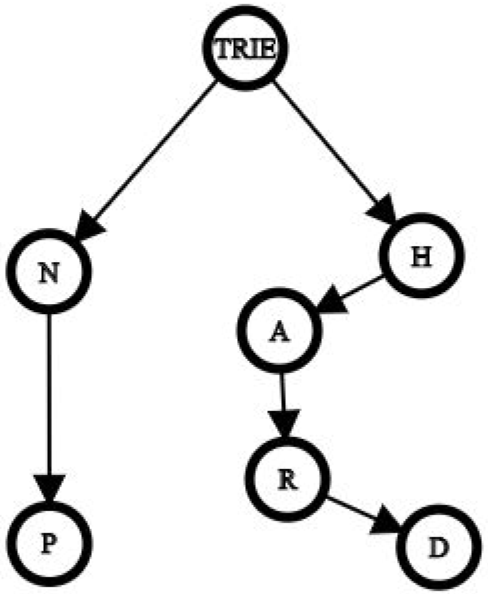
TRIE_NP_HARD (SLRTCE)



TEAM NOTEBOOK (ICPC KOLKATA)

Strongly Connected Components (Kasuraja's Algo):

```
void fillOrder(int v, bool visited[], stack<int> &Stack)
{
   visited[v] = true;
   list<int>::iterator i;
   for(i = adj[v].begin(); i != adj[v].end(); ++i)
      if(!visited[*i])
         fillOrder(*i, visited, Stack);
   Stack.push(v);
}
void printSCCs()
{
   stack<int> Stack;
   bool *visited = new bool[V];
   for(int i = 0; i < V; i++)
      visited[i] = false;
   // Fill vertices in stack according to their finishing times
   for(int i = 0; i < V; i++)
      if(visited[i] == false)
         fillOrder(i, visited, Stack);
   Graph gr = getTranspose();
   for(int i = 0; i < V; i++)
      visited[i] = false;
   while (Stack.empty() == false)
   {
      // Pop a vertex from stack
      int v = Stack.top();
      Stack.pop();
      if (visited[v] == false)
      {
         gr.DFSUtil(v, visited);
         cout << endl;
      }
   }}
```

Articulation Point (cut-vertices):

```
void APUtil(LL u, bool visited[], LL disc[],
                                    LL low[], LL parent[], bool ap[])
{
   static LL time = 0;
   LL children = 0;
   visited[u] = true;
   disc[u] = low[u] = ++time;
   list<LL>::iterator i;
   for (i = adj[u].begin(); i != adj[u].end(); ++i)
   {
      LL v = *i;
      if (!visited[v])
      {
         children++;
         parent[v] = u;
         APUtil(v, visited, disc, low, parent, ap);
         if (parent[u] == NIL && children > 1)
           ap[u] = true;
         if (parent[u] != NIL && low[v] >= disc[u])
           ap[u] = true;
      }.
      else if (v != parent[u])
         low[u]  = min(low[u], disc[v]);
   }
}

void AP()
{
   bool *visited = new bool[V];
   LL *disc = new LL[V];
   LL *low = new LL[V];
   LL *parent = new LL[V];
   bool *ap = new bool[V];
```

```
    for (LL i = 0; i < V; i++)
    {
        parent[i] = NIL;
        visited[i] = false;
        ap[i] = false;
    }
    for (LL i = 0; i < V; i++)
        if (visited[i] == false)
            APUtil(i, visited, disc, low, parent, ap);
    for (LL i = 0; i < V; i++)
        if (ap[i] == true)
            cout << i << " ";
}
```

Bridges:

Replace condition for articulation point with
if (low[v] > disc[u])

Euler path/circuit:

Euler path in undirected graph:
Graph is connected and all vertices have even degree except or 2 have odd degrees.

Euler Circuit in undirected graph:
All vertices have even degree and graph is connected.

Euler circuit in directed graph:
All vertices are a part of a single strongly connected component and indegree and outdegree of all vertices is same,

Bit Manipulation:

1. To multiply by 2^x : S = S<<x
2. To divide by 2^x : S = S>>x
3. To set jth bit : S|=(1<<j)
4. To check jth bit : T = S &(1<<j) (If T=0 not set else set)
5. To turn off jth bit : S&=~(1<<j)
6. To flip jth bit : S^=(1<<j)
7. To get value of LSB: T = (S &(-S)) (Gives 2^position)
8. To turn on all bits S = (1<<n) - 1
in a set of size n:

Techniques:

1. For counting problems, try counting number of incorrect ways instead of correct ways.
2. Prune Infeasible/Inferior Search Space Early
3. Utilize Symmetries
4. Try solving the problem backwards
5.Binary Search the answer
6. Meet in the middle (Solve left half, Solve right half, combine)
7. Greedy
8. DP
9. Analyse complexity carefully
10. Reduce the problem to some standard problem
11. Add m when doing modular arithmetic.
12. Carefully analyse reasoning behind adding small details in the Q.
13. Use exponential search in case of unbounded search.

