                         path[i][j] = (it.fs == 1) ? 'D' : (it.
64                             fs == -1) ? 'U' : (it.sc == 1) ? '
65                             R' : 'L';
66                         player[i][j] = player[u][v]+1;
67                         q.push(Cell{i,j,1});
68                         if (isExit.find({i,j}) != isExit.end()
69                             ) {
70                             if (player[i][j] < vis[i][j] ||
71                                 vis[i][j] == -1) {
72                                 restorePath(i, j, x, y);
73                                 return true;
74                             }
75                         }
76                     }
77                 }
78             }
79         }
80     }
81 }

```



```

77     }
78
79     return false;
80 }

```

4.10 Dijkstra

```

1  typedef pair<ll, ll> pll;
2
3  vector<ll> dijkstra(int n, int source, vector<vector<pll>> &adj) {
4      vector<ll> dist(n, INF);
5      priority_queue<pll, vector<pll>, greater<pll>> pq;
6      dist[source] = 0;
7      pq.push({0, source});
8
9      while (!pq.empty()) {
10         ll d = pq.top().first;
11         ll u = pq.top().second;
12         pq.pop();
13
14         if (d > dist[u]) continue;
15
16         for (auto &edge : adj[u]) {
17             ll v = edge.first;
18             ll weight = edge.second;
19
20             if (dist[u] + weight < dist[v]) {
21                 dist[v] = dist[u] + weight;
22                 pq.push({dist[v], v});
23             }
24         }
25     }
26
27     return dist;
28 }

```

4.11 Bellman Ford (With path restoring)

```

1  struct Edge {
2      int src, dest, weight;
3  };
4
5  void bellmanFord(int V, int E, vector<Edge>& edges, int start) {
6      vector<int> dist(V+1, INT_MAX);
7      dist[start] = 0;
8
9      for (int i = 1; i < V; i++) {
10         for (int j = 0; j < E; j++) {

```

```

11             int u = edges[j].src;
12             int v = edges[j].dest;
13             int weight = edges[j].weight;
14             if (dist[u] != INT_MAX && dist[u] + weight < dist[v])
15                 {
16                     dist[v] = dist[u] + weight;
17                 }
18         }
19     }
20
21     for (int j = 0; j < E; j++) {
22         int u = edges[j].src;
23         int v = edges[j].dest;
24         int weight = edges[j].weight;
25         if (dist[u] != INT_MAX && dist[u] + weight < dist[v]) {
26             //cout << "Graph contains a negative weight cycle\n";
27             return;
28         }
29     }
30
31     for (int i=1; i<=V; i++){
32         if (dist[i] != INT_MAX){
33             cout << dist[i] << " ";
34         } else {
35             cout << "30000 ";
36         }
37     }
38     cout << endl;
39 }
40
41 void solve()
42 {
43     vector<int> d(n, INF);
44     d[v] = 0;
45     vector<int> p(n, -1);
46
47     for (;) {
48         bool any = false;
49         for (Edge e : edges)
50             if (d[e.a] < INF)
51                 if (d[e.b] > d[e.a] + e.cost) {
52                     d[e.b] = d[e.a] + e.cost;
53                     p[e.b] = e.a;
54                     any = true;
55                 }
56         if (!any)
57             break;
58     }
59
60     if (d[t] == INF)

```

```

61     cout << "No path from " << v << " to " << t << ".";
62 else {
63     vector<int> path;
64     for (int cur = t; cur != -1; cur = p[cur])
65         path.push_back(cur);
66     reverse(path.begin(), path.end());
67
68     cout << "Path from " << v << " to " << t << ": ";
69     for (int u : path)
70         cout << u << ' ';
71 }
72 }

```

4.12 SPFA Bellman Ford

```

1  const int INF = 1000000000;
2  vector<vector<pair<int, int>>> adj;
3
4  bool spfa(int s, vector<int>& d) {
5      int n = adj.size();
6      d.assign(n, INF);
7      vector<int> cnt(n, 0);
8      vector<bool> inqueue(n, false);
9      queue<int> q;
10
11      d[s] = 0;
12      q.push(s);
13      inqueue[s] = true;
14      while (!q.empty()) {
15          int v = q.front();
16          q.pop();
17          inqueue[v] = false;
18
19          for (auto edge : adj[v]) {
20              int to = edge.first;
21              int len = edge.second;
22
23              if (d[v] + len < d[to]) {
24                  d[to] = d[v] + len;
25                  if (!inqueue[to]) {
26                      q.push(to);
27                      inqueue[to] = true;
28                      cnt[to]++;
29                      if (cnt[to] > n)
30                          return false; // negative cycle
31                  }
32              }
33          }
34      }
35  }

```

```

35     return true;
36 }

```

4.13 Floyd-Warshall

```

1  void floydWarshall(vector<vector<ll>> &d, int n){
2      for (int k = 0; k < n; ++k) {
3          for (int i = 0; i < n; ++i) {
4              for (int j = 0; j < n; ++j) {
5                  d[i][j] = min(d[i][j], d[i][k] + d[k][j]);
6              }
7          }
8      }
9  }

```

4.14 Prim's Algorithm (MST)

```

1  ll prim(int V, int E, vector<vector<pll>> &adj) {
2
3      priority_queue<pll, vector<pll>, greater<pll>> pq;
4
5      vector<bool> visited(V, false);
6
7      ll res = 0;
8
9      pq.push({0, 0});
10
11      while (!pq.empty()) {
12          auto p = pq.top();
13          pq.pop();
14
15          int wt = p.first;
16          int u = p.second;
17
18          if (visited[u] == true) {
19              continue;
20          }
21
22          res += wt;
23          visited[u] = true;
24
25          for (auto v : adj[u]) {
26              if (visited[v.first] == false) {
27                  pq.push({v.second, v.first});
28              }
29          }
30      }
31  }

```

```

32     for(int i=0; i<V; i++){
33         if(!visited[i])
34             return -1;
35     }
36
37     return res;
38 }

```

4.15 Kruskal's Algorithm (MST)

```

1 struct Edge { int u, v, weight; };
2
3 int kruskal(vector<Edge>& edges, int n) {
4     sort(edges.begin(), edges.end(),
5         [](Edge& a, Edge& b) { return a.weight < b.weight; });
6
7     DisjointSets dsu(n);
8     int total_weight = 0;
9
10    for (Edge& e : edges) {
11        if (!dsu.connected(e.u, e.v)) {
12            dsu.unite(e.u, e.v);
13            total_weight += e.weight;
14        }
15    }
16    return total_weight;
17 }

```

4.16 Another Kruskal

```

1 struct Edge {
2     int u, v, w;
3     bool operator< (Edge const& other) {
4         return w < other.w;
5     }
6 };
7
8 int kruskal(int n, vector<Edge> &edges, DisjointSets &dsu, vector<
9     Edge> &ans) {
10    int cost = 0;
11    sort(edges.begin(), edges.end());
12    for (Edge e : edges) {
13        if (ans.size() == n - 1) break;
14        if (dsu.unite(e.u, e.v)){
15            cost += e.w;
16            ans.push_back(e);
17        }
18    }
19 }

```

```

18
19     if(ans.size()!=n-1) return -1;
20     return cost;
21 }

```

4.17 Kosaraju Algorithm (SCC)

```

1 vector<bool> visited; // keeps track of which vertices are already
2   visited
3 // runs depth first search starting at vertex v.
4 // each visited vertex is appended to the output vector when dfs
5   leaves it.
6 void dfs(int v, vector<vector<int>> const& adj, vector<int> &
7   output) {
8     visited[v] = true;
9     for (auto u : adj[v])
10        if (!visited[u])
11            dfs(u, adj, output);
12    output.push_back(v);
13 }
14 // input: adj -- adjacency list of G
15 // output: components -- the strongly connected components in G
16 // output: adj_cond -- adjacency list of G^TSCC (by root vertices)
17 void strongly_connected_components(vector<vector<int>> const& adj,
18     vector<vector<int>> &components,
19     vector<vector<int>> &adj_cond) {
20
21     int n = adj.size();
22     components.clear(), adj_cond.clear();
23
24     vector<int> order; // will be a sorted list of G's vertices by
25       exit time
26
27     visited.assign(n, false);
28
29     // first series of depth first searches
30     for (int i = 0; i < n; i++)
31         if (!visited[i])
32             dfs(i, adj, order);
33
34     // create adjacency list of G^T
35     vector<vector<int>> adj_rev(n);
36     for (int v = 0; v < n; v++)
37         for (int u : adj[v])
38             adj_rev[u].push_back(v);
39
40     visited.assign(n, false);
41     reverse(order.begin(), order.end());
42 }

```

```

39     vector<int> roots(n, 0); // gives the root vertex of a vertex'
40         s SCC
41
42     // second series of depth first searches
43     for (auto v : order)
44         if (!visited[v]) {
45             std::vector<int> component;
46             dfs(v, adj_rev, component);
47             components.push_back(component);
48             int root = *min_element(begin(component), end(
49                 component));
50             for (auto u : component)
51                 roots[u] = root;
52         }
53
54     // add edges to condensation graph
55     adj_cond.assign(n, {});
56     for (int v = 0; v < n; v++)
57         for (auto u : adj[v])
58             if (roots[v] != roots[u])
59                 adj_cond[roots[v]].push_back(roots[u]);

```

4.18 SCC

```

1  typedef long long ll;
2  typedef vector<int> vec;
3  const ll mod=1e9+7;
4  const int MAX=1e5+3;
5  vector<vector<int>> g(MAX);
6  vector<vector<int>> r(MAX);
7  vector<int> id(MAX);
8  bool visitados[MAX]={false};
9  vector<int> l;
10
11 void dfs(int s){
12     visitados[s]=true;
13     for(int c:g[s]){
14         if(!visitados[c]) dfs(c);
15     }
16     l.push_back(s);
17 }
18
19 void rdfs(int s,int d)
20 {
21     visitados[s]=true;
22     id[s]=d;
23     for(int c:r[s])

```

```

24     {
25         if(!visitados[c]) rdfs(c,d);
26     }
27 }

```

4.19 Tarjan algorithm (SCC)

```

1  /** Takes in an adjacency list and calculates the SCCs of the
2     graph. */
3  class TarjanSolver {
4  private:
5       vector<vector<int>> rev_adj;
6       vector<int> post;
7       vector<int> comp;
8
9       vector<bool> visited;
10      int timer = 0;
11      int id = 0;
12
13      void fill_post(int at) {
14          visited[at] = true;
15          for (int n : rev_adj[at]) {
16              if (!visited[n]) { fill_post(n); }
17          }
18          post[at] = timer++;
19      }
20
21      void find_comp(int at) {
22          visited[at] = true;
23          comp[at] = id;
24          for (int n : adj[at]) {
25              if (!visited[n]) { find_comp(n); }
26          }
27      }
28
29  public:
30      const vector<vector<int>> &adj;
31
32      TarjanSolver(const vector<vector<int>> &adj)
33          : adj(adj), rev_adj(adj.size()), post(adj.size()), comp(
34              adj.size()), visited(adj.size()) {
35          vector<int> nodes(adj.size());
36          for (int n = 0; n < adj.size(); n++) {
37              nodes[n] = n;
38              for (int next : adj[n]) { rev_adj[next].push_back(n); }
39          }

```

```

40     for (int n = 0; n < adj.size(); n++) {
41         if (!visited[n]) { fill_post(n); }
42     }
43     std::sort(nodes.begin(), nodes.end(),
44         [&](int n1, int n2) { return post[n1] > post[n2]; });
45
46     visited.assign(adj.size(), false);
47     for (int n : nodes) {
48         if (!visited[n]) {
49             find_comp(n);
50             id++;
51         }
52     }
53 }
54
55 int comp_num() const { return id; }
56
57 int get_comp(int n) const { return comp[n]; }
58 };

```

4.20 Finding Articulation Points

```

1 // adj[u] = adjacent nodes of u
2 // ap = AP = articulation points
3 // p = parent
4 // disc[u] = discovery time of u
5 // low[u] = 'low' node of u
6
7 int dfsAP(int u, int p) {
8     int children = 0;
9     low[u] = disc[u] = ++Time;
10    for (int& v : adj[u]) {
11        if (v == p) continue; // we don't want to go back through the
12                               // same path.
13                               // if we go back is because we found
14                               // another way back
15        if (!disc[v]) { // if V has not been discovered before
16            children++;
17            dfsAP(v, u); // recursive DFS call
18            if (disc[u] <= low[v]) // condition #1
19                ap[u] = 1;
20            low[u] = min(low[u], low[v]); // low[v] might be an ancestor
21                                         // of u
22        } else // if v was already discovered means that we found an
23            ancestor
24            low[u] = min(low[u], disc[v]); // finds the ancestor with
25            the least discovery time
26    }
27 }

```

```

22     return children;
23 }
24
25 void AP() {
26     ap = low = disc = vector<int>(adj.size());
27     Time = 0;
28     for (int u = 0; u < adj.size(); u++)
29         if (!disc[u])
30             ap[u] = dfsAP(u, u) > 1; // condition #2
31 }

```

4.21 Finding bridges

```

1 // br = bridges, p = parent
2
3 vector<pair<int, int>> br;
4
5 int dfsBR(int u, int p) {
6     low[u] = disc[u] = ++Time;
7     for (int& v : adj[u]) {
8         if (v == p) continue; // we don't want to go back through the
9                               // same path.
9                               // if we go back is because we found
10                               // another way back
11         if (!disc[v]) { // if V has not been discovered before
12             dfsBR(v, u); // recursive DFS call
13             if (disc[u] < low[v]) // condition to find a bridge
14                 br.push_back({u, v});
15             low[u] = min(low[u], low[v]); // low[v] might be an ancestor
16                                         // of u
17         } else // if v was already discovered means that we found an
18             ancestor
19             low[u] = min(low[u], disc[v]); // finds the ancestor with
20             the least discovery time
21     }
22 }
23
24 void BR() {
25     low = disc = vector<int>(adj.size());
26     Time = 0;
27     for (int u = 0; u < adj.size(); u++)
28         if (!disc[u])
29             dfsBR(u, u)
30 }

```

4.22 Finding Bridges Online

