Chiang Mai University

# PramorKangDamCPP

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2024-09-03

# Contest (1)

## template.cpp

86 lines

```
#include<bits/stdc++.h>
using namespace std;
void __print(int x) {cerr << x;}
void __print(long x) {cerr << x;}
void __print(long long x) {cerr << x;}
void __print(unsigned x) {cerr << x;}
void __print(unsigned long x) {cerr << x;}
void __print(unsigned long long x) {cerr << x;}
void __print(float x) {cerr << x;}
void __print(double x) {cerr << x;}
void __print(long double x) {cerr << x;}
void __print(char x) {cerr << '\'' << x << '\'';}
void __print(const char *x) {cerr << '\"' << x << '\"';}
void __print(const string &x) {cerr << '\"' << x << '\"';}
void __print(bool x) {cerr << (x ? "true" : "false");}

template<typename T, typename V>
void __print(const pair<T, V> &x);
template<typename T>
void __print(const T &x) {int f = 0; cerr << '{'; for (auto &i:
     x) cerr << (f++ ? ", " : ""), __print(i); cerr << "}";}
template<typename T, typename V>
void __print(const pair<T, V> &x) {cerr << '{'; __print(x.first
    ); cerr << ", "; __print(x.second); cerr << '}';}
void _print() {cerr << "]\n";}
template <typename T, typename... V>
void _print(T t, V... v) {__print(t); if (sizeof...(v)) cerr <<
     ", "; _print(v...);}
//#ifdef DEBUG
#define dbg(x...) cerr << "\e[91m"<<__func__<<":"<<__LINE__<<"
    [" << #x << "] = ["; _print(x); cerr << "\e[39m" << endl;
//#else
//#define dbg(x...)
//#endif

typedef long long ll;
typedef long double ld;
typedef complex<ld> cd;

typedef pair<int, int> pi;
typedef pair<ll,ll> pl;
typedef pair<ld,ld> pd;

typedef vector<int> vi;
typedef vector<ld> vd;
typedef vector<ll> vl;
typedef vector<pi> vpi;
typedef vector<pl> vpl;
typedef vector<cd> vcd;

template<class T> using pq = priority_queue<T>;
template<class T> using pqg = priority_queue<T, vector<T>,
    greater<T>>;
#define rep(i, a) for(int i=0;i<a;++i)
#define FOR(i, a, b) for (int i=a; i<(b); i++)
#define F0R(i, a) for (int i=0; i<(a); i++)
#define FORd(i,a,b) for (int i = (b)-1; i >= a; i--)
#define F0Rd(i,a) for (int i = (a)-1; i >= 0; i--)
#define trav(a,x) for (auto& a : x)
#define uid(a, b) uniform_int_distribution<int>(a, b)(rng)

#define sz(x) (int)(x).size()
#define mp make_pair
#define pb push_back
//#define f first
//#define s second
#define lb lower_bound
#define ub upper_bound
#define all(x) x.begin(), x.end()
#define ins insert

template<class T> bool ckmin(T& a, const T& b) { return b < a ?
     a = b, 1 : 0; }
template<class T> bool ckmax(T& a, const T& b) { return a < b ?
     a = b, 1 : 0; }

mt19937 rng(chrono::steady_clock::now().time_since_epoch().
    count());

const char nl = '\n';
const int N =2e5+1;
const int INF = 1e9+7;
const long long LINF = 1e18+7;

void solve(){
}

int main(){
    ios::sync_with_stdio(false);cin.tie(nullptr);
    int t = 1;
    cin>>t;
    while(t--)solve();
}
```

## .vimrc

21 lines

```
"General editor settings
set tabstop=4
set nocompatible
set shiftwidth=4
set expandtab
set autoindent
set smartindent
set ruler
set showcmd
set incsearch
set shellslash
set number
set relativenumber
set cino+=L0

"keybindings for { completion, "jk" for escape, ctrl-a to
    select all
inoremap {<CR>  {<CR>}<Esc>O
inoremap {}     {}
imap jk         <Esc>
map <C-a> <esc>ggVG<CR>
set belloff=all
```

## .bashrc

1 lines

```
export PATH=$PATH:~/scripts/
```

## build.sh

1 lines

```
g++ -static -DLOCAL -lm -s -x c++ -Wall -Wextra -O2 -std=c++17
    -o $1 $1.cpp
```

## stress.sh

22 lines

```
#!/usr/bin/env bash

for ((testNum=0;testNum<$4;testNum++))
do
    ./$3 > input
    ./$2 < input > outSlow
    ./$1 < input > outWrong
    H1=`md5sum outWrong`
    H2=`md5sum outSlow`
    if !(cmp -s "outWrong" "outSlow")
    then
        echo "Error found!"
        echo "Input:"
        cat input
        echo "Wrong Output:"
        cat outWrong
        echo "Slow Output:"
        cat outSlow
        exit
    fi
done
echo Passed $4 tests
```

# Tanya (2)

## SegmentTree.h

**Description:** Segment tree with point update for range sum
**Time:** $\mathcal{O}(\log N)$

efd738, 29 lines

```
//TODO: use 0 base indexing
vector<long long>tree;
void update(int node,int n_l,int n_r,int q_i,long long value){
    if(n_r<q_i || q_i<n_l)return;
    if(q_i==n_l && n_r==q_i){
        tree[node] = value;
        return;
    }
    int mid = (n_r+n_l)/2;
    update(2*node,n_l,mid,q_i,value);
    update(2*node+1,mid+1,n_r,q_i,value);
    tree[node] = tree[2*node] + tree[2*node+1];
}

long long f(int node,int n_l,int n_r,int q_l,int q_r){
    if(n_r<q_l || q_r<n_l)return 0;
    if(q_l<=n_l && n_r<=q_r)return tree[node];
    int mid = (n_l+n_r)/2;
    return f(2*node,n_l,mid,q_l,q_r) + f(2*node+1,mid+1,n_r,q_l
        ,q_r);
}

void build_tree(vi &a,int n){
    tree.clear();
    int m=n;
    while(__builtin_popcount(m)!=1)++m;
    tree.resize(2*m+1,0);
    for(int i=0;i<n;++i)tree[i+m]=a[i];
    for(int i=m-1;i>=1;--i)tree[i]=tree[2*i]+tree[2*i+1];
```

```
}
```

