



American International University-Bangladesh

Aiub_Eclipse

MD Siyam Talukder
Kazi Shoaib Ahmed Saad
Faysal Ahammed Chowdhury

Contents

1 Setup	1
1.1 Sublime Build	1
1.2 Template	1
1.3 Input Gen	1
1.4 Bash Script	1
2 Number Theory	1
2.1 Euler Totient Function	1
2.2 Phi 1 to N	1
2.3 Segmented Sieve	1
2.4 Extended GCD	1
2.5 Linear Diophantine Equation . .	2
2.6 Modular Inverse using EGCD . .	2
2.7 Exclusion DP	2
2.8 Legendres Formula	2
2.9 Binary Expo	2
2.10 Digit Sum of 1 to N	2
2.11 Pollard Rho	2
2.12 [Problem] How Many Bases - UVa	2
2.13 [Problem] Power Tower - CF . .	3
2.14 Formula and Properties	3
3 Combinatorics and Probability	3
3.1 Combinations	3
3.2 nCr for any mod	3
3.3 nCk without mod in O(r)	3
3.4 Lucas Theorem	3
3.5 Catalan Number	3
3.6 Derangement	3
3.7 Stars and Bars Theorem	3
3.8 Properties of Pascal's Triangle .	3
3.9 Contribution Technique	3
3.10 Probability and Expected Value .	4
4 Data Structure	4
4.1 Next Greater using Stack	4
4.2 Segment Tree Lazy	4
4.3 First Element Greater than K in a Range	4
4.4 Number of Unique Element in a Range	4
4.5 Max Subarray Sum in a Range . .	4
4.6 Count of subarrays such that their XOR is 0 in a range with upd . .	4
4.7 Range Add, Set and Sum	5
4.8 a[i] = a[i] * b + c in a Range . .	5
4.9 [Trick] Historic Information - GSS2	5
4.10 [Problem] Strongest Community - LOJ	5
4.11 [Problem] Diablo - LOJ	6
4.12 Merge Sort Tree with Point Upd .	6
4.13 Sparse Table	6
4.14 DSU	6
5 Dynamic Programming	7
5.1 Knapsack 2	7
5.2 LIS using Segment Tree	7
5.3 Digit DP	7
5.4 Bitmask DP	8
5.5 MCM DP	8
5.6 Number of Unique Subsequence .	8
5.7 [Problem] Rose Land - SUST 24	8
5.8 [Problem] Sub-Palindromic Tree	9
6 Graph Theory	9
6.1 Binary Lifting and LCA	9
6.2 LCA and Sparse Table on Tree .	9
6.3 Dijkstra	9
6.4 Bellman Ford	9
6.5 Floyd Warshall	9
6.6 Strongly Connected Components	10
6.7 Articulation Points	10
6.8 Find Bridges	10
6.9 DSU on Tree	10
6.10 Heavy-Light Decomposition . .	10
6.11 Inverse Graph	10
6.12 [Problem] Rooted Tree - Hacker-rank	11
6.13 Dinic	11
7 String	11
7.1 Hashing	11
7.2 Hashing with Updates	11
7.3 Hashing with Upd and Deletes .	12
7.4 Hashing on Tree	13
7.5 Compare 2 strings Lexicographically	13
7.6 KMP	13
7.7 KMP Automata	13
7.8 Prefix Occurance Count	13
7.9 Number of palindromic substring in L to R using Wavelet Tree .	13
7.10 Trie	14
8 Game Theory	14
8.1 Notes	14
9 Misc.	14
9.1 [Trick] Median of Medians	14
9.2 Ternary Search	14
9.3 Pigeonhole Principle	14
9.4 Matrix Expo	14
9.5 2D Prefix Sum	15
9.6 2D Static Range Update	15
9.7 CHECK SET CLR	15
9.8 Graph Directions	15

4.15 MOs Algorithm	6
4.16 Wavelet Tree	6
4.17 Trie for bit	7
4.18 2D BIT	7
10 Geometry	15
10.1 Convex Hull	15
10.2 Area of 2 polygon intersection .	16
1 Setup	
1.1 Sublime Build	
"shell_cmd": "g++ -std=c++17 -o \"\$file_base_name\" \"\$file\" && timeout 2.5s ./\"\$file_base_name\" < input.txt > output.txt",	
"file_regex": "^(..[^\n]*)(:[0-9]+):?([0-9]+)?:(.*\$)",	
"working_dir": "\${file_path}",	
"selector": "source.c, source.c++"	
1.2 Template	
#include<bits/stdc++.h>	
#include<ext/pb_ds/assoc_container.hpp>	
#include<ext/pb_ds/tree_policy.hpp>	
using namespace __gnu_pbds;	
using namespace std;	
template <typename T> using o_set = tree<T, null_type, less<T>, rb_tree_tag, tree_order_statistics_node_update>;	
typedef long long ll;	
int32_t main() {	
ios_base::sync_with_stdio(0);	
cin.tie(0);	
}	
1.3 Input Gen	
mt19937_64 rnd(chrono::steady_clock::now().time_since_epoch().count());	
ll get_rand(ll l, ll r) {	
assert(l <= r);	
return l + rnd() % (r - l + 1);	
}	
1.4 Bash Script	
// run -> bash script.sh	
set -e	
g++ code.cpp -o code	
g++ gen.cpp -o gen	
g++ brute.cpp -o brute	
for((i = 1; ; ++i)); do	
./gen \$i > input_file	
./code < input_file > myAnswer	
./brute < input_file > correctAnswer	
diff -Z myAnswer correctAnswer > /dev/null break	
echo "Passed test: " \$i	
done	
echo "WA on the following test:"	

```
cat input_file
echo "Your answer is:"
cat myAnswer
echo "Correct answer is:"
cat correctAnswer
```