```

1 vector<int> par, dsu_2ecc, dsu_cc, dsu_cc_size;

```

```

2 int bridges;
3 int lca_iteration;
4 vector<int> last_visit;
5
6 void init(int n) {
7     par.resize(n);
8     dsu_2ecc.resize(n);
9     dsu_cc.resize(n);
10    dsu_cc_size.resize(n);
11    lca_iteration = 0;
12    last_visit.assign(n, 0);
13    for (int i=0; i<n; ++i) {
14        dsu_2ecc[i] = i;
15        dsu_cc[i] = i;
16        dsu_cc_size[i] = 1;
17        par[i] = -1;
18    }
19    bridges = 0;
20 }
21
22 int find_2ecc(int v) {
23     if (v == -1)
24         return -1;
25     return dsu_2ecc[v] == v ? v : dsu_2ecc[v] = find_2ecc(dsu_2ecc[v]);
26 }
27
28 int find_cc(int v) {
29     v = find_2ecc(v);
30     return dsu_cc[v] == v ? v : dsu_cc[v] = find_cc(dsu_cc[v]);
31 }
32
33 void make_root(int v) {
34     int root = v;
35     int child = -1;
36     while (v != -1) {
37         int p = find_2ecc(par[v]);
38         par[v] = child;
39         dsu_cc[v] = root;
40         child = v;
41         v = p;
42     }
43     dsu_cc_size[root] = dsu_cc_size[child];
44 }
45
46 void merge_path (int a, int b) {
47     ++lca_iteration;
48     vector<int> path_a, path_b;
49     int lca = -1;
50     while (lca == -1) {
51         if (a != -1) {

```

```

52         a = find_2ecc(a);
53         path_a.push_back(a);
54         if (last_visit[a] == lca_iteration){
55             lca = a;
56             break;
57         }
58         last_visit[a] = lca_iteration;
59         a = par[a];
60     }
61     if (b != -1) {
62         b = find_2ecc(b);
63         path_b.push_back(b);
64         if (last_visit[b] == lca_iteration){
65             lca = b;
66             break;
67         }
68         last_visit[b] = lca_iteration;
69         b = par[b];
70     }
71
72 }
73
74 for (int v : path_a) {
75     dsu_2ecc[v] = lca;
76     if (v == lca)
77         break;
78     --bridges;
79 }
80 for (int v : path_b) {
81     dsu_2ecc[v] = lca;
82     if (v == lca)
83         break;
84     --bridges;
85 }
86 }
87
88 void add_edge(int a, int b) {
89     a = find_2ecc(a);
90     b = find_2ecc(b);
91     if (a == b)
92         return;
93
94     int ca = find_cc(a);
95     int cb = find_cc(b);
96
97     if (ca != cb) {
98         ++bridges;
99         if (dsu_cc_size[ca] > dsu_cc_size[cb]) {
100             swap(a, b);
101             swap(ca, cb);
102         }

```

```

103     make_root(a);
104     par[a] = dsu_cc[a] = b;
105     dsu_cc_size[cb] += dsu_cc_size[a];
106 } else {
107     merge_path(a, b);
108 }
109 }

```

4.23 Bridge Tree

```

1 vector<pair<int, int>> g[MAXN];
2 bool used[MAXN], isBridge[MAXM];
3 int comp[MAXN], tin[MAXN], minAncestor[MAXN];
4
5 vector<int> tree[MAXN]; // Store 2-edge-connected component tree.(
6   Bridge tree).
7
8 void dfs(int v, int p) {
9     tin[v] = minAncestor[v] = ++timer;
10    used[v] = 1;
11    for(auto &e: g[v]) {
12        int to, id;
13        tie(to, id) = e;
14        if(to == p) continue;
15        if(used[to]) {
16            minAncestor[v] = min(minAncestor[v], tin[to]);
17        } else {
18            dfs(to, v);
19            minAncestor[v] = min(minAncestor[v], minAncestor[to]);
20            if(minAncestor[to] > tin[v]) {
21                isBridge[id] = true;
22            }
23        }
24    }
25
26 void dfs1(int v, int p) {
27     used[v] = 1;
28     comp[v] = compid;
29     for(auto &e: g[v]) {
30         int to, id;
31         tie(to, id) = e;
32
33         if(isBridge[id]) { // avoid traversing from this edge. so
34             we get full component.
35             continue;
36         }
37         if(used[to]) {
38             continue;

```

```

38     }
39     dfs1(to, v);
40 }
41 }
42
43 vector<pair<int, int>> edges;
44
45 void addEdge(int from, int to, int id) {
46     g[from].push_back({to, id});
47     g[to].push_back({from, id});
48     edges[id] = {from, to};
49 }
50
51 void initB() {
52
53     for(int i = 0; i <= compid; ++i)
54         tree[i].clear();
55     for(int i = 1; i <= N; ++i)
56         used[i] = false;
57     for(int i = 1; i <= M; ++i)
58         isBridge[i] = false;
59
60     timer = 0;
61     compid = 0;
62 }
63
64 void bridge_tree() {
65
66     initB();
67
68     dfs(1, -1); //Assuming graph is connected.
69
70     for(int i = 1; i <= N; ++i)
71         used[i] = 0;
72
73     for(int i = 1; i <= N; ++i) {
74         if(!used[i]) {
75             dfs1(i, -1);
76             ++compid;
77         }
78     }
79
80     for(int i = 1; i <= M; ++i) {
81         if(isBridge[i]) {
82             int u, v;
83             tie(u, v) = edges[i];
84             // connect two componets using edge.
85             tree[comp[u]].push_back(comp[v]);
86             tree[comp[v]].push_back(comp[u]);
87         }
88     }

```

```

89 }
90
91 void init() {
92     edges.clear(); edges.resize(M + 1);
93     for(int i = 1; i <= N; ++i)
94         g[i].clear();
95 }

```

4.24 2-SAT

```

1 struct TwoSatSolver {
2     int n_vars;
3     int n_vertices;
4     vector<vector<int>> adj, adj_t;
5     vector<bool> used;
6     vector<int> order, comp;
7     vector<bool> assignment;
8
9     TwoSatSolver(int _n_vars) : n_vars(_n_vars), n_vertices(2 *
10         n_vars), adj(n_vertices), adj_t(n_vertices), used(
11         n_vertices), order(), comp(n_vertices, -1), assignment(
12         n_vars) {
13         order.reserve(n_vertices);
14     }
15
16     void dfs1(int v) {
17         used[v] = true;
18         for (int u : adj[v]) {
19             if (!used[u])
20                 dfs1(u);
21         }
22         order.push_back(v);
23     }
24
25     void dfs2(int v, int cl) {
26         comp[v] = cl;
27         for (int u : adj_t[v]) {
28             if (comp[u] == -1)
29                 dfs2(u, cl);
30         }
31     }
32
33     bool solve_2SAT() {
34         order.clear();
35         used.assign(n_vertices, false);
36         for (int i = 0; i < n_vertices; ++i) {
37             if (!used[i])
38                 dfs1(i);
39         }
40     }

```

```

37     comp.assign(n_vertices, -1);
38     for (int i = 0, j = 0; i < n_vertices; ++i) {
39         int v = order[n_vertices - i - 1];
40         if (comp[v] == -1)
41             dfs2(v, j++);
42     }
43
44     assignment.assign(n_vars, false);
45     for (int i = 0; i < n_vertices; i += 2) {
46         if (comp[i] == comp[i + 1])
47             return false;
48         assignment[i / 2] = comp[i] > comp[i + 1];
49     }
50     return true;
51 }
52
53 void add_disjunction(int a, bool na, int b, bool nb) {
54     // na and nb signify whether a and b are to be negated
55     a = 2 * a ^ na;
56     b = 2 * b ^ nb;
57     int neg_a = a ^ 1;
58     int neg_b = b ^ 1;
59     adj[neg_a].push_back(b);
60     adj[neg_b].push_back(a);
61     adj_t[b].push_back(neg_a);
62     adj_t[a].push_back(neg_b);
63 }
64
65 static void example_usage() {
66     TwoSatSolver solver(3); // a, b, c
67     solver.add_disjunction(0, false, 1, true); // a v
68     solver.add_disjunction(0, true, 1, true); // not a v
69     solver.add_disjunction(1, false, 2, false); // b v
70     solver.add_disjunction(0, false, 0, false); // a v
71
72     assert(solver.solve_2SAT() == true);
73     auto expected = vector<bool>(True, False, True);
74     assert(solver.assignment == expected);
75 }

```

4.25 Hierholzer's Algorithm (Eulerian Path)

```

1 int n, m;
2 vector<vector<int>> g;
3 vector<int> in, out, path;

```



```

4
5 // Undirected
6
7 int n, m;
8 vector<vector<pair<int, int>>> g;
9 vector<int> path;
10 vector<bool> seen;
11
12 void dfs(int node) {
13     while (!g[node].empty()) {
14         auto [son, idx] = g[node].back();
15         g[node].pop_back();
16         if (seen[idx]) { continue; }
17         seen[idx] = true;
18         dfs(son);
19     }
20     path.push_back(node);
21 }
22
23 // Directed
24 void dfs(int node) {
25     while (!g[node].empty()) {
26         int son = g[node].back();
27         g[node].pop_back();
28         dfs(son);
29     }
30     path.push_back(node);
31 }

```

4.26 Gale-Shapley Algorithm (Stable marriage)

```

1 // Checks if woman 'w' prefers 'm1' over 'm'
2 bool wPrefersM1OverM(vector<vector<int>> &prefer, int w, int m,
3     int m1)
4 {
5     int N = prefer[0].size();
6     for (int i = 0; i < N; i++)
7     {
8         // If m1 comes before m, w prefers
9         // her current engagement
10        if (prefer[w][i] == m1)
11            return true;
12
13        // If m comes before m1, w prefers m
14        if (prefer[w][i] == m)
15            return false;
16    }
17 }

```

```

18 // Implements the stable marriage algorithm
19 vector<int> stableMarriage(vector<vector<int>> &prefer)
20 {
21     int N = prefer[0].size();
22
23     // Stores women's partners
24     vector<int> wPartner(N, -1);
25
26     // Tracks free men
27     vector<bool> mFree(N, false);
28     int freeCount = N;
29
30     while (freeCount > 0)
31     {
32         int m;
33         for (m = 0; m < N; m++)
34             if (!mFree[m])
35                 break;
36
37         // Process each woman in m's preference list
38         for (int i = 0; i < N && !mFree[m]; i++)
39         {
40             int w = prefer[m][i];
41             if (wPartner[w - N] == -1)
42             {
43                 // Engage m and w if w is free
44                 wPartner[w - N] = m;
45                 mFree[m] = true;
46                 freeCount--;
47             }
48             else
49             {
50                 int m1 = wPartner[w - N];
51                 // If w prefers m over her current partner,
52                 // reassign
53                 if (!wPrefersM1OverM(prefer, w, m, m1))
54                 {
55                     wPartner[w - N] = m;
56                     mFree[m] = true;
57                     mFree[m1] = false;
58                 }
59             }
60         }
61         return wPartner;
62 }

```

5 Trees

5.1 Sucesor

```

1 const ll mod=1e9+7;
2 const ll MAX=1e9+1;
3 const int limit=2e5+1;
4 const int m=30;
5 int sucesorM[limit][m];
6 //ascii https://elcodigoascii.com.ar/
7
8 inline void solve()
9 {
10     int n,q; cin>>n>>q;
11     int res,aux;
12     ll k;
13     lFOR(i,n){
14         cin>>sucesorM[i][0];
15     }
16     FOR(j,1,m)
17     {
18         lFOR(i,n)
19         {
20             sucesorM[i][j]=sucesorM[sucesorM[i][j-1]][j-1];
21         }
22     }
23     FO(i,q)
24     {
25         cin>>res>>k;
26         aux=0;
27         while(k)
28         {
29             if(k%2){
30                 res=sucesorM[res][aux];
31             }
32             k/=2;
33             aux++;
34         }
35         cout<<res<<endl;
36     }
37 }

```

5.2 Euler Tour

```

1 const int MAXN = 1e5 + 5;
2
3 vector<int> adj[MAXN];
4 int in_time[MAXN], out_time[MAXN];
5 int timer = 0;

```

```

6
7 struct FenwickTree {
8     vector<int> bit;
9     int n;
10
11     FenwickTree(int n) {
12         this->n = n;
13         bit.assign(n + 1, 0);
14     }
15
16     void update(int idx, int delta) {
17         for (; idx <= n; idx += idx & -idx)
18             bit[idx] += delta;
19     }
20
21     int query(int idx) {
22         int sum = 0;
23         for (; idx > 0; idx -= idx & -idx)
24             sum += bit[idx];
25         return sum;
26     }
27
28     int range_query(int l, int r) {
29         return query(r) - query(l - 1);
30     }
31 };
32
33 void euler_tour(int root) {
34     stack<tuple<int, int, bool>> st;
35     st.push({root, -1, false});
36
37     while (!st.empty()) {
38         auto [u, parent, visited] = st.top();
39         st.pop();
40
41         if (!visited) {
42             in_time[u] = ++timer;
43             st.push({u, parent, true});
44
45             for (auto it = adj[u].rbegin(); it != adj[u].rend(); ++it) {
46                 if (*it != parent) {
47                     st.push({*it, u, false});
48                 }
49             }
50         } else {
51             out_time[u] = ++timer;
52         }
53     }
54 }

```

5.3 Lowest Common Ancestor

```

1 struct LCA {
2     vector<int> height, euler, first, segtree;
3     vector<bool> visited;
4     int n;
5
6     LCA(vector<vector<int>> &adj, int root = 0) {
7         n = adj.size();
8         height.resize(n);
9         first.resize(n);
10        euler.reserve(n * 2);
11        visited.assign(n, false);
12        dfs(adj, root);
13        int m = euler.size();
14        segtree.resize(m * 4);
15        build(1, 0, m - 1);
16    }
17
18    void dfs(vector<vector<int>> &adj, int node, int h = 0) {
19        visited[node] = true;
20        height[node] = h;
21        first[node] = euler.size();
22        euler.push_back(node);
23        for (auto to : adj[node]) {
24            if (!visited[to]) {
25                dfs(adj, to, h + 1);
26                euler.push_back(node);
27            }
28        }
29    }
30
31    void build(int node, int b, int e) {
32        if (b == e) {
33            segtree[node] = euler[b];
34        } else {
35            int mid = (b + e) / 2;
36            build(node << 1, b, mid);
37            build(node << 1 | 1, mid + 1, e);
38            int l = segtree[node << 1], r = segtree[node << 1 |
39                1];
40            segtree[node] = (height[l] < height[r]) ? l : r;
41        }
42    }
43
44    int query(int node, int b, int e, int L, int R) {
45        if (b > R || e < L)
46            return -1;
47        if (b >= L && e <= R)
48            return segtree[node];
49        int mid = (b + e) >> 1;

```

