

# University of Tartu ICPC Team

## Notebook (2022-2023)

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**Maxflow Complexity**  
 $\mathcal{O}(V^2 E)$  – Dinic  
 $\Theta(VE \log U)$  – Capacity scaling  
 $\Theta(\text{flow} E)$  – Small flow  
 $\Theta(\min\{V^{\frac{2}{3}}, E^{\frac{1}{2}}\} E)$  – Unitary capacities  
 $\Theta(\sqrt{V} E)$  – Each vertex other than S,T has only a single incoming unitary edge or outgoing one (bipartite matching)  
 $\Theta(\text{flow} E \log V)$  – Min-cost-max flow

Diagram illustrating LR-flow. Nodes are arranged in two rows. Top row: S (blue circle), A (grey circle), B (grey circle), T (red circle). Bottom row: S' (blue circle), T' (red circle), S (grey circle), A (grey circle), T' (red circle). Edges: S to A (dotted), A to B (solid, labeled L≤F≤R), B to T (dotted), S' to T' (solid, labeled 0≤F≤L), T' to S (solid, labeled 0≤F≤L), S to A (solid, labeled 0≤F≤L), A to T' (solid, labeled 0≤F≤L). A curved arrow labeled LR-flow goes from B to A.

**Min Rotation of string**  

```

12 int a=0, N=s.size();
12 s += s;
13 ran(b,0,N){
13   ran(i,0,N) {
14     if (a+i == b || s[a+i] < s[b+i]) {
15       b += max(0, i-1);
16       break;
17     }
18   }
19   if (s[a+i] > s[b+i]) {
20     a = b;
21     break;
22   }
23 }
23 return a;

```

**Series**

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots, (-\infty < x < \infty)$$

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \dots, (-1 < x \leq 1)$$

$$\sqrt{1+x} = 1 + \frac{x}{2} - \frac{x^2}{8} + \frac{2x^3}{32} - \frac{5x^4}{128} + \dots, (-1 \leq x \leq 1)$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots, (-\infty < x < \infty)$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots, (-\infty < x < \infty)$$

**Symmetric Submodular Functions; Queyrannes's algorithm**

**SSF:** such function  $f : V \rightarrow R$  that satisfies  $f(A) = f(V/A)$  and for all  $x \in V, X \subseteq Y \subseteq V$  it holds that  $f(X+x) - f(X) \leq f(Y+x) - f(Y)$ .

**Hereditary family:** such set  $I \subseteq 2^V$  so that  $X \subset Y \wedge Y \in I \Rightarrow X \in I$ .

**Loop:** such  $v \in V$  so that  $v \notin I$ .

```

def minimize():
    s = merge_all_loops()
    while size >= 3:
        t, u = find_pp()
        {u} is a possible minimizer
        tu = merge(t, u)
        if tu not in I:
            s = merge(tu, s)
    for x in V:
        {x} is a possible minimizer

```

```

def find_pp():
    W = {s} # s as in minimizer()
    todo = V/W
    ord = []
    while len(todo) > 0:
        x = min(todo, key=lambda x: f(W+{x}) -
        ↪ f({x}))
        W += {x}
        todo -= {x}
        ord.append(x)
    return ord[-1], ord[-2]

def enum_all_minimal_minimizers(X):
    # X is a inclusionwise minimal minimizer
    s = merge(s, X)
    yield X
    for {v} in I:
        if f({v}) == f(X):
            yield X
            s = merge(v, s)
    while size(V) >= 3:
        t, u = find_pp()
        tu = merge(t, u)
        if tu not in I:
            s = merge(tu, s)
        elif f({tu}) = f(X):
            yield tu
            s = merge(tu, s)

Subset convolution  $\mathcal{O}(N \log N)$ 
 $c[z] = \sum_{z=x \oplus y} a[x] \cdot b[y]$ , where  $\oplus$  is one of AND, OR,
XOR. The size of  $a$  must be a power of two.

void FST(vi& a, bool inv) { //size(a) == 2x
    for (int n=(int)a.size(), step = 1; step <
    ↪ n; step *= 2) {
        for (int i = 0; i < n; i += 2 * step)
            ran(j, i, i + step) {
                int &u = a[j], &v = a[j + step];
                tie(u, v) =
                inv ? pii(v - u, u) : pii(v, u + v);
            ↪ // AND
            inv ? pii(v, u - v) : pii(u + v, u);
            ↪ // OR
            pii(u + v, u - v);
            ↪ // XOR
        }
    }
    if (inv) trav(x, a) x /= a.size(); // XOR
    ↪ only
}
vi conv(vi a, vi b) {

```

```

FST(a, 0);
FST(b, 0);
ran(i, 0, (int)a.size()) a[i] *= b[i];
FST(a, 1);
return a;
}

SOS-DP  $\mathcal{O}(N \log N)$ 
 $a[x] \leftarrow \bigoplus_{y \subseteq x} a[y]$ , where  $\oplus$  is any commutative,
associative operation.

for (int k = 0; k < K; k++) { // K = log N, N
    ↪ should be a power of two
    int m = 1 << k;
    for (int i = 0; i < 1 << K; i++) {
        if (i & m) {
            a[i] = op(a[i], a[i - m]); // replace op
            ↪ with your operation
        }
    }
}

```

### Pythagorean Triples

The Pythagorean triples are uniquely generated by

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

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

### Primes

$p = 962592769$  is such that  $2^{21} \mid p - 1$ , which may be useful. For hashing use 970592641 (31-bit number), 31443539979727 (45-bit), 3006703054056749 (52-bit). There are 78498 primes less than 1 000 000.

Primitive roots exist modulo any prime power  $p^a$ , except for  $p = 2, a > 2$ , and there are  $\varphi(\varphi(p^a))$  many. For  $p = 2, a > 2$ , the group  $\mathbb{Z}_{2^a}^\times$  is instead isomorphic to  $\mathbb{Z}_2 \times \mathbb{Z}_{2^{a-2}}$ .

### Estimates

$$\sum_{d|n} d = \mathcal{O}(n \log \log n).$$

The number of divisors of  $n$  is at most around 100 for  $n < 5e4$ , 500 for  $n < 1e7$ , 2000 for  $n < 1e10$ , 200 000 for  $n < 1e19$ .

### Möbius inversion

$$\forall n : g(n) = \sum_{d|n} f(d) \iff \forall n : f(n) = \sum_{d|n} \mu(d) g\left(\frac{n}{d}\right)$$

### Derangements

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

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

### Burnside's lemma

Given a group  $G$  of symmetries and a set  $X$ , the number of elements of  $X$  up to symmetry equals

$$\frac{1}{|G|} \sum_{g \in G} |X^g|,$$

where  $X^g$  are the elements fixed by  $g$  ( $g.x = x$ ).

If  $f(n)$  counts “configurations” (of some sort) of length  $n$ , we can ignore rotational symmetry using  $G = \mathbb{Z}_n$  to get

$$g(n) = \frac{1}{n} \sum_{k=0}^{n-1} f(\gcd(n, k)) = \frac{1}{n} \sum_{k|n} f(k) \varphi(n/k).$$

### Partition function

Number of ways of writing  $n$  as a sum of positive integers, disregarding the order of the summands.

$$p(0) = 1, p(n) = \sum_{k \in \mathbb{Z} \setminus \{0\}} (-1)^{k+1} p(n - k(3k-1)/2)$$

$$p(n) \sim 0.145/n \cdot \exp(2.56\sqrt{n})$$

$n$	0	1	2	3	4	5	6	7	8	9	20	50	100
$p(n)$	1	1	2	3	5	7	11	15	22	30	627	$\sim 2e5$	$\sim 2e8$

### Stirling numbers of the first kind

Number of permutations on  $n$  items with  $k$  cycles.

$$c(n, k) = c(n-1, k-1) + (n-1)c(n-1, k), \quad c(0, 0) = 1$$

$$\sum_{k=0}^n c(n, k) x^k = x(x+1) \dots (x+n-1)$$

$$c(8, k) = 8, 0, 5040, 13068, 13132, 6769, 1960, 322, 28, 1$$

$$c(n, 2) = 0, 0, 1, 3, 11, 50, 274, 1764, 13068, 109584, \dots$$

### Eulerian numbers

Number of permutations  $\pi \in S_n$  in which exactly  $k$  elements are greater than the previous element.  $k$   $j$ :s s.t.  $\pi(j) > \pi(j+1)$ ,  $k+1$   $j$ :s s.t.  $\pi(j) \geq j$ ,  $k$   $j$ :s s.t.  $\pi(j) > j$ .

$$E(n, k) = (n - k)E(n - 1, k - 1) + (k + 1)E(n - 1, k)$$

$$E(n, 0) = E(n, n - 1) = 1$$

$$E(n, k) = \sum_{j=0}^k (-1)^j \binom{n+1}{j} (k+1-j)^n$$

### Stirling numbers of the second kind

Partitions of  $n$  distinct elements into exactly  $k$  groups.

$$S(n, k) = S(n - 1, k - 1) + kS(n - 1, k)$$

$$S(n, 1) = S(n, n) = 1$$

$$S(n, k) = \frac{1}{k!} \sum_{j=0}^k (-1)^{k-j} \binom{k}{j} j^n$$

### Bell numbers

Total number of partitions of  $n$  distinct elements.  $B(n) = 1, 1, 2, 5, 15, 52, 203, 877, 4140, 21147, \dots$  For  $p$  prime,

$$B(p^m + n) \equiv mB(n) + B(n + 1) \pmod{p}$$

### Catalan numbers

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

$$C_0 = 1, C_{n+1} = \frac{2(2n+1)}{n+2} C_n, C_{n+1} = \sum C_i C_{n-i}$$

$$C_n = 1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796, 58786, \dots$$

- sub-diagonal monotone paths in an  $n \times n$  grid.
- strings with  $n$  pairs of parenthesis, correctly nested.
- binary trees with  $n+1$  leaves (0 or 2 children).
- ordered trees with  $n+1$  vertices.
- ways a convex polygon with  $n+2$  sides can be cut into triangles by connecting vertices with straight lines.
- permutations of  $[n]$  with no 3-term increasing subseq.

### Hall's marriage theorem

Let  $G$  be a bipartite graph consisting of sets  $X$  and  $Y$ . We can match every vertex in  $X$  if and only if for every  $W \subseteq X$ ,

$$|W| \leq |N(W)|.$$

### Prüfer sequences

Consider trees with  $n$  vertices. Prüfer sequences are sequences of length  $n-2$  in bijection with labeled trees.

To convert a tree to a sequence:

- while the tree has more than two vertices:
  - pick the leaf with the smallest label;
  - remove it and append its neighbor to the sequence.

### Pascal's Triangle

	0	1	2	3	4	5	6	7	8
0	1								
2	1	2	1						
4	1	4	6	4	1				
6	1	6	15	20	15	6	1		
8	1	8	28	56	70	56	28	8	1
10	1	10	45	120	210	252	210	120	45
12	1	12	66	220	495	792	924	792	495
14	1	14	91	364	1001	2002	3003	3432	3003
16	1	16	120	560	1820	4368	8008	11440	12870
18	1	18	153	816	3060	8568	18564	31824	43758
20	1	20	190	1140	4845	15504	38760	77520	$1 \cdot 10^5$
22	1	22	231	1540	7315	26334	74613	$2 \cdot 10^5$	$3 \cdot 10^5$
24	1	24	276	2024	10626	42504	$1 \cdot 10^5$	$3 \cdot 10^5$	$7 \cdot 10^5$
26	1	26	325	2600	14950	65780	$2 \cdot 10^5$	$7 \cdot 10^5$	$2 \cdot 10^6$
28	1	28	378	3276	20475	98280	$4 \cdot 10^5$	$1 \cdot 10^6$	$3 \cdot 10^6$
30	1	30	435	4060	27405	$1 \cdot 10^5$	$6 \cdot 10^5$	$2 \cdot 10^6$	$6 \cdot 10^6$
32	1	32	496	4960	35960	$2 \cdot 10^5$	$9 \cdot 10^5$	$3 \cdot 10^6$	$1 \cdot 10^7$
34	1	34	561	5984	46376	$3 \cdot 10^5$	$1 \cdot 10^6$	$5 \cdot 10^6$	$2 \cdot 10^7$
36	1	36	630	7140	58905	$4 \cdot 10^5$	$2 \cdot 10^6$	$8 \cdot 10^6$	$3 \cdot 10^7$
38	1	38	703	8436	73815	$5 \cdot 10^5$	$3 \cdot 10^6$	$1 \cdot 10^7$	$5 \cdot 10^7$
40	1	40	780	9880	91390	$7 \cdot 10^5$	$4 \cdot 10^6$	$2 \cdot 10^7$	$8 \cdot 10^7$
42	1	42	861	11480	$1 \cdot 10^5$	$9 \cdot 10^5$	$5 \cdot 10^6$	$3 \cdot 10^7$	$1 \cdot 10^8$
44	1	44	946	13244	$1 \cdot 10^5$	$1 \cdot 10^6$	$7 \cdot 10^6$	$4 \cdot 10^7$	$2 \cdot 10^8$
46	1	46	1035	15180	$2 \cdot 10^5$	$1 \cdot 10^6$	$9 \cdot 10^6$	$5 \cdot 10^7$	$3 \cdot 10^8$
48	1	48	1128	17296	$2 \cdot 10^5$	$2 \cdot 10^6$	$1 \cdot 10^7$	$7 \cdot 10^7$	$4 \cdot 10^8$
50	1	50	1225	19600	$2 \cdot 10^5$	$2 \cdot 10^6$	$2 \cdot 10^7$	$10 \cdot 10^7$	$5 \cdot 10^8$
52	1	52	1326	22100	$3 \cdot 10^5$	$3 \cdot 10^6$	$2 \cdot 10^7$	$1 \cdot 10^8$	$8 \cdot 10^8$
54	1	54	1431	24804	$3 \cdot 10^5$	$3 \cdot 10^6$	$3 \cdot 10^7$	$2 \cdot 10^8$	$1 \cdot 10^9$
56	1	56	1540	27720	$4 \cdot 10^5$	$4 \cdot 10^6$	$3 \cdot 10^7$	$2 \cdot 10^8$	$1 \cdot 10^9$
58	1	58	1653	30856	$4 \cdot 10^5$	$5 \cdot 10^6$	$4 \cdot 10^7$	$3 \cdot 10^8$	$2 \cdot 10^9$
60	1	60	1770	34220	$5 \cdot 10^5$	$5 \cdot 10^6$	$5 \cdot 10^7$	$4 \cdot 10^8$	$3 \cdot 10^9$

## 2D geometry

Define  $\text{orient}(A, B, C) = \overline{AB} \times \overline{AC}$ . CCW iff  $> 0$ .

Define  $\text{perp}((a, b)) = (-b, a)$ . The vectors are orthogonal.

For line  $ax + by = c$  def  $\bar{v} = (-b, a)$ .

Line through  $P$  and  $Q$  has  $\bar{v} = \overline{PQ}$  and  $c = \bar{v} \times P$ .

$\text{side}_l(P) = \bar{v}_l \times P - c_l$  sign determines which side  $P$  is on from  $l$ .

$\text{dist}_l(P) = \text{side}_l(P) / \|\bar{v}_l\|$  squared is integer.

Sorting points along a line: comparator is  $\bar{v} \cdot A < \bar{v} \cdot B$ .

Translating line by  $\bar{t}$ : new line has  $c' = c + \bar{v} \times \bar{t}$ .

Line intersection: is  $(c_l \bar{v}_m - c_m \bar{v}_l) / (\bar{v}_l \times \bar{v}_m)$ .

Project  $P$  onto  $l$ : is  $P - \text{perp}(v) \text{side}_l(P) / \|v\|^2$ .

Angle bisectors:  $\bar{v} = \bar{v}_l / \|\bar{v}_l\| + \bar{v}_m / \|\bar{v}_m\|$

$c = c_l / \|\bar{v}_l\| + c_m / \|\bar{v}_m\|$ .

$P$  is on segment  $AB$  iff  $\text{orient}(A, B, P) = 0$  and  $\overline{PA} \cdot \overline{PB} \leq 0$ .