2 Number Theory

2.1 Euler Totient Function

```
// Time: O(sqrt(N))
map<int, int> dp; // memo
int phi(int n) {
  if (dp.count(n)) return dp[n];
  int ans = n, m = n;
  for (int i = 2; i * i <= m; i++) {
    if (m % i == 0) {
      while (m % i == 0) m /= i;
      ans = ans / i * (i - 1);
    }
  }
  if (m > 1) ans = ans / m * (m - 1);
  return dp[n] = ans;
}
```

2.2 Phi 1 to N

```
void phi_1_to_n(int n) {
  vector<int> phi(n + 1);
  for (int i = 0; i <= n; i++) {
    phi[i] = i;
  }
  for (int i = 2; i <= n; i++) {
    if (phi[i] == i) {
      for (int j = i; j <= n; j += i)
        phi[j] -= phi[j] / i;
    }
  }
}
```

2.3 Segmented Sieve

```
vector<char> segmentedSieve(ll L, ll R) {
  // generate all primes up to sqrt(R)
  ll lim = sqrt(R);
  vector<char> mark(lim + 1, false);
  vector<ll> primes;
  for (ll i = 2; i <= lim; ++i) {
    if (!mark[i]) {
      primes.emplace_back(i);
      for (ll j = i * i; j <= lim; j += i)
        mark[j] = true;
    }
  }
  vector<char> isPrime(R - L + 1, true);
  for (ll i : primes)
    for (ll j = max(i * i, (L + i - 1) / i * i); j <= R; j += i)
      isPrime[j - L] = false;
  if (L == 1) isPrime[0] = false;
  return isPrime;
}
```

2.4 Extended GCD

```
// ax + by = gcd(a,b)
int egcd(int a, int b, int& x, int& y) {
  if (b == 0) {
    x = 1, y = 0;
    return a;
  }
}
```

```
int x1, y1;
int d = egcd(b, a % b, x1, y1);
x = y1;
y = x1 - y1 * (a / b);
return d;
}
```

2.5 Linear Diophantine Equation

```
// ax + by = c, find any x and y
bool find_any_solution(int a, int b, int
c, int &x0, int &y0, int &g) {
g = egcd(abs(a), abs(b), x0, y0);
if (c % g) return false;
x0 *= c / g;
y0 *= c / g;
if (a < 0) x0 = -x0;
if (b < 0) y0 = -y0;
return true;
}
```

```
void shift_solution(int &x, int &y,
int a, int b, int cnt) {
x += cnt * b;
y -= cnt * a;
}
int find_all_solutions(int a, int b, int
c, int minx, int maxx, int miny, int
maxy) {
int x, y, g;
if (!find_any_solution(a, b, c, x, y,
g)) return 0;
a /= g, b /= g;
int sign_a = a > 0 ? +1 : -1;
int sign_b = b > 0 ? +1 : -1;
shift_solution(x, y, a, b, (minx - x)
/ b);
if (x < minx) shift_solution(x, y, a,
b, sign_b);
if (x > maxx) return 0;
int lx1 = x;
shift_solution(x, y, a, b, (maxx - x)
/ b);
if (x > maxx) shift_solution(x, y, a,
b, -sign_b);
int rx1 = x;
shift_solution(x, y, a, b, -(miny - y)
/ a);
if (y < miny) shift_solution(x, y, a,
b, -sign_a);
if (y > maxy) return 0;
int lx2 = x;
shift_solution(x, y, a, b, -(maxy - y)
/ a);
if (y > maxy) shift_solution(x, y, a,
b, sign_a);
int rx2 = x;
if (lx2 > rx2) swap(lx2, rx2);
int lx = max(lx1, lx2);
int rx = min(rx1, rx2);
if (lx > rx) return 0;
return (rx - lx) / abs(b) + 1;
}
```

2.6 Modular Inverse using EGCD

```
// finding inverse(a) modulo m
int x, y;
```

```
int g = extended_euclidean(a, m, x, y);
if (g != 1) cout << "No solution!";
else {
    x = (x % m + m) % m;
    cout << x << endl;
}
```

2.7 Exclusion DP

```
ll f[N], g[N];
for (int i = N - 1; i >= 1; i--) {
    f[i] = nC4(div_cnt[i]);
    g[i] = f[i];
    for (int j = i + i; j < N; j += i) {
        g[i] -= g[j];
    }
}
```