```

49
50        int left = query(node << 1, b, mid, L, R);
51        int right = query(node << 1 | 1, mid + 1, e, L, R);
52        if (left == -1) return right;
53        if (right == -1) return left;
54        return height[left] < height[right] ? left : right;
55    }
56
57    int lca(int u, int v) {
58        int left = first[u], right = first[v];
59        if (left > right)
60            swap(left, right);
61        return query(1, 0, euler.size() - 1, left, right);
62    }
63};

```

5.4 Binary Lifting

```

1 int n, l;
2 vector<vector<int>> adj;
3
4 int timer;
5 vector<int> tin, tout;
6 vector<vector<int>> up;
7
8 void dfs(int v, int p)
9 {
10     tin[v] = ++timer;
11     up[v][0] = p;
12     for (int i = 1; i <= l; ++i)
13         up[v][i] = up[up[v][i-1]][i-1];
14
15     for (int u : adj[v]) {
16         if (u != p)
17             dfs(u, v);
18     }
19
20     tout[v] = ++timer;
21 }
22
23 bool is_ancestor(int u, int v)
24 {
25     return tin[u] <= tin[v] && tout[u] >= tout[v];
26 }
27
28 int lca(int u, int v)
29 {
30     if (is_ancestor(u, v))
31         return u;

```

```

32     if (is_ancestor(v, u))
33         return v;
34     for (int i = 1; i >= 0; --i) {
35         if (!is_ancestor(up[u][i], v))
36             u = up[u][i];
37     }
38     return up[u][0];
39 }
40
41 void preprocess(int root) {
42     tin.resize(n);
43     tout.resize(n);
44     timer = 0;
45     l = ceil(log2(n));
46     up.assign(n, vector<int>(l + 1));
47     dfs(root, root);
48 }

```

5.5 Cartesian Tree

```

1 vector<int> parent(n, -1);
2 stack<int> s;
3 for (int i = 0; i < n; i++) {
4     int last = -1;
5     while (!s.empty() && A[s.top()] >= A[i]) {
6         last = s.top();
7         s.pop();
8     }
9     if (!s.empty())
10         parent[i] = s.top();
11     if (last >= 0)
12         parent[last] = i;
13     s.push(i);
14 }

```

5.6 Heavy-Light Decomposition

```

1 vector<int> parent, depth, heavy, head, pos;
2 int cur_pos;
3
4 int dfs(int v, vector<vector<int>> const& adj) {
5     int size = 1;
6     int max_c_size = 0;
7     for (int c : adj[v]) {
8         if (c != parent[v]) {
9             parent[c] = v, depth[c] = depth[v] + 1;
10            int c_size = dfs(c, adj);
11            size += c_size;

```

```

12            if (c_size > max_c_size)
13                max_c_size = c_size, heavy[v] = c;
14        }
15    }
16    return size;
17 }
18
19 void decompose(int v, int h, vector<vector<int>> const& adj) {
20     head[v] = h, pos[v] = cur_pos++;
21     if (heavy[v] != -1)
22         decompose(heavy[v], h, adj);
23     for (int c : adj[v]) {
24         if (c != parent[v] && c != heavy[v])
25             decompose(c, c, adj);
26     }
27 }
28
29 void init(vector<vector<int>> const& adj) {
30     int n = adj.size();
31     parent = vector<int>(n);
32     depth = vector<int>(n);
33     heavy = vector<int>(n, -1);
34     head = vector<int>(n);
35     pos = vector<int>(n);
36     cur_pos = 0;
37
38     dfs(0, adj);
39     decompose(0, 0, adj);
40 }
41
42 int query(int a, int b) {
43     int res = 0;
44     for (; head[a] != head[b]; b = parent[head[b]]) {
45         if (depth[head[a]] > depth[head[b]])
46             swap(a, b);
47         int cur_heavy_path_max = segment_tree_query(pos[head[b]],
48             pos[b]);
49         res = max(res, cur_heavy_path_max);
50     }
51     if (depth[a] > depth[b])
52         swap(a, b);
53     int last_heavy_path_max = segment_tree_query(pos[a], pos[b]);
54     res = max(res, last_heavy_path_max);
55     return res;
56 }

```

5.7 Centroid Decomposition

```

1 vector<vector<int>> adj;

```

```

2 vector<bool> is_removed;
3 vector<int> subtree_size;
4
5 /** DFS to calculate the size of the subtree rooted at 'node' */
6 int get_subtree_size(int node, int parent = -1) {
7     subtree_size[node] = 1;
8     for (int child : adj[node]) {
9         if (child == parent || is_removed[child]) { continue; }
10        subtree_size[node] += get_subtree_size(child, node);
11    }
12    return subtree_size[node];
13 }
14
15 /**
16  * Returns a centroid (a tree may have two centroids) of the
17  * subtree
18  * containing node 'node' after node removals
19  * @param node current node
20  * @param tree_size size of current subtree after node removals
21  * @param parent parent of u
22  * @return first centroid found
23  */
24 int get_centroid(int node, int tree_size, int parent = -1) {
25     for (int child : adj[node]) {
26         if (child == parent || is_removed[child]) { continue; }
27         if (subtree_size[child] * 2 > tree_size) {
28             return get_centroid(child, tree_size, node);
29         }
30     }
31     return node;
32 }
33
34 /** Build up the centroid decomposition recursively */
35 void build_centroid_decomp(int node = 0) {
36     int centroid = get_centroid(node, get_subtree_size(node));
37
38     // do something
39
40     is_removed[centroid] = true;
41
42     for (int child : adj[centroid]) {
43         if (is_removed[child]) { continue; }
44         build_centroid_decomp(child);
45     }
46 }

```

5.8 Tree Distances

```

2 vector<int> graph[200001];
3 int fir[200001], sec[200001], ans[200001];
4
5 void dfs1(int node = 1, int parent = 0) {
6     for (int i : graph[node])
7         if (i != parent) {
8             dfs1(i, node);
9             if (fir[i] + 1 > fir[node]) {
10                sec[node] = fir[node];
11                fir[node] = fir[i] + 1;
12            } else if (fir[i] + 1 > sec[node]) {
13                sec[node] = fir[i] + 1;
14            }
15        }
16 }
17
18 void dfs2(int node = 1, int parent = 0, int to_p = 0) {
19     ans[node] = max(to_p, fir[node]);
20     for (int i : graph[node])
21         if (i != parent) {
22             if (fir[i] + 1 == fir[node]) dfs2(i, node, max(to_p,
23                sec[node]) + 1);
24             else dfs2(i, node, ans[node] + 1);
25         }
26 }

```

6 Flows

6.1 Ford-Fulkerson Maximum Flow

```

1 int n;
2 vector<vector<int>> capacity;
3 vector<vector<int>> adj;
4
5 int bfs(int s, int t, vector<int>& parent) {
6     fill(parent.begin(), parent.end(), -1);
7     parent[s] = -2;
8     queue<pair<int, int>> q;
9     q.push({s, INF});
10
11     while (!q.empty()) {
12         int cur = q.front().first;
13         int flow = q.front().second;
14         q.pop();
15
16         for (int next : adj[cur]) {
17             if (parent[next] == -1 && capacity[cur][next]) {
18                 parent[next] = cur;

```

```

19         int new_flow = min(flow, capacity[cur][next]);
20         if (next == t)
21             return new_flow;
22         q.push({next, new_flow});
23     }
24 }
25
26 return 0;
27 }
28
29 int maxflow(int s, int t) {
30     int flow = 0;
31     vector<int> parent(n);
32     int new_flow;
33
34     while (new_flow = bfs(s, t, parent)) {
35         flow += new_flow;
36         int cur = t;
37         while (cur != s) {
38             int prev = parent[cur];
39             capacity[prev][cur] -= new_flow;
40             capacity[cur][prev] += new_flow;
41             cur = prev;
42         }
43     }
44
45     return flow;
46 }
47

```

6.2 Dinic's Max Flow

```

1 struct FlowEdge {
2     int v, u;
3     long long cap, flow = 0;
4     FlowEdge(int v, int u, long long cap) : v(v), u(u), cap(cap)
5     {}
6 };
7
8 struct Dinic {
9     const long long flow_inf = 1e18;
10    vector<FlowEdge> edges;
11    vector<vector<int>> adj;
12    int n, m = 0;
13    int s, t;
14    vector<int> level, ptr;
15    queue<int> q;
16
17    Dinic(int n, int s, int t) : n(n), s(s), t(t) {

```

```

17        adj.resize(n);
18        level.resize(n);
19        ptr.resize(n);
20    }
21
22    void add_edge(int v, int u, long long cap) {
23        edges.emplace_back(v, u, cap);
24        edges.emplace_back(u, v, 0);
25        adj[v].push_back(m);
26        adj[u].push_back(m + 1);
27        m += 2;
28    }
29
30    bool bfs() {
31        while (!q.empty()) {
32            int v = q.front();
33            q.pop();
34            for (int id : adj[v]) {
35                if (edges[id].cap == edges[id].flow)
36                    continue;
37                if (level[edges[id].u] != -1)
38                    continue;
39                level[edges[id].u] = level[v] + 1;
40                q.push(edges[id].u);
41            }
42        }
43        return level[t] != -1;
44    }
45
46    long long dfs(int v, long long pushed) {
47        if (pushed == 0)
48            return 0;
49        if (v == t)
50            return pushed;
51        for (int& cid = ptr[v]; cid < (int)adj[v].size(); cid++) {
52            int id = adj[v][cid];
53            int u = edges[id].u;
54            if (level[v] + 1 != level[u])
55                continue;
56            long long tr = dfs(u, min(pushed, edges[id].cap -
57                edges[id].flow));
58            if (tr == 0)
59                continue;
60            edges[id].flow += tr;
61            edges[id ^ 1].flow -= tr;
62            return tr;
63        }
64        return 0;
65    }
66
67    long long flow() {

```

```

67     long long f = 0;
68     while (true) {
69         fill(level.begin(), level.end(), -1);
70         level[s] = 0;
71         q.push(s);
72         if (!bfs())
73             break;
74         fill(ptr.begin(), ptr.end(), 0);
75         while (long long pushed = dfs(s, flow_inf)) {
76             f += pushed;
77         }
78     }
79     return f;
80 }
81 };

```

6.3 Min-cost Flow

```

1 struct Edge
2 {
3     int from, to, capacity, cost;
4 };
5
6 vector<vector<int>> adj, cost, capacity;
7
8 const int INF = 1e9;
9
10 void shortest_paths(int n, int v0, vector<int>& d, vector<int>& p)
11 {
12     d.assign(n, INF);
13     d[v0] = 0;
14     vector<bool> inq(n, false);
15     queue<int> q;
16     q.push(v0);
17     p.assign(n, -1);
18
19     while (!q.empty()) {
20         int u = q.front();
21         q.pop();
22         inq[u] = false;
23         for (int v : adj[u]) {
24             if (capacity[u][v] > 0 && d[v] > d[u] + cost[u][v]) {
25                 d[v] = d[u] + cost[u][v];
26                 p[v] = u;
27                 if (!inq[v]) {
28                     inq[v] = true;
29                     q.push(v);
30                 }
31             }
32         }
33     }
34 }

```

```

31     }
32 }
33 }
34
35 int min_cost_flow(int N, vector<Edge> edges, int K, int s, int t)
36 {
37     adj.assign(N, vector<int>());
38     cost.assign(N, vector<int>(N, 0));
39     capacity.assign(N, vector<int>(N, 0));
40     for (Edge e : edges) {
41         adj[e.from].push_back(e.to);
42         adj[e.to].push_back(e.from);
43         cost[e.from][e.to] = e.cost;
44         cost[e.to][e.from] = -e.cost;
45         capacity[e.from][e.to] = e.capacity;
46     }
47
48     int flow = 0;
49     int cost = 0;
50     vector<int> d, p;
51     while (flow < K) {
52         shortest_paths(N, s, d, p);
53         if (d[t] == INF)
54             break;
55
56         // find max flow on that path
57         int f = K - flow;
58         int cur = t;
59         while (cur != s) {
60             f = min(f, capacity[p[cur]][cur]);
61             cur = p[cur];
62         }
63
64         // apply flow
65         flow += f;
66         cost += f * d[t];
67         cur = t;
68         while (cur != s) {
69             capacity[p[cur]][cur] -= f;
70             capacity[cur][p[cur]] += f;
71             cur = p[cur];
72         }
73
74         if (flow < K)
75             return -1;
76         else
77             return cost;
78     }

```

6.4 Hungarian Algorithm

```

1 vector<int> u (n+1), v (m+1), p (m+1), way (m+1);
2 for (int i=1; i<=n; ++i) {
3     p[0] = i;
4     int j0 = 0;
5     vector<int> minv (m+1, INF);
6     vector<bool> used (m+1, false);
7     do {
8         used[j0] = true;
9         int i0 = p[j0], delta = INF, j1;
10        for (int j=1; j<=m; ++j)
11            if (!used[j]) {
12                int cur = A[i0][j]-u[i0]-v[j];
13                if (cur < minv[j])
14                    minv[j] = cur, way[j] = j0;
15                if (minv[j] < delta)
16                    delta = minv[j], j1 = j;
17            }
18        for (int j=0; j<=m; ++j)
19            if (used[j])
20                u[p[j]] += delta, v[j] -= delta;
21        else
22            minv[j] -= delta;
23        j0 = j1;
24    } while (p[j0] != 0);
25    do {
26        int j1 = way[j0];
27        p[j0] = p[j1];
28        j0 = j1;
29    } while (j0);
30 }
31
32 vector<int> ans (n+1);
33 for (int j=1; j<=m; ++j)
34     ans[p[j]] = j;
35
36 int cost = -v[0];

```

6.5 Kuhn's Algorithm