Proper intersection of  $AB$  and  $CD$  exists iff  $\text{orient}(C, D, A)$  and  $\text{orient}(C, D, B)$  have opp. signs and  $\text{orient}(A, B, C)$  and  $\text{orient}(A, B, D)$  have opp. signs. Coordinates:

$$\frac{A \text{orient}(C, D, B) - B \text{orient}(C, D, A)}{\text{orient}(C, D, B) - \text{orient}(C, D, A)}.$$

Circumcircle center:

```
pt circumCenter(pt a, pt b, pt c) {
    b = b-a, c = c-a; // consider coordinates
    // relative to A
    assert(cross(b,c) != 0); // no circumcircle if
    // A,B,C aligned
    return a + perp(b*sq(c) - c*sq(b))/cross(b,c)
    /2;
```

Circle-line intersect:

```
int circleLine(pt o, double r, line l, pair<pt,pt>
    > &out) {
    double h2 = r*r - l.sqDist(o);
    if (h2 >= 0) { // the line touches the circle
        pt p = l.proj(o); // point P
        pt h = l.v*sqrt(h2)/abs(l.v); // vector paral
        // to l, of len h
        out = {p-h, p+h};
    }
    return 1 + sgn(h2);
```

Circle-circle intersect:

```
int circleCircle(pt o1, double r1, pt o2, double
    r2, pair<pt,pt> &out) {
```

```
    pt d=o2-o1; double d2=sq(d);
    if (d2 == 0) {assert(r1 != r2); return 0;} //
    // concentric circles
    double pd = (d2 + r1*r1 - r2*r2)/2; // = |O_1P|
    // * d
    double h2 = r1*r1 - pd*pd/d2; // = h^2
    if (h2 >= 0) {
        pt p = o1 + d*pd/d2, h = perp(d)*sqrt(h2/d2);
        out = {p-h, p+h};}
    return 1 + sgn(h2);
```

Tangent lines:

```
int tangents(pt o1, double r1, pt o2, double r2,
    bool inner, vector<pair<pt,pt>> &out) {
    if (inner) r2 = -r2;
    pt d = o2-o1;
    double dr = r1-r2, d2 = sq(d), h2 = d2-dr*dr;
    if (d2 == 0 || h2 < 0) {assert(h2 != 0); return
    0;}
    for (double sign : {-1,1}) {
        pt v = (d*dr + perp(d)*sqrt(h2)*sign)/d2;
        out.push_back({o1 + v*r1, o2 + v*r2});}
    return 1 + (h2 > 0);
```

## 3D geometry

$\text{orient}(P, Q, R, S) = (\overline{PQ} \times \overline{PR}) \cdot \overline{PS}$ .

$S$  above  $PQR$  iff  $> 0$ .

For plane  $ax + by + cz = d$  def  $\bar{n} = (a, b, c)$ .

Line with normal  $\bar{n}$  through point  $P$  has  $d = \bar{n} \cdot P$ .

$\text{side}_\Pi(P) = \bar{n} \cdot P - d$  sign determines side from  $\Pi$ .

$\text{dist}_\Pi(P) = \text{side}_\Pi(P) / \|\bar{n}\|$ .

Translating plane by  $\bar{t}$  makes  $d' = d + \bar{n} \cdot \bar{t}$ .

Plane-plane intersection of has direction  $\bar{n}_1 \times \bar{n}_2$  and goes through  $((d_1 \bar{n}_2 - d_2 \bar{n}_1) \times \bar{d}) / \|\bar{d}\|^2$ .

Line-line distance:

```
double dist(line3d l1, line3d l2) {
    p3 n = l1.d*l2.d;
    if (n == zero) // parallel
        return l1.dist(l2.o);
    return abs((l2.o-l1.o)|n)/abs(n);
```

Spherical to Cartesian:

$(r \cos \varphi \cos \lambda, r \cos \varphi \sin \lambda, r \sin \varphi)$ .

Sphere-line intersection:

```
int sphereLine(p3 o, double r, line3d l, pair<p3,
    p3> &out) {
    double h2 = r*r - l.sqDist(o);
    if (h2 < 0) return 0; // the line doesn't touch
    // the sphere
    p3 p = l.proj(o); // point P
    p3 h = l.d*sqrt(h2)/abs(l.d); // vector
```

```
    // parallel to l, of length h
    out = {p-h, p+h};
    return 1 + (h2 > 0);
```

Great-circle distance between points  $A$  and  $B$  is  $r \angle AOB$ .

Spherical segment intersection:

```
bool properInter(p3 a, p3 b, p3 c, p3 d, p3 &out)
    {
    p3 ab = a*b, cd = c*d; // normals of planes OAB
    // and OCD
    int oa = sgn(cd|a),
        ob = sgn(cd|b),
        oc = sgn(ab|c),
        od = sgn(ab|d);
    out = ab*cd*od; // four multiplications =>
    // careful with overflow !
    return (oa != ob && oc != od && oa != oc);
}
bool onSphSegment(p3 a, p3 b, p3 p) {
    p3 n = a*b;
    if (n == zero)
        return a*p == zero && (a|p) > 0;
    return (n|p) == 0 && (n|a*p) >= 0 && (n|b*p) <=
    0;
}
struct directionSet : vector<p3> {
    using vector::vector; // import constructors
    void insert(p3 p) {
        for (p3 q : *this) if (p*q == zero) return;
        push_back(p);
    }
};
directionSet intersSph(p3 a, p3 b, p3 c, p3 d) {
    assert(validSegment(a, b) && validSegment(c, d)
    );
    p3 out;
    if (properInter(a, b, c, d, out)) return {out};
    directionSet s;
    if (onSphSegment(c, d, a)) s.insert(a);
    if (onSphSegment(c, d, b)) s.insert(b);
    if (onSphSegment(a, b, c)) s.insert(c);
    if (onSphSegment(a, b, d)) s.insert(d);
    return s;
}
```

Angle between spherical segments  $AB$  and  $AC$  is angle between  $A \times B$  and  $A \times C$ .

Oriented angle: subtract from  $2\pi$  if mixed product is negative.

Area of a spherical polygon:

$$r^2 [\text{sum of interior angles} - (n - 2)\pi].$$

## Triangle centers

```

const double min_delta = 1e-13;
const double coord_max = 1e6;
typedef complex<double> point;
point A, B, C; // vertexes of the triangle
bool collinear() {
    double min_diff =
        min(abs(A - B), min(abs(A - C), abs(B - C)));
    if (min_diff < coord_max * min_delta) return true;
    point sp = (B - A) / (C - A);
    double ang = M_PI / 2 - abs(abs(arg(sp)) - M_PI / 2);
    return ang < min_delta;
    // positive angle with the real line
}
point circum_center() {
    if (collinear()) return point(NAN, NAN);
    // squared lengths of sides
    double a2 = norm(B - C);
    double b2 = norm(A - C);
    double c2 = norm(A - B);
    // barycentric coordinates of the circumcenter
    // sin(2 * alpha) works also
    double c_A = a2 * (b2 + c2 - a2);
    double c_B = b2 * (a2 + c2 - b2);
    double c_C = c2 * (a2 + b2 - c2);
    double sum = c_A + c_B + c_C;
    c_A /= sum;
    c_B /= sum;
    c_C /= sum;
    return c_A * A + c_B * B + c_C * C; // cartesian
}
point centroid() { // center of mass
    return (A + B + C) / 3.0;
}
point ortho_center() { // euler line
    point O = circum_center();
    return O + 3.0 * (centroid() - O);
};
point nine_point_circle_center() { // euler line
    point O = circum_center();
    return O + 1.5 * (centroid() - O);
};
point in_center() {
    if (collinear()) return point(NAN, NAN);
    double a = abs(B - C); // side lengths
    double b = abs(A - C);
    double c = abs(A - B);
    // trilinear coordinates are (1,1,1)
    double sum = a + b + c;
    a /= sum;

```

```

    b /= sum;
    c /= sum;
    return a * A + b * B + c * C; // cartesian
}
%9596

Seg-Seg intersection, halfplane intersection area

struct Seg {
    Vec a, b;
    Vec d() { return b - a; }
};
1709;
Vec intersection(Seg l, Seg r) {
    Vec dl = l.d(), dr = r.d();
    if (cross(dl, dr) == 0) return {nanl(""), nanl("")};
    double h = cross(dr, l.a - r.a) / len(dr);
    double dh = cross(dr, dl) / len(dr);
    return l.a + dl * (h / -dh);
    7485
    3280
    // Returns the area bounded by halfplanes
    double calc_area(const vector<Seg>& lines) {
        double lb = -HUGE_VAL, ub = HUGE_VAL;
        vector<Seg> slines[2];
        for (auto line : lines) {
            if (line.b.y == line.a.y) {
                if (line.a.x < line.b.x) {
                    lb = max(lb, line.a.y);
                } else {
                    ub = min(ub, line.a.y);
                }
            } else if (line.a.y < line.b.y) {
                slines[1].push_back(line);
            } else {
                slines[0].push_back({line.b, line.a});
            }
        }
        ran(i, 0, 2) {
            sort(slines[i].begin(), slines[i].end(),
                [&](Seg l, Seg r) {
                    if (cross(l.d(), r.d()) == 0)
                        return normal(l.d()) * l.a >
                            normal(r.d()) * r.a;
                    return (1 - 2 * i) * cross(l.d(), r.d()) < 0;
                });
            // Now find the application area of the lines and clean
            // up redundant ones
            vector<double> ap_s[2];
            ran(side, 0, 2) {
                vector<double>& apply = ap_s[side];
                vector<Seg> clines;
                for (auto line : slines[side]) {
                    while (clines.size() > 0) {
                        Seg other = clines.back();
                        if (cross(line.d(), other.d()) != 0) {
                            double start = intersection(line, other).y;
                            if (start > apply.back()) break;
                        }
                    }
                }
            }
        }
    }
    9341
    6193
    4781
    7279
    8690
    6958
    4919
    3134
    7378
    8193
    0814
    0015
    5287

```

```

        clines.pop_back();
        apply.pop_back();
    }
    if (clines.size() == 0) {
        apply.push_back(-HUGE_VAL);
    } else {
        apply.push_back(
            intersection(line, clines.back()).y);
    }
    clines.push_back(line);
    slines[side] = clines;
}
ap_s[0].push_back(HUGE_VALL);
ap_s[1].push_back(HUGE_VALL);
double result = 0;
{
    double lb = -HUGE_VALL, ub;
    for (int i = 0, j = 0; i < (int)slines[0].size() &&
        j < (int)slines[1].size();
        lb = ub) {
        ub = min(ap_s[0][i + 1], ap_s[1][j + 1]);
        double alb = lb, aub = ub;
        Seg l[2] = {slines[0][i], slines[1][j]};
        if (cross(l[1].d(), l[0].d()) > 0) {
            alb = max(alb, intersection(l[0], l[1]).y);
        } else if (cross(l[1].d(), l[0].d()) < 0) {
            aub = min(aub, intersection(l[0], l[1]).y);
        }
        alb = max(alb, lb);
        aub = min(aub, ub);
        aub = max(aub, alb);
        ran(k, 0, 2) {
            double x1 = l[0].a.x + (alb - l[0].a.y) /
                l[0].d().y * l[0].d().x;
            double x2 = l[0].a.x + (aub - l[0].a.y) /
                l[0].d().y * l[0].d().x;
            result +=
                (-1 + 2 * k) * (aub - alb) * (x1 + x2) / 2;
        }
        if (ap_s[0][i + 1] < ap_s[1][j + 1]) {
            i++;
        } else {
            j++;
        }
    }
}
return result;
}
%3672

```

## Convex polygon algorithms

```

typedef pair<int, int> Vec;
typedef pair<Vec, Vec> Seg;
typedef vector<Seg>::iterator SegIt;
#define F first
#define S second
    1443

```

```

#define MP(x, y) make_pair(x, y)
Vec sub(const Vec &v1, const Vec &v2) {
    return MP(v1.F - v2.F, v1.S - v2.S);
}
ll dot(const Vec &v1, const Vec &v2) {
    return (ll)v1.F * v2.F + (ll)v1.S * v2.S;
}
ll cross(const Vec &v1, const Vec &v2) {
    return (ll)v1.F * v2.S - (ll)v2.F * v1.S;
}
ll dist_sq(const Vec &p1, const Vec &p2) {
    return (ll)(p2.F - p1.F) * (p2.F - p1.F) +
        (ll)(p2.S - p1.S) * (p2.S - p1.S);
}
struct Point;
multiset<Point>::iterator end_node;
struct Point {
    Vec p;
    typename multiset<Point>::iterator get_it() const {
        // gcc rb_tree dependent
        tuple<void*> tmp = {(void*)this - 32};
        return *(multiset<Point>::iterator*)(&tmp);
    }
    bool operator<(const Point &rhs) const {
        return (p.F < rhs.p.F); // sort by x
    }
    bool operator<(const Vec &q) const {
        auto nxt = next(get_it()); // convex hull trick
        if (nxt == end_node) return 0; // nxt == end()
        return q.S * dot(p, {q.F, 1}) <
            q.S * dot(nxt->p, {q.F, 1});
    }
};
template <int part> // 1 = upper, -1 = lower
struct HullDynamic : public multiset<Point, less<>> {
    bool bad(iterator y) {
        if (y == begin()) return 0;
        auto x = prev(y);
        auto z = next(y);
        if (z == end())
            return y->p.F == x->p.F && y->p.S <= x->p.S;
        return part *
            cross(sub(y->p, x->p), sub(y->p, z->p)) <=
                0;
    }
    void insert_point(int m, int b) { // O(log(N))
        auto y = insert({m, b});
        if (bad(y)) {
            erase(y);
            return;
        }
        while (next(y) != end() && bad(next(y)))
            erase(next(y));
        while (y != begin() && bad(prev(y))) erase(prev(y));
    }
    ll eval(
        int x) { // O(log(N)) upper maximize dot({x, 1}, v)
end_node =
    end(); // lower minimize dot({x, 1}, v)
    auto it = lower_bound((Vec){x, part});
    return (ll)it->p.F * x + it->p.S;
};
struct Hull {
    vector<Seg> hull;
    SegIt up_beg;
    template <typename It>
    void extend(It beg, It end) { // O(n)
        vector<Vec> r;
        for (auto it = beg; it != end; ++it) {
            if (r.empty() || *it != r.back()) {
                while (r.size() >= 2) {
                    int n = r.size();
                    Vec v1 = {r[n - 1].F - r[n - 2].F,
                        r[n - 1].S - r[n - 2].S};
                    Vec v2 = {
                        it->F - r[n - 2].F, it->S - r[n - 2].S};
                    if (cross(v1, v2) > 0) break;
                    r.pop_back();
                }
                r.push_back(*it);
            }
        }
        ran(i, 0, (int)r.size() - 1)
        hull.emplace_back(r[i], r[i + 1]);
    }
    Hull(vector<Vec> &vert) { // at least 2 distinct points
        sort(vert.begin(), vert.end()); // O(n log(n))
        extend(vert.begin(), vert.end());
        int diff = hull.size();
        extend(vert.rbegin(), vert.rend());
        up_beg = hull.begin() + diff;
    }
    bool contains(Vec p) { // O(log(n))
        if (p < hull.front().F || p > up_beg->F)
            return false;
        {
            auto it_low = lower_bound(hull.begin(), up_beg,
                MP(MP(p.F, (int)-2e9), MP(0, 0)));
            if (it_low != hull.begin()) --it_low;
            Vec a = {it_low->S.F - it_low->F.F,
                it_low->S.S - it_low->F.S};
            Vec b = {p.F - it_low->F.F, p.S - it_low->F.S};
            if (cross(a, b) <
                0) // < 0 is inclusive, <= 0 is exclusive
                return false;
        }
        {
            auto it_up = lower_bound(hull.rbegin(),
                hull.rbegin() + (hull.end() - up_beg),
                MP(MP(p.F, (int)2e9), MP(0, 0)));
            if (it_up - hull.rbegin() == hull.end() - up_beg)
                --it_up;
            Vec a = {it_up->F.F - it_up->S.F,
                it_up->F.S - it_up->S.S};
            Vec b = {p.F - it_up->S.F, p.S - it_up->S.S};
            if (cross(a, b) >
                0) // > 0 is inclusive, >= 0 is exclusive
                return false;
            return true;
        }
    }
    // The function can have only one local min and max
    // and may be constant only at min and max.
    template <typename T>
    SegIt max(function<T(Seg &)> f) { // O(log(n))
        auto l = hull.begin();
        auto r = hull.end();
        SegIt b = hull.end();
        T b_v;
        while (r - l > 2) {
            auto m = l + (r - l) / 2;
            T l_v = f(*l);
            T l_n_v = f(*(l + 1));
            T m_v = f(*m);
            T m_n_v = f(*(m + 1));
            if (b == hull.end() || l_v > b_v) {
                b = l; // If max is at l we may remove it from
                    // the range.
                b_v = l_v;
            }
            if (l_n_v > l_v) {
                if (m_v < l_v) {
                    r = m;
                } else {
                    if (m_n_v > m_v) {
                        l = m + 1;
                    } else {
                        r = m + 1;
                    }
                }
            } else {
                if (m_v < l_v) {
                    l = m + 1;
                } else {
                    if (m_n_v > m_v) {
                        l = m + 1;
                    } else {
                        r = m + 1;
                    }
                }
            }
        }
        T l_v = f(*l);
        if (b == hull.end() || l_v > b_v) {
            b = l;
            b_v = l_v;
        }
        if (r - l > 1) {
            T l_n_v = f(*(l + 1));
            if (b == hull.end() || l_n_v > b_v) {