Hierholzer's algorithm for directed graph:

```
void printCircuit(vector< vector<int> > adj)
{
   unordered_map<int,int> edge_count;

   for (int i=0; i<adj.size(); i++)
   {
      edge_count[i] = adj[i].size();
   }

   if (!adj.size())
      return;
   stack<int> curr_path;
   vector<int> circuit;
   curr_path.push(0);
   int curr_v = 0;

   while (!curr_path.empty())
   {
      if (edge_count[curr_v])
      {
         curr_path.push(curr_v);
         int next_v = adj[curr_v].back();
         edge_count[curr_v]--;
         adj[curr_v].pop_back();
         curr_v = next_v;
      }
      else
      {
         circuit.push_back(curr_v);
         curr_v = curr_path.top();
         curr_path.pop();
      }
   }
```

STL DS:

stack<type> name
empty(),size(),pop(),top(),push(x)

queue<type> name
empty(),size(),pop(),front(),back(),push(x)

priority_queue <type> name
empty(),size(),pop(),top(),push(x)

deque<type> name
pop_front(),pop_back(),push_front(),push_back(),size(),at(index),front()
,back()

set/multiset/map/multimap<type>name
begin(),end(),size(),empty(),insert(val),erase(itr or val),find(val),
lower_bound(val),upper_bound(val)
(lower bound includes val, upper bound does not)
pair<type,type> name (first and second)

STL Algorithms:

1.sort(first_iterator, last_iterator) – To sort the given vector.

2. reverse(first_iterator, last_iterator) – To reverse a vector.

3. *max_element (first_iterator, last_iterator) – To find the maximum element of a vector.

4. *min_element (first_iterator, last_iterator) – To find the minimum element of a vector.

5. accumulate(first_iterator, last_iterator, initial value of sum) – Does the summation of vector elements

```
   for (int i=circuit.size()-1; i>=0; i--)
   {
      cout << circuit[i];
      if (i)
         cout<<" -> ";
   }
}
```

Bipartite graph: Coloring possible with 2 colors.

Ford-Fulkerson max flow Algorithm:

```
bool bfs(int rGraph[V][V], int s, int t, int parent[])
{
   bool visited[V];
   memset(visited, 0, sizeof(visited));
   queue <int> q;
   q.push(s);
   visited[s] = true;
   parent[s] = -1;
   while (!q.empty())
   {
      int u = q.front();
      q.pop();

      for (int v=0; v<V; v++)
      {
         if (visited[v]==false && rGraph[u][v] > 0)
         {
            q.push(v);
            parent[v] = u;
            visited[v] = true;
         }
      }
   }
   return (visited[t] == true);
}
```

6. binary_search(first_iterator, last_iterator, x) – Tests whether x exists in sorted vector or not.

7.lower_bound(first_iterator, last_iterator, x) – returns an iterator pointing to the first element in the range [first,last) which has a value not less than ‘x’.

8.upper_bound(first_iterator, last_iterator, x) – returns an iterator pointing to the first element in the range [first,last) which has a value greater than ‘x’.

9.count(first_iterator, last_iterator,x) – To count the occurrences of x in vector.

10.next_permutation(first_iterator, last_iterator) – This modified the vector to its next permutation.

11.prev_permutation(first_iterator, last_iterator) – This modified the vector to its previous permutation

12. random_shuffle(arr.begin(), arr.end());

13. ios_base::sync_with_stdio(false);
    cin.tie(NULL);

Number Theory:

1. To calculate sum of factors of a number, we can find the number of prime factors and their exponents. N = ae1 * be2 * ce3 …
Then sum = (1 + a + a^2….)(1 + b + b^2 ..)...
Number of factors=(a+1)*(b+1)...

2.Every even integer greater than 2 can be expressed as the sum of 2 primes.

3. For rootn prime method, check for 2, 3 then:

```
int fordFulkerson(int graph[V][V], int s, int t)
{
   int u, v;
   int rGraph[V][V];
   for (u = 0; u < V; u++)
      for (v = 0; v < V; v++)
           rGraph[u][v] = graph[u][v];

   int parent[V];

   int max_flow = 0;
   while (bfs(rGraph, s, t, parent))
   {
      int path_flow = INT_MAX;
      for (v=t; v!=s; v=parent[v])
      {
         u = parent[v];
         path_flow = min(path_flow, rGraph[u][v]);
      }
      for (v=t; v != s; v=parent[v])
      {
         u = parent[v];
         rGraph[u][v] -= path_flow;
         rGraph[v][u] += path_flow;
      }
      max_flow += path_flow;
   }
   return max_flow;
}
```

Maximum Bipartite Matching:

```
bool bpm(bool bpGraph[M][N], int u, bool seen[], int matchR[])
{
   // Try every job one by one
```

for (i=5; i*i<=n; i=i+6) n%i and n%(i+2)

4. Number of divisors will be prime only if N=p^x where p is prime.

5. Kth prime factor= store smallest factor in seive and repeatedly divide with it to get the answer.

6. fib(n+m)=fib(n)fib(m+1)+fib(n-1)fib(m)

7. A number is Fibonacci if and only if one or both of (5*n2 + 4) or (5*n2 – 4) is a perfect square

8. every positive Every positive integer can be written uniquely as a sum of distinct non-neighbouring Fibonacci numbers.