```

1 int n, k;
2 vector<vector<int>> g;
3 vector<int> mt;
4 vector<bool> used;
5
6 bool try_kuhn(int v) {
7     if (used[v])
8         return false;

```

```

9     used[v] = true;
10    for (int to : g[v]) {
11        if (mt[to] == -1 || try_kuhn(mt[to])) {
12            mt[to] = v;
13            return true;
14        }
15    }
16    return false;
17 }
18
19 int main() {
20     //... reading the graph ...
21
22     mt.assign(k, -1);
23     for (int v = 0; v < n; ++v) {
24         used.assign(n, false);
25         try_kuhn(v);
26     }
27
28     for (int i = 0; i < k; ++i)
29         if (mt[i] != -1)
30             printf("%d %d\n", mt[i] + 1, i + 1);
31 }

```

7 Dynamic Programming

7.1 Coin Problem (Count ways)

```

1 vector<ll> coins(n);
2 for(int i=0; i<n; i++){
3     cin>>coins[i];
4 }
5
6 vector<ll> dp(x+1,0);
7 dp[0] = 1;
8 for(int i=0; i<=x; i++){
9     for(int j=0; j<n; j++){
10        if(i-coins[j]>=0){
11            dp[i] = (dp[i] + dp[i-coins[j]]);
12            dp[i]%=MOD;
13        }
14    }
15 }
16
17
18 cout<<dp[x]<<endl;

```


7.2 Coin Problem (Count sorted ways)

```

1 vector<ll> coins(n);
2 for(int i=0; i<n; i++){
3     cin>>coins[i];
4 }
5
6 int dp[102][1000005];
7 dp[0][0] = 1;
8 for(int i=1; i<=n; i++){
9     for(int j=0; j<=x; j++){
10         dp[i][j] = dp[i-1][j];
11         int l = j-coins[i-1];
12         if(l>=0){
13             dp[i][j] += (dp[i][l])%MOD;
14             dp[i][j]%=MOD;
15         }
16     }
17 }
18
19 cout<<dp[n][x]%MOD<<endl;
20

```

7.3 Coin Problem (Minimum)

```

1 vector<ll> coins(n);
2 for(int i=0; i<n; i++){
3     cin>>coins[i];
4 }
5
6 vector<ll> dp(x+1, INT_MAX);
7 dp[0] = 0;
8 for(int i=0; i<=x; i++){
9     for(int j=0; j<n; j++){
10         if(i-coins[j]>=0){
11             dp[i] = min(dp[i], dp[i-coins[j]]+1);
12         }
13     }
14 }
15
16 if(dp[x] != INT_MAX){
17     cout<<dp[x]<<endl;
18 }else{
19     cout<<"-1"<<endl;
20 }
21

```

7.4 Counting paths

```

1 int n; cin>>n;
2 char grid[n][n];
3 int dp[n][n];
4
5 for(int i=0; i<n; i++){
6     for(int j=0; j<n; j++){
7         cin>>grid[i][j];
8         dp[i][j] = 0;
9     }
10 }
11 if(grid[0][0] != '*')dp[0][0] = 1;
12 else dp[0][0] = 0;
13 for(int i=0; i<n; i++){
14     for(int j=0; j<n; j++){
15         if(grid[i+1][j] == '.' and i+1 < n){
16             dp[i+1][j] += dp[i][j]%MOD;
17         }
18         if(grid[i][j+1] == '.' and j+1 < n){
19             dp[i][j+1] += dp[i][j]%MOD;
20         }
21
22         if(grid[i][j] == '*'){
23             dp[i][j] = 0;
24         }
25     }
26 }
27 cout<<dp[n-1][n-1]%MOD<<endl;
28

```

7.5 Longest Increasing Subsequence

```

1 vector<int> lis(vector<int> const& a) {
2     int n = a.size();
3     vector<int> d(n, 1), p(n, -1);
4     for (int i = 0; i < n; i++) {
5         for (int j = 0; j < i; j++) {
6             if (a[j] < a[i] && d[i] < d[j] + 1) {
7                 d[i] = d[j] + 1;
8                 p[i] = j;
9             }
10        }
11    }
12
13    int ans = d[0], pos = 0;
14    for (int i = 1; i < n; i++) {
15        if (d[i] > ans) {
16            ans = d[i];
17            pos = i;
18        }
19    }
20 }
21

```

```

20
21 vector<int> subseq;
22 while (pos != -1) {
23     subseq.push_back(a[pos]);
24     pos = p[pos];
25 }
26 reverse(subseq.begin(), subseq.end());
27 return subseq;
28 }

```

7.6 Length of LIS

```

1 int lis(vector<ll> const& a) {
2     int n = a.size();
3     const int INF = 1e9;
4     vector<int> d(n+1, INF);
5     d[0] = -INF;
6
7     for (int i = 0; i < n; i++) {
8         int l = upper_bound(d.begin(), d.end(), a[i]) - d.begin();
9         if (d[l-1] < a[i] && a[i] < d[l])
10             d[l] = a[i];
11     }
12
13     int ans = 0;
14     for (int l = 0; l <= n; l++) {
15         if (d[l] < INF)
16             ans = l;
17     }
18     return ans;
19 }

```

7.7 Longest Common Subsequence

```

1 // Returns length of LCS for s1[0..m-1], s2[0..n-1]
2 int lcs(string &s1, string &s2) {
3     int m = s1.size();
4     int n = s2.size();
5
6     // Initializing a matrix of size (m+1)*(n+1)
7     vector<vector<int>> dp(m + 1, vector<int>(n + 1, 0));
8
9     // Building dp[m+1][n+1] in bottom-up fashion
10    for (int i = 1; i <= m; ++i) {
11        for (int j = 1; j <= n; ++j) {
12            if (s1[i - 1] == s2[j - 1])
13                dp[i][j] = dp[i - 1][j - 1] + 1;
14            else

```

```

15                dp[i][j] = max(dp[i - 1][j], dp[i][j - 1]);
16        }
17    }
18
19    // dp[m][n] contains length of LCS for s1[0..m-1]
20    // and s2[0..n-1]
21    return dp[m][n];
22 }

```

7.8 Edit Distance

```

1 int editDistance(string &s1, string &s2) {
2
3     int m = s1.length();
4     int n = s2.length();
5
6     // Create a table to store results of subproblems
7     vector<vector<int>> dp(m + 1, vector<int>(n + 1));
8
9     // Fill the known entries in dp[][]
10    // If one string is empty, then answer
11    // is length of the other string
12    for (int i = 0; i <= m; i++)
13        dp[i][0] = i;
14    for (int j = 0; j <= n; j++)
15        dp[0][j] = j;
16
17    // Fill the rest of dp[][]
18    for (int i = 1; i <= m; i++) {
19        for (int j = 1; j <= n; j++) {
20            if (s1[i - 1] == s2[j - 1])
21                dp[i][j] = dp[i - 1][j - 1];
22            else
23                dp[i][j] = 1 + min({dp[i][j - 1],
24                                dp[i - 1][j],
25                                dp[i - 1][j - 1]});
26        }
27    }
28
29    return dp[m][n];
30 }

```

7.9 Bitmask DP

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 const int limit=20;

```

```

5 vector<pair<ll,ll>> dp((1<<limit));
6 //ascii https://elcodigoascii.com.ar/
7
8 inline void solve()
9 {
10     int n; cin>>n;
11     ll x; cin>>x;
12     vector<ll> weight(n);
13     dp[0]={1,0};
14     FO(i,n) cin>>weight[i];
15     for(ll i=1;i<(1<<n);i++)
16     {
17         dp[i]={n+1,0};
18         for(int j=0;j<n;j++)
19         {
20             if(i&(1<<j))
21             {
22                 pair<ll,ll> aux=dp[i^(1<<j)];
23                 if(aux.second+weight[j]<=x){
24                     aux.second+=weight[j];
25                 }
26                 else{
27                     aux.first++;
28                     aux.second=weight[j];
29                 }
30                 dp[i]=min(dp[i],aux);
31             }
32         }
33     }
34     cout<<dp[(1<<n)-1].first<<endl;
35 }

```

7.10 Digit DP

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 ll dp[20][10][2][2];
5 //ascii https://elcodigoascii.com.ar/
6
7 ll mem(int idx,int tight,int prev,int ld,string s)
8 {
9     if(idx==0)
10     {
11         return 1;
12     }
13     if(dp[idx][prev][ld][tight]!=-1){
14         return dp[idx][prev][ld][tight];
15     }

```

```

16     int k=9;
17     if(tight) k=s[s.size()-idx]-'0';
18     ll sum=0;
19     for(int i=0;i<=k;i++)
20     {
21         if(ld || prev!=i)
22         {
23             int new_ld,new_tight;
24             if(i==0 && ld) new_ld=1;
25             else new_ld=0;
26             if(tight && k==i) new_tight=1;
27             else new_tight=0;
28             sum+=mem(idx-1,new_tight,i,new_ld,s);
29         }
30     }
31     dp[idx][prev][ld][tight]=sum;
32     return sum;
33 }

```

7.11 Double DP

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 const ll MAX=1e6+3;
5 ll dp[MAX][2];
6 //ascii https://elcodigoascii.com.ar/
7
8 inline void solve()
9 {
10     int n; cin>>n;
11     dp[n][0]=1;
12     dp[n][1]=1;
13     for(int i=n-1;i>0;i--)
14     {
15         dp[i][1]=4*dp[i+1][1]+dp[i+1][0];
16         dp[i][0]=2*dp[i+1][0]+dp[i+1][1];
17         dp[i][1]%=mod;
18         dp[i][0]%=mod;
19     }
20     cout<<(dp[1][1]+dp[1][0])%mod<<endl;
21 }

```

8 Math

8.1 Miller Rabin

```

1 bool MillerRabin(u64 n) { // returns true if n is prime, else
  returns false.
2   if (n < 2)
3     return false;
4
5   int r = 0;
6   u64 d = n - 1;
7   while ((d & 1) == 0) {
8     d >>= 1;
9     r++;
10  }
11
12  for (int a : {2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37}) {
13    if (n == a)
14      return true;
15    if (check_composite(n, a, d, r))
16      return false;
17  }
18  return true;
19 }

```

8.2 Sieve of Erathostenes

```

1 int n;
2 vector<bool> is_prime(n+1, true);
3 is_prime[0] = is_prime[1] = false;
4 for (int i = 2; i * i <= n; i++) {
5   if (is_prime[i]) {
6     for (int j = i * i; j <= n; j += i)
7       is_prime[j] = false;
8   }
9 }

```

8.3 Sieve of Eratosthenes (count primes)

```

1 int count_primes(int n) {
2   const int S = 10000;
3
4   vector<int> primes;
5   int nsqrt = sqrt(n);
6   vector<char> is_prime(nsqrt + 2, true);
7   for (int i = 2; i <= nsqrt; i++) {
8     if (is_prime[i]) {
9       primes.push_back(i);
10      for (int j = i * i; j <= nsqrt; j += i)
11        is_prime[j] = false;
12    }

```

```

13  }
14
15  int result = 0;
16  vector<char> block(S);
17  for (int k = 0; k * S <= n; k++) {
18    fill(block.begin(), block.end(), true);
19    int start = k * S;
20    for (int p : primes) {
21      int start_idx = (start + p - 1) / p;
22      int j = max(start_idx, p) * p - start;
23      for (; j < S; j += p)
24        block[j] = false;
25    }
26    if (k == 0)
27      block[0] = block[1] = false;
28    for (int i = 0; i < S && start + i <= n; i++) {
29      if (block[i])
30        result++;
31    }
32  }
33  return result;
34 }

```

8.4 Segmented Sieve

```

1 vector<char> segmentedSieve(long long L, long long R) {
2   // generate all primes up to sqrt(R)
3   long long lim = sqrt(R);
4   vector<char> mark(lim + 1, false);
5   vector<long long> primes;
6   for (long long i = 2; i <= lim; ++i) {
7     if (!mark[i]) {
8       primes.emplace_back(i);
9       for (long long j = i * i; j <= lim; j += i)
10        mark[j] = true;
11    }
12  }
13
14  vector<char> isPrime(R - L + 1, true);
15  for (long long i : primes)
16    for (long long j = max(i * i, (L + i - 1) / i * i); j <= R; j += i)
17      isPrime[j - L] = false;
18  if (L == 1)
19    isPrime[0] = false;
20  return isPrime;
21 }

```

8.5 Linear sieve

[style=compactcpp]

```
const int N = 10000000;
vector<int> lp(N+1);
vector<int> pr;

for (int i=2; i <= N; ++i) {
    if (lp[i] == 0) {
        lp[i] = i;
        pr.push_back(i);
    }
    for (int j = 0; i * pr[j] <= N; ++j) {
        lp[i * pr[j]] = pr[j];
        if (pr[j] == lp[i]) {
            break;
        }
    }
}
```

8.6 Sum of divisors

```
long long SumOfDivisors(long long num) {
    long long total = 1;

    for (int i = 2; (long long)i * i <= num; i++) {
        if (num % i == 0) {
            int e = 0;
            do {
                e++;
                num /= i;
            } while (num % i == 0);

            long long sum = 0, pow = 1;
            do {
                sum += pow;
                pow *= i;
            } while (e-- > 0);
            total *= sum;
        }
    }
}
```

```
    }
    if (num > 1) {
        total *= (1 + num);
    }
    return total;
}
```

8.7 Finding the divisors of a number (Trial Division)

```
1 vector<long long> trial_division2(long long n) {
2     vector<long long> factorization;
3     while (n % 2 == 0) {
4         factorization.push_back(2);
5         n /= 2;
6     }
7     for (long long d = 3; d * d <= n; d += 2) {
8         while (n % d == 0) {
9             factorization.push_back(d);
10            n /= d;
11        }
12    }
13    if (n > 1)
14        factorization.push_back(n);
15    return factorization;
16 }
```

8.8 Finding the divisors of a number (Fermat)

```
1 int fermat(int n) {
2     int a = ceil(sqrt(n));
3     int b2 = a*a - n;
4     int b = round(sqrt(b2));
5     while (b * b != b2) {
6         a = a + 1;
7         b2 = a*a - n;
8         b = round(sqrt(b2));
9     }
10    return a - b;
11 }
```

