



University of Central Florida

UCF Narcissus

Kyle Cochran, Tyler Mark, David Santamaria

2022-03-03

- 1 Contest
- 2 Data structures
- 3 Geometry
- 4 Graphs
- 5 Mathematics
- 6 Miscellaneous
- 7 Strings

Contest (1)

template.cpp30 lines

```
#include <bits/stdc++.h>
#define all(x) begin(x), end(x)
using namespace std;

using ll = long long;

int main() {
    cin.tie(0)->sync_with_stdio(0);
    cin.exceptions(cin.failbit);
}
```

Data structures (2)

BIT.h33f78c, 22 lines

Description: Query [l, r] sums, and point updates. kth() returns the smallest index i s.t. query(0, i) >= k

Time: $\mathcal{O}(\log n)$ for all ops.

```
template <typename T>
struct BIT {
    vector<T> s;
    int n;
    BIT(int n): s(n + 1), n(n) {}
    void update(int i, T v) {
        for (i++; i <= n; i += i & -i) s[i] += v;
    }
    T query(int i) {
        T ans = 0;
        for (i++; i; i -= i & -i) ans += s[i];
        return ans;
    }
    T query(int l, int r) { return query(r) - query(l - 1); }
    int kth(T k) { // returns n if k > sum of tree
        if (k <= 0) return -1;
        int i = 0;
        for (int pw = 1 << __lg(n); pw; pw >>= 1)
            if (i + pw <= n && s[i + pw] < k) k -= s[i + pw];
        return i;
    }
};

dsu.h
Description: Maintains a collection of disjoint sets.
Time:  $\mathcal{O}(\alpha(1))$  amortized.
998a98, 32 lines
```

fenwicktree.h6c20de, 24 lines

```
class ufds {
public:
    vector<int> p, rank, size;
    int num_distincts;
    ufds(int n) {
        p.resize(n); rank.resize(n); size.resize(n);
        for (int i = 0; i < n; i++) {
            rank[i] = 0;
            size[i] = 1;
            p[i] = i;
        }
        distincts = n;
    }
    int find(int i) { return (p[i] == i) ? i : (p[i] = find(p[i])); }
    bool same(int i, int j) { return find(i) == find(j); }
    void union_set(int i, int j) {
        int pi = find(i), pj = find_set(j);
        if (pi == pj) return;
        distincts--;

        size[pi] = size[pj] = size[pi] + size[pj];

        if (rank[pi] > rank[pj]) {
            p[pj] = pi;
        } else {
            p[pi] = p[pj];
            if (rank[pi] == rank[pj]) {
                rank[pj]++;
            }
        }
    }
};

Description: Binary Indexed Tree to support logarithmic complexity on point update and range query
Memory:  $\mathcal{O}(N)$ 
Time:  $\mathcal{O}(\log(M))$  update/query,  $\mathcal{O}(n\log(n))$  build

#define lso(x) ((x) & -(x))
class bit {
public:
    int n;
    vector<ll> ft;
    bit(int n) {
        this->n = n;
        ft.resize(n + 1);
        fill(ft.begin(), ft.end(), 0);
    }
    void update(int i, int val) {
        for (; i < (int) ft.size(); i += lso(i))
            ft[i] += val;
    }
    ll rsq(int i) {
        ll ret = 0;
        for (; i; i -= lso(i))
            ret += ft[i];
        return ret;
    }
    ll rsq(int i, int j) {
        return rsq(j) - rsq(i - 1);
    }
};

SegmentTree.h
e003ae, 66 lines
typedef vector<int> vi;
class SegmentTree {
```

```
private:
    int n;
    vi A, st, lazy;
    int l(int p) { return p << 1; }
    int r(int p) { return (p << 1) + 1; }
    int conquer(int a, int b) {
        if (a == -1) return b;
        corner case
        if (b == -1) return a;
        return min(a, b);
    }
    void build(int p, int L, int R) {
        if (L == R)
            st[p] = A[L];
        base case
        else {
            int m = (L+R) / 2;
            build(l(p), L, m);
            build(r(p), m + 1, R);
            st[p] = conquer(st[l(p)], st[r(p)]);
        }
    }
    void propagate(int p, int L, int R) {
        if (lazy[p] != -1) {
            st[p] = lazy[p];
            if (L != R)
                lazy[l(p)] = lazy[r(p)] = lazy[p];
            else
                A[L] = lazy[p];
            lazy[p] = -1;
        }
    }
    int RMQ(int p, int L, int R, int i, int j) {
        propagate(p, L, R);
        if (i > j) return -1;
        if ((L >= i) && (R <= j)) return st[p];
        int m = (L+R) / 2;
        return conquer(RMQ(l(p), L, m, i, min(m, j)),
            RMQ(r(p), m+1, R, max(i, m+1), j));
    }
    void update(int p, int L, int R, int i, int j, int val) {
        propagate(p, L, R);
        if (i > j) return;
        if ((L >= i) && (R <= j)) {
            lazy[p] = val;
            propagate(p, L, R);
        }
        else {
            int m = (L+R)/2;
            update(l(p), L, m, i, min(m, j), val);
            update(r(p), m + 1, R, max(i, m + 1), j, val);
            int lsubtree = (lazy[l(p)] != -1) ? lazy[l(p)] : st[l(p)];
            int rsubtree = (lazy[r(p)] != -1) ? lazy[r(p)] : st[r(p)];
            st[p] = (lsubtree <= rsubtree) ? st[l(p)] : st[r(p)];
        }
    }
};

public:
    SegmentTree(int sz) : n(sz), st(4*n), lazy(4*n, -1) {}
    SegmentTree(const vi &initialA) : SegmentTree((int)
        initialA.size()) {
        A = initialA;
        build(1, 0, n-1);
    }
```

```
void update(int i, int j, int val) { update(1, 0, n -
    1, i, j, val); }
int RMQ(int i, int j) { return RMQ(1, 0, n - 1, i, j);
    }
};
```