## LazySegmentTree.h

**Description:** Segment tree with lazy propagation update for range sum
**Time:** $\mathcal{O}(\log N)$. 2f108e, 51 lines

```
//TODO: use 0 base indexing
vector<long long> tree,lazy;
void update(int node,int n_l,int n_r,int q_l,int q_r,int value){
    if(lazy[node]!=0){
        tree[node]+=(long long)(n_r-n_l+1)*lazy[node];
        // for range + update
        if(n_l!=n_r){
            lazy[2*node]+=lazy[node];
            lazy[2*node+1]+=lazy[node];
        }
        lazy[node] = 0;
    }
    if(n_r<q_l || q_r<n_l)return;
    if(q_l<=n_l && n_r<=q_r){
        tree[node]+=(long long)(n_r-n_l+1)*value;
        // for range + update
        if(n_l!=n_r){
            lazy[2*node]+=value;
            lazy[2*node+1]+=value;
        }
        return;
    }
    int mid = (n_r+n_l)/2;
    update(2*node,n_l,mid,q_l,q_r,value);
    update(2*node+1,mid+1,n_r,q_l,q_r,value);
    tree[node] = tree[2*node] + tree[2*node+1];
}

long long f(int node,int n_l,int n_r,int q_l,int q_r){
    if(lazy[node]!=0){
        tree[node]+=(long long)(n_r-n_l+1)*lazy[node];
        if(n_l!=n_r){
            lazy[2*node] += lazy[node];
            lazy[2*node+1] += lazy[node];
        }
        lazy[node] = 0;
    }
    if(n_r<q_l || q_r<n_l)return 0;
    if(q_l<=n_l && n_r<=q_r)return tree[node];
    int mid = (n_l+n_r)/2;
    return f(2*node,n_l,mid,q_l,q_r) + f(2*node+1,mid+1,n_r,q_l,q_r);
}

void build_tree(vi &a,int n){
    tree.clear(); lazy.clear();
    int m=n;
    while(__builtin_popcount(m)!=1)++m;
    tree.resize(2*m+1,0); lazy.resize(2*m+1,0);
    for(int i=0;i<n;++i)tree[i+m]=a[i];
    for(int i=m-1;i>=1;--i)tree[i]=tree[2*i]+tree[2*i+1];
}
```

## OrderStatisticTree.h

**Description:** find nth largest element, count elements strictly less than x
**Time:** $\mathcal{O}(\log N)$
<ext/pb_ds/assoc_container.hpp>, <ext/pb_ds/tree_policy.hpp> 033b41, 7 lines

```
typedef __gnu_pbds::tree<int, __gnu_pbds::null_type, less<int>, __gnu_pbds::rb_tree_tag, __gnu_pbds::tree_order_statistics_node_update> ordered_set;

ordered_set st;
//st.order_of_key(x) - find # of elements in st strictly less than x
//st.size() - size of st
//st.find_by_order(x) - return iterator to the x-th largest element
//st.clear() - clear container
```

## MergeSortTree.h

**Description:** do the same with orderstatistic tree but now over interval can be used/modify for some possible interval/subbarray queries
**Time:** $\mathcal{O}\left(\log N^3\right)$
<ext/pb_ds/assoc_container.hpp>, <ext/pb_ds/tree_policy.hpp>, <ext/pb_ds/assoc_container.hpp>, <ext/pb_ds/tree_policy.hpp> 2d0612, 94 lines

```
//merge sort tree with fenwick tree
typedef __gnu_pbds::tree<pair<int,int>, __gnu_pbds::null_type, less<pair<int,int>>, __gnu_pbds::rb_tree_tag, __gnu_pbds::tree_order_statistics_node_update> ordered_set;
ordered_set st;
//st.order_of_key({x,-1}) - find # of elements in st stricly less than x
//st.clear() - clear container

vector<ordered_set> mtree;

ordered_set merge(ordered_set &a, ordered_set &b){
    ordered_set result;
    for(auto&p:a){
        result.ins(p);
    }
    for(auto&p:b){
        result.ins(p);
    }
    return result;
}

void update(int node,int n_l,int n_r,int q_i,int id,int old_val,int value){
    if(n_r<q_i || q_i<n_l)return;
    if(q_i==n_l && n_r==q_i){
        auto it=mtree[node].find({old_val,id});
        mtree[node].erase(it);
        mtree[node].ins({value,id});
        return;
    }
    int mid = (n_r+n_l)/2;
    update(2*node,n_l,mid,q_i,id,old_val,value);
    update(2*node+1,mid+1,n_r,q_i,id,old_val,value);
    auto it=mtree[node].find({old_val,id});
    if(it!=mtree[node].end()){
        mtree[node].erase(it);
        mtree[node].ins({value,id});
    }
}

int f(int node,int n_l,int n_r,int q_l,int q_r, int value){
    if(n_r<q_l || q_r<n_l)return 0;
    if(q_l<=n_l && n_r<=q_r){
        return mtree[node].order_of_key({value,-1});
    }
    int mid = (n_l+n_r)/2;
    return f(2*node,n_l,mid,q_l,q_r,value)+f(2*node+1,mid+1,n_r,q_l,q_r,value);
}

void build_mtree(vi &a){
    int n=(int)a.size();
    int m=n; while(__builtin_popcount(m)!=1)++m;
    //for(int i=0;i<2*m;++i)mtree[i].clear();
    mtree.resize(2*m);
    for(int i=0;i<n;++i)mtree[i+m].ins({a[i],i});
    for(int i=m-1;i>=1;--i)mtree[i]=merge(mtree[2*i],mtree[2*i+1]);
}
//merge sort tree with fenwick tree(BIT) (4 times less space)

typedef __gnu_pbds::tree<pair<int,int>, __gnu_pbds::null_type, less<pair<int,int>>, __gnu_pbds::rb_tree_tag, __gnu_pbds::tree_order_statistics_node_update> ordered_set;
ordered_set st;
//st.order_of_key(x) - find # of elements in st stricly less than x

//TODO: use 1 base indexing
vector<ordered_set>bit;

void update(int i,int k,int old_value, int new_value){
    while(i<(int)bit.size()){
        auto it=bit[i].find({old_value,k});
        assert(it!=bit[i].end());
        if(it!=bit[i].end()){
            bit[i].erase(it);
        }
        bit[i].ins({new_value,k});
        i+=i&-i;//add last set bit
    }
}

int F(int i, int k){//culmulative sum to ith data
    int sum=0;
    while(i>0){
        sum+=bit[i].order_of_key({k,-1});
        i-=i&-i;
    }
    return sum;
}

void build_bit(vi &a){
    bit.resize((int)a.size());
    for(int i=1;i<(int)a.size();++i)bit[i].ins({a[i],i});
    for(int i=1;i<(int)bit.size();++i){
        int p=i+(i&-i);//index to parent
        if(p<(int)bit.size()){
            for(auto&x:bit[i])bit[p].ins(x);
        }
    }
}
```