9. Matrix multiplication
mul[i][j] += a[i][k]*b[k][j];

10. Root n under mod p exists only if
n^((p-1)/2) % p = 1

11.divisibility by 4: last 2 digits divisible by 4

12.divisibility by 8: last 3 digits divisible by 8

13. Divisibility by 3,9: sum of digs divisible by 3,9

14. Divisibility by 11: alternate (+ve,-ve) digit sum is divisible by 11

15. Divisibility by 12: divisible by 3 and 4

16. Divisibility by 13: alternating sum in blocks of 3 (L to R) div 13

17. Integral solution of ax+by=c exists if gcd(a,b) divides c

```
    for (int v = 0; v < N; v++)
    {
        // If applicant u is interested in job v and v is
        // not visited
        if (bpGraph[u][v] && !seen[v])
        {
            seen[v] = true; // Mark v as visited
            // If job 'v' is not assigned to an applicant OR
            // previously assigned applicant for job v (which is matchR[v])
            // has an alternate job available.
            // Since v is marked as visited in the above line, matchR[v]
            // in the following recursive call will not get job 'v' again
            if (matchR[v] < 0 || bpm(bpGraph, matchR[v], seen, matchR))
            {
                matchR[v] = u;
                return true;
            }
        }
    }
    return false;
}

int maxBPM(bool bpGraph[M][N])
{
// The value of matchR[i] is the applicant number
// assigned to job i
    int matchR[N];
    memset(matchR, -1, sizeof(matchR));

    int result = 0; // Count of jobs assigned to applicants
    for (int u = 0; u < M; u++)
    {
        // Mark all jobs as not seen for next applicant.
        bool seen[N];
        memset(seen, 0, sizeof(seen));
```

Probability:

P(all events) = P(E1) * P(E2) * ... * P(En)

P(at least one event) = 1 - P(E1') * P(E2') * ... * P(En')

$P(A \cap B) = P(A) + P(B) - P(A \cup B)$

Probability of A if B has happened:
$P(A|B) = P(A \cap B) / P(B)$

expected value is the sum of: [(each of the possible outcomes) × (the probability of the outcome occurring)].

Var(X) = E(X^2) – m^2

Extended Euclid's Algorithm:

```
LL gcde(LL a,LL b,LL *x,LL *y)
{
  if (a == 0)
  {
     *x = 0, *y = 1;
     return b;
  }
  LL x1, y1;
  LL gcd = gcde(b%a, a, &x1, &y1);
  *x = y1 - (b/a) * x1;
  *y = x1;
  return gcd;
}
```

To find inverse of a wrt m:
gcde(a,m,&x,&y);
x is the inverse of a.

```
        // Find if the applicant 'u' can get a job
        if (bpm(bpGraph, u, seen, matchR))
            result++;
    }
    return result;
}
```

Geometry:

1.Area of a regular polygon(equal sides):

$$area = \frac{s^2 n}{4 \tan\left(\frac{180}{n}\right)}$$

2. Angle between (m1, b1) and (m2, b2):

arctan ((m2 − m1) / (m1 · m2 + 1))

3. Triangle: Area = a · b · sin γ / 2

• Area = | x1 · y2 + x2 · y3 + x3 · y1 − y1 · x2 − y2 · x3 − y3 · x1 | / 2

• Heron's formula:

Let s = (a + b + c) / 2; then Area = s · (s − a) · (s − b) · (s − c)

4. Circle: (x − xc)^2+ (y − yc)^2= r^2

5.Polygon area (vertex cordinates):

| x1 · y2 + x2 · y3 + ... + xn · y1 − y1 · x2 − y2 · x3 − ... − yn · x1 | / 2

Segmented Sieve for primes

```
void segsieve(LL l,LL r)
{
  LL limit = floor(sqrt(r))+1;
  vector<LL> prime;
  sieve(limit, prime);
     limit=r-l+1;
     bool mark[limit+1];
     memset(mark, true, sizeof(mark));
    //True= is prime
     for (int i = 0; i < prime.size(); i++)
     {
        int loLim = floor(l/prime[i]) * prime[i];
        if (loLim < l)
           loLim += prime[i];

        for (int j=loLim; j<=r; j+=prime[i])
           mark[j-l] = false;
     }
}
```

Modular power

```
LL Mpow(LL x, unsigned LL y, LL m)
{
  LL res = 1;
  x = x % m;
  while (y > 0)
  {
     if (y & 1)
        res = (res*x) % m;
     y = y>>1; // y = y/2
     x = (x*x) % m; }
  Return res;}
```

Orientation:

```
LL orientation(PoLL p1, PoLL p2, PoLL p3)
{
   LL val = (p2.y - p1.y) * (p3.x - p2.x) -
           (p2.x - p1.x) * (p3.y - p2.y);

   if (val == 0) return 0;  // colinear

   return (val > 0)? 1: 2; // clock or counterclock wise
}
```

Line intersection:

```
bool onSegment(PoLL p, PoLL q, PoLL r)
{
   if (q.x <= max(p.x, r.x) && q.x >= min(p.x, r.x) &&
      q.y <= max(p.y, r.y) && q.y >= min(p.y, r.y))
     return true;
   return false;
}
bool doIntersect(PoLL p1, PoLL q1, PoLL p2, PoLL q2)
{
   LL o1 = orientation(p1, q1, p2);
   LL o2 = orientation(p1, q1, q2);
   LL o3 = orientation(p2, q2, p1);
   LL o4 = orientation(p2, q2, q1);
   if (o1 != o2 && o3 != o4)
      return true;
   if (o1 == 0 && onSegment(p1, p2, q1)) return true;
   if (o2 == 0 && onSegment(p1, q2, q1)) return true;
   if (o3 == 0 && onSegment(p2, p1, q2)) return true;
   if (o4 == 0 && onSegment(p2, q1, q2)) return true;

   return false;}
```