Geometry (3)

closestpairpoints.cpp993a04, 63 lines

```
struct vec{
    int x, y, id;
    explicit vec(int x=0, int y=0, int id=0) : x(x), y(y), id(id){}
};

int n;
vector<vec> a, t;
double mindist;
pair<int, int> best;

void updClosest(const vec& a, const vec& b){
    double dx = a.x - b.x, dy = a.y - b.y;
    double dist = sqrt(dx*dx + dy*dy);
    if(dist < mindist){
        mindist = dist;
        best = {a.id, b.id};
    }
}

bool cmpX(const vec& a, const vec& b){
    return a.x < b.x || (a.x == b.x && a.y < b.y);
}

bool cmpY(const vec& a, const vec& b){
    return a.y < b.y;
}

void solve(int l, int r){
    if(r-l <= 3){
        for(int i = l; i < r; i++){
            for(int j = i+1; j < r; j++){
                updClosest(a[i], a[j]);
            }
        }
        sort(a.begin()+l, a.begin()+r, cmpY);
        return;
    }

    int m = (l+r)/2;
    int midx = a[m].x;
    solve(l, m);
    solve(m, r);

    merge(a.begin() + l, a.begin() + m, a.begin() + m, a.begin() + r, t.begin(), cmpY);
    copy(t.begin(), t.begin() + (r-l), a.begin() + l);

    int tSz = 0;
    for(int i = l; i < r; i++){
        if(abs(a[i].x-midx) < mindist){
            for(int j = tSz - 1; j >= 0 && a[i].y - t[j].y < mindist; j--){
                updClosest(a[i], t[j]);
            }
            t[tSz++] = a[i];
        }
    }

    void clstPts(){
        t.resize(n);
        sort(a.begin(), a.end(), cmpX);
        mindist = DBL_MAX;
        solve(0, n);
    }
}
```