- Here, $f[i]$ = how many pairs/k-tuple such that their gcd is i or it's multiple (count of pairs those are divisible by i).
- $g[i]$ = how many pairs/k-tuple such that their gcd is i .
- $g[i] = f[i] - \sum_{i|j} g[j]$.
- **Sum of all pair gcd:**
We know, how many pairs are there such that their gcd is i for every i (1 to n). So now, $\sum_{i=1}^n g[i] * i$.
- **Sum of all pair lcm** ($1 \leq i, j \leq n$): We know, $\text{lcm}(a, b) = \frac{a*b}{\text{gcd}(a, b)}$.
- Now, $f[i]$ = All pair product sum of those, whose gcd is i or it's multiple.
- $g[i]$ = All pair product sum of those, whose gcd is i .
- Ans = $\sum_{i=1}^n \frac{g[i]}{i}$.
- All pair product sum = $(a_1 + a_2 + \dots + a_n) * (a_1 + a_2 + \dots + a_n)$

2.8 Legendres Formula

```
//  $\frac{n!}{p^x}$  - you will get the largest x
int legendre(int n, int p) {
    int ex = 0;
    while(n) {
        ex += (n / p);
        n /= p;
    }
    return ex;
}
```

2.9 Binary Expo

```
int power(int x, long long n, int mod) {
    int ans = 1 % mod;
    while (n > 0) {
        if (n & 1) {
            ans = 1LL * ans * x % mod;
        }
        x = 1LL * x * x % mod;
        n >>= 1;
    }
    return ans;
}
```

2.10 Digit Sum of 1 to N

```
// for n=10, ans = 1+2+...+9+1+0
ll solve(ll n) {
    ll res = 0, p = 1;
    while (n / p > 0) {
        ll left = n / (p * 10);
        ll cur = (n / p) % 10;
        ll right = n % p;
        res += left * 45 * p;
        res += (cur * (cur - 1) / 2) * p;
        res += cur * (right + 1);
        p *= 10;
    }
    return res;
}
```

2.11 Pollard Rho

```
namespace PollardRho {
mt19937 rnd(chrono::steady_clock::now().time_since_epoch().count());
const int P = 1e6 + 9;
ll seq[P];
int primes[P], spf[P];
inline ll add_mod(ll x, ll y, ll m) {
    return (x += y) < m ? x : x - m;
}
inline ll mul_mod(ll x, ll y, ll m) {
    ll res = __int128(x) * y % m;
    return res;
}
// ll res = x * y - (ll)((long double)x
// * y / m + 0.5) * m;
// return res < 0 ? res + m : res;
}
inline ll pow_mod(ll x, ll n, ll m) {
    ll res = 1 % m;
    for (; n; n >= 1) {
        if (n & 1) res = mul_mod(res, x, m);
        x = mul_mod(x, x, m);
    }
    return res;
}
// O(it * (log n)^3), it = number of rounds
// performed
inline bool miller_rabin(ll n) {
    if (n <= 2 || (n & 1 ^ 1)) return (n == 2);
    if (n < P) return spf[n] == n;
    ll c, d, s = 0, r = n - 1;
    for (; !(r & 1); r >>= 1, s++) {}
    // each iteration is a round
    for (int i = 0; primes[i] < n && primes[i] < 32; i++) {
        c = pow_mod(primes[i], r, n);
        for (int j = 0; j < s; j++) {
            d = mul_mod(c, c, n);
            if (d == 1 && c != 1 && c != (n - 1)) return false;
            c = d;
        }
        if (c != 1) return false;
    }
    return true;
}
void init() {
    int cnt = 0;
    for (int i = 2; i < P; i++) {
```

```
        if (!spf[i]) primes[cnt++] = spf[i]
            = i;
        for (int j = 0, k; (k = i * primes[j]) < P; j++) {
            spf[k] = primes[j];
            if (spf[i] == spf[k]) break;
        }
    }
    // returns O(n^{1/4})
    ll pollard_rho(ll n) {
        while (1) {
            ll x = rnd() % n, y = x, c = rnd() % n,
            u = 1, v, t = 0;
            ll *px = seq, *py = seq;
            while (1) {
                *py++ = y = add_mod(mul_mod(y, y,
                n), c, n);
                *py++ = y = add_mod(mul_mod(y, y,
                n), c, n);
                if ((x = *px++) == y) break;
                v = u;
                u = mul_mod(u, abs(y - x), n);
                if (!u) return __gcd(v, n);
                if (++t == 32) {
                    t = 0;
                    if ((u = __gcd(u, n)) > 1 && u < n) return u;
                }
            }
            if (t && (u = __gcd(u, n)) > 1 && u < n) return u;
        }
    }
    vector<ll> factorize(ll n) {
        if (n == 1) return vector<ll>();
        if (miller_rabin(n)) return vector<ll>{n};
        vector<ll> v, w;
        while (n > 1 && n < P) {
            v.push_back(spf[n]);
            n /= spf[n];
        }
        if (n >= P) {
            ll x = pollard_rho(n);
            v = factorize(x);
            w = factorize(n / x);
            v.insert(v.end(), w.begin(), w.end());
        }
        return v;
    }
}
```

```
2.12 [Problem] How Many Bases - UVa
// Given a number  $N^M$ , find out the
// number of integer bases in which it
// has exactly T trailing zeroes.
int solve_greater_or_equal(vector<int>
e, int t) {
    int ans = 1;
    for (auto i : e) {
        ans = 1LL * ans * (i / t + 1) % mod;
    }
    return ans;
}
```

```
// e contains e1, e2 -> p1e1, p2e2
int solve_equal(vector<int> e, int t) {
    return (solve_greater_or_equal(e, t) -
        solve_greater_or_equal(e, t + 1) +
        mod) % mod;
}
```

2.13 [Problem] Power Tower - CF

// A sequence w₁, w₂, ..., w_n and Q queries, l and r will be given.