## MoQueries.h

**Description:** answering offline quries
**Time:** $\mathcal{O}\left((N+Q)\sqrt{N}\right)$ 9df2fb, 46 lines

```
/* TODO: use 0 based indexing*/
void remove(int idx);  // TODO: remove value at idx from data structure
void add(int idx);     // TODO: add value at idx from data structure
int get_answer();  // TODO: extract the current answer of the data structure

int block_size;

struct Query {
    int l, r, idx;
    bool operator<(Query other) const
    {
        return make_pair(l / block_size, r) <
               make_pair(other.l / block_size, other.r);
    }
```

```
};

vector<int> mo_s_algorithm(vector<Query>& queries) {
    vector<int> answers(queries.size());
    sort(queries.begin(), queries.end());

    // TODO: initialize data structure

    int cur_l = 0;
    int cur_r = -1;
    // invariant: data structure will always reflect the range
        [cur_l, cur_r]
    for (Query q : queries) {
        while (cur_l > q.l) {
            cur_l--;
            add(cur_l);
        }
        while (cur_r < q.r) {
            cur_r++;
            add(cur_r);
        }
        while (cur_l < q.l) {
            remove(cur_l);
            cur_l++;
        }
        while (cur_r > q.r) {
            remove(cur_r);
            cur_r--;
        }
        answers[q.idx] = get_answer();
    }
    return answers;
}
```

## FenwickTree.h

**Description:** find culmulative sum to ith element
**Time:** $\mathcal{O}(\log N)$

a9def9, 27 lines

```
//TODO: use 1 base indexing
vector<long long>bit;

//range sum point update(k=new_val-old_val)
void add(int i, int k){//add k to ith data and it's parent
     range so on
    while(i<(int)bit.size()){
        bit[i]+=k;
        i+=i&-i;//add last set bit
    }
}

ll sum(int i){//culmulative sum to ith data
    ll sum=0;
    while(i>0){
        sum+=bit[i];
        i-=i&-i;
    }
    return sum;
}

void build_bit(vl &a){
    bit=a;
    for(int i=1;i<(int)bit.size();++i){
        int p=i+(i&-i);//index to parent
        if(p<(int)bit.size())bit[p]+=bit[i];
    }
}
```

## RMQ.h

**Description:** Range Minimum Queries on an array. solving offline queries in O(1)
**Time:** build $\mathcal{O}(N \log N)$ query $\mathcal{O}(1)$

e37d08, 24 lines

```
int rmq[N][20];

void build_rmq(vi &a){
    for(int j=0;j<20;++j){
        for(int i=0;i<(int)a.size();++i){
            if(j==0){
                rmq[i][0]=a[i];
            } else if(i+(1<<(j-1))<(int)a.size()){
                rmq[i][j]=min(rmq[i][j-1],rmq[i+(1<<(j-1))][j
                    -1]);
            }
        }
    }
}

int query(int l, int r){
    int i=l,sub_array_size=r-l+1, ans=INF;
    for(int j=0;j<30;++j){
        if((1<<j)&(sub_array_size)){
            ans=min(ans,rmq[i][j]);
            i+=(1<<j);
        }
    }
    return ans;
}
```

## HashMap.h

**Description:** Hash map with mostly the same API as unordered_map, but ~3x faster. Uses 1.5x memory. Initial capacity must be a power of 2 (if provided).

<ext/pb_ds/assoc_container.hpp> 3b295b, 7 lines

```
using namespace __gnu_pbds;

const int RANDOM = chrono::high_resolution_clock::now().
    time_since_epoch().count();
struct chash {
    int operator()(int x) const { return x ^ RANDOM; }
};
gp_hash_table<int, int, chash> table;
```

## DSU.h

**Description:** Disjoint-set data structure.
**Time:** $\mathcal{O}(\log N)$

7efb0c, 22 lines

```
//TODO: initialized parent[] and _rank[] array
int find_set(int v) {
    if (v == parent[v])
        return v;
    return parent[v] = find_set(parent[v]);
}

void make_set(int v) {
    parent[v] = v;
    _rank[v] = 1;
}

void union_sets(int a, int b) {
    a = find_set(a);
    b = find_set(b);
    if (a != b) {
        if (_rank[a] < _rank[b])
            swap(a, b);
        parent[b] = a;
        _rank[a]+=_rank[b];
    }
}
```