convexHull.cppDescription: Given a set of vertices, find a set that creates a polygon such that all vertices lie within that polygonMemory: O(n)Time: O(n)1e3255, 40 lines

```
using point = pair<int, int>;
#define xx first
#define yy second

int cross(point o, point a, point b){
    int dx1 = a.xx-o.xx, dy1 = a.yy-o.yy;
    int dx2 = o.xx-b.xx, dy2 = o.yy-b.yy;
    return dx1*dy2-dx2*dy1;
}

vector<point> convexHull(vector<point> p, int n){
    vector<point> hull(n);
    if(n <= 3){
        for(int i = 0; i < n; i++)
            hull[i] = p[i];

        return;
    }

    sort(p.begin(), p.end());

    int k = 0;
    for(int i = 0; i < n; i++){
        while(k >= 2 && cross(hull[k-2], hull[k-1], p[i]) <= 0)
            k--;

        hull[k++] = p[i];
    }

    for(int i = n-1, t = k+1; i > 0; i--){
        while(k >= t && cross(hull[k-2], hull[k-1], p[i-1]) <= 0)
            k--;

        hull[k++] = p[i];
    }

    hull.resize(k);

    return hull;
}

seg.cppDescription: Line segment geometryMemory: O(1)Time: O(1)3199ec, 66 lines

#define eps 1e9

using vec = pair<double, double>;
#define xx first
#define yy second

vec operator+(const vec & v, const vec & u) { return {v.xx+u.xx, v.yy+u.yy}; }
vec operator-(const vec & v, const vec & u) { return {v.xx-u.xx, v.yy-u.yy}; }
vec operator*(const vec & v, const double & c) { return {v.xx * c, v.yy * c}; }

double dotProd(vec v, vec u) { return v.xx*u.xx + v.yy*u.yy; }
```

double crossProd(vec v, vec u) { return v.xx*u.yy - v.yy*u.xx; }

double mag2(vec v) { return dotProd(v, v); }
double mag(vec v) { return sqrt(mag2(v)); }
vec unit(vec v) { return v * (1.0/mag(v)); }

vec rotate(vec v, double th){
 double newX = v.xx*cos(th) + v.yy*sin(th);
 double newY = v.xx*sin(th) + v.yy*cos(th);
 return {newX, newY};
}

double angle(vec v) { return atan2(v.yy, v.xx); }

//start

using seg = pair<vec, vec>;

vec lineIntersection(seg a, seg b){
 vec dirA = a.second - a.first, dirB = b.second - b.first;
 double det = crossProd(dirB, dirA);
 if(det == 0) return {INT_MAX, INT_MAX};
 double t = (crossProd(dirB, b.first-a.first)) / det;
 return a.first + dirA * t;
}

bool containsPoint(seg s, vec p){
 vec dir = s.second-s.first;
 double dist = crossProd(dir, p-s.first)/mag(dir);
 if(abs(dist) < eps) return false;
 return (mag(dir)-mag(s.first-p)-mag(s.second-p) < eps);
}

vec segIntersection(seg a, seg b){
 vec intersect = lineIntersection(a, b);
 if(intersect.first == INT_MAX && intersect.first == INT_MAX)
 return {INT_MAX, INT_MAX};
 if(containsPoint(a, intersect) && containsPoint(b, intersect))
 return intersect;
 return {INT_MAX, INT_MAX};
}

//returns 1 if above, 0 if on, -1 if below
int side(seg s, vec p){
 vec dir = s.second-s.first;
 double dist = crossProd(dir, p-s.first)/mag(dir);
 if(abs(dist) < eps) return 0;
 if(dist < 0) return -1;
 else return 1;
}

bool intersects(seg a, seg b){
 return side(a, b.first)!=side(a, b.second) && side(b, a.first)!=side(b, a.second);
}

vec.cppDescription: Vector codeMemory: O(1)Time: O(1)00645f, 24 lines

using vec = pair<double, double>;
#define xx first
#define yy second

```
vec operator+(const vec & v, const vec & u) { return {v.xx+u.xx
, v.yy+u.yy}; }
vec operator-(const vec & v, const vec & u) { return {v.xx-u.xx
, v.yy-u.yy}; }
vec operator*(const vec & v, const double & c) { return {v.xx *
c, v.yy * c}; }

double dotProd(vec v, vec u) { return v.xx*u.xx + v.yy*u.yy; }
double crossProd(vec v, vec u) { return v.xx*u.yy - v.yy*u.xx;
}

double mag2(vec v) { return dotProd(v, v); }
double mag(vec v) { return sqrt(mag2(v)); }
vec unit(vec v) { return v * (1.0/mag(v)); }

vec rotate90(vec v){ return{-v.yy, v.xx}; }
vec rotate270(vec v){ return{v.yy, -v.xx}; }
vec rotate(vec v, double th){
    double newX = v.xx*cos(th) + v.yy*sin(th);
    double newY = v.xx*sin(th) + v.yy*cos(th);
    return {newX, newY};
}

double angle(vec v) { return atan2(v.yy, v.xx); }
```