8.9 Factorials

```
// Precompute factorials and inverse factorials
void precompute(ll n = MAXN - 1) {
```

```

factorial[0] = factorial[1] = 1;

// Compute factorials
for (ll i = 2; i <= n; i++) {
    factorial[i] = (factorial[i - 1] * i) % MOD;
}

// Compute inverse factorials efficiently
inv_factorial[n] = modInv(factorial[n]);
for (ll i = n - 1; i >= 0; i--) {
    inv_factorial[i] =
        (inv_factorial[i + 1] * (i + 1)) % MOD;
}
}

```

8.10 Bincpow

```

1 long long binpow(long long a, long long b) {
2     long long res = 1;
3     while (b > 0) {
4         if (b & 1)
5             res = res * a;
6         a = a * a;
7         b >>= 1;
8     }
9     return res;
10 }

```

8.11 Modulo Inverse

```

1 int modInverse(int A, int M) {
2     int m0 = M;
3     int y = 0, x = 1;
4
5     if (M == 1)
6         return 0;
7
8     while (A > 1) {
9         // q is quotient
10        int q = A / M;
11        int t = M;
12
13        // m is remainder now, process same as
14        // Euclid's algo

```

```

15        M = A % M, A = t;
16        t = y;
17
18        // Update y and x
19        y = x - q * y;
20        x = t;
21    }
22
23    // Make x positive
24    if (x < 0)
25        x += m0;
26
27    return x;
28 }

```

8.12 BinPow Modulo Inv

```

ll modInv(ll a, ll mod = MOD) {
    return power(a, mod - 2, mod);
}

```

8.13 Binomial Coefficients

```

1 long long binomial_coefficient(int n, int k) {
2     return factorial[n] * inverse_factorial[k] % m *
3         inverse_factorial[n - k] % m;
}

```

8.14 Newton Method (Sqrt and iSqrt)

```

1 double sqrt_newton(double n) {
2     const double eps = 1E-15;
3     double x = 1;
4     for (;;) {
5         double nx = (x + n / x) / 2;
6         if (abs(x - nx) < eps)
7             break;
8         x = nx;
9     }
10    return x;
11 }
12
13 int isqrt_newton(int n) {
14     int x = 1;
15     bool decreased = false;
16     for (;;) {

```

```

17     int nx = (x + n / x) >> 1;
18     if (x == nx || nx > x && decreased)
19         break;
20     decreased = nx < x;
21     x = nx;
22 }
23 return x;
24 }

```

8.15 Integration with Simpson Method

```

1 const int N = 1000 * 1000; // number of steps (already multiplied
  by 2)
2
3 double simpson_integration(double a, double b){
4     double h = (b - a) / N;
5     double s = f(a) + f(b); // a = x_0 and b = x_2n
6     for (int i = 1; i <= N - 1; ++i) { // Refer to final Simpson's
7         // formula
8         double x = a + h * i;
9         s += f(x) * ((i & 1) ? 4 : 2);
10    }
11    s *= h / 3;
12    return s;
13 }

```

8.16 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)
14    in [l, r]
15 }

```

8.17 DP Pascal triangle 1D

```

1 int binomialCoeff(int n, int k) {
2     vector<int> dp(k + 1);
3
4     // nC0 is 1
5     dp[0] = 1;
6
7     for (int i = 1; i <= n; i++) {
8
9         // Compute next row of pascal triangle using
10        // the previous row
11        for (int j = min(i, k); j > 0; j--)
12            dp[j] = dp[j] + dp[j - 1];
13    }
14    return dp[k];
15 }

```

8.18 DP Pascal triangle 2D

```

1 // Returns value of Binomial Coefficient C(n, k)
2 int binomialCoeff(int n, int k) {
3     vector<vector<int>> dp(n + 1, vector<int> (k + 1));
4
5     // Calculate value of Binomial Coefficient
6     // in bottom up manner
7     for (int i = 0; i <= n; i++) {
8         for (int j = 0; j <= min(i, k); j++) {
9
10            // Base Cases
11            if (j == 0 || j == i)
12                dp[i][j] = 1;
13
14            // Calculate value using previously
15            // stored values
16            else
17                dp[i][j] = dp[i - 1][j - 1] + dp[i - 1][j];
18        }
19    }
20
21    return dp[n][k];
22 }

```

8.19 Euler's Totient

```

1 void phi_1_to_n(int n) {
2     vector<int> phi(n + 1);
3     for (int i = 0; i <= n; i++)
4         phi[i] = i;
5 }

```

```

5
6   for (int i = 2; i <= n; i++) {
7       if (phi[i] == i) {
8           for (int j = i; j <= n; j += i)
9               phi[j] -= phi[j] / i;
10      }
11  }
12 }
13
14 void phi_1_to_n(int n) {
15     vector<int> phi(n + 1);
16     phi[0] = 0;
17     phi[1] = 1;
18     for (int i = 2; i <= n; i++)
19         phi[i] = i - 1;
20
21     for (int i = 2; i <= n; i++)
22         for (int j = 2 * i; j <= n; j += i)
23             phi[j] -= phi[i];
24 }

```

8.20 Diophantine equations

```

1 void shift_solution(int & x, int & y, int a, int b, int cnt) {
2     x += cnt * b;
3     y -= cnt * a;
4 }
5
6 int find_all_solutions(int a, int b, int c, int minx, int maxx,
7 int miny, int maxy) {
8     int x, y, g;
9     if (!find_any_solution(a, b, c, x, y, g))
10         return 0;
11     a /= g;
12     b /= g;
13
14     int sign_a = a > 0 ? +1 : -1;
15     int sign_b = b > 0 ? +1 : -1;
16
17     shift_solution(x, y, a, b, (minx - x) / b);
18     if (x < minx)
19         shift_solution(x, y, a, b, sign_b);
20     if (x > maxx)
21         return 0;
22     int lx1 = x;
23
24     shift_solution(x, y, a, b, (maxx - x) / b);
25     if (x > maxx)
26         shift_solution(x, y, a, b, -sign_b);

```

```

26     int rx1 = x;
27
28     shift_solution(x, y, a, b, -(miny - y) / a);
29     if (y < miny)
30         shift_solution(x, y, a, b, -sign_a);
31     if (y > maxy)
32         return 0;
33     int lx2 = x;
34
35     shift_solution(x, y, a, b, -(maxy - y) / a);
36     if (y > maxy)
37         shift_solution(x, y, a, b, sign_a);
38     int rx2 = x;
39
40     if (lx2 > rx2)
41         swap(lx2, rx2);
42     int lx = max(lx1, lx2);
43     int rx = min(rx1, rx2);
44
45     if (lx > rx)
46         return 0;
47     return (rx - lx) / abs(b) + 1;
48 }

```

8.21 Discrete Log

```

1 // Returns minimum x for which a ^ x % m = b % m.
2 int solve(int a, int b, int m) {
3     a %= m, b %= m;
4     int k = 1, add = 0, g;
5     while ((g = gcd(a, m)) > 1) {
6         if (b == k)
7             return add;
8         if (b % g)
9             return -1;
10        b /= g, m /= g, ++add;
11        k = (k * 1ll * a / g) % m;
12    }
13
14    int n = sqrt(m) + 1;
15    int an = 1;
16    for (int i = 0; i < n; ++i)
17        an = (an * 1ll * a) % m;
18
19    unordered_map<int, int> vals;
20    for (int q = 0, cur = b; q <= n; ++q) {
21        vals[cur] = q;
22        cur = (cur * 1ll * a) % m;
23    }

```



```

24
25     for (int p = 1, cur = k; p <= n; ++p) {
26         cur = (cur * 1ll * an) % m;
27         if (vals.count(cur)) {
28             int ans = n * p - vals[cur] + add;
29             return ans;
30         }
31     }
32     return -1;
33 }

```

9 Polynomials

9.1 FFT

```

1  using cd = complex<double>;
2  const double PI = acos(-1);
3
4  int reverse(int num, int lg_n) {
5      int res = 0;
6      for (int i = 0; i < lg_n; i++) {
7          if (num & (1 << i))
8              res |= 1 << (lg_n - 1 - i);
9      }
10     return res;
11 }
12
13 void fft(vector<cd> & a, bool invert) {
14     int n = a.size();
15     int lg_n = 0;
16     while ((1 << lg_n) < n)
17         lg_n++;
18
19     for (int i = 0; i < n; i++) {
20         if (i < reverse(i, lg_n))
21             swap(a[i], a[reverse(i, lg_n)]);
22     }
23
24     for (int len = 2; len <= n; len <= 1) {
25         double ang = 2 * PI / len * (invert ? -1 : 1);
26         cd wlen(cos(ang), sin(ang));
27         for (int i = 0; i < n; i += len) {
28             cd w(1);
29             for (int j = 0; j < len / 2; j++) {
30                 cd u = a[i+j], v = a[i+j+len/2] * w;
31                 a[i+j] = u + v;
32                 a[i+j+len/2] = u - v;
33                 w *= wlen;

```

```

34     }
35 }
36
37 if (invert) {
38     for (cd & x : a)
39         x /= n;
40 }
41
42 }
43
44 vector<int> multiply(vector<int> const& a, vector<int> const& b) {
45     vector<cd> fa(a.begin(), a.end()), fb(b.begin(), b.end());
46     int n = 1;
47     while (n < a.size() + b.size())
48         n <= 1;
49     fa.resize(n);
50     fb.resize(n);
51
52     fft(fa, false);
53     fft(fb, false);
54     for (int i = 0; i < n; i++)
55         fa[i] *= fb[i];
56     fft(fa, true);
57
58     vector<int> result(n);
59     for (int i = 0; i < n; i++)
60         result[i] = round(fa[i].real());
61     return result;
62 }
63
64 // Normalization
65
66 int carry = 0;
67 for (int i = 0; i < n; i++){
68     result[i] += carry;
69     carry = result[i] / 10;
70     result[i] %= 10;
71 }

```

9.2 NTT

```

1  const int mod = 7340033;
2  const int root = 5;
3  const int root_1 = 4404020;
4  const int root_pw = 1 << 20;
5
6  void fft(vector<int> & a, bool invert) {
7      int n = a.size();
8

```

```

9   for (int i = 1, j = 0; i < n; i++) {
10       int bit = n >> 1;
11       for (; j & bit; bit >>= 1)
12           j ^= bit;
13       j ^= bit;
14
15       if (i < j)
16           swap(a[i], a[j]);
17   }
18
19   for (int len = 2; len <= n; len <= 1) {
20       int wlen = invert ? root_1 : root;
21       for (int i = len; i < root_pw; i <= 1)
22           wlen = (int)(1LL * wlen * wlen % mod);
23
24       for (int i = 0; i < n; i += len) {
25           int w = 1;
26           for (int j = 0; j < len / 2; j++) {
27               int u = a[i+j], v = (int)(1LL * a[i+j+len/2] * w %
28                   mod);
29               a[i+j] = u + v < mod ? u + v : u + v - mod;
30               a[i+j+len/2] = u - v >= 0 ? u - v : u - v + mod;
31               w = (int)(1LL * w * wlen % mod);
32           }
33       }
34
35       if (invert) {
36           int n_1 = inverse(n, mod);
37           for (int & x : a)
38               x = (int)(1LL * x * n_1 % mod);
39       }
40   }

```

9.3 Berlekamp Messey

```

1   vector<T> berlekampMassey(const vector<T> &s) {
2       vector<T> c; // the linear recurrence sequence we are
3           building
4       vector<T> oldC; // the best previous version of c to use (the
5           one with the rightmost left endpoint)
6       int f = -1; // the index at which the best previous
7           version of c failed on
8       for (int i=0; i<(int)s.size(); i++) {
9           // evaluate c(i)
10          // delta = s_i - \sum_{j=1}^n c_j s_{i-j}
11          // if delta == 0, c(i) is correct
12          T delta = s[i];
13          for (int j=1; j<=(int)c.size(); j++)

```

```

11          delta -= c[j-1] * s[i-j]; // c_j is one-indexed, so
12              we actually need index j - 1 in the code
13      if (delta == 0)
14          continue; // c(i) is correct, keep going
15      // now at this point, delta != 0, so we need to adjust it
16      if (f == -1) {
17          // this is the first time we're updating c
18          // s_i was the first non-zero element we encountered
19          // we make c of length i + 1 so that s_i is part of
20              the base case
21          c.resize(i + 1);
22          mt19937 rng(chrono::steady_clock::now().
23              time_since_epoch().count());
24          for (T &x : c)
25              x = rng(); // just to prove that the initial
26                  values don't matter in the first step, I will
27                  set to random values
28      }
29      f = i;
30      } else {
31          // we need to use a previous version of c to improve
32              on this one
33          // apply the 5 steps to build d
34          // 1. set d equal to our chosen sequence
35          vector<T> d = oldC;
36          // 2. multiply the sequence by -1
37          for (T &x : d)
38              x = -x;
39          // 3. insert a 1 on the left
40          d.insert(d.begin(), 1);
41          // 4. multiply the sequence by delta / d(f + 1)
42          T df1 = 0; // d(f + 1)
43          for (int j=1; j<=(int)d.size(); j++)
44              df1 += d[j-1] * s[f+1-j];
45          assert(df1 != 0);
46          T coef = delta / df1; // storing this in outer
47              variable so it's O(n^2) instead of O(n^2 log MOD)
48          for (T &x : d)
49              x *= coef;
50          // 5. insert i - f - 1 zeros on the left
51          vector<T> zeros(i - f - 1);
52          zeros.insert(zeros.end(), d.begin(), d.end());
53          d = zeros;
54          // now we have our new recurrence: c + d
55          vector<T> temp = c; // save the last version of c
56              because it might have a better left endpoint
57          c.resize(max(c.size(), d.size()));
58          for (int j=0; j<(int)d.size(); j++)
59              c[j] += d[j];
60          // finally, let's consider updating oldC
61          if (i - (int) temp.size() > f - (int) oldC.size()) {
62              // better left endpoint, let's update!

```

```

54         oldC = temp;
55         f = i;
56     }
57 }
58 }
59 return c;
60 }

```

10 Linear Algebra

10.1 Determinant of a Matrix