Calculate w_l^{(w_{i+1}^(w_r))}

```
// nx mod m = nφ(m)+x mod φ(m) mod m
inline int MOD(int x, int m) {
    if (x < m) return x;
    return x % m + m;
}

int power(int n, int k, int mod) {
    int ans = MOD(1, mod);
    while (k) {
        if (k & 1) ans = MOD(ans * n, mod);
        n = MOD(n * n, mod);
        k >>= 1;
    }
    return ans;
}

int f(int l, int r, int m) {
    if (l == r) return MOD(a[l], m);
    if (m == 1) return 1;
    return power(a[l], f(l + 1, r,
        phi(m)), m);
}
```

2.14 Formula and Properties

- $\phi(n) = n \cdot \frac{p_1-1}{p_1} \cdot \frac{p_2-1}{p_2} \dots$
- $\phi(p^e) = p^e - \frac{p^e}{p} = p^e \cdot \frac{p-1}{p}$
- For $n > 2$, $\phi(n)$ is always even.
- $\sum_{d|n} \phi(d) = n$
- NOD: $(e_1 + 1) \cdot (e_2 + 1) \dots$
- SOD: $\frac{p_1^{e_1+1}-1}{p_1-1} \cdot \frac{p_2^{e_2+1}-1}{p_2-1} \dots$
- $\log(a \cdot b) = \log(a) + \log(b)$
- $\log(a^x) = x \cdot \log(a)$
- $\log_a(x) = \frac{\log_b(x)}{\log_b(a)}$
- Digit Count of n: $\lfloor \log_{10}(n) \rfloor + 1$
- Arithmetic Progression Sum: $\frac{n}{2} \cdot (a + p), \quad \frac{n}{2} \cdot (2a + (n-1)d)$
- Geometric Sum: $S_n = a \cdot \frac{r^n - 1}{r-1}$
- $(1^2 + 2^2 + \dots + n^2) = \frac{n(n+1)(2n+1)}{6}$
- $(1^3 + 2^3 + \dots + n^3) = \frac{n^2(n+1)^2}{4}$
- $(2^2 + 4^2 + \dots + (2n)^2) = \frac{2n(n+1)(2n+1)}{3}$
- $(1^2 + 3^2 + \dots + (2n-1)^2) = \frac{n(2n-1)(2n+1)}{3}$
- $(2^3 + 4^3 + \dots + (2n)^3) = 2n^2(n+1)^2$
- $(1^3 + 3^3 + \dots + (2n-1)^3) = n^2(2n^2 - 1)$

- For any number n and bases $> \sqrt{n}$, there will be no representation where the number contains 0 at its second least significant digit. So it is enough to check for bases $\leq \sqrt{n}$.
- For some x and y , let's try to find all m such that $x \bmod m \equiv y \bmod m$. We can rearrange the equation into $(x - y) \equiv 0 \pmod{m}$. Thus, if m is a factor of $|x - y|$, then x and y will be equal modulo m .

3 Combinatorics and Probability

3.1 Combinations

```
// Prime Mod in O(n)
void prec() {
    fact[0] = 1;
    for (int i = 1; i < N; i++) {
        fact[i] = 1ll * fact[i - 1] * i % mod;
    }
    ifact[N - 1] = inverse(fact[N - 1]);
    for (int i = N - 2; i >= 0; i--) {
        ifact[i] = 1ll * ifact[i + 1] * (i +
            1) % mod;
    }
}

int nCr(int n, int r) {
    if (r > n) return 0;
    return 1ll * fact[n] * ifact[r] % mod
        * ifact[n - r] % mod;
}

int nPr(int n, int r) {
    if (r > n) return 0;
    return 1ll * fact[n] * ifact[n - r] %
        mod;
}
```

3.2 nCr for any mod

```
// Time: O(n2)
// nCr = (n-1)C(r-1) + (n-1)Cr
for (int i = 0; i < N; i++) {
    C[i][i] = 1;
    for (int j = 0; j < i; j++) {
        C[i][j] = (C[i - 1][j] + C[i - 1][j -
            1]) % mod;
    }
}
```

3.3 nCk without mod in O(r)

```
ll nCk(ll n, ll k) {
    double res = 1;
    for (ll i = 1; i <= k; ++i)
        res = res * (n - k + i) / i;
    return (ll)(res + 0.01);
}
```

3.4 Lucas Theorem

```
// returns nCr modulo mod where mod is a
// prime
// Complexity: ?
ll Lucas(ll n, ll r) {
    if (r < 0 || r > n) return 0;
    if (r == 0 || r == n) return 1;
    if (n >= MOD) {
        return (Lucas(n / MOD, r / MOD) %
            MOD * Lucas(n % MOD, r % MOD) %
            MOD) % MOD;
    }
}
```

```
}
return (((fact[n] * invFact[r]) % MOD)
        * invFact[n - r]) % MOD;
}
```

3.5 Catalan Number

```
const int MOD = 1e9 + 7, int MAX = 1e7;
int catalan[MAX];
void init(ll n) {
    catalan[0] = catalan[1] = 1;
    for (ll i = 2; i <= n; i++) {
        catalan[i] = 0;
        for (ll j = 0; j < i; j++) {
            catalan[i] += (catalan[j] *
                catalan[i - j - 1]) % MOD;
        }
        if (catalan[i] >= MOD) {
            catalan[i] -= MOD;
        }
    }
}
```