Graphs (4)

bellmanFord.cpp

Description: Single Source Shortest Path (SSSP)

Memory: $\mathcal{O}(V^2)$

Time: $\mathcal{O}(V^3)$

```
#define vv first
#define ww second
using edge = pair<int, int>;

void bellmanFord(vector<edge> g[], int v, int s){
    int dist[v];
    memset(dist, 0, sizeof(0));

    for(int i = 0; i < v-1; i++)
        for(int u = 0; u < v; u++){
            for(edge e : g[u])
                if(dist[u] + e.ww < dist[e.vv])
                    dist[e.vv] = dist[u] + e.ww;

            //check for negative cycles
            for(int u = 0; u < v; u++){
                for(edge e : g[u]){
                    if(dist[u]!=INT_MAX && dist[u] + e.ww < dist[e.vv])
                        {
                            //negative cycle reached
                            return;
                        }
                }
            }
        }
}
```

dijkstraTylerM.cpp

```
<bits/stdc++.h>
using namespace std;

#define vv first
#define ww second
using edge = pair<int, int>;

void djikstras(vector<edge> g[], int v, int s){
    priority_queue<edge, vector<edge>, greater<edge>> pq;
    vector<int> dist(v, INT_MAX);

    dist[s] = 0;
    pq.push(make_pair(0,s));

    while(!pq.empty()){
        if(pq.top().first > dist[pq.top().first])
            continue;

        int u = pq.top().second;
        pq.pop();

        for(edge e : g[u]){
            if(dist[e.vv] > dist[u] + e.ww){
                dist[e.vv] = dist[u] + e.ww;
                pq.push(make_pair(dist[e.vv], e.vv));
            }
        }
    }
}
```

floydWarshall.cpp

Description: FindAll-Pairs Shortest Paths (APSP)

Memory: $\mathcal{O}(n^2)$

```
Time:  $\mathcal{O}(n^3)$ 
calaff, 25 lines

#define vv first
#define ww second
using edge = pair<int, int>;

void floydWarshall(vector<edge> g[], int n){
    int d[n][n];
    memset(d, INT_MAX, sizeof(d));
    for(int i = 0; i < n; i++) d[i][i] = 0;

    for(int i = 0; i < n; i++){
        for(edge e : g[i]){
            if(e.ww < d[i][e.vv])
                d[i][e.vv] = d[e.vv][i] = e.ww;
        }
    }

    for(int k = 0; k < n; k++){
        for(int i = 0; i < n; i++){
            for(int j = 0; j < n; j++){
                d[i][j] = min(d[i][j], d[i][k] + d[k][j]);
            }
        }
    }
}
```

kruskalMST.cpp

Description: Construct a Minimum Spanning Tree using Kruskal's algorithm

Time: $\mathcal{O}(E\alpha)$

```
30806f, 50 lines

#define vv first
#define ww second
using edge = tuple<int, int, int>;

struct disjoint_set{
    int n;
    int *par, *height;

    disjoint_set(int nn){
        n = nn;
        par = new int[n];
        memset(par, -1, sizeof(par));
        height = new int[n];
        memset(height, 1, sizeof(height));
    }

    int parent(int i){
        return par[i] == -1 ? i : (par[i] = parent(par[i]));
    }

    void unionize(int a, int b){
        a = parent(a);
        b = parent(b);

        if(a==b) return;
        if(height[a] == height[b])
            height[a]++;

        if(height[a] >= height[b])
            par[b] = a;
        else par[a] = b;
    }
};

vector<edge> kruskalMST(vector<edge> edges, int n){
    sort(edges.begin(), edges.end(), [&](edge & a, edge & b) ->
        bool { return get<2>(a) < get<2>(b); });
}
```

```
disjoint_set ds(n);

int tot = 0;
vector<edge> out;
for(edge e : edges){
    if(ds.parent(get<0>(e)) != ds.parent(get<1>(e))){
        tot += get<2>(e);
        out.push_back(e);
        ds.unionize(get<0>(e), get<1>(e));
    }
}

return out;
}
```

Dinic.cpp

Description: Compute maximum flow in a graph. The basic principle is that a Maximum flow = minimum cut and Breadth First Search is used as a sub-routine.