Matrix Exponentiation

```
LL power(LL F[3][3], LL n)
{
   LL M[3][3] = {{1,1,1}, {1,0,0}, {0,1,0}};
   if (n==1)
      return F[0][0] + F[0][1];
   power(F, n/2);
   multiply(F, F);
   if (n%2 != 0)
      multiply(F, M);
   return F[0][0] + F[0][1] ;
}

LL findNthTerm(LL n)
{
   LL F[3][3] = {{1,1,1}, {1,0,0}, {0,1,0}} ;
   return power(F, n-2);
}
```

Euler’s totient:

Number of integers coprime to n less than n

```
LL phi(LL n)
{
   LL result = n;
   for (LL p=2; p*p<=n; ++p)
   {
      if (n % p == 0)
      {
         while (n % p == 0)
            n /= p;
         result -= result / p;
      }
   }
```

Circle intersection area:

```
int areaOfIntersection(x0, y0, r0, x1, y1, r1){
var rr0 = r0*r0;
var rr1 = r1*r1;
var c = Math.sqrt((x1-x0)*(x1- x0) +(y1-y0)*(y1- y0));
var phi =(Math.acos((rr0+(c*c)-rr1) /(2*r0*c)))*2;
var theta =(Math.acos((rr1+(c*c)-rr0) /(2*r1*c)))*2;
var area1 = 0.5*theta*rr1 - 0.5*rr1*Math.sin(theta);
var area2 = 0.5*phi*rr0 - 0.5*rr0*Math.sin(phi);
return area1 + area2;
}
```

Convex Hull:

```
Point nextToTop(stack<Point> &S)
{
   Point p = S.top();
   S.pop();
   Point res = S.top();
   S.push(p);
   return res;
}

int distSq(Point p1, Point p2)
{
   return (p1.x - p2.x)*(p1.x - p2.x) +
         (p1.y - p2.y)*(p1.y - p2.y);
}

int compare(const void *vp1, const void *vp2)
{
  Point *p1 = (Point *)vp1;
  Point *p2 = (Point *)vp2;
```

```
    if (n > 1)
        result -= result / n;
    return result;
}
```

Largest power of p that divides n!

```
// Returns largest power of p that divides n!
int largestPower(int n, int p)
{
    // Initialize result
    int x = 0;

    // Calculate x = n/p + n/(p^2) + n/(p^3) + ....
    while (n)
    {
        n /= p;
        x += n;
    }
    return x;
}
```

nCr (with lucas Theorem):

```
LL ncrp(LL n, LL r, LL p)
{
   LL C[r+1];
   memset(C, 0, sizeof(C));
   C[0] = 1;
   for (LL i = 1; i <= n; i++)
   {
       for ( LL j = min(i, r); j > 0; j--)
           C[j] = (C[j] + C[j-1])%p;
   }
   return C[r];
}
```

```
  int o = orientation(p0, *p1, *p2);
  if (o == 0)
    return (distSq(p0, *p2) >= distSq(p0, *p1))? -1 : 1;
  return (o == 2)? -1: 1;
}

void convexHull(Point points[], int n)
{
  int ymin = points[0].y, min = 0;
  for (int i = 1; i < n; i++)
  {
    int y = points[i].y;
    if ((y < ymin) || (ymin == y &&
        points[i].x < points[min].x))
      ymin = points[i].y, min = i;
  }
  swap(points[0], points[min]);
  p0 = points[0];
  qsort(&points[1], n-1, sizeof(Point), compare);
  int m = 1;
  for (int i=1; i<n; i++)
  {
     // Keep removing i while angle of i and i+1 is same
     while (i < n-1 && orientation(p0, points[i],
                                    points[i+1]) == 0)
        i++;
     points[m] = points[i];
     m++;
  }
  if (m < 3) return;
  stack<Point> S;
  S.push(points[0]);
  S.push(points[1]);
  S.push(points[2]);
  for (int i = 3; i < m; i++)
  {
```

```
LL ncrpl(LL n,LL r, LL p)
{
  if (r==0)
    return 1;
  int ni = n%p, ri = r%p;
  return (ncrpl(n/p, r/p, p) *
          ncrp(ni, ri, p)) % p;
}
```

Chinese Remainder Theorem

```
LL crt(LL num[], LL rem[], LL k)
{
   LL prod = 1;
   for (int i = 0; i < k; i++)
       prod *= num[i];
   LL result = 0;
   for (int i = 0; i < k; i++)
   {
       LL pp = prod / num[i];
       LL inv,y;
       gcde(pp,num[i],&inv,&y);
       result += rem[i] * inv * pp;
   }
   return result % prod;
}
```

For combining wrt a large number, use it 2 numbers at a time.