```

1 const double EPS = 1E-9;
2 int n;
3 vector < vector<double> > a (n, vector<double> (n));
4
5 double det = 1;
6 for (int i=0; i<n; ++i) {
7     int k = i;
8     for (int j=i+1; j<n; ++j)
9         if (abs (a[j][i]) > abs (a[k][i]))
10             k = j;
11     if (abs (a[k][i]) < EPS) {
12         det = 0;
13         break;
14     }
15     swap (a[i], a[k]);
16     if (i != k)
17         det = -det;
18     det *= a[i][i];
19     for (int j=i+1; j<n; ++j)
20         a[i][j] /= a[i][i];
21     for (int j=0; j<n; ++j)
22         if (j != i && abs (a[j][i]) > EPS)
23             for (int k=i+1; k<n; ++k)
24                 a[j][k] -= a[i][k] * a[j][i];
25 }
26
27 cout << det;

```

10.2 Rank of a Matrix

```

1 const double EPS = 1E-9;
2
3 int compute_rank(vector<vector<double>> A) {
4     int n = A.size();
5     int m = A[0].size();

```

```

6
7     int rank = 0;
8     vector<bool> row_selected(n, false);
9     for (int i = 0; i < m; ++i) {
10         int j;
11         for (j = 0; j < n; ++j) {
12             if (!row_selected[j] && abs(A[j][i]) > EPS)
13                 break;
14         }
15
16         if (j != n) {
17             ++rank;
18             row_selected[j] = true;
19             for (int p = i + 1; p < m; ++p)
20                 A[j][p] /= A[j][i];
21             for (int k = 0; k < n; ++k) {
22                 if (k != j && abs(A[k][i]) > EPS) {
23                     for (int p = i + 1; p < m; ++p)
24                         A[k][p] -= A[j][p] * A[k][i];
25                 }
26             }
27         }
28     }
29     return rank;
30 }

```

10.3 Gauss-Jordan

```

1 const double EPS = 1e-9;
2 const int INF = 2; // it doesn't actually have to be infinity or a
3                     // big number
4
5 int gauss (vector < vector<double> > a, vector<double> & ans) {
6     int n = (int) a.size();
7     int m = (int) a[0].size() - 1;
8
9     vector<int> where (m, -1);
10    for (int col=0, row=0; col<m && row<n; ++col) {
11        int sel = row;
12        for (int i=row; i<n; ++i)
13            if (abs (a[i][col]) > abs (a[sel][col]))
14                sel = i;
15        if (abs (a[sel][col]) < EPS)
16            continue;
17        for (int i=col; i<=m; ++i)
18            swap (a[sel][i], a[row][i]);
19        where[col] = row;
20
21        for (int i=0; i<n; ++i)

```

```

21         if (i != row) {
22             double c = a[i][col] / a[row][col];
23             for (int j=col; j<=m; ++j)
24                 a[i][j] -= a[row][j] * c;
25         }
26         ++row;
27     }
28
29     ans.assign (m, 0);
30     for (int i=0; i<m; ++i)
31         if (where[i] != -1)
32             ans[i] = a[where[i]][m] / a[where[i]][i];
33     for (int i=0; i<n; ++i) {
34         double sum = 0;
35         for (int j=0; j<m; ++j)
36             sum += ans[j] * a[i][j];
37         if (abs (sum - a[i][m]) > EPS)
38             return 0;
39     }
40
41     for (int i=0; i<m; ++i)
42         if (where[i] == -1)
43             return INF;
44     return 1;
45 }

```

10.4 Matrix Exponentiation

```

1 #include <bits/stdc++.h>
2 using namespace std;
3
4 using ll = long long;
5
6 const ll MOD = 1e9 + 7;
7
8 using Matrix = array<array<ll, 2>, 2>;
9
10 Matrix mul(Matrix a, Matrix b) {
11     Matrix res = {{0, 0}, {0, 0}};
12     for (int i = 0; i < 2; i++) {
13         for (int j = 0; j < 2; j++) {
14             for (int k = 0; k < 2; k++) {
15                 res[i][j] += a[i][k] * b[k][j];
16                 res[i][j] %= MOD;
17             }
18         }
19     }
20
21     return res;

```

```

22 }
23
24 int main() {
25     ll n;
26     cin >> n;
27
28     Matrix base = {{1, 0}, {0, 1}};
29     Matrix m = {{1, 1}, {1, 0}};
30
31     for (; n > 0; n /= 2, m = mul(m, m)) {
32         if (n & 1) base = mul(base, m);
33     }
34
35     cout << base[0][1];
36 }

```

11 Geometry

11.1 Line Segment Intersection

```

1 // BeginCodeSnip{Point Class}
2 struct Point {
3     int x, y;
4     Point(int a = 0, int b = 0) : x(a), y(b) {}
5
6     friend istream &operator>>(istream &in, Point &p) {
7         int x, y;
8         in >> p.x >> p.y;
9         return in;
10    }
11 };
12 // EndCodeSnip
13
14 int sign(long long num) {
15     if (num < 0) {
16         return -1;
17     } else if (num == 0) {
18         return 0;
19     } else {
20         return 1;
21     }
22 }
23
24 long long trigonometric_sense(Point p, Point p1, Point p2) {
25     return sign(1LL * (p1.x - p.x) * (p2.y - p.y) -
26                1LL * (p2.x - p.x) * (p1.y - p.y));
27 }
28

```

```

29 // Check if the rectangles with [P1, P2] and [P3, P4] as diagonals
    intersect
30 bool quick_check(Point p1, Point p2, Point p3, Point p4) {
31     int x1, x2, x3, x4, y1, y2, y3, y4;
32     x1 = min(p1.x, p2.x), x2 = max(p1.x, p2.x);
33     y1 = min(p1.y, p2.y), y2 = max(p1.y, p2.y);
34     x3 = min(p3.x, p4.x), x4 = max(p3.x, p4.x);
35     y3 = min(p3.y, p4.y), y4 = max(p3.y, p4.y);
36     return x2 < x3 || x4 < x1 || y2 < y3 || y4 < y1;
37 }
38
39 bool check(Point p1, Point p2, Point p3, Point p4) {
40     if (trigonometric_sense(p1, p2, p3) * trigonometric_sense(p1,
41         p2, p4) > 0) {
42         return false;
43     }
44     if (trigonometric_sense(p3, p4, p1) * trigonometric_sense(p3,
45         p4, p2) > 0) {
46         return false;
47     }
48     return true;
49 }
50
51 int main() {
52     int test_num;
53     cin >> test_num;
54     for (int t = 0; t < test_num; t++) {
55         Point p1, p2, p3, p4;
56         cin >> p1 >> p2 >> p3 >> p4;
57
58         if (quick_check(p1, p2, p3, p4)) {
59             cout << "NO" << endl;
60         } else if (check(p1, p2, p3, p4)) {
61             cout << "YES" << endl;
62         } else {
63             cout << "NO" << endl;
64         }
65     }
66 }

```

11.2 Minimum Euclidian Distance

```

1 const ll mod=1e9+7;
2 const ll MAX=8e18;
3 const ll limit=1e9+1;
4 //ascii https://elcodigoascii.com.ar/
5
6 ll distance(point a, point b){
7     return (a.X-b.X)*(a.X-b.X)+(a.Y-b.Y)*(a.Y-b.Y);

```

```

8 }
9
10 inline void solve()
11 {
12     int n; cin>>n;
13     vector<point> sortedX(n);
14     set<point> sortedY;
15     F0(i,n)
16     {
17         ll x,y; cin>>x>>y;
18         sortedX[i]=make_pair(x,y);
19     }
20     sort(all(sortedX));
21     sortedY.insert(make_pair(sortedX[0].Y,sortedX[0].X));
22     ll d,minSquare=MAX;
23     int j=0;
24     FOR(i,1,n)
25     {
26         d=ceil(sqrt(minSquare));
27         while(sortedX[i].X-sortedX[j].X>d)
28         {
29             sortedY.erase(make_pair(sortedX[j].Y,sortedX[j].X));
30             j++;
31         }
32         auto lower=sortedY.lower_bound(make_pair(sortedX[i].Y-d,0)
33             );
34         auto upper=sortedY.upper_bound(make_pair(sortedX[i].Y+d,0)
35             );
36         for(auto pointer=lower;pointer!=upper;pointer++)
37         {
38             minSquare=min(minSquare,distance(*pointer,make_pair(
39                 sortedX[i].Y,sortedX[i].X)));
40         }
41         sortedY.insert(make_pair(sortedX[i].Y,sortedX[i].X));
42     }
43     cout<<minSquare<<endl;
44 }

```

11.3 Point in polygon

```

1 struct point{
2     ll x,y;
3     void show(){
4         cout<<x<<" "<<y<<endl;
5     }
6 };
7
8 int sign(ll a){
9     if(a<0) return -1;

```

```

10     if(a==0) return 0;
11     if(a>0) return 1;
12 }
13
14 int signCP(point p,point p1,point p2)
15 {
16     return sign(1LL*((p1.x-p.x)*(p2.y-p.y)-(p1.y-p.y)*(p2.x-p.x)))
17     ;
18 }
19 bool intersect(point n, point m,point a,point b)
20 {
21     if(signCP(n,a,b)*signCP(m,a,b)>0) return false;
22     if(signCP(a,n,m)*signCP(b,n,m)>0) return false;
23     return true;
24 }
25
26 bool inside(point a,point b,point c){
27     return a.x>=min(b.x,c.x) && a.x<=max(b.x,c.x) && a.y>=min(b.y,
28         c.y)
29     && a.y<=max(b.y,c.y);
30 }
31 inline void solve()
32 {
33     int n,m; cin>>n>>m;
34     vector<point> vertices(n);
35     F0(i,n)
36     {
37         cin>>vertices[i].x>>vertices[i].y;
38     }
39     point query,par,init,first,second;
40     int counter;
41     int resta=0;
42     F0(i,m)
43     {
44         resta=0;
45         counter=0;
46         cin>>query.x>>query.y;
47         par.x=query.x;
48         par.y=-MAX-1;
49         init.x=vertices[0].x;
50         init.y=vertices[0].y;
51         first.x=init.x;
52         first.y=init.y;
53         bool ver=false;
54         for(int j=1;j<=n;j++)
55         {
56             second.x=vertices[j%n].x;
57             second.y=vertices[j%n].y;
58             point AB,u;

```

```

59             AB.x=second.x-first.x;
60             AB.y=second.y-first.y;
61             u.x=second.x-query.x;
62             u.y=second.y-query.y;
63             if((AB.x*u.y-AB.y*u.x)==0 && inside(query,first,second
64                 )){
65                 cout<<"BOUNDARY"<<endl;
66                 ver=true;
67                 break;
68             }
69             if(intersect(query,par,first,second) && first.x<=query
70                 .x && query.x<second.x)
71             {
72                 counter++;
73             }
74             if(intersect(query,par,first,second) && second.x<=
75                 query.x && query.x<first.x){
76                 counter++;
77             }
78             first.x=second.x;
79             first.y=second.y;
80         }
81         point AB,u;
82         AB.x=init.x-first.x;
83         AB.y=init.y-first.y;
84         u.x=init.x-query.x;
85         u.y=init.y-query.y;
86         if(!ver){
87             //if(intersect(query,par,first,init)) counter++;
88             if((counter)&1) cout<<"INSIDE";
89             else cout<<"OUTSIDE";
90             cout<<endl;
91         }
92     }
93 }

```

11.4 Point Location Test

```

1 struct point{
2     double x,y;
3 };
4
5 struct Vector{
6     double a=0,b=0;
7     void getVector(point p1,point p2){
8         a=p2.x-p1.x;
9         b=p2.y-p1.y;
10    }
11 }

```

```

12 double getModulo(){
13     return pow(a*a+b*b,0.5);
14 }
15
16 Vector getUnitarian(){
17     Vector x;
18     x.a=a/getModulo();
19     x.b=b/getModulo();
20     //cout<<x.a<<" "<<x.b<<endl;
21     return x;
22 }
23
24 };
25
26 double dotProduct(Vector x,Vector y)
27 {
28     return x.a*y.a+x.b*y.b;
29 }
30
31 double CrossProduct(Vector x,Vector y)
32 {
33     return x.a*y.b-x.b*y.a;
34 }
35
36 inline void solve()
37 {
38
39     point p1,p2,p3,p4;
40     cin>>p1.x>>p1.y>>p2.x>>p2.y>>p3.x>>p3.y;
41     Vector u,v,t;
42     u.getVector(p1,p3);
43     //cout<<u.a<<" "<<u.b<<endl;
44     v.getVector(p2,p3);
45     if(CrossProduct(u,v)>0) cout<<"LEFT"<<endl;
46     else if(CrossProduct(u,v)<0) cout<<"RIGHT"<<endl;
47     else cout<<"TOUCH"<<endl;
48 }
49

```

11.5 Polygon Area

```

1 struct point{
2     ll x,y;
3 };
4
5 ll CrossP(point a,point b){
6     return a.x*b.y-a.y*b.x;
7 }
8

```

```

9 inline void solve()
10 {
11     int n; cin>>n;
12     ll res=0;
13     point p1,p2,p3;
14     cin>>p3.x>>p3.y;
15     p1.x=p3.x;
16     p1.y=p3.y;
17     F0(i,n-1)
18     {
19         cin>>p2.x>>p2.y;
20         res+=CrossP(p1,p2);
21         p1.x=p2.x;
22         p1.y=p2.y;
23     }
24     res+=CrossP(p1,p3);
25     cout<<abs(res)<<endl;
26 }

```

11.6 Convex Hull

```

1 const ll mod=1e9+7;
2 const ll limit=4e9;
3 //ascii https://elcodigoascii.com.ar/
4
5 int orientation(point a,point b,point c){
6     ll ori=(b.y-c.y)*(b.x-a.x)-(b.y-a.y)*(b.x-c.x);
7     if(ori==0) return 0;
8     if(ori>0) return 1;
9     return 2;
10 }
11
12 void getLastTwo(point &a,point &b,stack<point> &s)
13 {
14     a=s.top();
15     s.pop();
16     b=s.top();
17     s.pop();
18 }
19
20 void show(point a){
21     cout<<a.x<<" "<<a.y<<endl;
22 }
23
24 //Graham scan
25
26 void solve(){
27     int n; cin>>n;
28     vector<point> puntos(n);

```