## Geometry.h

**Description:** pt, line, polygon, circle

963fd3, 167 lines

```
//Geometry
#pragma GCC target("avx2")
#pragma GCC optimize("O3")
#pragma GCC optimize("unroll-loops")

typedef long long int ll;
typedef long double ld;
typedef complex<ld> pt;
struct line {
  pt P, D; bool S = false;
  line(pt p, pt q, bool b = false) : P(p), D(q - p), S(b) {}
  line(pt p, ld th) : P(p), D(polar((ld)1, th)) {}
};
struct circ { pt C; ld R; };

#define X real()
#define Y imag()
#define CRS(a, b) (conj(a) * (b)).Y //scalar cross product
#define DOT(a, b) (conj(a) * (b)).X //dot product
#define U(p) ((p) / abs(p)) //unit vector in direction of p (
     don't use if Z(p) == true)
#define Z(x) (abs(x) < EPS)
#define A(a) (a).begin(), (a).end() //shortens sort(),
     upper_bound(), etc. for vectors

//constants (INF and EPS may need to be modified)
ld PI = acosl(-1), INF = 1e20, EPS = 1e-12;
pt I = {0, 1};

//true if d1 and d2 parallel (zero vectors considered parallel
     to everything)
bool parallel(pt d1, pt d2) { return Z(d1) || Z(d2) || Z(CRS(U(
     d1), U(d2))); }

//"above" here means if l & p are rotated such that l.D points
     in the +x direction, then p is above l. Returns arbitrary
     boolean if p is on l
bool above_line(pt p, line l) { return CRS(p - l.P, l.D) > 0; }

//true if p is on line l
bool on_line(pt p, line l) { return parallel(l.P - p, l.D) &&
     (!l.S || DOT(l.P - p, l.P + l.D - p) <= EPS); }

//returns 0 for no intersection, 2 for infinite intersections,
     1 otherwise. p holds intersection pt
ll intsct(line l1, line l2, pt& p) {
  if(parallel(l1.D, l2.D)) //note that two parallel segments
       sharing one endpoint are considered to have infinite
       intersections here
    return 2 * (on_line(l1.P, l2) || on_line(l1.P + l1.D, l2)
         || on_line(l2.P, l1) || on_line(l2.P + l2.D, l1));
  pt q = l1.P + l1.D * CRS(l2.D, l2.P - l1.P) / CRS(l2.D, l1.D)
       ;
  if(on_line(q, l1) && on_line(q, l2)) { p = q; return 1; }
  return 0;
}

//closest pt on l to p
pt cl_pt_on_l(pt p, line l) {
  pt q = l.P + DOT(U(l.D), p - l.P) * U(l.D);
  if(on_line(q, l)) return q;
  return abs(p - l.P) < abs(p - l.P - l.D) ? l.P : l.P + l.D;
}
```

```
//distance from p to l
ld dist_to(pt p, line l) { return abs(p - cl_pt_on_l(p, l)); }

//p reflected over l
pt refl_pt(pt p, line l) { return conj((p - l.P) / U(l.D)) * U(
    l.D) + l.P; }

//ray r reflected off l (if no intersection, returns original
    ray)
line reflect_line(line r, line l) {
  pt p; if(intsct(r, l, p) - 1) return r;
  return line(p, p + INF * (p - refl_pt(r.P, l)), 1);
}

//altitude from p to l
line alt(pt p, line l) { l.S = 0; return line(p, cl_pt_on_l(p,
    l)); }

//angle bisector of angle abc
line ang_bis(pt a, pt b, pt c) { return line(b, b + INF * (U(a
    - b) + U(c - b)), 1); }

//perpendicular bisector of l (assumes l.S == 1)
line perp_bis(line l) { return line(l.P + l.D / (ld)2, arg(l.D
    * I)); }

//orthocenter of triangle abc
pt orthocent(pt a, pt b, pt c) { pt p; intsct(alt(a, line(b, c)
    ), alt(b, line(a, c)), p); return p; }

//incircle of triangle abc
circ incirc(pt a, pt b, pt c) {
  pt cent; intsct(ang_bis(a, b, c), ang_bis(b, a, c), cent);
  return {cent, dist_to(cent, line(a, b))};
}

//circumcircle of triangle abc
circ circumcirc(pt a, pt b, pt c) {
  pt cent; intsct(perp_bis(line(a, b, 1)), perp_bis(line(a, c,
      1)), cent);
  return {cent, abs(cent - a)};
}

//is pt p inside the (not necessarily convex) polygon given by
    poly
bool in_poly(pt p, vector<pt>& poly) {
  line l = line(p, {INF, INF * PI}, 1);
  bool ans = false;
  pt lst = poly.back(), tmp;
  for(pt q : poly) {
    line s = line(q, lst, 1); lst = q;
    if(on_line(p, s)) return false; //change if border included
    else if(intsct(l, s, tmp)) ans = !ans;
  }
  return ans;
}

//area of polygon, vertices in order (cw or ccw)
ld area(vector<pt>& poly) {
  ld ans = 0;
  pt lst = poly.back();
  for(pt p : poly) ans += CRS(lst, p), lst = p;
  return abs(ans / 2);
}

//perimeter of polygon, vertices in order (cw or ccw)
ld perim(vector<pt>& poly) {
  ld ans = 0;
  pt lst = poly.back();
  for(pt p : poly) ans += abs(lst - p), lst = p;
  return ans;
}

//centroid of polygon, vertices in order (cw or ccw)
pt centroid(vector<pt>& poly) {
  ld area = 0;
  pt lst = poly.back(), ans = {0, 0};
  for(pt p : poly) {
    area += CRS(lst, p);
    ans += CRS(lst, p) * (lst + p) / (ld)3;
    lst = p;
  }
  return ans / area;
}

//invert a point over a circle (doesn't work for center of
    circle)
pt circInv(pt p, circ c) {
    return c.R * c.R / conj(p - c.C) + c.C;
}

//vector of intersection pts of two circs (up to 2) (if circles
    same, returns empty vector)
vector<pt> intsctCC(circ c1, circ c2) {
  if(c1.R < c2.R) swap(c1, c2);
  pt d = c2.C - c1.C;
  if(Z(abs(d) - c1.R - c2.R)) return {c1.C + polar(c1.R, arg(c2
      .C - c1.C))};
  if(!Z(d) && Z(abs(d) - c1.R + c2.R)) return {c1.C + c1.R * U(
      d)};
  if(abs(abs(d) - c1.R) >= c2.R - EPS) return {};
  ld th = acosl((c1.R * c1.R + norm(d) - c2.R * c2.R) / (2 * c1
      .R * abs(d)));
  return {c1.C + polar(c1.R, arg(d) + th), c1.C + polar(c1.R,
      arg(d) - th)};
}

//vector of intersection pts of a line and a circ (up to 2)
vector<pt> intsctCL(circ c, line l) {
  vector<pt> v, ans;
  if(parallel(l.D, c.C - l.P)) v = {c.C + c.R * U(l.D), c.C - c
      .R * U(l.D)};
  else v = intsctCC(c, circ{refl_pt(c.C, l), c.R});
  for(pt p : v) if(on_line(p, l)) ans.push_back(p);
  return ans;
}

//external tangents of two circles (negate c2.R for internal
    tangents)
vector<line> circTangents(circ c1, circ c2) {
  pt d = c2.C - c1.C;
  ld dr = c1.R - c2.R, d2 = norm(d), h2 = d2 - dr * dr;
  if(Z(d2) || h2 < 0) return {};
  vector<line> ans;
  for(ld sg : {-1, 1}) {
    pt u = (d * dr + d * I * sqrt(h2) * sg) / d2;
    ans.push_back(line(c1.C + u * c1.R, c2.C + u * c2.R, 1));
  }
  if(Z(h2)) ans.pop_back();
  return ans;
}
```