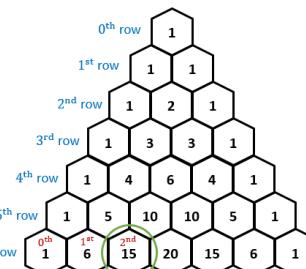
3.6 Derangement

```
// number of combinations such that
// ai! = i of a permutation a
const int N = 1e6 + 100, int p = 1e9 + 7;
ll der[N];
void countDer() {
    der[1] = 0;
    der[2] = 1;
    for (ll i = 3; i <= N; ++i) {
        der[i] = (i - 1) % p * (der[i - 1] %
            p + der[i - 2] % p);
        der[i] %= p;
    }
}
```

3.7 Stars and Bars Theorem

- Find the number of k -tuples of non-negative integers whose sum is n . $\binom{n+k-1}{n}$
- Find the number of k -tuples of non-negative integers whose sum is $\leq n$. $\binom{n+k}{k}$
- Combination with Repetition (choose k elements from n objects, same element can be chosen multiple times). $\binom{n+k-1}{k}$
- How many ways to go from $(0,0)$ to (n,m) . $\binom{n+m}{m}$

Pascals Triangle is equivalent to nCr:



3.8 Properties of Pascal's Triangle

- $(a+b)^n = \sum_{k=0}^n \binom{n}{k} a^k b^{n-k}$
- $(k+1)^n = \sum_{i=0}^n k^i \cdot \binom{n}{i}$
- $\sum_{i=0}^n \binom{n}{i} = 2^n$
- $\binom{k}{n} = \frac{k}{n} \binom{k-1}{n-1}$
- $\sum_{k=0}^m \binom{n+k}{k} = \binom{n+m+1}{m}$
- $\binom{n}{2}^2 + \binom{n}{1}^2 + \dots + \binom{n}{n}^2 = \binom{2n}{n}$
- $1\binom{n}{1} + 2\binom{n}{2} + \dots + n\binom{n}{n} = n2^{n-1}$

3.9 Contribution Technique

- Sum of all pair sums: $\sum_{i=1}^n \sum_{j=1}^n (a_i + a_j)$
Every element will be added $2n$ times. $\sum_{i=1}^n (2 \times n \times a_i) = 2 \times n \times \sum_{i=1}^n a_i$.
- Sum of all subarray sums — $\sum_{i=1}^n (a_i \times i \times (n-i+1))$.
- Sum of all Subsets sums — $\sum_{i=1}^n (2^{n-1} \times a_i)$.
- Product of all pair product — $\prod_{i=1}^n (a_i^{2 \times n})$.
- XOR of subarray XORS — How many subarrays does an element have? $(i \cdot (n-i+1)$ times). If subarray count is odd then this element can contribute in total XORs.
- Sum of max minus min over all subset — Sort the array. $\text{Min} = 2^{n-i}, \text{Max} = 2^{i-1}$. $\sum_{i=1}^n (a_i \cdot 2^{i-1} - a_i \cdot 2^{n-i})$
- Sum using bits — $\sum_{k=0}^{30} (cnt_k[1] \times 2^k)$.
- Sum of Pair XORs — XOR will 1 if two bits are different $\sum_{k=0}^{30} (cnt_k[0] \times cnt_k[1] \times 2^k)$.
- Sum of Pair ANDs — $\sum_{k=0}^{30} (cnt_k[1]^2 \times 2^k)$.
- Sum of Pair ORs — $\sum_{k=0}^{30} ((cnt_k[1]^2 + 2 \times cnt_k[1] \times cnt_k[0]) \times 2^k)$.
- Sum of Subset XORs — where $cnt0! = 0$ $\sum_{k=0}^{30} (2^{cnt_k[1]+cnt_k[0]-1} \times 2^k)$.
- Sum of Subset ANDs — $\sum_{k=0}^{30} ((2^{cnt_k[1]} - 1) \times 2^k)$.
- Sum of Subset ORs — $\sum_{k=0}^{30} ((2^n - 2^{cnt_k[0]}) \times 2^k)$.
- Sum of subarray XORs — Convert to prefix xor, then solve for pairs.
- Sum of product of all subsequence — $\prod_{i=1}^n (a_i + 1) - 1$. Example array — $[a, b]$ the subsequences are $\{a\}, \{b\}, \{a, b\}$ so ans is $a + b + (a \cdot b)$

3.10 Probability and Expected Value

- Expected Value: $E = \frac{\text{Sum of all possible values}}{\text{Total number of outcomes}}$
- Expected Value: $E = \sum_{i=1}^n P_i \cdot i$
- Variance: $V(x) = E(x^2) - \{E(x)\}^2$
- Expected Value with DP: $E(i) = \sum P(i \rightarrow j) \times (R(i \rightarrow j) + E(j))$ Where $R()$ is Immediate Reward(cost/count)
- Linearity of Expectation:

$$\begin{aligned} - E[X+Y] &= E[X] + E[Y] \\ - E[\text{Total}] &= E[I_1] + E[I_2] + \dots = \sum P(I_i = 1) \end{aligned}$$

We need to define the Indicator Random Variable (I) correctly. Some Examples below —

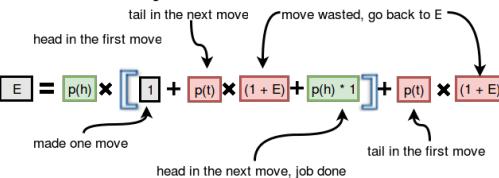
Problem-1: Find $E[\text{correct hats}]$ in a random permutation. Indicator I_i : "Does person i get their own hat?"