```

29  F0(i,n){
30      ll a,b; cin>>a>>b;
31      puntos[i]=make_pair(a,b);
32  }
33  sort(all(puntos));
34  //Lower Part
35  stack<point> lower;
36  F0(i,n)
37  {
38      if(lower.size()<2){
39          lower.push(puntos[i]);
40          continue;
41      }
42      point a,b;
43      getLastTwo(a,b,lower);
44      if(orientation(a,b,puntos[i])<2)
45      {
46          lower.push(b);
47          lower.push(a);
48          lower.push(puntos[i]);
49      }
50      else{
51          lower.push(b);
52          i--;
53      }
54  }
55  stack<point> upper;
56  for(int i=n-1;i>=0;i--)
57  {
58      if(upper.size()<2){
59          upper.push(puntos[i]);
60          continue;
61      }
62      point a,b;
63      getLastTwo(a,b,upper);
64      if(orientation(a,b,puntos[i])<2)
65      {
66          upper.push(b);
67          upper.push(a);
68          upper.push(puntos[i]);
69      }
70      else{
71          upper.push(b);
72          i++;
73      }
74  }
75
76  set<point> res;
77
78  while(!lower.empty()){
79      res.insert(lower.top());

```

```

80      lower.pop();
81  }
82  while(!upper.empty()){
83      res.insert(upper.top());
84      upper.pop();
85  }
86  cout<<res.size()<<endl;
87  for(auto c:res) show(c);
88  }

```

11.7 Complex point

```

typedef double T;
typedef complex<T> pt;
#define x real()
#define y imag()

```

```

typedef long long ll;
typedef vector<int> vec;
const ll mod=1e9+7;
const int MAX=2e5+3;

```

// ascii <https://elcodigoascii.com.ar/>

```
T norma(pt a){return a.x*a.x+a.y*a.y;}
```

```

int sgn(T X){
    return (T(0)<X)-(T(0)>X);
}

```

```

pt translate(pt a,pt v){return a+v;}
pt scale(pt p,pt c,T factor){return c+(p-c)*factor;}
pt rot(pt p,T a){return p*polar(1.0,a);}
pt perp(pt p){return pt({-p.y,p.x});}
pt linearFunc(pt p,pt q,pt r,pt fp,pt fq){
    return fp+(r-p)*(fq-fp)/(q-p);
}
T dot(pt v,pt w){ return v.x*w.x+v.y*w.y;}
T cross(pt v,pt w){ return v.x*w.y-v.y*w.x;}

```



```

bool isperp(pt a,pt b){return dot(a,b)==0;}

double angle(pt v,pt w){
    return acos(clamp(dot(v,w)/abs(v)/abs(w),-1.0,-1.0));
}

T orientation(pt a,pt b,pt c){return cross(b-a,c-a);}

bool inAngle(pt a,pt b,pt c,pt p){
    if(orientation(a,b,c)<0) swap(b,c);
    return sgn(orientation(a,b,p))*sgn(orientation(a,c,p))<=0;
}

bool isconvex(vector<pt> p){
    bool hasPos=false,hasNeg=false;
    for(int i=0,n=p.size();i<n;i++){
        int o=orientation(p[i],p[(i+1)%n],p[(i+2)%n]);
        if(o>0) hasPos=true;
        if(o<0) hasNeg=true;
    }
    return !(hasPos && hasNeg);
}

inline void solve()
{
    pt p{3,-4};
    p+=pt({1,2});
    cout<<p<<endl;
    cout<<norma(p)<<endl;
}

```

11.8 Polar sort

```

1 #define x real()
2 #define y imag()
3
4 typedef long long ll;
5 typedef double T;
6 typedef complex<T> pt;
7 typedef vector<int> vec;

```

```

8 const ll mod=1e9+7;
9 const int MAX=2e5+3;
10
11 T cross(pt v,pt w){ return v.x*w.y-v.y*w.x;}
12 T norma(pt a){return a.x*a.x+a.y*a.y;}
13 //ascii https://elcodigoascii.com.ar/
14
15 bool half(pt p){
16     assert(p.x!=0 || p.y!=0);
17     return p.y>0 || (p.y==0 && p.x<0);
18 }
19
20 void polarSort(vector<pt> &v){
21     sort(all(v),[](pt v,pt w){
22         return make_tuple(half(v),0)<make_tuple(half(w),cross(v,w));
23     });
24 }
25
26 void polarSortNorm(vector<pt> &v){
27     sort(all(v),[](pt v,pt w){
28         return make_tuple(half(v),0,norma(v))<make_tuple(half(w),
29             cross(v,w),norma(w));
30     });
31 }
32 inline void solve()
33 {
34 }

```

12 Strings

12.1 Marranadas de Quique

```

1
2 //To Upper and Lower
3 transform(s.begin(), s.end(), s.begin(), ::toupper);
4 transform(s.begin(), s.end(), s.begin(), ::tolower);
5
6 // From i to the end
7 string a = s.substr(i);
8 // From i to j
9 string a = s.substr(i,j);
10
11 int a;
12 int b;
13 int c;
14 char comma;

```

```

15 char colon;
16
17 // Create a stringstream object
18 stringstream ss(fullString);
19 // Extract the strings
20 ss >> a >> colon >> b >> comma >> c;

```

12.2 KMP Algorithm

```

1 // LPS for s, lps[i] could also be defined as the longest prefix
  // which is also a proper suffix
2 vi computeLPS(string s){
3     size_t len = 0;
4     size_t M = s.size();
5     vi lps(M, 0);
6
7     size_t i = 1;
8     while(i < M) {
9         if( s[i] == s[len]){
10             len++;
11             lps[i] = len;
12             i++;
13         } else {
14             if(len != 0){
15                 len = lps[len-1];
16             } else {
17                 lps[i] = 0;
18                 i++;
19             }
20         }
21     }
22
23     return lps;
24 }
25
26 // Get number of occurrences of a pattern in a text using KMP
27 // O(N+M)
28 size_t KMPOccurrences(string pattern, string text){
29     vi lps = computeLPS(pattern); // LPS array
30
31     size_t M = pattern.size();
32     size_t N = text.size();
33
34     size_t i = 0; // Index for text
35     size_t j = 0; // Index for pattern
36
37     size_t cnt = 0; // Counter
38
39     while ((N - i) >= (M - j)) {

```

```

40         // Watch for the pattern
41         if (pattern[j] == text[i]) {
42             j++;
43             i++;
44         }
45
46         // If the full match found
47         if (j == M) {
48             cnt++;
49             j = lps[j - 1];
50         }
51
52         // Mismatch after j matches
53         else if (i < N && pattern[j] != text[i]) {
54             // Do not match lps[0..lps[j-1]] characters,
55             // they will match anyway
56             if (j != 0)
57                 j = lps[j - 1];
58             else
59                 i++;
60         }
61     }
62
63     return cnt;
64 }

```

12.3 Rolling Hash

```

1 // Rolling hash
2 struct Hash {
3     // Prime number and modulo
4     long long p = 31, m = 1e9 + 7;
5     long long hash_value;
6     Hash(const string& s)
7     {
8         long long hash_so_far = 0;
9         long long p_pow = 1;
10        const long long n = s.length();
11        for (long long i = 0; i < n; ++i) {
12            hash_so_far
13                = (hash_so_far + (s[i] - 'a' + 1) * p_pow)
14                  % m;
15            p_pow = (p_pow * p) % m;
16        }
17        hash_value = hash_so_far;
18    }
19    bool operator==(const Hash& other)
20    {
21        return (hash_value == other.hash_value);

```

```

22     }
23 };
24
25 // Usage
26 int main(){
27     string s = "hello";
28
29     return 0;
30 }

```

12.4 Hash marrano

```

1 vector<vector<int>> group_identical_strings(vector<string> const&
  s) {
2     int n = s.size();
3     vector<pair<long long, int>> hashes(n);
4     for (int i = 0; i < n; i++)
5         hashes[i] = {compute_hash(s[i]), i};
6
7     sort(hashes.begin(), hashes.end());
8
9     vector<vector<int>> groups;
10    for (int i = 0; i < n; i++) {
11        if (i == 0 || hashes[i].first != hashes[i-1].first)
12            groups.emplace_back();
13        groups.back().push_back(hashes[i].second);
14    }
15    return groups;
16 }

```

12.5 Suffix Array

```

1 // Structure to store information of a suffix
2 struct suffix
3 {
4     int index;
5     char *suff;
6 };
7
8 // A comparison function used by sort() to compare two suffixes
9 int cmp(struct suffix a, struct suffix b)
10 {
11     return strcmp(a.suff, b.suff) < 0? 1 : 0;
12 }
13
14 // This is the main function that takes a string 'txt' of size n
   as an

```

```

15 // argument, builds and return the suffix array for the given
   string
16 int *buildSuffixArray(char *txt, int n)
17 {
18     // A structure to store suffixes and their indexes
19     struct suffix suffixes[n];
20
21     // Store suffixes and their indexes in an array of structures.
22     // The structure is needed to sort the suffixes alphabetically
23     // and maintain their old indexes while sorting
24     for (int i = 0; i < n; i++)
25     {
26         suffixes[i].index = i;
27         suffixes[i].suff = (txt+i);
28     }
29
30     // Sort the suffixes using the comparison function
31     // defined above.
32     sort(suffixes, suffixes+n, cmp);
33
34     // Store indexes of all sorted suffixes in the suffix array
35     int *suffixArr = new int[n];
36     for (int i = 0; i < n; i++)
37         suffixArr[i] = suffixes[i].index;
38
39     // Return the suffix array
40     return suffixArr;
41 }
42
43 // A utility function to print an array of given size
44 void printArr(int arr[], int n)
45 {
46     for(int i = 0; i < n; i++)
47         cout << arr[i] << " ";
48     cout << endl;
49 }

```

12.6 LCP

```

1 // Structure to store information of a suffix
2 struct suffix
3 {
4     int index; // To store original index
5     int rank[2]; // To store ranks and next rank pair
6 };
7
8 // A comparison function used by sort() to compare two suffixes
9 // Compares two pairs, returns 1 if first pair is smaller
10 int cmp(struct suffix a, struct suffix b)

```

```

11 {
12     return (a.rank[0] == b.rank[0])? (a.rank[1] < b.rank[1] ?1: 0)
13     :
14         (a.rank[0] < b.rank[0] ?1: 0);
15 }
16 // This is the main function that takes a string 'txt' of size n
17 // as an
18 // argument, builds and return the suffix array for the given
19 // string
20 vector<int> buildSuffixArray(string txt, int n)
21 {
22     // A structure to store suffixes and their indexes
23     struct suffix suffixes[n];
24
25     // Store suffixes and their indexes in an array of structures.
26     // The structure is needed to sort the suffixes alphabetically
27     // and maintain their old indexes while sorting
28     for (int i = 0; i < n; i++)
29     {
30         suffixes[i].index = i;
31         suffixes[i].rank[0] = txt[i] - 'a';
32         suffixes[i].rank[1] = ((i+1) < n)? (txt[i + 1] - 'a'): -1;
33     }
34
35     // Sort the suffixes using the comparison function
36     // defined above.
37     sort(suffixes, suffixes+n, cmp);
38
39     // At this point, all suffixes are sorted according to first
40     // 2 characters. Let us sort suffixes according to first 4
41     // characters, then first 8 and so on
42     int ind[n]; // This array is needed to get the index in
43     // suffixes[]
44     // from original index. This mapping is needed to get
45     // next suffix.
46     for (int k = 4; k < 2*n; k = k*2)
47     {
48         // Assigning rank and index values to first suffix
49         int rank = 0;
50         int prev_rank = suffixes[0].rank[0];
51         suffixes[0].rank[0] = rank;
52         ind[suffixes[0].index] = 0;
53
54         // Assigning rank to suffixes
55         for (int i = 1; i < n; i++)
56         {
57             // If first rank and next ranks are same as that of
58             // previous
59             // suffix in array, assign the same new rank to this
60             // suffix

```

```

56         if (suffixes[i].rank[0] == prev_rank &&
57             suffixes[i].rank[1] == suffixes[i-1].rank[1])
58         {
59             prev_rank = suffixes[i].rank[0];
60             suffixes[i].rank[0] = rank;
61         }
62         else // Otherwise increment rank and assign
63         {
64             prev_rank = suffixes[i].rank[0];
65             suffixes[i].rank[0] = ++rank;
66         }
67         ind[suffixes[i].index] = i;
68     }
69
70     // Assign next rank to every suffix
71     for (int i = 0; i < n; i++)
72     {
73         int nextindex = suffixes[i].index + k/2;
74         suffixes[i].rank[1] = (nextindex < n)?
75             suffixes[ind[nextindex]].rank
76             [0]: -1;
77     }
78
79     // Sort the suffixes according to first k characters
80     sort(suffixes, suffixes+n, cmp);
81 }
82
83 // Store indexes of all sorted suffixes in the suffix array
84 vector<int> suffixArr;
85 for (int i = 0; i < n; i++)
86     suffixArr.push_back(suffixes[i].index);
87
88 // Return the suffix array
89 return suffixArr;
90 }
91
92 /* To construct and return LCP */
93 vector<int> kasai(string txt, vector<int> suffixArr)
94 {
95     int n = suffixArr.size();
96
97     // To store LCP array
98     vector<int> lcp(n, 0);
99
100     // An auxiliary array to store inverse of suffix array
101     // elements. For example if suffixArr[0] is 5, the
102     // invSuff[5] would store 0. This is used to get next
103     // suffix string from suffix array.
104     vector<int> invSuff(n, 0);
105
106     // Fill values in invSuff[]

```