Memory: $\mathcal{O}(E+V)$

Time: $\mathcal{O}(EV^2)$

```
ef99cb, 47 lines

using ll = long long;

struct Dinic {
    struct Edge {
        int to, rev;
        ll c, oc;
        ll flow() { return max(oc - c, 0LL); } // if you need flows
        Edge(int tt, int rr, ll cc, ll oo){
            to = tt; rev = rr; c = cc; oc = oo;
        }
    };
    vector<int> lvl, ptr, q;
    vector<vector<Edge>> adj;
    Dinic(int n) : lvl(n), ptr(n), q(n), adj(n) {}
    void add(int a, int b, ll c, ll rcap = 0) {
        adj[a].push_back(Edge((ll)b, adj[b].size(), c, c));
        adj[b].push_back({a, (int)adj[a].size() - 1, rcap, rcap});
    }
    ll dfs(int v, int t, ll f) {
        if (v == t || !f) return f;
        for (int& i = ptr[v]; i < adj[v].size(); i++) {
            Edge& e = adj[v][i];
            if (lvl[e.to] == lvl[v] + 1)
                if (ll p = dfs(e.to, t, min(f, e.c))) {
                    e.c -= p, adj[e.to][e.rev].c += p;
                    return p;
                }
        }
        return 0;
    }
    ll calc(int s, int t) {
        ll flow = 0; q[0] = s;
        for(int L = 0; L < 31; L++) do { // 'int L=30' maybe faster
            for random data
                lvl = ptr = vector<int>(q.size());
                int qi = 0, qe = lvl[s] = 1;
                while (qi < qe && !lvl[t]) {
                    int v = q[qi++];
                    for (Edge e : adj[v])
                        if (!lvl[e.to] && e.c >> (30 - L))
                            q[qe++] = e.to, lvl[e.to] = lvl[v] + 1;
                }
                while (ll p = dfs(s, t, LLONG_MAX)) flow += p;
            } while (lvl[t]);
        }
        return flow;
    }
    bool leftOfMinCut(int a) { return lvl[a] != 0; }
}
```

```
};

topSort.cpp
Description: Find a toposort of a directed graph
Memory:  $\mathcal{O}(V)$ 
Time:  $\mathcal{O}(V + E)$ 
36bfac, 27 lines

using namespace std;

#define vv first
#define ww second
using edge = pair<int, int>;

void topSortUtil(vector<edge> g[], int v, stack<int> s, bool seen[]){
    seen[v] = true;
    for(edge e : g[v])
        if(!seen[e.vv])
            topSortUtil(g, e.vv, s, seen);
    s.push(v);
}

vector<int> topSort(vector<edge> g[], int v){
    stack<int> out;
    bool seen[v];
    for(int i = 0; i < v; i++)
        if(!seen[i])
            topSortUtil(g, i, out, seen);
    vector<int> ts(v);
    for(int i = v-1; i >= 0; i--){
        ts[i] = out.top();
        out.pop();
    }
    return ts;
}
```

```
SCCTarjan.h
Description: Finds strongly connected components of a directed graph.
Visits/indexes SCCs in reverse topological order.
Usage: scc(graph) returns an array that has the ID of each node's SCC. scc(graph, [&](vector<int>& v) { ... }) calls the lambda on each SCC, and returns the same array.
Time:  $\mathcal{O}(|V| + |E|)$ 
358d18, 37 lines

namespace SCCTarjan {
    vector<int> val, comp, z, cont;