Problem-2: Find $E[\text{total inversions}]$ in a random permutation. Indicator I_{ij} : "Is pair (i, j) an inversion?"

Problem-3: Given a string S , delete a random index until it becomes empty. Find the expected count of palindromes seen (exclude S , include empty string). Indicator I_L : "Is the string of length L a palindrome?"

Problem-4: Pick N random integers from $[1, k]$. Merge consecutive equal values (e.g., $1, 1, 2, 2, 1, 1 \rightarrow 1, 2, 1$). Find the expected final length. Indicator I_i : "Is item i different from item $i-1$?"

- To get two consecutive heads, what is the expected number of tosses?



To get n heads, what is the expected number of tosses? Let's define: to get n heads, we need to toss $E(n)$ times. Now — I can get a head; I need to toss $E(n-1)$ more times, or if I get a tail; I need to toss $E(n)$ times. So, the recurrence is: $E(n) = 0.5 \cdot (1 + E(n-1)) + 0.5 \cdot (1 + E(n))$

- You have n bulbs, all of which are initially off. In each move, you randomly select one bulb. If the selected bulb is off, you toss a coin:

- If you get head, you turn it on.
- If you get tail, you do nothing.

If the bulb is already on, you skip that move (nothing happens).

Now, what is the expected number of moves required to turn all bulbs on?

The coin is not fair — the probability of getting tail is p . This problem can also be solved recursively.

Let's assume at some moment, x bulbs are already on, and the expected number of moves needed from here is $e(x)$.

The probability of picking an already on bulb is $\frac{x}{n}$. In that case, the expected number of moves is $\frac{x}{n} \times (1 + e(x))$.

The probability of picking an off bulb is $\frac{n-x}{n}$.

Now two things can happen:

- With probability p , you get tail, so you stay at the same state ($e(x)$ more moves).
- With probability $(1-p)$, you get head, so one more bulb turns on ($e(x+1)$ moves from there).

So, the recurrence relation is:

$$e(x) = \frac{x}{n}(1 + e(x)) + \frac{n-x}{n}(p(1 + e(x)) + (1-p)(1 + e(x+1)))$$

4 Data Structure

4.1 Next Greater using Stack

```
stack<pair<int, int>> st;
    int right[n + 1]; // a[i] is maximum
    from index i to right[i]
for (int i = 1; i <= n; i++) {
    while (!st.empty() and st.top().first
        < a[i]) {
        right[st.top().second] = i - 1;
        st.pop();
    }
    st.push({a[i], i});
}
while (!st.empty()) {
    right[st.top().second] = n;
    st.pop();
}
```

4.2 Segment Tree Lazy

```
struct ST {
    int tree[4 * N], lazy[4 * N];
    void push(int n, int b, int e) {
        if (lazy[n] == 0) return;
        tree[n] += lazy[n] * (e - b + 1); // change here
        if (b != e) {
            int l = n << 1, r = l + 1;
            lazy[l] += lazy[n]; // change here
            lazy[r] += lazy[n]; // change here
        }
        lazy[n] = 0;
    }
    void build(int n, int b, int e) {
        lazy[n] = 0;
        if (b == e) {
            tree[n] = a[b]; // change here
            return;
        }
        int mid = (b + e) >> 1, l = n << 1,
            r = l + 1;
        build(l, b, mid);
        build(r, mid + 1, e);
        tree[n] = tree[l] + tree[r]; // change here
    }
    void upd(int n, int b, int e, int i,
            int j, int x) {
```

```
push(n, b, e);
if(b > j || e < i) return;
if(b >= i && e <= j) {
    lazy[n] += x; // change here
    push(n, b, e);
    return;
}
int mid = (b + e) >> 1, l = n << 1,
r = l + 1;
upd(l, b, mid, i, j, x);
upd(r, mid + 1, e, i, j, x);
tree[n] = tree[l] + tree[r]; // change here
}
```

```
} st;
```

4.3 First Element Greater than K in a Range

```
// tree[n] = max in range
int get_first(int n, int b, int e, int
    i, int j, int x) { // return index
push(n, b, e);
if (b > j || e < i) return -1;
if (tree[n] <= x) return -1;
if (b == e) return b;
int mid = (b + e) >> 1, l = n << 1, r
    = l + 1;
int left = get_first(l, b, mid, i, j,
    x);
if (left != -1) return left;
return get_first(r, mid + 1, e, i, j,
    x);
}
```