```

106 for (int i=0; i < n; i++)
107     invSuff[suffixArr[i]] = i;
108
109 // Initialize length of previous LCP
110 int k = 0;
111
112 // Process all suffixes one by one starting from
113 // first suffix in txt[]
114 for (int i=0; i<n; i++)
115 {
116     /* If the current suffix is at n-1, then we dont
117     have next substring to consider. So lcp is not
118     defined for this substring, we put zero. */
119     if (invSuff[i] == n-1)
120     {
121         k = 0;
122         continue;
123     }
124
125     /* j contains index of the next substring to
126     be considered to compare with the present
127     substring, i.e., next string in suffix array */
128     int j = suffixArr[invSuff[i]+1];
129
130     // Directly start matching from k'th index as
131     // at-least k-1 characters will match
132     while (i+k<n && j+k<n && txt[i+k]==txt[j+k])
133         k++;
134
135     lcp[invSuff[i]] = k; // lcp for the present suffix.
136
137     // Deleting the starting character from the string.
138     if (k>0)
139         k--;
140 }
141
142 // return the constructed lcp array
143 return lcp;
144 }
145
146 // Utility function to print an array
147 void printArr(vector<int>arr, int n)
148 {
149     for (int i = 0; i < n; i++)
150         cout << arr[i] << " ";
151     cout << endl;
152 }

```

12.7 Z Function

```

1 vector<int> z_function(string s) {
2     int n = s.size();
3     vector<int> z(n);
4     int l = 0, r = 0;
5     for(int i = 1; i < n; i++) {
6         if(i < r) {
7             z[i] = min(r - i, z[i - l]);
8         }
9         while(i + z[i] < n && s[z[i]] == s[i + z[i]]) {
10             z[i]++;
11         }
12         if(i + z[i] > r) {
13             l = i;
14             r = i + z[i];
15         }
16     }
17     return z;
18 }

```

12.8 Longest Palindrome

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 const int MAX=1e6+3;
5 vector<int> lps(2*MAX);
6 int n;
7 string s;
8
9 //ascii https://elcodigoascii.com.ar/
10
11 void show(int idx)
12 {
13     int start=(idx-lps[idx])/2;
14     int end=start+lps[idx];
15     for(int i=start;i<end;i++){
16         cout<<s[i];
17     }
18 }
19
20
21 inline void solve()
22 {
23     cin>>s;
24     n=s.size();
25     lps[0]=0;
26     lps[1]=1;
27     int rightCenter,leftCenter,center,curRightCenter,curLeftCenter
28     ;

```

```

28 center=1;
29 rightCenter=center+lps[center];
30 leftCenter=center-lps[center];
31 int maxLPSCenter=1;
32 int diff=-1;
33 bool exp;
34 for(curRightCenter=2; curRightCenter<2*n+1; curRightCenter++)
35 {
36     //Condicion de cambio de centro
37     curLeftCenter=2*center-curRightCenter;
38     diff=rightCenter-curRightCenter;
39     exp=false;
40     if(diff>=0){
41         if(lps[curLeftCenter]<diff){
42             lps[curRightCenter]=lps[curLeftCenter];
43         }
44         else if(lps[curLeftCenter]==diff && rightCenter==2*n)
45         {
46             lps[curRightCenter]=lps[curLeftCenter];
47         }
48         else if(lps[curLeftCenter]==diff && rightCenter<2*n){
49             lps[curRightCenter]=lps[curLeftCenter];
50             exp=true;
51         }
52         else if(lps[curLeftCenter]>diff){
53             lps[curRightCenter]=diff;
54             exp=true;
55         }
56     }
57     else{
58         lps[curRightCenter]=0;
59         exp=true;
60     }
61     if(exp)
62     {
63         while(((curRightCenter+lps[curRightCenter])<2*n &&
64             curRightCenter-lps[curRightCenter]>0)
65             && ((curRightCenter+lps[curRightCenter]+1)%2==0 || s[(
66             curRightCenter+lps[curRightCenter]+1)/2]==s[(
67             curRightCenter-lps[curRightCenter]-1)/2])){
68                 lps[curRightCenter]++;
69             }
70         if(lps[curRightCenter]>lps[maxLPSCenter])
71         {
72             maxLPSCenter=curRightCenter;
73         }
74         if(curRightCenter+lps[curRightCenter]>rightCenter){
75             center=curRightCenter;
76             rightCenter=curRightCenter+lps[curRightCenter];
77         }
78     }
79 }

```

```

76 }
77 show(maxLPSCenter);
78
79 }

```

12.9 String Hashing

```

1 typedef long long ll;
2 typedef vector<int> vec;
3 const ll mod=1e9+7;
4 const int MAX=1e6+3;
5 const ll A=911382323;
6 const ll B=972663749;
7 ll str[MAX];
8 ll pk[MAX];
9 bool prefix[MAX]={false};
10
11
12
13 ll subs(int i,int j)
14 {
15     if(i)
16         return ((str[j]-pk[j-i+1]*str[i-1])%B+B)%B;
17     else
18         return str[j];
19 }
20
21 //ascii https://elcodigoascii.com.ar/
22
23 inline void solve()
24 {
25     string s; cin>>s;
26     memset(prefix,true,sizeof(prefix));
27     str[0]=s[0];
28     pk[0]=1;
29     int n=s.size();
30     for(int i=1;i<n;i++)
31     {
32         str[i]=A*str[i-1]+s[i];
33         pk[i]=pk[i-1]*A;
34         pk[i]%=B;
35         str[i]%=B;
36     }
37     ll aux;
38     bool ver;
39     for(int i=1;i<=n;i++)
40     {
41         aux=subs(0,i-1);
42         for(int j=0;j+i<=n;j+=i)

```

```

43     {
44         if(aux!=subs(j,j+i-1))
45         {
46             //cout<<aux<<" "<<subs(j,j+i-1)<<" "<<i<<" "<<j<<
47             endl;
48             prefix[i]=false;
49             break;
50         }
51         if(!prefix[i]) continue;
52         if(n%i && (subs(n-n%i,n-1)!=subs(0,n%i-1)))
53         {
54             continue;
55         }
56         cout<<i<<" ";
57     }
58 }

```

12.10 Manacher Algorithm

```

1 vector<int> manacher(string s) {
2     string t;
3     for(auto c: s) {
4         t += string("#") + c;
5     }
6     auto res = manacher_odd(t + "#");
7     return vector<int>(begin(res) + 1, end(res) - 1);
8 }

```

12.11 Suffix Automaton

```

1 struct state {
2     int len, link;
3     map<char, int> next;
4 };
5
6 const int MAXLEN = 100000;
7 state st[MAXLEN * 2];
8 int sz, last;
9
10 void sa_init() {
11     st[0].len = 0;
12     st[0].link = -1;
13     sz++;
14     last = 0;
15 }
16
17 void sa_extend(char c) {

```

```

18     int cur = sz++;
19     st[cur].len = st[last].len + 1;
20     int p = last;
21     while (p != -1 && !st[p].next.count(c)) {
22         st[p].next[c] = cur;
23         p = st[p].link;
24     }
25     if (p == -1) {
26         st[cur].link = 0;
27     } else {
28         int q = st[p].next[c];
29         if (st[p].len + 1 == st[q].len) {
30             st[cur].link = q;
31         } else {
32             int clone = sz++;
33             st[clone].len = st[p].len + 1;
34             st[clone].next = st[q].next;
35             st[clone].link = st[q].link;
36             while (p != -1 && st[p].next[c] == q) {
37                 st[p].next[c] = clone;
38                 p = st[p].link;
39             }
40             st[q].link = st[cur].link = clone;
41         }
42     }
43     last = cur;
44 }
45
46 long long get_diff_strings(){
47     long long tot = 0;
48     for(int i = 1; i < sz; i++) {
49         tot += st[i].len - st[st[i].link].len;
50     }
51     return tot;
52 }
53
54 long long get_tot_len_diff_substings() {
55     long long tot = 0;
56     for(int i = 1; i < sz; i++) {
57         long long shortest = st[st[i].link].len + 1;
58         long long longest = st[i].len;
59
60         long long num_strings = longest - shortest + 1;
61         long long cur = num_strings * (longest + shortest) / 2;
62         tot += cur;
63     }
64     return tot;
65 }
66
67 string lcs (string S, string T) {
68     sa_init();

```

```

69   for (int i = 0; i < S.size(); i++)
70       sa_extend(S[i]);
71
72   int v = 0, l = 0, best = 0, bestpos = 0;
73   for (int i = 0; i < T.size(); i++) {
74       while (v && !st[v].next.count(T[i])) {
75           v = st[v].link ;
76           l = st[v].len;
77       }
78       if (st[v].next.count(T[i])) {
79           v = st[v].next[T[i]];
80           l++;
81       }
82       if (l > best) {
83           best = l;
84           bestpos = i;
85       }
86   }
87   return T.substr(bestpos - best + 1, best);
88 }

```

13 Formulas

13.1 Sums

$$c^a + c^{a+1} + \dots + c^b = \frac{c^{b+1} - c^a}{c - 1}, c \neq 1$$

Gauss

$$1 + 2 + 3 + \dots + n = \frac{n(n+1)}{2}$$

Gauss squares

$$1^2 + 2^2 + 3^2 + \dots + n^2 = \frac{n(2n+1)(n+1)}{6}$$

Cubes

$$1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{n^2(n+1)^2}{4}$$

Powers of 4

$$1^4 + 2^4 + 3^4 + \dots + n^4 = \frac{n(2n+1)(n+1)(3n^2+3n-1)}{30}$$

13.2 Catalan numbers

$$C_0 = 1, \quad C_{n+1} = \sum_{i=0}^n C_i C_{n-i} \quad (\text{Recursive})$$

$$C_n = \frac{1}{n+1} \binom{2n}{n} = \binom{2n}{n} - \binom{2n}{n+1} = \frac{(2n)!}{(n+1)!n!} \quad (\text{Closed-form})$$

- **Valid Parentheses:** Count of balanced parentheses expressions with n pairs.
- **Full Binary Trees:** Structurally unique full binary trees with $n+1$ leaves.
- **Polygon Triangulation:** Ways to triangulate a convex $(n+2)$ -gon.
- **Dyck Paths:** Paths from $(0,0)$ to $(2n,0)$ that never dip below the x-axis.
- **Non-Crossing Partitions:** Ways to connect $2n$ points on a circle without crossing chords.
- **Stack Permutations:** Valid stack-sortable permutations of length n .
- **Mountain Ranges:** Sequences of $2n$ up/down steps forming valid mountain ranges.
- **Unique BSTs:** Number of distinct binary search trees with n keys.
- **Diagonal-Avoiding Paths:** Paths in a grid from $(0,0)$ to (n,n) without crossing the diagonal.

13.3 Cayley's Formula

Number of labeled trees of n vertices: n^{n-2} .

Number of rooted forest of n vertices is: $(n+1)^{n-1}$

13.4 Geometric series

Finite:

$$\sum_{k=0}^n ar^k = \begin{cases} a \frac{1-r^{n+1}}{1-r} & \text{if } r \neq 1, \\ a(n+1) & \text{if } r = 1. \end{cases}$$

Infinite:

$$\sum_{k=0}^{\infty} ar^k = \frac{a}{1-r} \quad (\text{converges iff } |r| < 1)$$

13.5 Divisors

The number of divisors of any number n is:

$$\begin{cases} \approx 100 & n < 5 \times 10^4 \\ \approx 500 & n < 1 \times 10^7 \\ \approx 2000 & n < 1 \times 10^{10} \\ \approx 200000 & n < 1 \times 10^{19} \end{cases}$$

13.6 Number of primes between 1 and n

$$\frac{n}{\ln(n)}$$

13.7 Pythagorean triplets

$$a = k \cdot (m^2 - n^2), \quad b = k \cdot (2mn), \quad c = k \cdot (m^2 + n^2)$$

With $m > n > 0$, $k = 0$, $m \perp n$, and either m or n even.

13.8 Derangments

Permutations of a set such that none of the elements appear in their original position.

$$D(n) = (n-1)(D(n-1) + D(n-2)) = nD(n-1) + (-1)^n = \left\lfloor \frac{n!}{e} \right\rfloor$$

14 Miscellaneous

Gus, this is a reminder to add more stuff here

14.1 Kadane's Algorithm

```
1 inline void solve()
2 {
3     int n; cin>>n;
4     vector<int> normal(n);
5     vector<int> rever(n);
6     FO(i,n){
7         cin>>normal[i];
8         rever[i]=-normal[i];
9     }
```

```
10     ll sum = 0, max_sum = -1e9;
11     ll sumr=0;
12     for (int i = 0; i < n; i++) {
13         sum += normal[i];
14         max_sum = max(max_sum, sum);
15         sumr+= rever[i];
16         max_sum=max(max_sum,sumr);
17         if(i%2==1){
18             sum=max(sum,sumr);
19             sumr=max(sum,sumr);
20         }
21         if (sum < 0) sum = 0;
22         if (sumr<0) sumr=0;
23     }
24     cout<<max_sum<<endl;
25     //Geeks for geeks
26     //https://www.geeksforgeeks.org/cses-solutions-maximum-
27     subarray-sum/
```

14.2 Moore's Voting Algorithm

```
1 int majorityElement(vector<int>& nums) {
2     int vote = 0, r = 0;
3     for(int i=0; i<nums.size();i++){
4         if(nums[i] == nums[r])
5             vote++;
6         else
7             vote--;
8         if(vote == 0){
9             r = i;
10            vote = 1;
11        }
12    }
13
14    int cnt = 0;
15    int goal = (nums.size())/2;
16    for(int i=0; i<nums.size(); i++){
17        if(nums[i] == nums[r]){
18            cnt++;
19            if(cnt > goal){
20                break;
21            }
22        }
23    }
24
25    return nums[r];
26 }
```

15 Marranadas de C++

15.1 Compilation

```
g++-13 -std=c++20 name.cpp
```

15.2 Compiler optimizations

```
1 // Makes bit operations faster
2 #pragma GCC target("popcnt")
3
4 //Auto vectorize for-loops and optimizes floating points (assumes
5   associativity and turns off denormals)
6 #pragma GCC optimize("Ofast")
7
8 // Doubles performance of vectorized code, crashes in old
9   computers
10 #pragma GCC target("avx2")
11
12 #pragma GCC optimize("O3,unroll-loops")
13 #pragma GCC target("avx2,bmi,bmi2,lzcnt,popcnt")
```

15.3 Decimal printing

Friendly reminder to use `printf()` with decimals

```
1 cout<< fixed << setprecision(n)<<endl;
```

15.4 Bit tricks

$x \& -x$ is the least bit in x

$c = x \& -x, r = x + c, (((\text{bin_pow}(r, x)) \gg 2) / c)$ OR r next number bigger than x same number of bits set.