## KMP.h

**Description:** pattern searching
**Time:** $\mathcal{O}(N + M)$

4dfee5, 37 lines

```
int b[N];
int cnt = 0;

void knp_proc(string t,string p){
    int i=0,j=-1;b[0] = -1;
    while(i<(int)p.length()){
        while(j>=0 && p[i]!=p[j]) j =b[j];
        ++i;++j;
        b[i] = j;
    }
}

void knp_search(string t,string p){//count number of occurence
      of p in t
    int i=0,j=0;
    while(i<(int)t.length()){
        while(j>=0 && t[i] != p[j]) j = b[j];
        ++i;++j;
        if(j==(int)p.length()){
            ++cnt;
            j = b[j];
        }
    }
}

vector<int> prefix_function(string s) {
    int n = (int)s.length();
    vector<int> pi(n);
    for (int i = 1; i < n; i++) {
        int j = pi[i-1];
        while (j > 0 && s[i] != s[j])
            j = pi[j-1];
        if (s[i] == s[j])
            j++;
        pi[i] = j;
    }
    return pi;
}
```

## StringHashing.h

**Description:** check equality of two substrings
**Time:** $\mathcal{O}(N)$ preprocessing $\mathcal{O}(1)$ query

276f01, 25 lines

```
typedef long long ll;
typedef pair<ll,ll> pl;
#define M 1000000321
#define OP(x, y) pl operator x (pl a, pl b){return {a.first x b
    .first, (a.second y b.second) % M }; }
OP(+, +) OP(*, *) OP(-, + M -)
//random number generator
mt19937 gen(chrono::steady_clock::now().time_since_epoch().
    count());
uniform_int_distribution<ll> dist(256, M - 1);
//queries - check if S[i:i+l] == S[j:j+l](inclusive), S is a
    string, [:] is slice
#define H(i, l) (h[(i) + (l)] - h[i] * p[l])
#define EQ(i, j, l) (H(i, l) == H(j, l))
//preprocessing
const int N = 2e5;
string s;
pl p[N], h[N];
ll n;

int main(){
    cin >> n >> s;
    p[0] = {1,1}, p[1] = {dist(gen) | 1, dist(gen) };
    for(ll i=1;i<=(ll)s.length();++i){
        p[i] = p[i-1] * p[1];
        h[i] = h[i-1] * p[1] + make_pair(s[i-1], s[i-1]);
    }
```

```
}
```

## DnQDp.h

**Description:** find best k consecutive subbarray partition
**Time:** $\mathcal{O}(N \log N)$

108b88, 55 lines

```
//TODO: initialize dp , initialize cost() function of use slide
     ()
//ll dp[N][M];

//generic implementation for sliding range technique for logn
     cost()
//(persistent segtree alternative)
ll ccost = 0;
int cl = 0, cr = -1;
void slide(int l, int r){
    while(cr < r){
        ++cr;
        //add();
        //...
    }
    while(cl > l){
        --cl;
        //add();
        //...
    }
    while(cr > r){
        //remove();
        //...
        --cr;
    }
    while(cl < l){
        //remove();
        //...
        ++cl;
    }
}

void compute(int l, int r, int optl, int optr, int j){
    if(l>r)return;

    int mid = (l+r)>>1;
    //pair<ll, int> best = {0,-1};
    //pair<ll, int> best = {LINF,-1};

    //dp is satisfy quadrangle IE if cost() satisfy qudrangle
         IE
    //if cost() is QF => opt() is nondecreasing
    for(int k=optl;k<=min(mid,optr);++k){
        slide(k,mid);
        //best = max(best, {((k>0)?dp[k-1][j-1]:0) + ccost, k }
             );
        //best = min(best, {((k>0)?dp[k-1][j-1]:0) + ccost, k }
             );
    }

    //dp[mid][j] = max(dp[mid][j], best.first);
    //dp[mid][j] = min(dp[mid][j], best.first);
    int opt = best.second;
    if(l!=r){
        compute(l,mid-1,optl,opt,j);
        compute(mid+1,r,opt,optr,j);
    }
}

//TODO: set dp to LINF or -LINF
```