```



```

    b = 1 + 1;
    b_v = 1_n_v;
}
}
return b;
}
SegIt closest(
    Vec p) { // p can't be internal(can be on border),
            // hull must have atleast 3 points
    Seg &ref_p = hull.front(); // O(log(n))
    return max(function<double>(Seg &>(&p, &ref_p](Seg &seg) { // accuracy of used type
            // should be coord^2
            if (p == seg.F) return 10 - M_PI;
            Vec v1 = {seg.S.F - seg.F.F, seg.S.S - seg.F.S};
            Vec v2 = {p.F - seg.F.F, p.S - seg.F.S};
            ll c_p = cross(v1, v2);
            if (c_p > 0) { // order the backside by angle
                Vec v1 = {ref_p.F.F - p.F, ref_p.F.S - p.S};
                Vec v2 = {seg.F.F - p.F, seg.F.S - p.S};
                ll d_p = dot(v1, v2);
                ll c_p = cross(v2, v1);
                return atan2(c_p, d_p) / 2;
            }
            ll d_p = dot(v1, v2);
            double res = atan2(d_p, c_p);
            if (d_p <= 0 && res > 0) res = -M_PI;
            if (res > 0) {
                res += 20;
            } else {
                res = 10 - res;
            }
            return res;
        }));
}
template <int DIRECTION> // 1 or -1
Vec tan_point(
    Vec p) { // can't be internal or on border
            // -1 iff CCW rotation of ray from p to res takes it
            // away from
            // polygon?
    Seg &ref_p = hull.front(); // O(log(n))
    auto best_seg = max(function<double>(Seg &>(&p, &ref_p](Seg &seg) { // accuracy of used type
            // should be coord^2
            Vec v1 = {ref_p.F.F - p.F, ref_p.F.S - p.S};
            Vec v2 = {seg.F.F - p.F, seg.F.S - p.S};
            ll d_p = dot(v1, v2);
            ll c_p = DIRECTION * cross(v2, v1);
            return atan2(c_p, d_p); // order by signed angle
        }));
    return best_seg->F;
}
SegIt max_in_dir(
    Vec v) { // first is the ans. O(log(n))
    return max(function<ll>(Seg &>(&v](Seg &seg) { return dot(v, seg.F); }));
}
}
pair<SegIt, SegIt> intersections(Seg l) { // O(log(n))
    int x = l.S.F - l.F.F;
    int y = l.S.S - l.F.S;
    Vec dir = {-y, x};
    auto it_max = max_in_dir(dir);
    auto it_min = max_in_dir(MP(y, -x));
    ll opt_val = dot(dir, l.F);
    if (dot(dir, it_max->F) < opt_val ||
        dot(dir, it_min->F) > opt_val)
        return MP(hull.end(), hull.end());
    SegIt it_r1, it_r2;
    function<bool>(const Seg &, const Seg &> inc_c(
        [&dir](const Seg &lft, const Seg &rgt) {
            return dot(dir, lft.F) < dot(dir, rgt.F);
        });
    function<bool>(const Seg &, const Seg &> dec_c(
        [&dir](const Seg &lft, const Seg &rgt) {
            return dot(dir, lft.F) > dot(dir, rgt.F);
        });
    if (it_min <= it_max) {
        it_r1 =
            upper_bound(it_min, it_max + 1, 1, inc_c) - 1;
        if (dot(dir, hull.front().F) >= opt_val) {
            it_r2 = upper_bound(
                hull.begin(), it_min + 1, 1, dec_c) -
                1;
        } else {
            it_r2 =
                upper_bound(it_max, hull.end(), 1, dec_c) - 1;
        }
    } else {
        it_r1 =
            upper_bound(it_max, it_min + 1, 1, dec_c) - 1;
        if (dot(dir, hull.front().F) <= opt_val) {
            it_r2 = upper_bound(
                hull.begin(), it_max + 1, 1, inc_c) -
                1;
        } else {
            it_r2 =
                upper_bound(it_min, hull.end(), 1, inc_c) - 1;
        }
    }
    return MP(it_r1, it_r2);
}
Seg diameter() { // O(n)
    Seg res;
    ll dia_sq = 0;
    auto it1 = hull.begin();
    auto it2 = up_beg;
    Vec v1 = {hull.back().S.F - hull.back().F.F,
        hull.back().S.S - hull.back().F.S};
    while (it2 != hull.begin()) {
        Vec v2 = {(it2 - 1)->S.F - (it2 - 1)->F.F,
            (it2 - 1)->S.S - (it2 - 1)->F.S};
        if (cross(v1, v2) > 0) break;
        --it2;
    }
}
while (
    it2 != hull.end()) { // check all antipodal pairs
    if (dist_sq(it1->F, it2->F) > dia_sq) {
        res = {it1->F, it2->F};
        dia_sq = dist_sq(res.F, res.S);
    }
    Vec v1 = {
        it1->S.F - it1->F.F, it1->S.S - it1->F.S};
    Vec v2 = {
        it2->S.F - it2->F.F, it2->S.S - it2->F.S};
    if (cross(v1, v2) == 0) {
        if (dist_sq(it1->S, it2->S) > dia_sq) {
            res = {it1->S, it2->S};
            dia_sq = dist_sq(res.F, res.S);
        }
        if (dist_sq(it1->F, it2->S) > dia_sq) {
            res = {it1->F, it2->S};
            dia_sq = dist_sq(res.F, res.S);
        } // report cross pairs at parallel lines.
        ++it1;
        ++it2;
    } else if (cross(v1, v2) < 0) {
        ++it1;
    } else {
        ++it2;
    }
}
return res;
}
}
Delaunay triangulation O(nlogn)
const int max_co = (1 << 28) - 5;
struct Vec {
    int x, y;
    bool operator==(const Vec &oth) {
        return x == oth.x && y == oth.y;
    }
    bool operator!=(const Vec &oth) {
        return !operator==(oth);
    }
    Vec operator-(const Vec &oth) {
        return {x - oth.x, y - oth.y};
    }
};
ll cross(Vec a, Vec b) {
    return (ll)a.x * b.y - (ll)a.y * b.x;
}
ll dot(Vec a, Vec b) {
    return (ll)a.x * b.x + (ll)a.y * b.y;
}
struct Edge {
    Vec tar;
    Edge *nxt;
    Edge *inv = NULL;
}

```

```

Edge *rep = NULL;
bool vis = false;
};
struct Seg {
    Vec a, b;
    bool operator==(const Seg &oth) {
        return a == oth.a && b == oth.b;
    }
    bool operator!=(const Seg &oth) {
        return !operator==(oth);
    }
};
11 orient(Vec a, Vec b, Vec c) {
    return (11)a.x * (b.y - c.y) + (11)b.x * (c.y - a.y) +
        (11)c.x * (a.y - b.y);
}
bool in_c_circle(Vec *arr, Vec d) {
    if (cross(arr[1] - arr[0], arr[2] - arr[0]) == 0)
        return true; // degenerate
    11 m[3][3];
    ran(i, 0, 3) {
        m[i][0] = arr[i].x - d.x;
        m[i][1] = arr[i].y - d.y;
        m[i][2] = m[i][0] * m[i][0];
        m[i][2] += m[i][1] * m[i][1];
    }
    __int128 res = 0; //double seems to work as well
    res +=
        (__int128)(m[0][0] * m[1][1] - m[0][1] * m[1][0]) *
        m[2][2];
    res +=
        (__int128)(m[1][0] * m[2][1] - m[1][1] * m[2][0]) *
        m[0][2];
    res -=
        (__int128)(m[0][0] * m[2][1] - m[0][1] * m[2][0]) *
        m[1][2];
    return res > 0;
}
Edge *add_triangle(Edge *a, Edge *b, Edge *c) {
    Edge *old[] = {a, b, c};
    Edge *tmp = new Edge[3];
    ran(i, 0, 3) {
        old[i]->rep = tmp + i;
        tmp[i] = {
            old[i]->tar, tmp + (i + 1) % 3, old[i]->inv;
        };
        if (tmp[i].inv) tmp[i].inv->inv = tmp + i;
    }
    return tmp;
}
Edge *add_point(
    Vec p, Edge *cur) { // returns outgoing edge
    Edge *triangle[] = {cur, cur->nxt, cur->nxt->nxt};
    ran(i, 0, 3) {
        if (orient(triangle[i]->tar,
            triangle[(i + 1) % 3]->tar, p) < 0)
            return NULL;
    }
    ran(i, 0, 3) {
        if (triangle[i]->rep) {
            Edge *res = add_point(p, triangle[i]->rep);
            if (res)
                return res; // unless we are on last layer we
                            // must exit here
        }
    }
    Edge p_as_e[p];
    Edge tmp{cur->tar};
    tmp.inv = add_triangle(&p_as_e, &tmp, cur = cur->nxt);
    Edge *res = tmp.inv->nxt;
    tmp.tar = cur->tar;
    tmp.inv = add_triangle(&p_as_e, &tmp, cur = cur->nxt);
    tmp.tar = cur->tar;
    res->inv = add_triangle(&p_as_e, &tmp, cur = cur->nxt);
    res->inv->inv = res;
    return res;
}
Edge *delanay(vector<Vec> &points) {
    random_shuffle(points.begin(), points.end());
    Vec arr[0] = {{4 * max_co, 4 * max_co},
        {-4 * max_co, max_co}, {max_co, -4 * max_co}};
    Edge *res = new Edge[3];
    ran(i, 0, 3) res[i] = {arr[i], res + (i + 1) % 3};
    for (Vec &cur : points) {
        Edge *loc = add_point(cur, res);
        Edge *out = loc;
        arr[0] = cur;
        while (true) {
            arr[1] = out->tar;
            arr[2] = out->nxt->tar;
            Edge *e = out->nxt->inv;
            if (e && in_c_circle(arr, e->nxt->tar)) {
                Edge tmp{cur};
                tmp.inv = add_triangle(&tmp, out, e->nxt);
                tmp.tar = e->nxt->tar;
                tmp.inv->inv =
                    add_triangle(&tmp, e->nxt->nxt, out->nxt->nxt);
                out = tmp.inv->nxt;
                continue;
            }
            out = out->nxt->nxt->inv;
            if (out->tar == loc->tar) break;
        }
    }
    return res;
}
void extract_triangles(
    Edge *cur, vector<vector<Seg> > &res) {
    if (!cur->vis) {
        bool inc = true;
        Edge *it = cur;
        do {
            it->vis = true;
            if (it->rep) {
                extract_triangles(it->rep, res);
            }
        } while (it != cur);
    }
    res.push_back({cur, cur->nxt, cur->nxt->nxt});
    res.resize(res.size() + 1);
    vector<Seg> &tar = res.back();
    ran(i, 0, 3) {
        if ((abs(triangle[i]->tar.x) < max_co &&
            abs(triangle[(i + 1) % 3]->tar.x) <
            max_co))
            tar.push_back({triangle[i]->tar,
                triangle[(i + 1) % 3]->tar});
        if (tar.empty()) res.pop_back();
    }
}

Contest setup

alias g++='g++ -g -Wall -Wshadow -Wconversion \ #.bashrc
-fsanitize=undefined,address -DCDEBUG' #.bashrc
alias a='setxkbmap us -option' #.bashrc
alias m='setxkbmap us -option caps:escape' #.bashrc
alias ma='setxkbmap us -variant dvp \ #.bashrc
-option caps:escape' #.bashrc
gsettings set org.compiz.core: \ #settings
/org/compiz/profiles/Default/plugins/core/ hsize 4
gsettings set org.gnome.desktop.wm.preferences \ #settings
focus-mode 'sloppy'
gvim template.cpp #copy everything
cd samps
for d in *; do cd $d; for f in *; do \
cp $f "$d/$f"; done; \
cd ..; cp "$d/template.cpp" "$d/.cpp"; done
cd ..
set si cin #.vimrc
set ts=4 sw=4 noet #.vimrc
set cb=unnamedplus #.vimrc
(global-set-key (kbd "C-x <next>") 'other-window) #.emacs
(global-set-key (kbd "C-x <prior>") \ #.emacs
'previous-multiframe-window) #.emacs
(global-set-key (kbd "C-M-z") 'ansi-term) #.emacs
#.emacs
(global-linum-mode 1) #.emacs
(column-number-mode 1) #.emacs
(show-paren-mode 1) #.emacs
(setq-default indent-tabs-mode nil) #.emacs
valgrind --vgdb-error=0 ./a <inp & #valgrind
gdb a #valgrind
target remote | vgdb #valgrind

crc.sh

#!/bin/envbash

```



```

for j in `seq $2 1 $3`; do #whitespaces don't matter.
    sed '/^\s*$/d' $1 | head -$j | tr -d '[:space:]' \
    | cksum | cut -f1 -d ' ' | tail -c 5
done #there shouldn't be any COMMENTS.
#copy lines being checked to separate file.
# $ ./crc.sh tmp.cpp 999 999
# $ ./crc.sh tmp.cpp 1 333 | grep XXXX

```

### Template

```

using namespace std;
#include <iomanip>
#include <iostream>
#include <fstream>
#ifdef LOCAL
bool DEBUG = true;
#else
bool DEBUG = false;
#endif
#define FAST {ios::sync_with_stdio(0);cin.tie(0);cout<<setprecision(10)<<fixed;}
#define FOR(a,b,c) for(int a=(b); a<(int)(c); ++a)
#define DB(a) if(DEBUG) cerr<<"a<<" "<<a<<" "\n";
#define all(v) (v).begin(),(v).end()
using ll = long long;
int MAXINT=2e9;
ll MAXLL=9e18;
// Includes
#include <vector>
#include <cmath>
int main()
{
    #ifdef LOCAL
        ifstream cin("input.txt");
        ofstream cout("output.txt");
    #endif
    FAST
    //
}

```

### gcc ordered set, hashtable

```

#define DEBUG(...) cerr << __VA_ARGS__ << endl;
#ifdef CDEBUG
#undef DEBUG
#define DEBUG(...) ((void)0);
#define NDEBUG
#endif
#define ran(i, a, b) for (auto i = (a); i < (b); i++)
#include <bits/stdc++.h>
typedef long long ll;
typedef long double ld;
using namespace std;
#pragma GCC optimize("Ofast") // better vectorization
#pragma GCC target("avx,avx2")
// double vectorized performance
#include <bits/extc++.h>
using namespace __gnu_pbds;

```

```

template <typename T, typename U>
using hashmap = gp_hash_table<T, U>;
// dumb, 3x faster than stl
template <typename T>
using ordered_set = tree<T, null_type, less<T>,
    rb_tree_tag, tree_order_statistics_node_update>;
int main() {
    ordered_set<int> cur;
    cur.insert(1);
    cur.insert(3);
    cout << cur.order_of_key(2) << endl;
    // the number of elements in the set less than 2
    cout << *cur.find_by_order(1) << endl;
    // the 1-st smallest number in the set(0-based)
    ordered_set<int> oth;
    oth.insert(5); // to join: cur < oth
    cur.join(oth); // cur = {1, 3, 5}, oth = {}
    cur.split(1, oth); // cur = {1}, oth = {3, 5}
    hashmap<int, int> h({}, {}, {}, {}, {1 << 16});
    precision(10)<<fixed;}