    int Time, ncomps;
    template <class G, class F>
    int dfs(int j, G& g, F& f) {
        int low = val[j] = ++Time, x;
        z.push_back(j);
        for (auto e : g[j])
            if (comp[e] < 0) low = min(low, val[e] ? dfs(e, g, f));
        if (low == val[j]) {
            do {
                x = z.back();
                z.pop_back();
                comp[x] = ncomps;
                cont.push_back(x);
            } while (x != j);
            f(cont);
            cont.clear();
            ncomps++;
        }
        return val[j] = low;
    }
    template <class G, class F>
    vector<int> scc(G& g, F f) {
        int n = g.size();
```

```
        val.assign(n, 0);
        comp.assign(n, -1);
        Time = ncomps = 0;
        for (int i = 0; i < n; i++)
            if (comp[i] < 0) dfs(i, g, f);
        return comp;
    }
    template <class G> // convenience function w/o lambda
    vector<int> scc(G& g) {
        return scc(g, [](auto& v) {});
    }
} // namespace SCCTarjan
```

```
SCCKosaraju.h
Description: Finds strongly connected components of a directed graph.
Visits/indexes SCCs in topological order.
Usage: scc(graph) returns an array that has the ID of each node's SCC.
Time:  $\mathcal{O}(|V| + |E|)$ 
9b78e7, 29 lines

namespace SCCKosaraju {
    vector<vector<int>>> adj, radj;
    vector<int> todo, comp;
    vector<bool> vis;
    void dfs1(int x) {
        vis[x] = 1;
        for (int y : adj[x])
            if (!vis[y]) dfs1(y);
        todo.push_back(x);
    }
    void dfs2(int x, int i) {
        comp[x] = i;
        for (int y : radj[x])
            if (comp[y] == -1) dfs2(y, i);
    }
    vector<int> scc(vector<vector<int>>& _adj) {
        adj = _adj;
        int time = 0, n = adj.size();
        comp.resize(n, -1), radj.resize(n), vis.resize(n);
        for (int x = 0; x < n; x++)
            for (int y : adj[x]) radj[y].push_back(x);
        for (int x = 0; x < n; x++)
            if (!vis[x]) dfs1(x);
        reverse(todo.begin(), todo.end());
        for (int x : todo)
            if (comp[x] == -1) dfs2(x, time++);
        return comp;
    }
}; // namespace SCCKosaraju
```

```
dijkstra.h
Description: Computes shortest paths from s to any node reachable from s. Pass in an adjacency list of pairs (node, weight) and a starting node s.
Time:  $\mathcal{O}((|V| + |E|) \log |V|)$ 
e0bb66, 16 lines

constexpr int INF = (int) 1e9;
vector<int> dijkstra(
    vector<vector<ii>> adjlist, int s) {
    using ii = pair<int, int>;
    vector<int> dist(V, INF); dist[s] = 0;
    priority_queue<ii, vector<ii>, greater<ii>> pq;
    pq.push(ii(0, s));
    while (!pq.empty()) {
        auto [d, u] = pq.top(); pq.pop();
        if (d > dist[u]) continue;
        for (auto [v, w] : adjlist[u])
            if (d + w < dist[v])
                pq.push(ii(dist[v] = d + w, v));
    }
}
```

```
        return dist;
    }
```