4.4 Number of Unique Element in a Range

```
vector<pair<int, int>> Q[QQ];
int main() {
    int n; cin >> n;
    for(int i = 1; i <= n; i++) cin >> a[i];
    int q; cin >> q;
    for(int i = 1; i <= q; i++) {
        int l, r; cin >> l >> r;
        Q[r].push_back({l, i});
    }
    st.build(1, 1, n); // range sum and
    point add
map<int, int> last_idx;
for(int r = 1; r <= n; r++) {
    if(last_idx.find(a[r]) !=
        last_idx.end()) {
        st.upd(1, 1, n, last_idx[a[r]], -1);
    }
```

```
}
```

4.5 Max Subarray Sum in a Range

```
struct node {
    ll tot_sum;
    ll prefix_max, suffix_max;
    ll max_subarray_sum;
};
node merge(node l, node r) {
    if (l.tot_sum == -inf) return r;
    if (r.tot_sum == -inf) return l;
    node ans;
    ans.max_subarray_sum =
        max(l.max_subarray_sum,
            r.max_subarray_sum);
    ans.max_subarray_sum =
        max(ans.max_subarray_sum,
            l.suffix_max + r.prefix_max);
    ans.tot_sum = l.tot_sum + r.tot_sum;
    ans.prefix_max = l.prefix_max;
    if (l.tot_sum + r.prefix_max >=
        l.prefix_max) {
        ans.prefix_max = l.tot_sum +
            r.prefix_max;
    }
    ans.suffix_max = r.suffix_max;
    if (r.tot_sum + l.suffix_max >=
        r.suffix_max) {
        ans.suffix_max = r.tot_sum +
            l.suffix_max;
    }
    return ans;
}
```

4.6 Count of subarrays such that their XOR is 0 in a range with upd

```
struct node {
    int cnt[64];
    node() {
        memset(cnt, 0, sizeof cnt);
    }
};
struct ST {
    node tree[4 * N]; int lazy[4 * N];
    void push(int n, int b, int e) {
        if (lazy[n] == 0) return;
        for (int k = 0; k < 64; k++) {
            if ((k ^ lazy[n]) > k) {
                swap(tree[n].cnt[k],
                    tree[n].cnt[k ^ lazy[n]]);
            }
        }
        if (b != e) {
            int l = n << 1, r = l + 1;
            lazy[l] ^= lazy[n];
            lazy[r] ^= lazy[n];
        }
        lazy[n] = 0;
    }
    void build(int n, int b, int e) {
```

```

lazy[n] = 0;
}
node merge(node a, node b) {
    for (int k = 0; k < 64; k++)
        a.cnt[k] += b.cnt[k];
    return a;
}
void build(int n, int b, int e) {
    lazy[n] = 0;
    if (b == e) {
        tree[n].cnt[0] = 1;
        return;
    }
    int mid = (b + e) >> 1, l = n << 1,
        r = l + 1;
    build(l, b, mid);
    build(r, mid + 1, e);
    tree[n] = merge(tree[l], tree[r]);
}
void upd(int n, int b, int e, int i,
         int j, int x) {
    push(n, b, e);
    if (b > j || e < i) return;
    if (b >= i && e <= j) {
        lazy[n] ^= x;
        push(n, b, e);
        return;
    }
}
node query(int n, int b, int e, int i,
           int j) {
    push(n, b, e);
    if (b > j || e < i)
        node tmp;
        return tmp;
    }
    if (b >= i && e <= j) return tree[n];
    return merge(L, R);
}
} st;
int32_t main() {
    string s; cin >> s;
    int n = s.size();
    s = '!' + s;
    st.build(1, 1, n);
    for (int i = 1; i <= n; i++) {
        int x = (1 << (s[i] - 'a'));
        st.upd(1, 1, n, i, n, x); // segtree
        contains prefix xor
    }
    int q; cin >> q;
    while (q--) {
        int type; cin >> type;
        if (type == 1) {
            int l, r; cin >> l >> r;
            node tmp = st.query(1, 1, n, l -
                1, r);
            ll ans = 0;
            for (int k = 0; k < 64; k++) {
                int x = tmp.cnt[k];
                if (l == 1 && k == 0) x++;
                ans += (ll * x * (x - 1)) / 2;
            }
            cout << ans << '\n';
        }
    }
}

```

```

else {
    int i; cin >> i;
    char c; cin >> c;
    int mask = (1 << (s[i] - 'a'));
    mask ^= (1 << (c - 'a'));
    st.upd(1, 1, n, i, n, mask);
    s[i] = c;
}
}



### 4.7 Range Add, Set and Sum



---



```

// Problem: Range Updates and Sums - CSES
struct ST {
 int tree[4 * N];
 pair<int, int> lazy[4 * N];
 void push(int n, int b, int e) {
 if (lazy[n].first == 0) return;
 if (lazy[n].second == 1) { // set
 tree[n] = lazy[n].first * (e - b +
 1);
 } else { // add
 tree[n] += lazy[n].first * (e - b
 + 1);
 }
 if (b != e) {
 int l = n << 1, r = l + 1;
 if (lazy[l].second == 1) {
 if (lazy[n].second == 1)
 lazy[l].first =
 lazy[n].first;
 else lazy[l].first +=
 lazy[n].first;
 }
 else {
 if (lazy[n].second == 1) {
 lazy[l].first = lazy[n].first;
 lazy[l].second = 1;
 } else lazy[l].first +=
 lazy[n].first;
 }
 if (lazy[r].second == 1) {
 if (lazy[n].second == 1)
 lazy[r].first =
 lazy[n].first;
 else lazy[r].first +=
 lazy[n].first;
 }
 else {
 if (lazy[n].second == 1) {
 lazy[r].first = lazy[n].first;
 lazy[r].second = 1;
 } else lazy[r].first +=
 lazy[n].first;
 }
 }
 lazy[n].first = 0; lazy[n].second =
 -1;
 }
 void build(int n, int b, int e) {
 lazy[n].first = 0; lazy[n].second =
 -1;
 }
}

```