```

### PRNGs and Hash functions

```

mt19937 gen;
uint64_t rand64() {
    return gen() ^ ((uint64_t)gen() << 32);
}
uint64_t rand64() {
    static uint64_t x = 1; //x != 0
    x ^= x >> 12;
    x ^= x << 25;
    x ^= x >> 27;
    return x * 0x2545f4914f6cdd1d; // can remove mult
}
uint64_t mix(uint64_t x){ // deadbeef -> y allowed
variable uint64_t mem[2] = { x, 0xdeadbeeffeebdaedull };
asm volatile (
    "pxor %%xmm0, %%xmm0;"
    "movdqa (%0), %%xmm1;"
    "aesenc %%xmm0, %%xmm1;"
    "movdqa %%xmm1, (%0);"
    :
    : "r" (&mem[0])
    : "memory"
);
return mem[0]; // use both slots for 128 bit
}
uint64_t mix64(uint64_t x) { //x != 0
    x = (x ^ (x >> 30)) * 0xbf58476d1ce4e5b9;
    x = (x ^ (x >> 27)) * 0x94d049bb133111eb;
    x = x ^ (x >> 31);
    return x;
}
uint64_t unmix64(uint64_t x) {
    x = (x ^ (x >> 31) ^ (x >> 62)) * 0x319642b2d24d8ec3;
    x = (x ^ (x >> 27) ^ (x >> 54)) * 0x96de1b173f119089;
    x = x ^ (x >> 30) ^ (x >> 60);
}

```

```

return x;
uint64_t combine64(uint64_t x, uint64_t y) {
    if (y < x) swap(x, y); // remove for ord
    return mix64(mix64(x) + y);
}

```

### Memorypool

```

const int BLOCK = 8;
const int MEM_SIZE = 1 << 26;
char glob_buf[MEM_SIZE];
int glob_idx;
vector<bool> glob_used;
void init_mem() {
    glob_used.resize(MEM_SIZE / BLOCK);
    glob_used[0] = true;
}
template <typename T>
struct Ptr {
    unsigned idx;
    explicit Ptr(T *tar) { idx = (char *)tar - glob_buf; }
    Ptr() { idx = 0; }
    template <typename... Args>
    void construct(Args... args) {
        new (glob_buf + idx) T(args...);
    }
    T *operator->() {
        assert(idx);
        return (T *) (glob_buf + idx);
    }
    T &operator*() { return *operator->(); }
    bool operator==(const Ptr &oth) const {
        return idx == oth.idx;
    }
    operator unsigned() const { return idx; }
    Ptr &operator+=(int diff) {
        idx += diff * sizeof(T);
        return *this;
    }
    Ptr operator+(int diff) {
        Ptr res;
        res.idx = idx;
        return res += diff;
    }
    T &operator[](int diff) { return *operator+(diff); }
};
template <typename T, typename... Args>
Ptr<T> alloc(int n, Args... args) {
    unsigned len = 0; // TLE if running low on mem
    while (len < sizeof(T) * n) {
        if (!glob_idx) glob_idx = MEM_SIZE / BLOCK;
        if (glob_used[--glob_idx]) {
            len = 0;
        } else {
            len += BLOCK;
        }
    }
}

```

```

}
ran(i, 0, ((int)sizeof(T) * n + BLOCK - 1) / BLOCK)
  glob_used[glob_idx + i] = true;
Ptr<T> res;
if (n) res.idx = BLOCK * glob_idx;
ran(i, 0, n)(res + i).construct(args...);
return res;
}
template <typename T>
void dealloc(Ptr<T> ptr, int n) {
  ran(i, 0, ((int)sizeof(T) * n + BLOCK - 1) / BLOCK)
    glob_used[ptr.idx / BLOCK + i] = false;
}
template <typename T>
struct hash<Ptr<T> > {
  std::size_t operator()(const Ptr<T> &cur) const {
    return cur.idx;
  }
};

Radixsort 50M 64 bit integers as single array in 1
sec

template <typename T>
void rsort(T *a, T *b, int size, int d = sizeof(T) - 1) {
  int b_s[256]{};
  ran(i, 0, size) { ++b_s[(a[i] >> (d * 8)) & 255]; }
  // ++b_s[*((uchar *) (a + i) + d)];
  T *mem[257];
  mem[0] = b;
  T *l_b = mem + 1;
  l_b[0] = b;
  ran(i, 0, 255) { l_b[i + 1] = l_b[i] + b_s[i]; }
  for (T *it = a; it != a + size; ++it) {
    T id = ((*it) >> (d * 8)) & 255;
    *(l_b[id]++) = *it;
  }
  l_b = mem;
  if (d) {
    T *l_a[256];
    l_a[0] = a;
    ran(i, 0, 255) l_a[i + 1] = l_a[i] + b_s[i];
    ran(i, 0, 256) {
      if (l_b[i + 1] - l_b[i] < 100) {
        sort(l_b[i], l_b[i + 1]);
        if (d & 1) copy(l_b[i], l_b[i + 1], l_a[i]);
      } else {
        rsort(l_b[i], l_a[i], b_s[i], d - 1);
      }
    }
  }
}

const int nmax = 5e7;
ll arr[nmax], tmp[nmax];
int main() {
  for (int i = 0; i < nmax; ++i)
    arr[i] = ((ll)rand() << 32) | rand();
  rsort(arr, tmp, nmax);
  assert(is_sorted(arr, arr + nmax));
}

FFT 10-15M length/sec

// integer c = a*b is accurate if c_i < 2^49
#pragma GCC optimize ("Ofast") //10% performance
#include <complex.h>
extern "C" __complex__ double __muldc3(
  double a, double b, double c, double d){
  return a*c-b*d+I*(a*d+b*c); // 40% performance
}
#include <bits/stdc++.h>
typedef complex<double> Comp;
void fft_rec(Comp *arr, Comp *root_pow, int len) {
  if (len != 1) {
    fft_rec(arr, root_pow, len >> 1);
    fft_rec(arr + len, root_pow, len >> 1);
  }
  root_pow += len;
  ran(i, 0, len){
    tie(arr[i], arr[i + len]) = pair<Comp, Comp> {
      arr[i] + root_pow[i] * arr[i + len],
      arr[i] - root_pow[i] * arr[i + len] };
  }
}
void fft(vector<Comp> &arr, int ord, bool invert) {
  assert(arr.size() == 1 << ord);
  static vector<Comp> root_pow(1);
  static int inc_pow = 1;
  static bool is_inv = false;
  if (inc_pow <= ord) {
    int idx = root_pow.size();
    root_pow.resize(1 << ord);
    for (; inc_pow <= ord; ++inc_pow) {
      for (int idx_p = 0; idx_p < 1 << (ord - 1);
           idx_p += 1 << (ord - inc_pow), ++idx) {
        root_pow[idx] = Comp {
          cos(-idx_p * M_PI / (1 << (ord - 1))),
          sin(-idx_p * M_PI / (1 << (ord - 1))) };
        if (is_inv) root_pow[idx] = conj(root_pow[idx]);
      }
    }
    if (invert != is_inv) {
      is_inv = invert;
      for (Comp &cur : root_pow) cur = conj(cur);
    }
  }
  int j = 0;
  ran(i, 1, (1 << ord)){
    int m = 1 << (ord - 1);
    bool cont = true;
    while (cont) {
      cont = j & m;
      j ^= m;
      m >>= 1;
    }
    if (i < j) swap(arr[i], arr[j]);
  }
  fft_rec(arr.data(), root_pow.data(), 1 << (ord - 1));
  if (invert)
    ran(i, 0, 1 << ord) arr[i] /= (1 << ord);
}

void mult_poly_mod(vector<int> &a, vector<int> &b,
  vector<int> &c) { // c += a*b
  static vector<Comp> arr[4];
  // correct upto 0.5-2M elements(mod ~= 1e9)
  if (c.size() < 400) {
    ran(i, 0, (int)a.size())
      ran(j, 0, min((int)b.size(), (int)c.size()-i))
        c[i + j] = ((ll)a[i] * b[j] + c[i + j]) % mod;
  } else {
    int ord = 32 - __builtin_clz((int)c.size()-1);
    if ((int)arr[0].size() != 1 << ord){
      ran(i, 0, 4) arr[i].resize(1 << ord);
    }
    ran(i, 0, 4)
      fill(arr[i].begin(), arr[i].end(), Comp{});
    for (int &cur : a) if (cur < 0) cur += mod;
    for (int &cur : b) if (cur < 0) cur += mod;
    const int shift = 15;
    const int mask = (1 << shift) - 1;
    ran(i, 0, (int)min(a.size(), c.size())){
      arr[0][i] += a[i] & mask;
      arr[1][i] += a[i] >> shift;
    }
    ran(i, 0, (int)min(b.size(), c.size())){
      arr[0][i] += Comp{0, (b[i] & mask)};
      arr[1][i] += Comp{0, (b[i] >> shift)};
    }
    ran(i, 0, 2) fft(arr[i], ord, false);
    ran(i, 0, 2){
      ran(j, 0, 2){
        int tar = 2 + (i + j) / 2;
        Comp mult = {0, -0.25};
        if (i ^ j) mult = {0.25, 0};
        ran(k, 0, 1 << ord){
          int rev_k = ((1 << ord) - k) % (1 << ord);
          Comp ca = arr[i][k] + conj(arr[i][rev_k]);
          Comp cb = arr[j][k] + conj(arr[j][rev_k]);
          arr[tar][k] = arr[tar][k] + mult * ca * cb;
        }
      }
    }
    ran(i, 2, 4){
      fft(arr[i], ord, true);
      ran(k, 0, (int)c.size()){
        c[k] = (c[k] + (((ll)(arr[i][k].real()+0.5)%mod)
          << (shift * (2 * (i-2) + 0)))) % mod;
        c[k] = (c[k] + (((ll)(arr[i][k].imag()+0.5)%mod)
          << (shift * (2 * (i-2) + 1)))) % mod;
      }
    }
  }
}

```

```

}
} %4758

Fast mod mult, Rabbin Miller prime check, Pollard
rho factorization O(p^0.5)

struct ModArithm {
    ull n;
    ld rec;
    ModArithm(ull _n) : n(_n) { // n in [2, 1<<63)
        rec = 1.0L / n;
    }
    // a, b in [0, min(2*n, 1<<63))
    ull multf(ull a, ull b) {
        ull mult = (ld)a * b * rec + 0.5L;
        ll res = a * b - mult * n;
        if (res < 0) res += n;
        return res; // in [0, n-1)
    }
    ull sqp1(ull a) { return multf(a, a) + 1; }
}; %7403

ull pow_mod(ull a, ull n, ModArithm &arithm) {
    ull res = 1;
    for (ull i = 1; i <= n; i <= 1) {
        if (n & i) res = arithm.multf(res, a);
        a = arithm.multf(a, a);
    }
    return res;
} %1380

vector<char> small_primes = {
    2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37};
bool is_prime(ull n) { // n <= 1<<63, 1M rand/s
    ModArithm arithm(n);
    if (n == 2 || n == 3) return true;
    if (!(n & 1) || n == 1) return false;
    int s = __builtin_ctzll(n - 1);
    ull d = (n - 1) >> s;
    for (ull a : small_primes) {
        if (a >= n) break;
        a = pow_mod(a, d, arithm);
        if (a == 1 || a == n - 1) continue;
        ran(r, 1, s) {
            a = arithm.multf(a, a);
            if (a == 1) return false;
            if (a == n - 1) break;
        }
        if (a != n - 1) return false;
    }
    return true;
}

ll pollard_rho(ll n) {
    ModArithm arithm(n);
    int cum_cnt = 64 - __builtin_clzll(n);
    cum_cnt *= cum_cnt / 5 + 1;
    while (true) {
        ll lv = rand() % n;
        ll v = arithm.sqp1(lv);

```

```

        int idx = 1;
        int tar = 1;
        while (true) {
            ll cur = 1;
            ll v_cur = v;
            int j_stop = min(cum_cnt, tar - idx);
            for (int j = 0; j < j_stop; ++j) {
                cur = arithm.multf(cur, abs(v_cur - lv));
                v_cur = arithm.sqp1(v_cur);
                ++idx;
            }
            if (!cur) {
                for (int j = 0; j < cum_cnt; ++j) {
                    ll g = __gcd(abs(v - lv), n);
                    if (g == 1) {
                        v = arithm.sqp1(v);
                        break;
                    } else if (g == n) {
                        break;
                    } else {
                        return g;
                    }
                }
                break;
            } else {
                ll g = __gcd(cur, n);
                if (g != 1) return g;
            }
            v = v_cur;
            idx += j_stop;
            if (idx == tar) {
                lv = v;
                tar *= 2;
                v = arithm.sqp1(v);
                ++idx;
            }
        }
    }
}

map<ll, int> prime_factor(
    ll n, map<ll, int> *res = NULL) {
    // n <= 1<<62, ~1000/s (<500/s on CF)
    if (!res) {
        map<ll, int> res_act;
        for (int p : small_primes) {
            while (!(n % p)) {
                ++res_act[p];
                n /= p;
            }
        }
        if (n != 1) prime_factor(n, &res_act);
        return res_act;
    }
    if (is_prime(n)) {
        ++(*res)[n];
    } else {
        ll factor = pollard_rho(n);
        prime_factor(factor, res);
    }
}

```

```

0415 prime_factor(n / factor, res);
}
} return map<ll, int>(); // Usage: fact = prime_factor(n); 1140 %1140

Berlekamp-Massey O(LN)

template <typename T, T P>
struct intmod {
    intmod() {}
    constexpr intmod(T t) : x((t + P) % P) {}
    T value() const { return x; }
    bool operator!=(const intmod<T, P> i) { return x != i.x; }
    bool operator==(const intmod<T, P> i) { return x == i.x; }
    intmod<T, P> &operator+=(const intmod<T, P> i) {
        x = (x + i.x) % P;
        return *this;
    }
    intmod<T, P> &operator-=(const intmod<T, P> i) {
        x = (x + P - i.x) % P;
        return *this;
    }
    intmod<T, P> &operator*=(const intmod<T, P> i) {
        x = ((ll)x * i.x) % P;
        return *this;
    }
    intmod<T, P> &operator/=(const intmod<T, P> i) {
        x = ((ll)x * i.inverse().x) % P;
        return *this;
    }
    intmod<T, P> operator+(const intmod<T, P> i) const {
        auto j = *this;
        return j += i;
    }
    intmod<T, P> operator-(const intmod<T, P> i) const {
        auto j = *this;
        return j -= i;
    }
    intmod<T, P> operator*(const intmod<T, P> i) const {
        auto j = *this;
        return j *= i;
    }
    intmod<T, P> operator/(const intmod<T, P> i) const {
        auto j = *this;
        return j /= i;
    }
    intmod<T, P> operator-() const {
        intmod<T, P> n;
        n.x = (P - x) % P;
        return n;
    }
    intmod<T, P> inverse() const {
        if (x == 0) return 0;
        T a = x, b = P;
        T aa = 1, ab = 0;
        T ba = 0, bb = 1;
        while (a) {

```

```

    T q = b / a;
    T r = b % a;
    ba -= aa * q;
    bb -= ab * q;
    swap(ba, aa);
    swap(bb, ab);
    b = a;
    a = r;
}
intmod<T, P> ix = intmod<T, P>(aa) + intmod<T, P>(ba);
assert(ix * x == unity);
return ix;
}
static const intmod<T, P> zero;
static const intmod<T, P> unity;
private:
    T x;
};
template <typename T, T P>
constexpr intmod<T, P> intmod<T, P>::zero = 0;
template <typename T, T P>
constexpr intmod<T, P> intmod<T, P>::unity = 1;
using rem = intmod<char, 2>;
template <typename K>
static vector<K> berlekamp_massey(vector<K> ss) {
    vector<K> ts(ss.size());
    vector<K> cs(ss.size());
    cs[0] = K::unity;
    fill(cs.begin() + 1, cs.end(), K::zero);
    vector<K> bs = cs;
    int l = 0, m = 1;
    K b = K::unity;
    for (int k = 0; k < (int)ss.size(); k++) {
        K d = ss[k];
        assert(l <= k);
        for (int i = 1; i <= l; i++) d += cs[i] * ss[k - i];
        if (d == K::zero) {
            m++;
        } else if (2 * l <= k) {
            K w = d / b;
            ts = cs;
            for (int i = 0; i < (int)cs.size() - m; i++)
                cs[i + m] -= w * bs[i];
            l = k + 1 - l;
            swap(bs, ts);
            b = d;
            m = 1;
        } else {
            K w = d / b;
            for (int i = 0; i < (int)cs.size() - m; i++)
                cs[i + m] -= w * bs[i];
            m++;
        }
    }
    cs.resize(l + 1);
    while (cs.back() == K::zero) cs.pop_back();
    return cs;
}