Mathematics (5)

Fraction.h

Description: Struct for representing fractions/rationals. All ops are $O(\log N)$ due to GCD in constructor. Uses cross multiplication.

```
template <typename T>
struct Q {
    T a, b;
    Q(T p, T q = 1) {
        T g = gcd(p, q);
        a = p / g;
        b = q / g;
        if (b < 0) a = -a, b = -b;
    }
    T gcd(T x, T y) const { return __gcd(x, y); }
    Q operator+(const Q& o) const {
        return {a * o.b + o.a * b, b * o.b};
    }
    Q operator-(const Q& o) const {
        return *this + Q(-o.a, o.b);
    }
    Q operator*(const Q& o) const { return {a * o.a, b * o.b}; }
    Q operator/(const Q& o) const { return *this * Q(o.b, o.a); }
    Q recip() const { return {b, a}; }
    int signum() const { return (a > 0) - (a < 0); }
    bool operator<(const Q& o) const {
        return a * o.b < o.a * b;
    }
    friend ostream& operator<<(ostream& cout, const Q& o) {
        return cout << o.a << "/" << o.b;
    }
};
```

FractionOverflow.h

Description: Safer struct for representing fractions/rationals. Comparison is 100% overflow safe; other ops are safer but can still overflow. All ops are $O(\log N)$.

```
template <typename T>
struct QO {
    T a, b;
    QO(T p, T q = 1) {
        T g = gcd(p, q);
        a = p / g;
        b = q / g;
        if (b < 0) a = -a, b = -b;
    }
    T gcd(T x, T y) const { return __gcd(x, y); }
    QO operator+(const QO& o) const {
        T g = gcd(b, o.b), bb = b / g, obb = o.b / g;
        return {a * obb + o.a * bb, b * obb};
    }
    QO operator-(const QO& o) const {
        return *this + QO(-o.a, o.b);
    }
    QO operator*(const QO& o) const {
        T g1 = gcd(a, o.b), g2 = gcd(o.a, b);
        return {(a / g1) * (o.a / g2), (b / g2) * (o.b / g1)};
    }
    QO operator/(const QO& o) const {
        return *this * QO(o.b, o.a);
    }
    QO recip() const { return {b, a}; }
    int signum() const { return (a > 0) - (a < 0); }
    static bool lessThan(T a, T b, T x, T y) {
        if (a / b != x / y) return a / b < x / y;
        if (x % y == 0) return false;
        if (a % b == 0) return true;
    }
};
```

```
        return lessThan(y, x % y, b, a % b);
    }
    bool operator<(const QO& o) const {
        if (this->signum() != o.signum() || a == 0) return a < o.a;
        if (a < 0)
            return lessThan(abs(o.a), o.b, abs(a), b);
        else
            return lessThan(a, b, o.a, o.b);
    }
    friend ostream& operator<<(ostream& cout, const QO& o) {
        return cout << o.a << "/" << o.b;
    }
};
```

PrimeSieve.h

Description: Prime sieve for generating all primes up to a certain limit. isprime[i] is true iff i is a prime.

Time: lim=100'000'000 \approx 0.8 s. Runs 30% faster if only odd indices are stored.

```
const int MAX_PR = 5'000'000;
bitset<MAX_PR> isprime;
vector<int> primeSieve(int lim) {
    isprime.set();
    isprime[0] = isprime[1] = 0;
    for (int i = 4; i < lim; i += 2) isprime[i] = 0;
    for (int i = 3; i * i < lim; i += 2)
        if (isprime[i])
            for (int j = i * i; j < lim; j += i * 2) isprime[j] = 0;
    vector<int> pr;
    for (int i = 2; i < lim; i++)
        if (isprime[i]) pr.push_back(i);
    return pr;
}
```

PrimeSieveFast.h

Description: Prime sieve for generating all primes smaller than LIM.

Time: LIM=1e9 \approx 1.5s

```
const int LIM = 1e8;
bitset<LIM> isPrime;
vector<int> primeSieve() {
    const int S = round(sqrt(LIM)), R = LIM / 2;
    vector<int> pr = {2}, sieve(S + 1);
    pr.reserve(int(LIM / log(LIM) * 1.1));
    vector<pair<int, int>> cp;
    for (int i = 3; i <= S; i += 2)
        if (!sieve[i]) {
            cp.push_back({i, i * i / 2});
            for (int j = i * i; j <= S; j += 2 * i) sieve[j] = 1;
        }
    for (int L = 1; L <= R; L += S) {
        array<bool, S> block{};
        for (auto& [p, idx] : cp)
            for (int i = idx; i < S + L; idx = (i += p))
                block[i - L] = 1;
        for (int i = 0; i < min(S, R - L); i++)
            if (!block[i]) pr.push_back((L + i) * 2 + 1);
    }
    for (int i : pr) isPrime[i] = 1;
    return pr;
}
```


Miscellaneous (6)

NDimensionalVector.h3c0f61, 12 lines

```
template <int D, typename T>
struct Vec : public vector<Vec<D - 1, T>> {
    static_assert(D >= 1,
        "Vector dimension must be greater than zero!");
    template <typename... Args>
    Vec(int n = 0, Args... args):
        vector<Vec<D - 1, T>>(n, Vec<D - 1, T>(args...)) {}
};
template <typename T>
struct Vec<1, T> : public vector<T> {
    Vec(int n = 0, const T& val = T()): vector<T>(n, val) {}
};
```

Submasks.h35424b, 3 lines

```
for (int mask = 0; mask < (1 << n); mask++)
    for (int sub = mask; sub; sub = (sub - 1) & mask)
        // do thing
```

Strings (7)

ZValues.h

151ee3, 10 lines

```
vector<int> zValues(string& s) {  
    int n = ( int )s.length();  
    vector<int> z(n);  
    for (int i = 1, l = 0, r = 0; i < n; ++i) {  
        if (i <= r) z[i] = min(r - i + 1, z[i - l]);  
        while (i + z[i] < n && s[z[i]] == s[i + z[i]]) ++z[i];  
        if (i + z[i] - 1 > r) l = i, r = i + z[i] - 1;  
    }  
    return z;  
}
```