Wilson’s theorem

((p-1)!)%p=-1

Inclusion-Exclusion:

(A U B)= add 1 at a time, subtract 2 at a time ……

```
      while (orientation(nextToTop(S), S.top(), points[i]) != 2)
        S.pop();
      S.push(points[i]);
   }
   while (!S.empty())
   {
      Point p = S.top();
      cout << "(" << p.x << ", " << p.y <<")" << endl;
      S.pop();
   }
}
```

Point in a polygon:

```
bool isInside(Point polygon[], int n, Point p)
{
    if (n < 3)  return false;
    Point extreme = {INF, p.y};
    int count = 0, i = 0;
    do
    {
        int next = (i+1)%n;
        if (doIntersect(polygon[i], polygon[next], p, extreme))
        {
            if (orientation(polygon[i], p, polygon[next]) == 0)
               return onSegment(polygon[i], p, polygon[next]);

            count++;
        }
        i = next;
    } while (i != 0);
    return count&1;  // Same as (count%2 == 1)
}
```

Number of solutions to a linear eqn:

```
LL countSol(LL coeff[], LL start, LL end, LL rhs)
{
   // Base case
   if (rhs == 0)
      return 1;

   LL result = 0;  // Initialize count of solutions

   // One by subtract all smaller or equal coefficiants and recur
   for (LL i=start; i<=end; i++)
     if (coeff[i] <= rhs)
       result += countSol(coeff, i, end, rhs-coeff[i]);

   return result;
}
```

Sum of GP:

```
long long gp(LL r, LL p,LL m){
if(p==0)
return 1;
if(p==1)
return 1;
LL ans=0;
if(p%2==1){
ans=Mpow(r,p-1,m);
ans=(ans+((1+r)*gp(Mpow(r,2,m),(p-1)/2,m))%m)%m;
}
else{
   ans=((1+r)*gp(Mpow(r,2,m),p/2,m))%m;
}
return ans;
}
```

Game Theory:

1. If nim-sum is non-zero, player starting first wins.
2. Mex: smallest non-negative number not present in a set.
3. Grundy=0 means game lost.
4. Grundy=mex of all possible next states.
5. Sprague-Grundy theorem:

If a game consists of sub games (nim with multiple piles)
Calculate grundy number of each sub game (each pile)
Take xor of all grundy numbers:
If non-zero, player starting first wins.

Pattern Matching:

Suffix Arrays:

```
struct suffix
{
   int index; // To store original index
   int rank[2]; // To store ranks and next rank pair
};
int cmp(struct suffix a, struct suffix b)
{
   return (a.rank[0] == b.rank[0])? (a.rank[1] < b.rank[1] ?1: 0):
             (a.rank[0] < b.rank[0] ?1: 0);
}
int *buildSuffixArray(char *txt, int n)
{
   struct suffix suffixes[n];
   for (int i = 0; i < n; i++)
   {
      suffixes[i].index = i;
      suffixes[i].rank[0] = txt[i] - 'a';
```

Ternary Search (max of unimodal function):

```
double ts(double start, double end)
{
   double l = start, r = end;

   for(int i=0; i<200; i++) {
     double l1 = (l*2+r)/3;
     double l2 = (l+2*r)/3;
     //cout<<l1<<" "<<l2<<endl;
     if(func(l1) > func(l2)) r = l2; else l = l1;
     }
   return func(r);
}
```

Data Structures:

Iterative trie:

```
int trie[MAX_N * 30][3], nxt;
void trie_init(int n) {
   int nn = (n+2)*30;
   for(int i=0; i<nn; i++)
      trie[i][0] = trie[i][1] = trie[i][2] = -1;
   nxt = 1;
}

void trie_insert(int v, int x) {
   int cur = 0;
   for(int i=29; i>=0; i--) {
      int bit = v>>i & 1;
      if(trie[cur][bit]==-1)
         trie[cur][bit] = nxt++;
      cur = trie[cur][bit];
```

```
   suffixes[i].rank[1] = ((i+1) < n)? (txt[i + 1] - 'a'): -1;
}
sort(suffixes, suffixes+n, cmp);
int ind[n];
for (int k = 4; k < 2*n; k = k*2)
{
   int rank = 0;
   int prev_rank = suffixes[0].rank[0];
   suffixes[0].rank[0] = rank;
   ind[suffixes[0].index] = 0;
   for (int i = 1; i < n; i++)
   {
      if (suffixes[i].rank[0] == prev_rank &&
            suffixes[i].rank[1] == suffixes[i-1].rank[1])
      {
         prev_rank = suffixes[i].rank[0];
         suffixes[i].rank[0] = rank;
      }
      else
      {
         prev_rank = suffixes[i].rank[0];
         suffixes[i].rank[0] = ++rank;
      }
      ind[suffixes[i].index] = i;
   }
   for (int i = 0; i < n; i++)
   {
      int nextindex = suffixes[i].index + k/2;
      suffixes[i].rank[1] = (nextindex < n)?
                     suffixes[ind[nextindex]].rank[0]: -1;
   }
   sort(suffixes, suffixes+n, cmp);
}

 // Store indexes of all sorted suffixes in the suffix array
int *suffixArr = new int[n];
```

```
      trie[cur][2] = max(trie[cur][2], x);
   }
}

int trie_getmax(int v, int m) {
   int cur = 0, mx = -1;
   for(int i=29; i>=0; i--) {
      int bit = v>>i & 1;
      if(m>>i & 1)
         cur = trie[cur][!bit];
      else {
         int lt = trie[cur][!bit];
         if(lt!=-1) mx = max(mx, trie[lt][2]);
         cur = trie[cur][bit];
      }
      if(cur==-1) break;
   }
   if(cur!=-1) mx = max(mx, trie[cur][2]);
   return mx;
}
```