```

5403

## Linear algebra

```

bitset<10> add(bitset<10> p, bitset<10> q) {
    return p ^ q;
}
bitset<10> mult(bitset<10> v, bool k) {
    if (k) {
        return v;
    } else {
        return bitset<10>(0);
    }
}
bitset<10> normalize(bitset<10> v, int idx) { return v; }
bitset<10> neg(bitset<10> v) { return v; }
template <typename T>
vector<T> add(vector<T> p, vector<T> q) {
    ran(i, 0, (int)p.size()) p[i] += q[i];
    return p;
}
template <typename T>
vector<T> mult(vector<T> p, T k) {
    ran(i, 0, (int)p.size()) p[i] *= k;
    return p;
}
template <typename T>
vector<T> normalize(vector<T> v, int idx) {
    return mult(v, (T)1 / v[idx]);
}
template <typename T>
vector<T> neg(vector<T> p) {
    return mult(p, (T)-1);
}
/* V is the class implementing a vector, T is the type
 * within. examples: <bitset<10>, bool>; <vector<double>,
 * double> etc. V must have an "add" operation defined */
template <typename V, typename T>
pair<vector<V>, pair<vector<int>, vector<int>>>
diagonalize(vector<V> matrix, int width) {
    /* width is the number of columns we consider for
     * diagonalizing. all columns after that can be used
     * for things after equal sign etc */
    int cur_row = 0;
    vector<int> crap_columns;
    vector<int> diag_columns;
    ran(i, 0, width) {
        int row_id = -1;
        T best_val = 0; /* may want to replace with epsilon
                        * if working over reals */
        ran(j, cur_row, (int)matrix.size()) {
            if (abs(matrix[j][i]) > abs(best_val)) {
                row_id = j;
                best_val = matrix[j][i];
            }
        }
        if (row_id == -1) {

```

1934

9068

8676

8756

7200

8023

5745

3157

2591

%8013

1113

5844

1444

0664

1772

%1000

9747

1006

3484

```

    crap_columns.push_back(i);
} else {
    diag_columns.push_back(i);
    swap(matrix[cur_row], matrix[row_id]);
    matrix[cur_row] = normalize(matrix[cur_row], i);
    ran(j, cur_row + 1, j < (int)matrix.size()) {
        if (matrix[j][i] != 0) {
            matrix[j] = add(neg(normalize(matrix[j], i)),
                            matrix[cur_row]);
        }
    }
    cur_row++;
}
for (int i = (int)diag_columns.size() - 1; i >= 0; --i) {
    for (int j = i - 1; j >= 0; --j) {
        matrix[j] = add(matrix[j],
                        neg(
                            mult(matrix[i], matrix[j][diag_columns[i]])));
    }
    return {matrix, {diag_columns, crap_columns}};
}
template <typename V, typename T>
int matrix_rank(vector<V> matrix, int width) {
    return diagonalize<V, T>(matrix, width)
        .second.first.size();
}
template <typename V, typename T>
vector<T> one_solution(
    vector<V> matrix, int width, vector<T> y) {
    /* finds one solution to the system Ax = y.
     * each row in matrix must have width at least width
     * + 1. aborts if there is no solution (you can check
     * whether solution exists using matrix_rank) */
    assert(matrix.size() == y.size());
    ran(i, 0, (int)matrix.size()) matrix[i][width] = y[i];
    pair<vector<V>, pair<vector<int>, vector<int>>> prr =
        diagonalize<V, T>(matrix, width);
    vector<V> diag = prr.first;
    vector<int> diag_cols = prr.second.first;
    vector<T> ans(width, 0);
    ran(i, 0, (int)matrix.size()) {
        if (i < (int)diag_cols.size()) {
            ans[diag_cols[i]] = diag[i][width];
        } else {
            assert(diag[i][width] == T(0));
            /* replace with epsilon if working over reals */
        }
    }
    return ans;
}
template <typename V, typename T>
vector<vector<T>> homog_basis(
    vector<V> matrix, int width) {
    /* finds the basis of the nullspace of matrix */

```

4585

6006

5201

0074

1641

%9471

5622

%6175

8765

5091

5278

7136

%4744

7924

```

pair<vector<V>, pair<vector<int>, vector<int>>> prr =
    diagonalize<V, T>(matrix, width);
vector<V> diag = prr.first;
vector<int> diag_cols = prr.second.first;
vector<int> crap_cols = prr.second.second;
vector<vector<T>>> ans;
for (int u : crap_cols) {
    vector<T> row(width, 0);
    row[u] = 1;
    ran(i, 0, (int)diag_cols.size())
        row[diag_cols[i]] = -diag[i][u];
    ans.push_back(row);
}
return ans;

```

### Polynomial roots and $O(n^2)$ interpolation

```

struct Poly {
    vector<double> a;
    double operator()(double x) const {
        double val = 0;
        for (int i = (int)a.size(); i--;) (val += x) += a[i];
        return val;
    }
    void diff() {
        ran(i, 1, (int)a.size()) a[i - 1] = i * a[i];
        a.pop_back();
    }
    void divroot(double x0) {
        double b = a.back(), c;
        a.back() = 0;
        for (int i = (int)a.size() - 1; i--;)
            c = a[i], a[i] = a[i + 1] * x0 + b, b = c;
        a.pop_back();
    }
};
/* Description: Finds the real roots to a polynomial.
 * Usage: poly_roots({{2,-3,1}}, -1e9, 1e9) // solve
 * x^2-3x+2 = 0 Time:  $O(n^2 \log(1/\epsilon))$  */
vector<double> poly_roots(
    Poly p, double xmin, double xmax) {
    if (sz(p.a) == 2) return {-p.a[0] / p.a[1]};
    vector<double> ret;
    Poly der = p;
    der.diff();
    auto dr = poly_roots(der, xmin, xmax);
    dr.push_back(xmin - 1);
    dr.push_back(xmax + 1);
    sort(dr.begin(), dr.end());
    ran(i, 0, (int)dr.size() - 1) {
        double l = dr[i], h = dr[i + 1];
        bool sign = p(l) > 0;
        if (sign ^ (p(h) > 0)) {
            ran(it, 0, 60) { // while (h - l > 1e-8)
                double m = (l + h) / 2, f = p(m);
                if ((f <= 0) ^ sign) {

```

```

        l = m;
        } else {
            h = m;
        }
    }
    ret.push_back((l + h) / 2);
}
return ret;
/* Description: Given  $n$  points  $(x[i], y[i])$ , computes
 * an  $n-1$ -degree polynomial  $p(x)$  that passes through them:
 *  $p(x) = a[0]*x^0 + \dots + a[n-1]*x^{n-1}$ . For
 * numerical precision, pick  $x[k] = c*\cos(k/(n-1)*\pi)$ ,
 *  $k=0 \dots n-1$ . Time:  $O(n^2)$  */
typedef vector<double> vd;
vd interpolate(vd x, vd y, int n) {
    vd res(n), temp(n);
    ran(k, 0, n - 1) ran(i, k + 1, n) y[i] =
        (y[i] - y[k]) / (x[i] - x[k]);
    double last = 0;
    temp[0] = 1;
    ran(k, 0, n) {
        ran(i, 0, n) {
            res[i] += y[k] * temp[i];
            swap(last, temp[i]);
            temp[i] -= last * x[k];
        }
    }
    return res;
}

```

### Simplex algorithm

```

/* Description: Solves a general linear maximization
 * problem: maximize  $c^T x$  subject to  $Ax \leq b$ ,  $x \geq 0$ . Returns -inf if there is no solution, inf if
 * there are arbitrarily good solutions, or the maximum
 * value of  $c^T x$  otherwise. The input vector is set to
 * an optimal  $x$  (or in the unbounded case, an arbitrary
 * solution fulfilling the constraints). Numerical
 * stability is not guaranteed. For better performance,
 * define variables such that  $x = 0$  is viable. Usage:
 * vvd A = {{1,-1}, {-1,1}, {-1,-2}};
 * vd b = {1,1,-4}, c = {-1,-1}, x;
 * T val = LPSolver(A, b, c).solve(x);
 * Time:  $O(NM * \#\text{pivots})$ , where a pivot may be e.g. an
 * edge relaxation.  $O(2^n)$  in the general case. Status:
 * seems to work? */
typedef double
T; // long double, Rational, double + mod<P>...
typedef vector<T> vd;
typedef vector<vd> vvd;
const T eps = 1e-8, inf = 1 / .0;
#define MP make_pair
#define ltj(X) \
    if (s == -1 || MP(X[j], N[j]) < MP(X[s], N[s])) s = j

```

```

struct LPSolver {
    int m, n;
    vi N, B;
    vvd D;
    LPSolver(const vvd& A, const vd& b, const vd& c)
        : m(sz(b)),
          n(sz(c)),
          N(n + 1),
          B(m),
          D(m + 2, vd(n + 2)) {
        ran(i, 0, m) ran(j, 0, n) D[i][j] = A[i][j];
        ran(i, 0, m) {
            B[i] = n + i;
            D[i][n] = -1;
            D[i][n + 1] = b[i];
        }
        ran(j, 0, n) {
            N[j] = j;
            D[m][j] = -c[j];
        }
        N[n] = -1;
        D[m + 1][n] = 1;
    }
    void pivot(int r, int s) {
        T *a = D[r].data(), inv = 1 / a[s];
        ran(i, 0, m + 2) if (i != r && abs(D[i][s]) > eps) {
            T *b = D[i].data(), inv2 = b[s] * inv;
            ran(j, 0, n + 2) b[j] -= a[j] * inv2;
            b[s] = a[s] * inv2;
        }
        ran(j, 0, n + 2) if (j != s) D[r][j] *= inv;
        ran(i, 0, m + 2) if (i != r) D[i][s] *= -inv;
        D[r][s] = inv;
        swap(B[r], N[s]);
    }
    bool simplex(int phase) {
        int x = m + phase - 1;
        for (;;) {
            int s = -1;
            ran(j, 0, n + 1) if (N[j] != -phase) ltj(D[x]);
            if (D[x][s] >= -eps) return true;
            int r = -1;
            ran(i, 0, m) {
                if (D[i][s] <= eps) continue;
                if (r == -1 || MP(D[i][n + 1] / D[i][s], B[i]) <
                    MP(D[r][n + 1] / D[r][s], B[r]))
                    r = i;
            }
            if (r == -1) return false;
            pivot(r, s);
        }
    }
    T solve(vd& x) {
        int r = 0;
        ran(i, 1, m) if (D[i][n + 1] < D[r][n + 1]) r = i;
        if (D[r][n + 1] < -eps) {
            pivot(r, n);

```



```

    if (!simplex(2) || D[m + 1][n + 1] < -eps)
        return -inf;
    ran(i, 0, m) if (B[i] == -1) {
        int s = 0;
        ran(j, 1, n + 1) ltj(D[i]);
        pivot(i, s);
    }
}
bool ok = simplex(1);
x = vd(n);
ran(i, 0, m) if (B[i] < n) x[B[i]] = D[i][n + 1];
return ok ? D[m][n + 1] : inf;
};

```

### Dinic

```

struct MaxFlow {
    const static ll INF = 1e18;
    int source, sink;
    vector<int> start, now, lvl, adj, rcap, cap_loc, bfs;
    vector<int> cap, orig_cap;
    ll sink_pot = 0;
    vector<bool> visited;
    vector<ll> cost;
    priority_queue<pair<ll, int>, vector<pair<ll, int> >,
        greater<pair<ll, int> >>
        dist_que;
    void add_flow(int idx, ll flow, bool cont = true) {
        cap[idx] -= flow;
        if (cont) add_flow(rcap[idx], -flow, false);
    }
    MaxFlow(
        const vector<tuple<int, int, ll, ll, ll> > &edges) {
        for (auto &cur : edges) { //from, to, cap, rcap, cost
            start.resize(max(max(get<0>(cur), get<1>(cur)) + 2,
                (int)start.size()));
            ++start[get<0>(cur) + 1];
            ++start[get<1>(cur) + 1];
        }
        ran(i, 1, (int)start.size()) start[i] += start[i-1];
        now = start;
        adj.resize(start.back());
        cap.resize(start.back());
        rcap.resize(start.back());
        cost.resize(start.back());
        for (auto &cur : edges) {
            int u, v;
            ll c, rc, c_cost;
            tie(u, v, c, rc, c_cost) = cur;
            assert(u != v);
            adj[now[u]] = v;
            adj[now[v]] = u;
            rcap[now[u]] = now[v];
            rcap[now[v]] = now[u];
            cap_loc.push_back(now[u]);
            cost[now[u]] = c_cost;

```

```

            cost[now[v]] = -c_cost;
            cap[now[u]++] = c;
            cap[now[v]++] = rc;
            orig_cap.push_back(c);
        }
    }
    bool dinic_bfs(int min_cap) {
        lvl.clear();
        lvl.resize(start.size());
        bfs.clear();
        bfs.resize(1, source);
        now = start;
        lvl[source] = 1;
        ran(i, 0, (int)bfs.size()) {
            int u = bfs[i];
            while (now[u] < start[u + 1]) {
                int v = adj[now[u]];
                if (cost[now[u]] == 0 &&
                    cap[now[u]] >= min_cap && lvl[v] == 0) {
                    lvl[v] = lvl[u] + 1;
                    if (v == sink) return true;
                    bfs.push_back(v);
                }
                ++now[u];
            }
        }
        return false;
    }
    ll dinic_dfs(int u, ll flow, int min_cap) {
        if (u == sink) return flow;
        if (lvl[u] == lvl[sink]) return 0;
        ll res = 0;
        while (now[u] < start[u + 1]) {
            int v = adj[now[u]];
            if (lvl[v] == lvl[u] + 1 && cost[now[u]] == 0 &&
                cap[now[u]] >= min_cap) {
                ll cur = dinic_dfs(v, min(flow, (ll)cap[now[u]]),
                    min_cap);
                if (cur) {
                    add_flow(now[u], cur);
                    flow -= cur;
                    res += cur;
                    if (!flow) break;
                }
                ++now[u];
            }
        }
        return res;
    }
    bool recalc_dist(bool check_imp = false) {
        now = start;
        visited.clear();
        visited.resize(start.size());
        dist_que.emplace(0, source);
        bool imp = false;
        while (!dist_que.empty()) {
            int u;

```

```

            ll dist;
            tie(dist, u) = dist_que.top();
            dist_que.pop();
            if (!visited[u]) {
                visited[u] = true;
                if (check_imp && dist != 0) imp = true;
                if (u == sink) sink_pot += dist;
                while (now[u] < start[u + 1]) {
                    int v = adj[now[u]];
                    if (!visited[v] && cap[now[u]])
                        dist_que.emplace(dist + cost[now[u]], v);
                    cost[now[u]] += dist;
                    cost[rcap[now[u]++]] -= dist;
                }
            }
            if (check_imp) return imp;
            return visited[sink];
        }
        // return whether there is a negative cycle
        bool recalc_dist_bellman_ford() {
            int i = 0;
            for (; i < (int)start.size() - 1 &&
                recalc_dist(true); ++i) {}
            return i == (int)start.size() - 1;
        }
        pair<ll, ll> calc_flow(int _source, int _sink) {
            source = _source;
            sink = _sink;
            assert(max(source, sink) < start.size() - 1);
            ll tot_flow = 0;
            ll tot_cost = 0;
            if (recalc_dist_bellman_ford()) {
                assert(false);
            } else {
                while (recalc_dist()) {
                    ll flow = 0;
                    for (int min_cap = 1 << 30; min_cap; min_cap >= 1) {
                        while (dinic_bfs(min_cap)) {
                            now = start;
                            ll cur;
                            while (cur = dinic_dfs(source, INF, min_cap))
                                flow += cur;
                        }
                        tot_flow += flow;
                        tot_cost += sink_pot * flow;
                    }
                }
                return {tot_flow, tot_cost};
            }
            ll flow_on_edge(int idx) {
                assert(idx < cap.size());
                return orig_cap[idx] - cap[cap_loc[idx]];
            }
        };
        const int nmax = 1055;