## CHT.h

**Description:** convex-hull trick
**Time:** $\mathcal{O}(N)$ or $\mathcal{O}(N \log N)$ if sort the slope

87ad47, 28 lines

```
struct line {
    long long m, c;
    long long eval(long long x) { return m * x + c; }
    long double intersectX(line l) { return (long double) (c -
         l.c) / (l.m - m); }
};

deque<line> dq;
dq.push_front({0, 0});//cant be put in global, remove this to
     local function
//if query ask for minimum remove this line after 1st insertion

//TODO NOTE***: maximum and minimum value exist in bot left
     most and rightmost of convex hull so do search on both l
     to r and r to l

//constructing hull from l to r, maintain correct hull at
     rightmost
/*  ***inserting line (maximum hull)
    line cur = line{...some m, ...some c}
    while(dq.size()>=2&&cur.intersectX(dq.back())
        <=cur.intersectX(dq[dq.size()-2]))dq.pop_back();
    dq.pb(cur);
*/

//constructing hull from r to l, maintain correct hull at
     leftmost
/*  inserting line (maximum hull)
    line cur = line{...some m, ...some c}
    while(dq.size()>=2&&cur.intersectX(dq[0])>=cur.intersectX(
         dq[1])){
        dq.pop_front();
    }
    dq.push_front(cur);
*/
```

## KthAncestor.h

**Description:** find kth-ancestor of a tree-node
**Time:** $\mathcal{O}(\log N)$

62aeee, 9 lines

```
int kth_ancestor(int node,int k){
    if(depth[node] < k)return -1;
    for(int i = 0;i < LOG; ++i){
        if(k & (1<<i)){
            node = up[node][i];
        }
    }
    return node;
}
```

## LCA.h

**Description:** find lowest common ancestor of two tree-nodes
**Time:** $\mathcal{O}(\log N)$

300c4f, 36 lines

```
//TODO: initialize tree(adj list)
const int LOG = 20;
int depth[N], parent[N];
int up[N][LOG]; // 2^j-th ancestor of n

void dfs(int a,int e){
    for(auto b:adj[a]){
        if(b == e)continue;
        depth[b] = depth[a] + 1;
        parent[b] = a;
        up[b][0] = parent[b];
        for(int i=1;i<LOG;++i){
            up[b][i] = up[up[b][i-1]][i-1];
        }
        dfs(b,a);
    }
}

int lca(int a, int b){
    if(depth[a]<depth[b])swap(a,b);
    int k = depth[a] - depth[b];
    for(int i=LOG-1;i>=0;--i){
        if(k &(1<<i)){
            a = up[a][i];
        }
    }

    if(a == b)return a;
    for(int i=LOG-1;i>=0;--i){
        if(up[a][i] != up[b][i]){
            a = up[a][i];
            b = up[b][i];
        }
    }
    return up[a][0];
}
```

## Sieve.h

**Description:** prime sieve
**Time:** $\mathcal{O}(N \log \log N)$

abb3a3, 21 lines

```
//can use to find all prime factor of a number in O(log n)
const int M = 2e5+1;
vector<bool> is_prime(M+1, true);
void sieve(){
    is_prime[0] = is_prime[1] = false;
    for (int i = 2; i * i <= M; i++) {
        if (is_prime[i]) {
            for (int j = i * i; j <= M; j += i)
                is_prime[j] = false;
        }
    }
    /* log n sieve (use sieve to find all prime factors in O(
         log n) )
    for (int i = 2; i <= M; i++)is_prime[i] = i;
    for (int i = 2; i * i <= M; i++) {
        if (is_prime[i] == i) {
            for (int j = i * i; j <= M; j += i)
                is_prime[j] = i;
        }
    }
    */
}
```

## IntFact.h

**Description:** integer factorization algorithm
**Time:** $\mathcal{O}\left(\sqrt{N}\right)$

497201, 40 lines

```
//in general any natural number n has at most n^1/3 divisors in
     practice
bool isPrime(ll x) {
    for (ll d = 2; d * d <= x; d++) {
        if (x % d == 0)
            return false;
    }
    return x >= 2;
}

void decompose(ll x){
    vl temp;
    while(x % 2 == 0){
```

```
        temp.pb(2);
        x/=2;
    }

    for(ll i=3;i*i <= x;i+=2){
        if(x % i == 0){
            while(x % i == 0){
                x/=i;
                temp.pb(i);
            }
        }
    }
    if(x>1)temp.pb(x);
    //do something
}

void find_all_divisors(ll x){
    vl temp;
    for(int i=1;(ll)i*i<=x;++i){
        if(x%i==0){
            if(i==x/i)temp.pb(i);
            else {
                temp.pb(i); temp.pb(x/i);
            }
        }
    }
    //temp == all divisors of x
}
```

### PhiSieve.h

**Description:** euler totient function precal
**Time:** $\mathcal{O}(N \log\log N)$ 0815d0, 12 lines

```
void phi_1_to_n(int n) {
    vector<int> phi(n + 1);
    for (int i = 0; i <= n; i++)
        phi[i] = i;

    for (int i = 2; i <= n; i++) {
        if (phi[i] == i) {
            for (int j = i; j <= n; j += i)
                phi[j] -= phi[j] / i;
        }
    }
}
```

### PhiFunction.h

**Description:** euler totient function
**Time:** $\mathcal{O}\left(\sqrt{N}\right)$ fb8d57, 13 lines

```
int phi(int n) {
    int result = n;
    for (int i = 2; i * i <= n; i++) {
        if (n % i == 0) {
            while (n % i == 0)
                n /= i;
            result -= result / i;
        }
    }
    if (n > 1)
        result -= result / n;
    return result;
}
```