Iterative segment tree:

```
void build() {
  for (LL i = n - 1; i > 0; --i) t[i] = t[i<<1] + t[i<<1|1];}

void modify(LL p, LL value) {  // set value at position p
  for (t[p += n] = value; p > 1; p >>= 1) t[p>>1] = t[p] + t[p^1];}

LL query(LL l, LL r) {  // sum on LLerval [l, r)
  LL res = 0;
  for (l += n, r += n; l < r; l >>= 1, r >>= 1) {
    if (l&1) res += t[l++];
    if (r&1) res += t[--r];
  }
  return res;
}
```

```
   for (int i = 0; i < n; i++)
      suffixArr[i] = suffixes[i].index;
   return  suffixArr;
}

void search(char *pat, char *txt, int *suffArr, int n)
{
   int m = strlen(pat);
   int l = 0, r = n-1;
   while (l <= r)
   {
      int mid = l + (r - l)/2;
      int res = strncmp(pat, txt+suffArr[mid], m);
      if (res == 0)
      {
         cout << "Pattern found at index " << suffArr[mid];
         return;
      }
      if (res < 0) r = mid - 1;
      else l = mid + 1;
   }
   cout << "Pattern not found";
}
```

KMP Algorithm:

```
void KMPSearch(char *pat, char *txt)
{
   int M = strlen(pat);
   int N = strlen(txt);
   int lps[M];
   computeLPSArray(pat, M, lps);

   int i = 0;  // index for txt[]
   int j  = 0;  // index for pat[]
```

Lazy Segment tree:

```
LL lconstruct(LL *a,LL *st,LL ss,LL se,LL si)
{
   if(ss==se)
   {
      st[si]=a[ss];
      return st[si];
   }
   LL mid=ss+(se-ss)/2;
   st[si]=(lconstruct(a,st,ss,mid,si*2+1)+lconstruct(a,st,mid+1,se,si*2+2));
   return st[si];
}

LL lgs(LL *st,LL l,LL r,LL ss,LL se,LL si,LL *lazy)
{
   if(lazy[si])
   //same as update
   if(ss>r||se<l||ss>se)
   return 0;
   if(l<=ss&&r>=se)
   {
   return st[si];
   }
   LL mid=ss+(se-ss)/2;
   return (lgs(st,l,r,ss,mid,si*2+1,lazy)+lgs(st,l,r,mid+1,se,si*2+2,lazy));
}


void lupdate(LL *st,LL ss,LL se,LL ql,LL qr,LL diff,LL si,LL *lazy)
{
   if(lazy[si])
   {
      st[si]=(st[si]+(se-ss+1)*lazy[si]);
```

```
   while (i < N)
   {
      if (pat[j] == txt[i])
      {
         j++;
         i++;
      }

      if (j == M)
      {
         printf("Found pattern at index %d n", i-j);
         j = lps[j-1];
      }
      else if (i < N && pat[j] != txt[i])
      {
         if (j != 0)
            j = lps[j-1];
         else
            i = i+1;
      }
   }
}

void computeLPSArray(char *pat, int M, int *lps)
{
   int len = 0;
   lps[0] = 0; // lps[0] is always 0
   int i = 1;
   while (i < M)
   {
      if (pat[i] == pat[len])
      {
         len++;
         lps[i] = len;
         i++;
      }
```

```
    if(ss!=se)
    {
      lazy[si*2+1]=(lazy[si*2+1]+lazy[si]);
      lazy[si*2+2]=(lazy[si*2+2]+lazy[si]);
    }
    lazy[si]=0;
  }
  if(ss>se||qr<ss||ql>se)
  return;
  if(ss>=ql&&se<=qr)
  {
    st[si]=(st[si]+(se-ss+1)*diff);
    if(ss!=se)
    {
      lazy[si*2+1]=(lazy[si*2+1]+diff);
      lazy[si*2+2]=(lazy[si*2+2]+diff);
    }
    return;
  }
  if(ss!=se)
  {
    LL mid=ss+(se-ss)/2;
    lupdate(st,ss,mid,ql,qr,diff,si*2+1,lazy);
    lupdate(st,mid+1,se,ql,qr,diff,si*2+2,lazy);
  }
  st[si]=(st[2*si+1]+st[2*si+2]);
}
```

Policy based DS:

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
typedef tree<int, null_type, less<int>, rb_tree_tag,
tree_order_statistics_node_update> pbds;
insert(val),erase(),order_of_key(),find_by_order()
```

```
      else // (pat[i] != pat[len])
      {
        if (len != 0)
        {
          len = lps[len-1];
        }
        else // if (len == 0)
        {
          lps[i] = 0;
          i++;
        }
      }
    }
}
```

Standard DP

LCS:

```
void lcs( char *X, char *Y, LL m, LL n )
{
  LL L[m+1][n+1];
  for (LL i=0; i<=m; i++)
  {
   for (LL j=0; j<=n; j++)
   {
    if (i == 0 || j == 0)
      L[i][j] = 0;
    else if (X[i-1] == Y[j-1])
      L[i][j] = L[i-1][j-1] + 1;
    else
      L[i][j] = max(L[i-1][j], L[i][j-1]);
   }
  }
  // Following code is used to prLL LCS
```

Union-Find:

```
LL find(struct subset subsets[], LL i)
{
   if (subsets[i].parent != i)
      subsets[i].parent = find(subsets, subsets[i].parent);
   return subsets[i].parent;
}

void Union(struct subset subsets[], LL x, LL y)
{
   LL xroot = find(subsets, x);
   LL yroot = find(subsets, y);
   // Attach smaller rank tree under root of high rank tree
   if (subsets[xroot].rank < subsets[yroot].rank)
      subsets[xroot].parent = yroot;
   else if (subsets[xroot].rank > subsets[yroot].rank)
      subsets[yroot].parent = xroot;
   else
   {
      subsets[yroot].parent = xroot;
      subsets[xroot].rank++;
   }
}
```

Graph Theory

Dijkstra's Algorithm:

```
  LL index = L[m][n];
  char lcs[index+1];
  lcs[index] = '\0'; // Set the terminating character
  LL i = m, j = n;
  while (i > 0 && j > 0)
  {
    if (X[i-1] == Y[j-1])
    {
       lcs[index-1] = X[i-1]; // Put current character in result
       i--; j--; index--;     // reduce values of i, j and index
    }
    else if (L[i-1][j] > L[i][j-1])
      i--;
    else
      j--;
  }
  cout << "LCS of " << X << " and " << Y << " is " << lcs;
}
```

Max contiguous subarray sum (Kadane's Algo):

```
LL maxSubArraySum(LL a[], LL size)
{
  LL max_so_far = a[0];
  LL curr_max = a[0];

  for (LL i = 1; i < size; i++)
  {
      curr_max = max(a[i], curr_max+a[i]);
      max_so_far = max(max_so_far, curr_max);
  }
  return max_so_far;
}
```

```
void Dijkstra(LL src,LL V)
{
   set< pair<LL, LL> > setds;
   vector<LL> dist(V, INF);
   setds.insert(make_pair(0, src));
   dist[src] = 0;
   while (!setds.empty())
   {
      pair<int, int> tmp = *(setds.begin());
      setds.erase(setds.begin());
      int u = tmp.second;
      vector< pair<int, int> >::iterator i;
      for (i = adj[u].begin(); i != adj[u].end(); ++i)
      {
         int v = (*i).first;
         int weight = (*i).second;
         if (dist[v] > dist[u] + weight)
         {
            if (dist[v] != INF)
               setds.erase(setds.find(make_pair(dist[v], v)));
            dist[v] = dist[u] + weight;
            setds.insert(make_pair(dist[v], v));
         }
      }
   }
}
```

Floyd Warshall(All pair)

```
for (k = 0; k < V; k++)
      for (i = 0; i < V; i++)
         for (j = 0; j < V; j++)
            if (dist[i][k] + dist[k][j] < dist[i][j])
               dist[i][j] = dist[i][k] + dist[k][j];
```

LIS in nlogn:

```
LL CeilIndex(std::vector<LL> &v, LL l, LL r, LL key) {
   while (r-l > 1) {
   LL m = l + (r-l)/2;
   if (v[m] >= key)
      r = m;
   else
      l = m;
   }
   return r;
}

LL LongestIncreasingSubsequenceLength(std::vector<LL> &v) {
   if (v.size() == 0)
      return 0;

   std::vector<LL> tail(v.size(), 0);
   LL length = 1; // always poLLs empty slot in tail

   tail[0] = v[0];
   for (size_t i = 1; i < v.size(); i++) {
      if (v[i] < tail[0])
         tail[0] = v[i];
      else if (v[i] > tail[length-1])
         tail[length++] = v[i];
      else
         tail[CeilIndex(tail, -1, length-1, v[i])] = v[i];
   }

   return length;
}
```

Bellman-Ford(for negative edges):

```
void BellmanFord(struct Graph* graph, LL src)
{
   LL V = graph->V;
   LL E = graph->E;
   LL dist[V];
   for (LL i = 0; i < V; i++)
      dist[i]   = INT_MAX;
   dist[src] = 0;
   for (LL i = 1; i <= V-1; i++)
   {
      for (LL j = 0; j < E; j++)
      {
         LL u = graph->edge[j].src;
         LL v = graph->edge[j].dest;
         LL weight = graph->edge[j].weight;
         if (dist[u] != INT_MAX && dist[u] + weight < dist[v])
            dist[v] = dist[u] + weight;
      }
   }//to check for negative weight cycle, repeat above
}   // if shorter path is found, cycle exists
```

Prim's Algorithm for MST

```
void primMST()
{
   priority_queue<pair<LL,LL>,greater<pair<LL,LL>>> pq;
   LL src = 0;
   vector<LL> key(V, INF);
   vector<LL> parent(V, -1);
   vector<bool> inMST(V, false);
   pq.push(make_pair(0, src));
   key[src] = 0;
```

Coin Change Problem:

```
int count( int S[], int m, int n )
{
   int table[n+1];
   memset(table, 0, sizeof(table));

   // Base case (If given value is 0)
   table[0] = 1;
   for(int i=0; i<m; i++)
      for(int j=S[i]; j<=n; j++)
         table[j] += table[j-S[i]];

   return table[n];
}
```

Rod Cutting Problem:

```
LL cutRod(LL price[], LL n)
{
  LL val[n+1];
  val[0] = 0;
  LL i, j;