```



```

int main() {
    int t;
    scanf("%d", &t);
    for (int i = 0; i < t; ++i) {
        vector<tuple<int, int, ll, ll, ll>> edges;
        int n;
        scanf("%d", &n);
        for (int j = 1; j <= n; ++j) {
            edges.emplace_back(j, 2 * n + 1, 1, 0, 0);
        }
        for (int j = 1; j <= n; ++j) {
            int card;
            scanf("%d", &card);
            edges.emplace_back(0, card, 1, 0, 0);
        }
        int ex_c;
        scanf("%d", &ex_c);
        for (int j = 0; j < ex_c; ++j) {
            int a, b;
            scanf("%d %d", &a, &b);
            if (b < a) swap(a, b);
            edges.emplace_back(a, b, nmax, 0, 1);
            edges.emplace_back(b, n + b, nmax, 0, 0);
            edges.emplace_back(n + b, a, nmax, 0, 1);
        }
        int v = 2 * n + 2;
        MaxFlow mf(edges);
        printf("%d\n", (int)mf.calc_flow(0, v - 1).second);
        //cout << mf.flow_on_edge(edge_index) << endl;
    }
}

Gomory-Hu O(N Dinic)

struct Edge {
    int u, v, w;
    Edge () {}
    Edge (int _u, int _v, int _w) :
        u(_u), v(_v), w(_w) {}
};

class GomoryHu {
    int vertexc;
    vector<vector<int>> capac;
    vector<int> comp;
    vector<int> compsz;
    vector<Edge> tree_edges;
    void find_cut (int vertex, int source,
        vector<int> &partition,
        vector<vector<int>> &curcapac,
        vector<vector<int>> &indices,
        MaxFlow &mf) {
        partition[vertex] = 1;
        for (int nxt = 0; nxt < vertexc; nxt++) {
            if (comp[nxt] == source || comp[nxt] == nxt) {
                if (!partition[nxt]) {
                    if (curcapac[vertex][nxt] > 0) {

```

```

                        < curcapac[vertex][nxt]) {
                            find_cut(nxt, source, partition,
                                curcapac, indices, mf);
                        }
                    }
                }
            }
        }
    }
    void split_component (int vertex) {
        int source = vertex;
        int sink = -1;
        for (int i = 0; i < vertexc; i++) {
            if (comp[i] == vertex && i != vertex) {
                sink = i;
            }
        }
        vector<vector<int>> newcapac
            (vertexc, vector<int> (vertexc, 0));
        for (int i = 0; i < vertexc; i++) {
            int ic = (comp[i] == vertex ? i : comp[i]);
            for (int j = 0; j < vertexc; j++) {
                int jc = (comp[j] == vertex ? j : comp[j]);
                newcapac[ic][jc] += capac[i][j];
            }
        }
        vector<vector<int>> edgeIndices
            (vertexc, vector<int> (vertexc, 0));
        MaxFlow mf (source, sink);
        for (int i = 0; i < vertexc; i++) {
            if (comp[i] == vertex || comp[i] == i) {
                for (int j = i + 1; j < vertexc; j++) {
                    if (comp[j] == vertex || comp[j] == j) {
                        if (newcapac[i][j] > 0) {
                            edgeIndices[i][j] =
                                mf.add_edge(i, j, newcapac[i][j],
                                    newcapac[i][j]);
                            edgeIndices[j][i] = edgeIndices[i][j];
                        }
                    }
                }
            }
        }
        int newWeight = mf.calc_max_flow();
        vector<int> partition (vertexc, 0);
        find_cut(sink, source, partition, newcapac,
            edgeIndices, mf);
        for (int i = 0; i < vertexc; i++) {
            if (comp[i] == source && partition[i]) {
                comp[i] = sink;
                compsz[source]--;
                compsz[sink]++;
            }
        }
        vector<Edge> newedges;
        for (Edge e : tree_edges) {
            if (e.u == source) {

```

```

8641         if (partition[e.v]) {
            e.u = sink;
        }
    }
    if (e.v == source) {
        if (partition[e.u]) {
            e.v = sink;
        }
    }
    newedges.push_back(e);
}
newedges.push_back(Edge(source, sink, newWeight));
tree_edges = newedges;
2299
}
1861 public:
GomoryHu (int _vertexc) {
    vertexc = _vertexc;
    capac = vector<vector<int>>
        (vertexc, vector<int> (vertexc, 0));
    0552
    comp = vector<int> (vertexc, 0);
    compsz = vector<int> (vertexc, 0);
    1901
    compsz[0] = vertexc;
    tree_edges = vector<Edge> ();
    2390
}
void set_capac (int u, int v, int w) {
    4279
    capac[u][v] = w;
    capac[v][u] = w;
}
vector<Edge> build_tree () {
    1141
    for (int i = 0; i < vertexc - 1; i++) {
        for (int j = 0; j < vertexc; j++) {
            4902
            if (compsz[j] >= 2) {
                split_component(j); // will happen N - 1 times
            }
        }
    }
    return tree_edges;
}
7186};
int main () {
    0742
    int vertexc, edgec;
    cin >> vertexc >> edgec;
    GomoryHu gh (vertexc);
    for (int i = 0; i < edgec; i++) {
        2456
        int u, v, w;
        cin >> u >> v >> w;
        u--; v--;
        gh.set_capac(u, v, w);
    }
    6483
    vector<Edge> tree = gh.build_tree();
    %6483
}

Min Cost Max Flow with Cycle Cancelling O(Cnm)

struct Network {
    struct Node;
    struct Edge {

```

```

Node *u, *v;
int f, c, cost;
Node* from(Node* pos) {
    if (pos == u) return v;
    return u;
}
int getCap(Node* pos) {
    if (pos == u) return c - f;
    return f;
}
int addFlow(Node* pos, int toAdd) {
    if (pos == u) {
        f += toAdd;
        return toAdd * cost;
    } else {
        f -= toAdd;
        return -toAdd * cost;
    }
}
};
struct Node {
    vector<Edge*> conn;
    int index;
};
deque<Node> nodes;
deque<Edge> edges;
Node* addNode() {
    nodes.push_back(Node());
    nodes.back().index = nodes.size() - 1;
    return &nodes.back();
}
Edge* addEdge(
    Node* u, Node* v, int f, int c, int cost) {
    edges.push_back({u, v, f, c, cost});
    u->conn.push_back(&edges.back());
    v->conn.push_back(&edges.back());
    return &edges.back();
}
// Assumes all needed flow has already been added
int minCostMaxFlow() {
    int n = nodes.size();
    int result = 0;
    struct State {
        int p;
        Edge* used;
    };
    while (1) {
        vector<vector<State>> state(
            1, vector<State>(n, {0, 0}));
        for (int lev = 0; lev < n; lev++) {
            state.push_back(state[lev]);
            for (int i = 0; i < n; i++) {
                if (lev == 0 ||
                    state[lev][i].p < state[lev - 1][i].p) {
                    for (Edge* edge : nodes[i].conn) {
                        if (edge->getCap(&nodes[i]) > 0) {
                            int np =
                                state[lev][i].p + (edge->u == &nodes[i]
                                    ? edge->cost
                                    : -edge->cost);
                            int ni = edge->from(&nodes[i])->index;
                            if (np < state[lev + 1][ni].p) {
                                state[lev + 1][ni].p = np;
                                state[lev + 1][ni].used = edge;
                            }
                        }
                    }
                }
            }
            // Now look at the last level
            bool valid = false;
            for (int i = 0; i < n; i++)
                if (state[n - 1][i].p > state[n][i].p) {
                    valid = true;
                    vector<Edge*> path;
                    int cap = 1000000000;
                    Node* cur = &nodes[i];
                    int clev = n;
                    vector<bool> explr(n, false);
                    while (!explr[cur->index]) {
                        explr[cur->index] = true;
                        State cstate = state[clev][cur->index];
                        cur = cstate.used->from(cur);
                        path.push_back(cstate.used);
                    }
                    reverse(path.begin(), path.end());
                    {
                        int i = 0;
                        Node* cur2 = cur;
                        do {
                            cur2 = path[i]->from(cur2);
                            i++;
                        } while (cur2 != cur);
                        path.resize(i);
                    }
                    for (auto edge : path) {
                        cap = min(cap, edge->getCap(cur));
                        cur = edge->from(cur);
                    }
                    for (auto edge : path) {
                        result += edge->addFlow(cur, cap);
                        cur = edge->from(cur);
                    }
                }
            if (!valid) break;
        }
        return result;
    }
}

Global Min Cut  $O(V^3)$ 
pair<int, vi> GetMinCut(vector<vi>& weights) {
    int N = sz(weights);
    vi used(N), cut, best_cut;
    int best_weight = -1;
    for (int phase = N - 1; phase >= 0; phase--) {
        vi w = weights[0], added = used;
        int prev, k = 0;
        rep(i, 0, phase) {
            prev = k;
            k = -1;
            rep(j, 1, N)
                if (!added[j] && (k == -1 || w[j] > w[k])) k = j;
            if (i == phase - 1) {
                rep(j, 0, N) weights[prev][j] += weights[k][j];
                rep(j, 0, N) weights[j][prev] = weights[prev][j];
                used[k] = true;
                cut.push_back(k);
                if (best_weight == -1 || w[k] < best_weight) {
                    best_cut = cut;
                    best_weight = w[k];
                }
            } else {
                rep(j, 0, N) w[j] += weights[k][j];
                added[k] = true;
            }
        }
    }
    return {best_weight, best_cut};
}

Aho Corasick  $O(|\alpha| * \text{sum}(\text{len}))$ 
const int alpha_size = 26;
struct Node {
    Node *nxt[alpha_size]; // May use other structures to
                          // move in trie
    Node *suffix;
    Node() { memset(nxt, 0, alpha_size * sizeof(Node *)); }
    int cnt = 0;
};
Node *aho_corasick(vector<vector<char>> &dict) {
    Node *root = new Node;
    root->suffix = 0;
    vector<pair<vector<char> *, Node *>> state;
    for (vector<char> &s : dict)
        state.emplace_back(&s, root);
    for (int i = 0; !state.empty(); ++i) {
        vector<pair<vector<char> *, Node *>> nstate;
        for (auto &cur : state) {
            Node *nxt = cur.second->nxt[(cur.first)[i]];
            if (nxt) {
                cur.second = nxt;
            } else {
                nxt = new Node;
                cur.second->nxt[(cur.first)[i]] = nxt;
                Node *suf = cur.second->suffix;
                cur.second = nxt;
                nxt->suffix = root; // set correct suffix link
            }
        }
        state = nstate;
    }
}

```

```

while (suf) {
    if (suf->nxt[(cur.first)[i]]) {
        nxt->suffix = suf->nxt[(cur.first)[i]];
        break;
    }
    suf = suf->suffix;
}
if (cur.first->size() > i + 1)
    nstate.push_back(cur);
state = nstate;
}
return root;
}
// auxiliary functions for searching and counting
Node *walk(Node *cur,
char c) { // longest prefix in dict that is suffix of
// walked string.
while (true) {
    if (cur->nxt[c]) return cur->nxt[c];
    if (!cur->suffix) return cur;
    cur = cur->suffix;
}
}
void cnt_matches(Node *root, vector<char> &match_in) {
    Node *cur = root;
    for (char c : match_in) {
        cur = walk(cur, c);
        ++cur->cnt;
    }
}
void add_cnt(
Node *root) { // After counting matches propagate ONCE
// to suffixes for final counts
vector<Node *> to_visit = {root};
ran(i, 0, to_visit.size()) {
    Node *cur = to_visit[i];
    ran(j, 0, alpha_size) {
        if (cur->nxt[j]) to_visit.push_back(cur->nxt[j]);
    }
}
for (int i = to_visit.size() - 1; i > 0; --i)
    to_visit[i]->suffix->cnt += to_visit[i]->cnt;
}
int main() {
    int n, len;
    scanf("%d %d", &len, &n);
    vector<char> a(len + 1);
    scanf("%s", a.data());
    a.pop_back();
    for (char &c : a) c -= 'a';
    vector<vector<char>> > dict(n);
    ran(i, 0, n) {
        scanf("%d", &len);
        dict[i].resize(len + 1);
        scanf("%s", dict[i].data());
        dict[i].pop_back();
        for (char &c : dict[i]) c -= 'a';
        Node *root = aho_corasick(dict);
        cnt_matches(root, a);
        add_cnt(root);
        ran(i, 0, n) {
            Node *cur = root;
            for (char c : dict[i]) cur = walk(cur, c);
            printf("%d\n", cur->cnt);
        }
    }
}
Suffix automaton and tree  $O((n+q)\log(|\alpha|)) - 10+M$  length/s
struct Node;
typedef Ptr<Node> P;
struct Node {
    int act = 0;
    Ptr<P> out;
    int len; // Length of longest suffix in equivalence
    P suf; // class.
    char size = 0;
    char cap = 0;
    Node(int _len) : len(_len) {};
    Node(int &act, Ptr<P> &out, int &len, P &suf,
        int _size, int _cap) : act(_act), len(_len),
        suf(_suf), size(_size), cap(_cap) {
        out = alloc<P>(cap);
        ran(i, 0, size)
            out[i] = _out[i];
    }
    int has_nxt(char c) {
        return act & (1<<(c-'a'));
    }
    P nxt(char c) {
        return
            out[__builtin_popcount(act & ((1<<(c-'a'))-1))];
    }
    void set_nxt(char c, P nxt) {
        int idx = __builtin_popcount(act & ((1<<(c-'a'))-1));
        if (has_nxt(c)) {
            out[idx] = nxt;
        } else {
            if (size == cap) {
                cap *= 2;
                if (!size)
                    cap = 2;
                Ptr<P> nout = alloc<P>(cap);
                ran(i, 0, idx)
                    nout[i] = out[i];
                ran(i, idx, size)
                    nout[i+1] = out[i];
                dealloc(out, size);
                out = nout;
            } else {
                for (int i = size; i > idx; --i)
                    out[i] = out[i-1];
                act |= (1<<(c-'a'));
                out[idx] = nxt;
                ++size;
            }
        }
        P split(int new_len) {
            return suf = alloc<Node>(1, act, out, new_len,
                suf, size, cap);
        }
        // Extra functions for matching and counting
        P lower(int depth) {
            // move to longest suf of current with a maximum
            // length of depth.
            if (suf->len >= depth) return suf->lower(depth);
            return (P)this;
        }
        P walk(char c, int depth, int &match_len) {
            // move to longest suffix of walked path that is a
            // substring
            match_len = min(match_len, len);
            // includes depth limit (needed for finding matches)
            if (has_nxt(c)) { // as suffixes are in classes,
                // match_len must be tracked externally
                ++match_len;
                return nxt(c)->lower(depth);
            }
            if (suf) return suf->walk(c, depth, match_len);
            return (P)this;
        }
        bool vis = false;
        bool vis_t = false;
        int paths_to_end = 0;
        void set_as_end() { // All suffixes of current node are
            paths_to_end += 1; // marked as ending nodes.
            if (suf) suf->set_as_end();
        }
        void calc_paths() {
            /* Call ONCE from ROOT. For each node calculates
            * number of ways to reach an end node. paths_to_end
            * is occurrence count for any strings in current
            * suffix equivalence class. */
            if (!vis) {
                vis = true;
                ran(i, 0, size) {
                    out[i]->calc_paths();
                    paths_to_end += out[i]->paths_to_end;
                }
            }
            // Transform into suffix tree of reverse string
            P tree_links[26];
            int end_d_v = 1 << 30;
            int end_d() {
                if (end_d_v == 1 << 30) {

```

```

    ran(i, 0, size){
        end_d_v = min(end_d_v, 1 + out[i]->end_d());
    }
    if (end_d_v == 1 << 30)
        end_d_v = 0;
    return end_d_v;
}
void build_suffix_tree(
    string &s) { // Call ONCE from ROOT.
    if (!vis_t) {
        vis_t = true;
        if (suf)
            suf->tree_links[s[(int)s.size() - end_d() -
                suf->len - 1] - 'a'] = (P)this;
        ran(i, 0, size){
            out[i]->build_suffix_tree(s);
        }
    }
};
struct SufAuto {
    P last;
    P root;
    void extend(char new_c) {
        P nlast = alloc<Node>(1, last->len + 1);
        P sw_n = last;
        while (sw_n && !sw_n->has_nxt(new_c)) {
            sw_n->set_nxt(new_c, nlast);
            sw_n = sw_n->suf;
        }
        if (!sw_n) {
            nlast->suf = root;
        } else {
            P max_sbstr = sw_n->nxt(new_c);
            if (sw_n->len + 1 == max_sbstr->len) {
                nlast->suf = max_sbstr;
            } else { // remove for minimal DFA that matches
                // suffixes and crap
                P eq_sbstr = max_sbstr->split(sw_n->len + 1);
                nlast->suf = eq_sbstr;
                P x = sw_n; // x = with_edge_to_eq_sbstr
                while (x != 0 && x->nxt(new_c) == max_sbstr) {
                    x->set_nxt(new_c, eq_sbstr);
                    x = x->suf;
                }
            }
        }
        last = nlast;
    }
    SufAuto(string &s) {
        last = root = alloc<Node>(1, 0);
        for (char c : s) extend(c);
        // To build suffix tree use reversed string
        root->build_suffix_tree(s);
    }
};