### GcdExtended.h

**Description:** find Bezout's coefficient
**Time:** $\mathcal{O}(\log N)$ af07ae, 12 lines

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

### Matrix.h

**Description:** mainly for matrix exponentation and find nth recurrence
**Time:** $\mathcal{O}(\log N)$ 1e389f, 28 lines

```
struct Matrix{
    double a[2][2] = {{0,0},{0,0}};
    Matrix operator *(const Matrix& other){
        Matrix product;
        for(int i=0;i<2;++i){
            for(int j=0;j<2;++j){
                for(int k=0;k<2;++k){
                    product.a[i][k] += a[i][j] * other.a[j][k];
                }
            }
        }
        return product;
    }
};
//for calculating nth recurrence of function
//entry Matrix[i][j] is problability/number of way ith state
    change to jth state
Matrix expo_power(Matrix a, int n){
    Matrix product;
    for(int i=0;i<2;++i)product.a[i][i]=1;
    while(n>0){
        if(n&1){
            product = product * a;
        }
        a = a * a;
        n>>=1;
    }
    return product;
}
```

### Binpow.h

**Description:** binary exponentation
**Time:** $\mathcal{O}(\log N)$ d4debd, 11 lines

```
long long binpow(long long a, int n){
    long long res = 1;
    while(n>0){
        if(n&1){
            res = res * a;
        }
        a = a * a;
        n>>=1;
    }
    return res;
}
```

### Ceil2.h

**Description:** integer ceiling
**Time:** $\mathcal{O}(1)$ 60a42a, 7 lines

```
//ceil2 work for bot positive and nagative a(maybe. never test
    it)
//ceil(a/b)
int ceil2(int a,int b){
  int res=a/b;
  if(b*res!=a)res+=(a>0)&(b>0);
  return res;
}
```

# cellul4r (3)

### DSU.h

**Description:** disjoint union set with rank union and path compression. 5d985a, 10 lines

```
ll parent[NN], sz[NN];
ll find(ll a){ return a == parent[a] ? a : parent[a] = find(
    parent[a]); }
void merge(ll u, ll v) {
    u = find(u), v=find(v);
    if (u!=v) {
        if (sz[u]<sz[v]) swap(u, v);
        sz[u] += sz[v];
        parent[v] = u;
    }
}
```

# Mathematics (4)

## 4.1 Equations

$$ax^2 + bx + c = 0 \Rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

The extremum is given by $x = -b/2a$.

$$\begin{array}{c} ax + by = e \\ cx + dy = f \end{array} \Rightarrow \begin{array}{c} x = \dfrac{ed - bf}{ad - bc} \\ y = \dfrac{af - ec}{ad - bc} \end{array}$$

In general, given an equation $Ax = b$, the solution to a variable $x_i$ is given by

$$x_i = \frac{\det A_i'}{\det A}$$

where $A_i'$ is $A$ with the $i$'th column replaced by $b$.

Non-distinct roots $r$ become polynomial factors, e.g. $a_n = (d_1 n + d_2) r^n$.

## 4.2 Trigonometry

$$\sin(v + w) = \sin v \cos w + \cos v \sin w$$
$$\cos(v + w) = \cos v \cos w - \sin v \sin w$$

$$\tan(v + w) = \frac{\tan v + \tan w}{1 - \tan v \tan w}$$
$$\sin v + \sin w = 2 \sin \frac{v + w}{2} \cos \frac{v - w}{2}$$
$$\cos v + \cos w = 2 \cos \frac{v + w}{2} \cos \frac{v - w}{2}$$

$$(V+W)\tan(v-w)/2=(V-W)\tan(v+w)/2$$

where $V, W$ are lengths of sides opposite angles $v, w$.

$$a\cos x+b\sin x=r\cos(x-\phi)$$
$$a\sin x+b\cos x=r\sin(x+\phi)$$

where $r=\sqrt{a^2+b^2}, \phi=\operatorname{atan2}(b,a)$.

## 4.3 Geometry

### 4.3.1 Triangles

Side lengths: $a, b, c$

Semiperimeter: $p=\frac{a+b+c}{2}$

Area: $A=\sqrt{p(p-a)(p-b)(p-c)}$

Circumradius: $R=\frac{abc}{4A}$

Inradius: $r=\frac{A}{p}$

Length of median (divides triangle into two equal-area triangles): $m_a=\frac{1}{2}\sqrt{2b^2+2c^2-a^2}$

Length of bisector (divides angles in two):

$$s_a=\sqrt{bc\left[1-\left(\frac{a}{b+c}\right)^2\right]}$$

Law of sines: $\frac{\sin\alpha}{a}=\frac{\sin\beta}{b}=\frac{\sin\gamma}{c}=\frac{1}{2R}$

Law of cosines: $a^2=b^2+c^2-2bc\cos\alpha$

Law of tangents: $\frac{a+b}{a-b}=\frac{\tan\frac{\alpha+\beta}{2}}{\tan\frac{\alpha-\beta}{2}}$

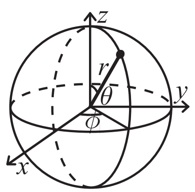
### 4.3.2 Quadrilaterals

With side lengths $a, b, c, d$, diagonals $e, f$, diagonals angle $\theta$, area $A$ and magic flux $F=b^2+d^2-a^2-c^2$:

$$4A=2ef\cdot\sin\theta=F\tan\theta=\sqrt{4e^2f^2-F^2}$$

For cyclic quadrilaterals the sum of opposite angles is $180^\circ$, $ef=ac+bd$, and $A=\sqrt{(p-a)(p-b)(p-c)(p-d)}$.