  // Build the table val[] in bottom up manner and return the last entry
  // from the table
  for (i = 1; i<=n; i++)
  {
     LL max_val = INT_MIN;
     for (j = 0; j < i; j++)
       max_val = max(max_val, price[j] + val[i-j-1]);
     val[i] = max_val;
  }

  return val[n];}
```

```
    while (!pq.empty())
    {
        LL u = pq.top().second;
        pq.pop();
        inMST[u] = true;  // Include vertex in MST
        list< pair<LL, LL> >::iterator i;
        for (i = adj[u].begin(); i != adj[u].end(); ++i)
        {
            LL v = (*i).first;
            LL weight = (*i).second;
            if (inMST[v] == false && key[v] > weight)
            {
                key[v] = weight;
                pq.push(make_pair(key[v], v));
                parent[v] = u;
            }
        }}}
```

LCA:

```
LL par[MAXN][MAXLOG]; // initially all -1
void dfs(LL v,LL p = -1){
        par[v][0] = p;
        if(p + 1)
                h[v] = h[p] + 1;
        for(LL i = 1;i < MAXLOG;i ++)
                if(par[v][i-1] + 1)
                        par[v][i] = par[par[v][i-1]][i-1];
        for(auto u : adj[v])      if(p - u)
                dfs(u,v);
}

LL LCA(LL v,LL u){
        if(h[v] < h[u])
                swap(v,u);
```

Sum Of Subset:

```
bool isSubsetSum(LL set[], LL n, LL sum)
{
    bool subset[n+1][sum+1];
    for (LL i = 0; i <= n; i++)
      subset[i][0] = true;
    for (LL i = 1; i <= sum; i++)
      subset[0][i] = false;
     for (LL i = 1; i <= n; i++)
     {
       for (LL j = 1; j <= sum; j++)
       {
         if(j<set[i-1])
         subset[i][j] = subset[i-1][j];
         if (j >= set[i-1])
           subset[i][j] = subset[i-1][j] ||
                                 subset[i - 1][j-set[i-1]];
       }
     }
     return subset[n][sum];
}
```

Catalan numbers:

1, 1, 2, 5, 14, 42, 132, 429, 1430,........

C(n) =(1/(n+1)) * choose(2n, n);

C(n+1) = Summation(i = 0 to n) [C(i) * C(n-i)]

```
        for(LL i = MAXLOG - 1;i >= 0;i --)
                if(par[v][i] + 1 and h[par[v][i]] >= h[u])
                        v = par[v][i];
        // now h[v] = h[u]
        if(v == u)
                return v;
        for(LL i = MAXLOG - 1;i >= 0;i --)
                if(par[v][i] - par[u][i])
                        v = par[v][i], u = par[u][i];
        return par[v][0];
}
```

Topological Sort:

```
void topologicalSortUtil(LL v, bool visited[],
                    stack<LL> &Stack)
{
   visited[v] = true;
   list<LL>::iterator i;
   for (i = adj[v].begin(); i != adj[v].end(); ++i)
      if (!visited[*i])
         topologicalSortUtil(*i, visited, Stack);
   Stack.push(v);
}

void topologicalSort()
{
   stack<LL> Stack;
   bool *visited = new bool[V];
   for (LL i = 0; i < V; i++)
      visited[i] = false;
   for (LL i = 0; i < V; i++)
     if (visited[i] == false)
      topologicalSortUtil(i, visited, Stack);
```

0/1 Knapsack:

```
LL knapSack(LL W, LL wt[], LL val[], LL n)
{
  LL i, w;
  LL K[n+1][W+1];
  for (i = 0; i <= n; i++)
  {
     for (w = 0; w <= W; w++)
     {
        if (i==0 || w==0)
           K[i][w] = 0;
        else if (wt[i-1] <= w)
             K[i][w] = max(val[i-1] + K[i-1][w-wt[i-1]],  K[i-1][w]);
        else
             K[i][w] = K[i-1][w];
     }
  }
  return K[n][W];
}
```

Egg Drop Problem:

```
LL eggDrop(LL n, LL k)
{
   LL eggFloor[n+1][k+1];
   LL res;
   LL i, j, x;
   for (i = 1; i <= n; i++)
   {
      eggFloor[i][1] = 1;
      eggFloor[i][0] = 0;
   }
   // We always need j trials for one egg and j floors.
   for (j = 1; j <= k; j++)
      eggFloor[1][j] = j;
```

```
    while (Stack.empty() == false)
    {
        cout << Stack.top() << " ";
        Stack.pop();
    }
}
```

```
    for (i = 2; i <= n; i++)
    {
        for (j = 2; j <= k; j++)
        {
            eggFloor[i][j] = INT_MAX;
            for (x = 1; x <= j; x++)
            {
                res = 1 + max(eggFloor[i-1][x-1], eggFloor[i][j-x]);
                if (res < eggFloor[i][j])
                    eggFloor[i][j] = res;
            }
        }
    }
    return eggFloor[n][k];
}
```

Cap Assignment (bit-mask):

```
long long int countWaysUtil(int mask, int i)
{
    if (mask == allmask) return 1;
    if (i > 100) return 0;
    if (dp[mask][i] != -1) return dp[mask][i];
    long long int ways = countWaysUtil(mask, i+1);
    int size = capList[i].size();
    for (int j = 0; j < size; j++)
    {
        if (mask & (1 << capList[i][j])) continue;
        else ways += countWaysUtil(mask | (1 << capList[i][j]), i+1);
        ways %= MOD;
    }
    return dp[mask][i] = ways;
}
```