```

### Palindromic tree O(n)

```

struct palindromic_tree {
    int len[MAXN], link[MAXN], cnt[MAXN];
    char s[MAXN];
    vector<pair<char, int>> to[MAXN];
    int n, last, sz;
    void clear() {
        fill(to, to + MAXN, vector<pair<char, int>>());
        memset(len, 0, sizeof(len));
        memset(link, 0, sizeof(link));
        memset(cnt, 0, sizeof(cnt));
        memset(s, 0, sizeof(s));
        n = last = 0;
        link[0] = 1;
        len[1] = -1;
        s[n++] = 27;
        sz = 2;
    }
    palindromic_tree() { clear(); }
    int get_link(int v) {
        while (s[n - len[v] - 2] != s[n - 1]) v = link[v];
        return v;
    }
    int tr(int v, int c) {
        for (auto it : to[v])
            if (it.first == c) return it.second;
        return 0;
    }
    int add_letter(int c) {
        s[n++] = c;
        int cur = get_link(last);
        if (!tr(cur, c)) {
            len[sz] = len[cur] + 2;
            link[sz] = tr(get_link(link[cur]), c);
            to[cur].push_back({c, sz++});
        }
        last = tr(cur, c);
        return cnt[last] = cnt[link[last]] + 1;
    }
};

DMST O(E log V)

struct EdgeDesc {
    int from, to, w;
};
struct DMST {
    struct Node;
    struct Edge {
        Node *from;
        Node *tar;
        int w;
        bool inc;
    };
    struct Circle {

```

```

        bool vis = false;
        vector<Edge *> cont;
        void clean(int idx);
    };
    const static greater<pair<ll, Edge *> > comp;
    static vector<Circle> to_proc;
    static bool no_dmst;
    static Node *root; // Can use inline static since C++17
    struct Node {
        Node *par = NULL;
        vector<pair<int, int> > out_cands; // Circ, edge idx
        vector<pair<ll, Edge *> > con;
        bool in_use = false;
        ll w = 0; // extra to add to edges in con
        Node *anc() {
            if (!par) return this;
            while (par->par) par = par->par;
            return par;
        }
        void clean() {
            if (!no_dmst) {
                in_use = false;
                for (auto &cur : out_cands)
                    to_proc[cur.first].clean(cur.second);
            }
        }
        Node *con_to_root() {
            if (anc() == root) return root;
            in_use = true;
            Node *super = this;
            // Will become root or the first Node encountered
            // in a loop.
            while (super == this) {
                while (!con.empty() &&
                    con.front().second->tar->anc() == anc()) {
                    pop_heap(con.begin(), con.end(), comp);
                    con.pop_back();
                }
                if (con.empty()) {
                    no_dmst = true;
                    return root;
                }
                pop_heap(con.begin(), con.end(), comp);
                auto nxt = con.back();
                con.pop_back();
                w = -nxt.first;
                if (nxt.second->tar->in_use) {
                    super = nxt.second->tar->anc();
                    to_proc.resize(to_proc.size() + 1);
                } else {
                    super = nxt.second->tar->con_to_root();
                }
                if (super != root) {
                    to_proc.back().cont.push_back(nxt.second);
                    out_cands.emplace_back(to_proc.size() - 1,
                        to_proc.back().cont.size() - 1);
                } else { // Clean circles

```

```

    nxt.second->inc = true;
    nxt.second->from->clean();
}
}
if (super != root) {
    // we are some loops non first Node.
    if (con.size() > super->con.size()) {
        swap(con, super->con);
        // Largest con in loop should not be copied.
        swap(w, super->w);
    }
    for (auto cur : con) {
        super->con.emplace_back(
            cur.first - super->w + w, cur.second);
        push_heap(
            super->con.begin(), super->con.end(), comp);
    }
    par = super; // root or anc() of first Node
                // encountered in a loop
    return super;
}
};
Node *croot;
vector<Node> graph;
vector<Edge> edges;
DMST(int n, vector<EdgeDesc> &desc, int r) {
    // Self loops and multiple edges are okay.
    graph.resize(n);
    croot = &graph[r];
    for (auto &cur : desc)
        // Edges are reversed internally
        edges.push_back(
            Edge(&graph[cur.to], &graph[cur.from], cur.w));
    for (int i = 0; i < desc.size(); ++i)
        graph[desc[i].to].con.emplace_back(
            desc[i].w, &edges[i]);
    for (int i = 0; i < n; ++i)
        make_heap(
            graph[i].con.begin(), graph[i].con.end(), comp);
}
bool find() {
    root = croot;
    no_dmst = false;
    for (auto &cur : graph) {
        cur.con_to_root();
        to_proc.clear();
        if (no_dmst) return false;
    }
    return true;
}
ll weight() {
    ll res = 0;
    for (auto &cur : edges) {
        if (cur.inc) res += cur.w;
    }
    return res;
}

};
void DMST::Circle::clean(int idx) {
    if (!vis) {
        vis = true;
        for (int i = 0; i < cont.size(); ++i) {
            if (i != idx) {
                cont[i]->inc = true;
                cont[i]->from->clean();
            }
        }
    }
}
const greater<pair<ll, DMST::Edge *> > DMST::comp;
vector<DMST::Circle> DMST::to_proc;
bool DMST::no_dmst;
DMST::Node *DMST::root;

Dominator tree O(NlogN)

struct Tree {
    /* insert structure here */
    void set_root(int u) {
        cout << "root is " << u << endl;
    }
    void add_edge(int u, int v) {
        cout << u << "-" << v << endl;
    }
};

struct Graph {
    vector<vector<int>> in_edges, out_edges;
    vector<int> ord, dfs_idx, parent;
    vector<int> sdом, idом;
    vector<vector<int>> rsdom; /* inverse of sdом */
    /* slightly modified version of dsu-s root[] */
    vector<int> dsu;
    vector<int> label;
    void dfs(int cur, int par, vector<int> &vis) {
        ord.push_back(cur);
        parent[cur] = par;
        dfs_idx[cur] = (int)ord.size() - 1;
        vis[cur] = 1;
        for (int nxt : out_edges[cur]) {
            in_edges[nxt].push_back(cur);
            if (!vis[nxt])
                dfs(nxt, cur, vis);
        }
    }
    void add_edge(int u, int v) {
        out_edges[u].push_back(v);
    }
    Graph(int n) {
        in_edges.resize(n, vector<int>());
        out_edges.resize(n, vector<int>());
        rsdom.resize(n, vector<int>());
        dfs_idx.resize(n, -1);
        parent.resize(n, -1);
    }
};

ran(i, 0, n) {
    sdом.push_back(i);
    idом.push_back(i);
    dsu.push_back(i);
    label.push_back(i);
}
int find(int u, int x = 0) {
    if (u == dsu[u]) {
        if (x) {
            return -1;
        } else {
            return u;
        }
    }
    int v = find(dsu[u], x + 1);
    if (v < 0) {
        return u;
    }
    if (dfs_idx[sdom[label[dsu[u]]]] <
        dfs_idx[sdom[label[u]]]) {
        label[u] = label[dsu[u]];
    }
    dsu[u] = v;
    return x ? v : label[u];
}
void merge(int u, int v) { dsu[v] = u; }
Tree dom_tree(int src) {
    vector<int> vis(idом.size(), 0);
    dfs(src, -1, vis);
    for (int i = (int)ord.size() - 1; i >= 0; --i) {
        int u = ord[i];
        for (int v : in_edges[u]) {
            int w = find(v);
            if (dfs_idx[sdom[u]] > dfs_idx[sdom[w]]) {
                sdом[u] = sdом[w];
            }
        }
        if (i > 0) {
            rsdom[sdom[u]].push_back(u);
        }
        for (int w : rsdom[u]) {
            int v = find(w);
            if (sdом[v] == sdом[w]) {
                idом[w] = sdом[w];
            } else {
                idом[w] = v;
            }
        }
        if (i > 0) {
            merge(parent[u], u);
        }
    }
    Tree ans; /* if your constructor needs # of vertices,
               * use (int) idом.size() + 5 for example */
    ran(i, 1, (int)ord.size()) {
        int u = ord[i];

```

```

    if (idom[u] != sdom[u]) {
        idom[u] = idom[idom[u]];
    }
    ans.add_edge(idom[u], u);
}
ans.set_root(src);
return ans;
};

```

### Bridges $O(n)$

```

struct vert;
struct edge {
    bool exists = true;
    vert *dest;
    edge *rev;
    edge(vert *_dest) : dest(_dest) { rev = NULL; }
    vert &operator*() { return *dest; }
    vert *operator->() { return dest; }
    bool is_bridge();
};

struct vert {
    deque<edge> con;
    int val = 0;
    int seen;
    int dfs(int upd, edge *ban) { // handles multiple edges
        if (!val) {
            val = upd;
            seen = val;
            for (edge &nxt : con) {
                if (nxt.exists && (&nxt) != ban)
                    seen = min(seen, nxt->dfs(upd + 1, nxt.rev));
            }
            return seen;
        }
    }

    void remove_adj_bridges() {
        for (edge &nxt : con) {
            if (nxt.is_bridge()) nxt.exists = false;
        }
    }

    int cnt_adj_bridges() {
        int res = 0;
        for (edge &nxt : con) res += nxt.is_bridge();
        return res;
    }
};

bool edge::is_bridge() {
    return exists && (dest->seen > rev->dest->val ||
                    dest->val < rev->dest->seen);
}

vert graph[nmax];
int main() { // Mechanics Practice BRIDGES
    int n, m;
    cin >> n >> m;
    for (int i = 0; i < m; ++i) {

```

1731 0094

2307

%7388%1935%7257

```

    int u, v;
    scanf("%d %d", &u, &v);
    graph[u].con.emplace_back(graph + v);
    graph[v].con.emplace_back(graph + u);
    graph[u].con.back().rev = &graph[v].con.back();
    graph[v].con.back().rev = &graph[u].con.back();
}
graph[1].dfs(1, NULL);
int res = 0;
for (int i = 1; i <= n; ++i)
    res += graph[i].cnt_adj_bridges();
cout << res / 2 << endl;
}

```

### 2-Sat $O(n)$ and SCC $O(n)$

```

struct Graph {
    int n;
    vector<vector<int>> con;
    Graph(int nsize) {
        n = nsize;
        con.resize(n);
    }

    void add_edge(int u, int v) { con[u].push_back(v); }
    void top_dfs(int pos, vector<int> &result,
                vector<bool> &explr, vector<vector<int>> &revcon) {
        if (explr[pos]) return;
        explr[pos] = true;
        for (auto next : revcon[pos])
            top_dfs(next, result, explr, revcon);
        result.push_back(pos);
    }

    vector<int> topsort() {
        vector<vector<int>> > revcon(n);
        ran(u, 0, n) {
            for (auto v : con[u]) revcon[v].push_back(u);
        }
        vector<int> result;
        vector<bool> explr(n, false);
        ran(i, 0, n) top_dfs(i, result, explr, revcon);
        reverse(result.begin(), result.end());
        return result;
    }

    void dfs(
        int pos, vector<int> &result, vector<bool> &explr) {
        if (explr[pos]) return;
        explr[pos] = true;
        for (auto next : con[pos]) dfs(next, result, explr);
        result.push_back(pos);
    }

    vector<vector<int>> scc() {
        vector<int> order = topsort();
        reverse(order.begin(), order.end());
        vector<bool> explr(n, false);
        vector<vector<int>> > res;
        for (auto it = order.rbegin(); it != order.rend();
            ++it) {

```

8609

5261

0263

9673

6679

0800

%3548%8614%4558

```

        vector<int> comp;
        top_dfs(*it, comp, explr, con);
        sort(comp.begin(), comp.end());
        res.push_back(comp);
    }
    sort(res.begin(), res.end());
    return res;
}

int main() {
    int n, m;
    cin >> n >> m;
    Graph g(2 * m);
    ran(i, 0, n) {
        int a, sa, b, sb;
        cin >> a >> sa >> b >> sb;
        a--, b--;
        g.add_edge(2 * a + 1 - sa, 2 * b + sb);
        g.add_edge(2 * b + 1 - sb, 2 * a + sa);
    }
    vector<int> state(2 * m, 0);
    {
        vector<int> order = g.topsort();
        vector<bool> explr(2 * m, false);
        for (auto u : order) {
            vector<int> traversed;
            g.dfs(u, traversed, explr);
            if (traversed.size() > 0 &&
                !state[traversed[0] ^ 1]) {
                for (auto c : traversed) state[c] = 1;
            }
        }
        ran(i, 0, m) {
            if (state[2 * i] == state[2 * i + 1]) {
                cout << "IMPOSSIBLE\n";
                return 0;
            }
        }
        ran(i, 0, m) cout << state[2 * i + 1] << '\n';
        return 0;
    }
}

```

8640

%0503%6965%4511

### Templated multi dimensional BIT $O(\log(n)^d)$ per query

```

// Fully overloaded any dimensional BIT, use any type for
// coordinates, elements, return_value. Includes
// coordinate compression.
template <class E_T, class C_T, C_T n_inf, class R_T>
struct BIT {
    vector<C_T> pos;
    vector<E_T> elems;
    bool act = false;
    BIT() { pos.push_back(n_inf); }
    void init() {
        if (act) {

```

6191

8228

8807



```

    for (E_T &c_elem : elems) c_elem.init();
} else {
    act = true;
    sort(pos.begin(), pos.end());
    pos.resize(
        unique(pos.begin(), pos.end()) - pos.begin());
    elems.resize(pos.size());
}
}
template <typename... loc_form>
void update(C_T cx, loc_form... args) {
    if (act) {
        int x = lower_bound(pos.begin(), pos.end(), cx) -
            pos.begin();
        for (; x < (int)pos.size(); x += x & -x)
            elems[x].update(args...);
    } else {
        pos.push_back(cx);
    }
}
template <typename... loc_form>
R_T query(
    C_T cx, loc_form... args) { // sum in (-inf, cx)
    R_T res = 0;
    int x = lower_bound(pos.begin(), pos.end(), cx) -
        pos.begin() - 1;
    for (; x > 0; x -= x & -x)
        res += elems[x].query(args...);
    return res;
}
};
template <typename I_T>
struct wrapped {
    I_T a = 0;
    void update(I_T b) { a += b; }
    I_T query() { return a; }
    // Should never be called, needed for compilation
    void init() { DEBUG('i') }
    void update() { DEBUG('u') }
};
int main() {
    // return type should be same as type inside wrapped
    BIT<BIT<wrapped<ll>, int, INT_MIN, ll>, int, INT_MIN,
        ll>
        fenwick;
    int dim = 2;
    vector<tuple<int, int, ll> > to_insert;
    to_insert.emplace_back(1, 1, 1);
    // set up all pos that are to be used for update
    for (int i = 0; i < dim; ++i) {
        for (auto &cur : to_insert)
            fenwick.update(get<0>(cur), get<1>(cur));
        // May include value which won't be used
        fenwick.init();
    }
    // actual use
    for (auto &cur : to_insert)
        fenwick.update(
            get<0>(cur), get<1>(cur), get<2>(cur));
    cout << fenwick.query(2, 2) << '\n';
}