### 4.3.3 Spherical coordinates




$$x=r\sin\theta\cos\phi \qquad r=\sqrt{x^2+y^2+z^2}$$
$$y=r\sin\theta\sin\phi \qquad \theta=\operatorname{acos}(z/\sqrt{x^2+y^2+z^2})$$
$$z=r\cos\theta \qquad \phi=\operatorname{atan2}(y,x)$$

## 4.4 Derivatives/Integrals

$$\frac{d}{dx}\arcsin x=\frac{1}{\sqrt{1-x^2}} \qquad \frac{d}{dx}\arccos x=-\frac{1}{\sqrt{1-x^2}}$$
$$\frac{d}{dx}\tan x=1+\tan^2 x \qquad \frac{d}{dx}\arctan x=\frac{1}{1+x^2}$$
$$\int\tan ax=-\frac{\ln|\cos ax|}{a} \qquad \int x\sin ax=\frac{\sin ax-ax\cos ax}{a^2}$$
$$\int e^{-x^2}=\frac{\sqrt{\pi}}{2}\operatorname{erf}(x) \qquad \int xe^{ax}dx=\frac{e^{ax}}{a^2}(ax-1)$$

Integration by parts:

$$\int_a^b f(x)g(x)dx=[F(x)g(x)]_a^b-\int_a^b F(x)g'(x)dx$$

## 4.5 Sums

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

$$1+2+3+\cdots+n=\frac{n(n+1)}{2}$$
$$1^2+2^2+3^2+\cdots+n^2=\frac{n(2n+1)(n+1)}{6}$$
$$1^3+2^3+3^3+\cdots+n^3=\frac{n^2(n+1)^2}{4}$$
$$1^4+2^4+3^4+\cdots+n^4=\frac{n(n+1)(2n+1)(3n^2+3n-1)}{30}$$

## 4.6 Series

$$e^x=1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+\ldots,\ (-\infty<x<\infty)$$
$$\ln(1+x)=x-\frac{x^2}{2}+\frac{x^3}{3}-\frac{x^4}{4}+\ldots,\ (-1<x\leq 1)$$
$$\sqrt{1+x}=1+\frac{x}{2}-\frac{x^2}{8}+\frac{2x^3}{32}-\frac{5x^4}{128}+\ldots,\ (-1\leq x\leq 1)$$
$$\sin x=x-\frac{x^3}{3!}+\frac{x^5}{5!}-\frac{x^7}{7!}+\ldots,\ (-\infty<x<\infty)$$
$$\cos x=1-\frac{x^2}{2!}+\frac{x^4}{4!}-\frac{x^6}{6!}+\ldots,\ (-\infty<x<\infty)$$

## 4.7 Probability theory

Let $X$ be a discrete random variable with probability $p_X(x)$ of assuming the value $x$. It will then have an expected value (mean) $\mu=\mathbb{E}(X)=\sum_x xp_X(x)$ and variance $\sigma^2=V(X)=\mathbb{E}(X^2)-(\mathbb{E}(X))^2=\sum_x(x-\mathbb{E}(X))^2p_X(x)$ where $\sigma$ is the standard deviation. If $X$ is instead continuous it will have a probability density function $f_X(x)$ and the sums above will instead be integrals with $p_X(x)$ replaced by $f_X(x)$.

Expectation is linear:

$$\mathbb{E}(aX+bY)=a\mathbb{E}(X)+b\mathbb{E}(Y)$$

For independent $X$ and $Y$,

$$V(aX+bY)=a^2V(X)+b^2V(Y).$$

### 4.7.1 Discrete distributions

#### Binomial distribution

The number of successes in $n$ independent yes/no experiments, each which yields success with probability $p$ is $\operatorname{Bin}(n,p)$, $n=1,2,\ldots$, $0\leq p\leq 1$.

$$p(k)=\binom{n}{k}p^k(1-p)^{n-k}$$

$$\mu=np,\ \sigma^2=np(1-p)$$

$\operatorname{Bin}(n,p)$ is approximately $\operatorname{Po}(np)$ for small $p$.

#### First success distribution

The number of trials needed to get the first success in independent yes/no experiments, each which yields success with probability $p$ is $\operatorname{Fs}(p)$, $0\leq p\leq 1$.

$$p(k)=p(1-p)^{k-1},\ k=1,2,\ldots$$

$$\mu=\frac{1}{p},\ \sigma^2=\frac{1-p}{p^2}$$

#### Poisson distribution

The number of events occurring in a fixed period of time $t$ if these events occur with a known average rate $\kappa$ and independently of the time since the last event is $\operatorname{Po}(\lambda)$, $\lambda=t\kappa$.

$$p(k)=e^{-\lambda}\frac{\lambda^k}{k!}, k=0,1,2,\ldots$$

$$\mu=\lambda,\ \sigma^2=\lambda$$

### 4.7.2 Continuous distributions

#### Uniform distribution

If the probability density function is constant between $a$ and $b$ and 0 elsewhere it is $\mathrm{U}(a, b)$, $a < b$.

$$f(x) = \begin{cases} \frac{1}{b-a} & a < x < b \\ 0 & \text{otherwise} \end{cases}$$

$$\mu = \frac{a+b}{2},\ \sigma^2 = \frac{(b-a)^2}{12}$$

#### Exponential distribution

The time between events in a Poisson process is $\mathrm{Exp}(\lambda)$, $\lambda > 0$.

$$f(x) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0 \\ 0 & x < 0 \end{cases}$$

$$\mu = \frac{1}{\lambda},\ \sigma^2 = \frac{1}{\lambda^2}$$

#### Normal distribution

Most real random values with mean $\mu$ and variance $\sigma^2$ are well described by $\mathcal{N}(\mu, \sigma^2)$, $\sigma > 0$.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

If $X_1 \sim \mathcal{N}(\mu_1, \sigma_1^2)$ and $X_2 \sim \mathcal{N}(\mu_2, \sigma_2^2)$ then

$$aX_1 + bX_2 + c \sim \mathcal{N}(\mu_1 + \mu_2 + c, a^2\sigma_1^2 + b^2\sigma_2^2)$$