```

**Treap  $O(\log(n))$  per query**

```

mt19937 randgen;
struct Treap {
    struct Node {
        int key;
        int value;
        unsigned int priority;
        ll total;
        Node* lch;
        Node* rch;
        Node(int new_key, int new_value) {
            key = new_key;
            value = new_value;
            priority = randgen();
            total = new_value;
            lch = 0;
            rch = 0;
        }
        void update() {
            total = value;
            if (lch) total += lch->total;
            if (rch) total += rch->total;
        }
    };
    deque<Node> nodes;
    Node* root = 0;
    pair<Node*, Node*> split(int key, Node* cur) {
        if (cur == 0) return {0, 0};
        pair<Node*, Node*> result;
        if (key <= cur->key) {
            auto ret = split(key, cur->lch);
            cur->lch = ret.second;
            result = {ret.first, cur};
        } else {
            auto ret = split(key, cur->rch);
            cur->rch = ret.first;
            result = {cur, ret.second};
        }
        cur->update();
        return result;
    }
    Node* merge(Node* left, Node* right) {
        if (left == 0) return right;
        if (right == 0) return left;
        Node* top;
        if (left->priority < right->priority) {
            left->rch = merge(left->rch, right);
            top = left;
        } else {
            right->lch = merge(left, right->lch);
            top = right;
        }
        top->update();
        return top;
    }
    void insert(int key, int value) {
        nodes.push_back(Node(key, value));
        Node* cur = &nodes.back();
        pair<Node*, Node*> ret = split(key, root);
        cur = merge(ret.first, cur);
        cur = merge(cur, ret.second);
        root = cur;
    }
    void erase(int key) {
        Node *left, *mid, *right;
        tie(left, mid) = split(key, root);
        tie(mid, right) = split(key + 1, mid);
        root = merge(left, right);
    }
    ll sum_upto(int key, Node* cur) {
        if (cur == 0) return 0;
        if (key <= cur->key) {
            return sum_upto(key, cur->lch);
        } else {
            ll result = cur->value + sum_upto(key, cur->rch);
            if (cur->lch) result += cur->lch->total;
            return result;
        }
    }
    ll get(int l, int r) {
        return sum_upto(r + 1, root) - sum_upto(l, root);
    }
};
int main() {
    ios_base::sync_with_stdio(false);
    cin.tie(0);
    int m;
    Treap treap;
    cin >> m;
    for (int i = 0; i < m; i++) {
        int type;
        cin >> type;
        if (type == 1) {
            int x, y;
            cin >> x >> y;
            treap.insert(x, y);
        } else if (type == 2) {
            int x;
            cin >> x;
            treap.erase(x);
        } else {
            int l, r;
            cin >> l >> r;
            cout << treap.get(l, r) << endl;
        }
    }
    return 0;
}

```

## Generic persistent compressed lazy segment tree

```

struct Seg {
    ll sum = 0;
    void recalc(const Seg &lhs_seg, int lhs_len,
               const Seg &rhs_seg, int rhs_len) {
        sum = lhs_seg.sum + rhs_seg.sum;
    }
} __attribute__((packed));
struct Lazy {
    ll add;
    ll assign_val; // LLONG_MIN if no assign;
    void init() {
        add = 0;
        assign_val = LLONG_MIN;
    }
    Lazy() { init(); }
    void split(Lazy &lhs_lazy, Lazy &rhs_lazy, int len) {
        lhs_lazy = *this;
        rhs_lazy = *this;
        init();
    }
    void merge(Lazy &oth, int len) {
        if (oth.assign_val != LLONG_MIN) {
            add = 0;
            assign_val = oth.assign_val;
        }
        add += oth.add;
    }
    void apply_to_seg(Seg &cur, int len) const {
        if (assign_val != LLONG_MIN) {
            cur.sum = len * assign_val;
        }
        cur.sum += len * add;
    }
} __attribute__((packed));
struct Node { // Following code should not need to be
              // modified
    int ver;
    bool is_lazy = false;
    Seg seg;
    Lazy lazy;
    Node *lc = NULL, *rc = NULL;
    void init() {
        if (!lc) {
            lc = new Node{ver};
            rc = new Node{ver};
        }
    }
    Node *upd(
        int L, int R, int l, int r, Lazy &val, int tar_ver) {
        if (ver != tar_ver) {
            Node *rep = new Node(*this);
            rep->ver = tar_ver;
            return rep->upd(L, R, l, r, val, tar_ver);
        }
    }

```

```

    if (L >= 1 && R <= r) {
        val.apply_to_seg(seg, R - L);
        lazy.merge(val, R - L);
        is_lazy = true;
    } else {
        init();
        int M = (L + R) / 2;
        if (is_lazy) {
            Lazy l_val, r_val;
            lazy.split(l_val, r_val, R - L);
            lc = lc->upd(L, M, L, M, l_val, ver);
            rc = rc->upd(M, R, M, R, r_val, ver);
            is_lazy = false;
        }
        Lazy l_val, r_val;
        val.split(l_val, r_val, R - L);
        if (l < M) lc = lc->upd(L, M, l, r, l_val, ver);
        if (M < r) rc = rc->upd(M, R, l, r, r_val, ver);
        seg.recalc(lc->seg, M - L, rc->seg, R - M);
    }
    return this;
}
void get(int L, int R, int l, int r, Seg *lft_res,
         Seg *rht_res, bool last_ver) {
    if (L >= 1 && R <= r) {
        tmp->recalc(*lft_res, L - 1, seg, R - L);
        swap(lft_res, tmp);
    } else {
        init();
        int M = (L + R) / 2;
        if (is_lazy) {
            Lazy l_val, r_val;
            lazy.split(l_val, r_val, R - L);
            lc = lc->upd(L, M, l, r, l_val, ver + last_ver);
            rc = rc->upd(M, R, l, r, r_val, ver + last_ver);
            rc->ver = ver;
            is_lazy = false;
        }
        if (l < M)
            lc->get(L, M, l, r, lft_res, tmp, last_ver);
        if (M < r)
            rc->get(M, R, l, r, rht_res, tmp, last_ver);
    }
}
} __attribute__((packed));
struct SegTree { // indexes start from 0, ranges are
                 // [beg, end)
    vector<Node> roots; // versions start from 0
    int len;
    SegTree(int len) : len(len) {
        roots.push_back(new Node{0});
    }
    int upd(
        int l, int r, Lazy &val, bool new_ver = false) {
        Node *cur_root = roots.back()->upd(
            0, len, l, r, val, roots.size() - !new_ver);
    }

```

```

    if (cur_root != roots.back())
        roots.push_back(cur_root);
    return roots.size() - 1;
}
Seg get(int l, int r, int ver = -1) {
    if (ver == -1) ver = roots.size() - 1;
    Seg seg1, seg2;
    Seg *pres = &seg1, *ptmp = &seg2;
    roots[ver]->get(
        0, len, l, r, pres, ptmp, roots.size() - 1);
    return *pres;
}
int main() {
    int n, m; // solves Mechanics Practice LAZY
    cin >> n >> m;
    SegTree seg_tree(1 << 17);
    for (int i = 0; i < n; ++i) {
        Lazy tmp;
        scanf("%lld", &tmp.assign_val);
        seg_tree.upd(i, i + 1, tmp);
    }
    for (int i = 0; i < m; ++i) {
        int o;
        int l, r;
        scanf("%d %d %d", &o, &l, &r);
        --l;
        if (o == 1) {
            Lazy tmp;
            scanf("%lld", &tmp.add);
            seg_tree.upd(l, r, tmp);
        } else if (o == 2) {
            Lazy tmp;
            scanf("%lld", &tmp.assign_val);
            seg_tree.upd(l, r, tmp);
        } else {
            Seg res = seg_tree.get(l, r);
            printf("%lld\n", res.sum);
        }
    }
}

```

Templated HLD  $O(M(n) \log n)$  per query

```

class dummy {
public:
    dummy() {}
    dummy(int, int) {}
    void set(int, int) {}
    int query(int left, int right) {
        cout << this << ' ' << left << ' ' << right << endl;
    }
};
/* T should be the type of the data stored in each
 * vertex; DS should be the underlying data structure
 * that is used to perform the group operation. It should
 * have the following methods:

```

```

* * DS () - empty constructor
* * DS (int size, T initial) - constructs the structure
* with the given size, initially filled with initial.
* * void set (int index, T value) - set the value at
* index 'index' to 'value'
* * T query (int left, int right) - return the "sum" of
* elements between left and right, inclusive.
*/
template <typename T, class DS>
class HLD {
    int vertexc;
    vector<int> *adj;
    vector<int> subtree_size;
    DS structure;
    DS aux;
    void build_sizes(int vertex, int parent) {
        subtree_size[vertex] = 1;
        for (int child : adj[vertex]) {
            if (child != parent) {
                build_sizes(child, vertex);
                subtree_size[vertex] += subtree_size[child];
            }
        }
    }
    int cur;
    vector<int> ord;
    vector<int> chain_root;
    vector<int> par;
    void build_hld(
        int vertex, int parent, int chain_source) {
        cur++;
        ord[vertex] = cur;
        chain_root[vertex] = chain_source;
        par[vertex] = parent;
        if (adj[vertex].size() > 1 ||
            (vertex == 1 && adj[vertex].size() == 1)) {
            int big_child, big_size = -1;
            for (int child : adj[vertex]) {
                if ((child != parent) &&
                    (subtree_size[child] > big_size)) {
                    big_child = child;
                    big_size = subtree_size[child];
                }
            }
            build_hld(big_child, vertex, chain_source);
            for (int child : adj[vertex]) {
                if ((child != parent) && (child != big_child))
                    build_hld(child, vertex, child);
            }
        }
    }
public:
    HLD(int _vertexc) {
        vertexc = _vertexc;
        adj = new vector<int>[vertexc + 5];
    }
    void add_edge(int u, int v) {

```

```

        adj[u].push_back(v);
        adj[v].push_back(u);
    }
    void build(T initial) {
        subtree_size = vector<int>(vertexc + 5);
        ord = vector<int>(vertexc + 5);
        chain_root = vector<int>(vertexc + 5);
        par = vector<int>(vertexc + 5);
        cur = 0;
        build_sizes(1, -1);
        build_hld(1, -1, 1);
        structure = DS(vertexc + 5, initial);
        aux = DS(50, initial);
    }
    void set(int vertex, int value) {
        structure.set(ord[vertex], value);
    }
    T query_path(int u,
        int v) { /* returns the "sum" of the path u->v */
        int cur_id = 0;
        while (chain_root[u] != chain_root[v]) {
            if (ord[u] > ord[v]) {
                cur_id++;
                aux.set(cur_id,
                    structure.query(ord[chain_root[u]], ord[u]));
                u = par[chain_root[u]];
            } else {
                cur_id++;
                aux.set(cur_id,
                    structure.query(ord[chain_root[v]], ord[v]));
                v = par[chain_root[v]];
            }
            cur_id++;
            aux.set(cur_id, structure.query(min(ord[u], ord[v]),
                max(ord[u], ord[v])));
        }
        return aux.query(1, cur_id);
    }
    void print() {
        for (int i = 1; i <= vertexc; i++)
            cout << i << ' ' << ord[i] << ' ' << chain_root[i]
                << ' ' << par[i] << endl;
    }
};
int main() {
    int vertexc;
    cin >> vertexc;
    HLD<int, dummy> hld(vertexc);
    for (int i = 0; i < vertexc - 1; i++) {
        int u, v;
        cin >> u >> v;
        hld.add_edge(u, v);
    }
    hld.build(0);
    hld.print();
    int queryc;
    cin >> queryc;

```

```

    for (int i = 0; i < queryc; i++) {
        int u, v;
        cin >> u >> v;
        hld.query_path(u, v);
        cout << endl;
    }
}

Splay Tree + Link-Cut O(NlogN)

struct Tree *treev;
struct Tree {
    struct T {
        int i;
        constexpr T() : i(-1) {}
        T(int _i) : i(_i) {}
        operator int() const { return i; }
        explicit operator bool() const { return i != -1; }
        Tree *operator->() { return treev + i; }
    };
    T c[2], p;
    /* insert monoid here */
    T link;
    Tree() {
        /* init monoid here */
        link = -1;
    }
};
using T = Tree::T;
constexpr T NIL;
void update(T t) { /* recalculate the monoid here */
}
void propagate(T t) {
    assert(t);
    for (T c : t->c)
        if (c) c->link = t->link;
    /* lazily propagate updates here */
}
void lazy_reverse(T t) { /* lazily reverse t here */
}
T splay(T n) {
    for (;;) {
        propagate(n);
        T p = n->p;
        if (p == NIL) break;
        propagate(p);
        ll px = p->c[1] == n;
        assert(p->c[px] == n);
        T g = p->p;
        if (g == NIL) { /* zig */
            p->c[px] = n->c[px ^ 1];
            p->c[px ^ 1] = p;
            n->c[px ^ 1] = p;
            n->c[px] = g;
            n->p = NIL;
            update(p);
            update(n);

```

```

    break;
}
propagate(g);
ll gx = g->c[1] == p;
assert(g->c[gx] == p);
T gg = g->p;
ll ggx = gg && gg->c[1] == g;
if (gg) assert(gg->c[ggx] == g);
if (gx == px) { /* zig zag */
    g->c[gx] = p->c[gx ^ 1];
    g->c[gx]->p = g;
    p->c[gx ^ 1] = g;
    p->c[gx ^ 1]->p = p;
    p->c[gx] = n->c[gx ^ 1];
    p->c[gx]->p = p;
    n->c[gx ^ 1] = p;
    n->c[gx ^ 1]->p = n;
} else { /* zig zag */
    g->c[gx] = n->c[gx ^ 1];
    g->c[gx]->p = g;
    n->c[gx ^ 1] = g;
    n->c[gx ^ 1]->p = n;
    p->c[gx ^ 1] = n->c[gx];
    p->c[gx ^ 1]->p = p;
    n->c[gx] = p;
    n->c[gx]->p = n;
}
if (gg) gg->c[ggx] = n;
n->p = gg;
update(g);
update(p);
update(n);
if (gg) update(gg);
}
return n;
}
T extreme(T t, int x) {
    while (t->c[x]) t = t->c[x];
    return t;
}
T set_child(T t, int x, T a) {
    T o = t->c[x];
    t->c[x] = a;
    update(t);
    o->p = NIL;
    a->p = t;
    return o;
}
%8008%4627%1017
/***** Link-Cut Tree: *****/
T expose(T t) {
    set_child(splay(t), 1, NIL);

```

```

    T leader = splay(extreme(t, 0));
    if (leader->link == NIL) return t;
    set_child(splay(leader), 0, expose(leader->link));
    return splay(t);
}
void link(T t, T p) {
    assert(t->link == NIL);
    t->link = p;
}
T cut(T t) {
    T p = t->link;
    if (p) expose(p);
    t->link = NIL;
    return p;
}
void make_root(T t) {
    expose(t);
    lazy_reverse(extreme(splay(t), 0));
}
%7295%6269

    Suffix array and longest common prefix

using vii = vector<pair<pair<int,int>,int>>;
void radix(vii &a){
    {
        int n=a.size();
        vector<int>pos(n),cnt(n);
        for(int i=0;i<n;i++){
            int el=a[i].first.second;
            cnt[el]++;
        }
        for(int i=1;i<n;i++)pos[i]=pos[i-1]+cnt[i-1];
        vii b(n);
        for(int i=0;i<n;i++){
            int el=a[i].first.second;
            b[pos[el]]=a[i];
            pos[el]++;
        }
        a=b;
    }
    {
        int n=a.size();
        vector<int>pos(n),cnt(n);
        for(int i=0;i<n;i++){
            int el=a[i].first.first;
            cnt[el]++;
        }
        for(int i=1;i<n;i++)pos[i]=pos[i-1]+cnt[i-1];
        vii b(n);
        for(int i=0;i<n;i++){
            int el=a[i].first.first;

```

```

        b[pos[el]]=a[i];
        pos[el]++;
    }
    a=b;
}
vector<vector<int>> suf_arr(string s){
    int n=s.size();
    vector<int>p(n),c(n); //positions,class
    {
        vector<pair<char,int>>a(n);
        for(int i=0;i<n;i++)a[i]={s[i],i};
        sort(a.begin(),a.end());
        for(int i=0;i<n;i++)p[i]=a[i].second;
        char pr='&';
        int cnt=-1;
        for(int i=0;i<n;i++){
            if(a[i].first!=pr)cnt++;
            c[a[i].second]=cnt;
            pr=a[i].first;
        }
    }
    int k=1;
    while(k<n){
        vii a(n);
        for(int i=0;i<n;i++){
            a[i]={c[i],c[(i+k)%n]},i};
        }
        radix(a);
        for(int i=0;i<n;i++)p[i]=a[i].second;
        pair<int,int>pr={-1,-1};
        int cnt=-1;
        for(int i=0;i<n;i++){
            if(a[i].first!=pr)cnt++;
            c[a[i].second]=cnt;
            pr=a[i].first;
        }
        k*=2;
    }
    return {p,c};
}

```