```

```

tree[n] = tree[l] + tree[r];
}
void upd(int n, int b, int e, int i,
         int j, int type, int x) {
    lazy[n] = {x, type};
}
} st;


### 4.8 a[i] = a[i] * b + c in a Range



---



```

// Problem: Range Affine Range Sum
lazy1[n] = 1; lazy2[n] = 0; // init in
build
lazy1[n] *= x; lazy2[n] += y; // when upd
mint tree[4 * N], lazy1[4 * N], lazy2[4
* N];
void push(int n, int b, int e) {
 if (lazy1[n] == 1 || lazy2[n] == 0)
 return;
 tree[n] = tree[n] * lazy1[n] +
 lazy2[n] * (e - b + 1);
 if (b != e) {
 int mid = (b + e) >> 1, l = n << 1,
 r = l + 1;
 lazy1[l] *= lazy1[n];
 lazy2[l] = lazy2[l] * lazy1[n] +
 lazy2[n];
 lazy1[r] *= lazy1[n];
 lazy2[r] = lazy2[r] * lazy1[n] +
 lazy2[n];
 }
 lazy1[n] = 1; lazy2[n] = 0;
}

```


```

4.9 [Trick] Historic Information - GSS2

```

// Statement: Max Subarray Sum in a Range
// but only Unique Value can contrib.
int ans[QQ];
vector<pair<int, int>> Q[QQ];
struct ST {
    int tree[4 * N], lazy[4 * N];
    int tree2[4 * N], lazy2[4 * N];
    void push(int n, int b, int e) {
        tree2[n] = max(tree2[n], tree[n] +
            lazy2[n]);
        tree[n] += lazy[n];
        if (b != e) {
            int l = n << 1, r = l + 1;
            lazy2[l] = max(lazy2[l], lazy[l] +
                lazy2[n]);
            lazy2[r] = max(lazy2[r], lazy[r] +
                lazy2[n]);
            lazy[l] += lazy[n];
            lazy[r] += lazy[n];
        }
        lazy[n] = 0; lazy2[n] = 0;
    }
    void upd(int n, int b, int e, int i,
             int j, int x) {
        if (b >= i && e <= j) {
            lazy[n] += x;
            lazy2[n] = max(lazy2[n], lazy[n]);
            push(n, b, e);
            return;
        }
        tree[n] = max(tree[l], tree[r]);
    }
}

```

```

tree2[n] = max(tree2[l], tree2[r]);
}
int query(int n, int b, int e, int i,
          int j) {
    if (b >= i && e <= j) return tree2[n];
    return max(L, R);
}
} st;
int32_t main() {
    int n; cin >> n; int a[n + 1];
    for (int i = 1; i <= n; i++) cin >>
        a[i];
    int q; cin >> q;
    for (int i = 1; i <= q; i++) {
        int l, r; cin >> l >> r;
        Q[r].push_back({l, i});
    }
    map<int, int> last;
    for (int r = 1; r <= n; r++) {
        // for (int i = last[a[r]] + 1; i <=
        //     r; i++) {
        //     sum[i] += a[r];
        //     p[i] = max(p[i], sum[i]);
        // }
        st.upd(1, 1, n, last[a[r]] + 1, r,
               a[r]);
        last[a[r]] = r;
        for (auto i : Q[r]) {
            int l = i.first, id = i.second;
            ans[id] = st.query(1, 1, n, l, r);
        }
    }
}

```

4.10 [Problem] Strongest Community - LOJ

```

// Given an Array, if any a_i = x
exist all x are consecutive. Given
[L, R] Q times, Print Max Freq.
struct node {
    int first_element, first_element_cnt;
    int last_element, last_element_cnt;
    int max_cnt;
};
node merge(node l, node r) {
    if (l.first_element == -1) return r;
    if (r.first_element == -1) return l;
    node ans;
    ans.max_cnt = max(l.max_cnt, r.max_cnt);
    if (l.last_element == r.first_element) {
        ans.max_cnt = max(ans.max_cnt,
            l.last_element_cnt +
            r.first_element_cnt);
    }
    ans.first_element = l.first_element;
    ans.first_element_cnt =
        l.first_element_cnt;
    if (l.first_element == r.first_element) {
        ans.first_element_cnt +=
            r.first_element_cnt;
    }
    ans.last_element = r.last_element;
}

```

```

ans.last_element_cnt =
    r.last_element_cnt;
if(r.last_element == l.last_element) {
    ans.last_element_cnt += 
        l.last_element_cnt;
}
return ans;
}

```

4.11 [Problem] Diablo - LOJ

```

// Add element at the End, and Remove Kth
// Index (also print it's value)
int deleted_idx;
struct ST {
    pair<int, int> tree[4 * (N + Q)]; // 
    sum, alive_cnt
    pair<int, int> query(int n, int b, int
        e, int x) {
        if (b > e) return { -1, -1 };
        if (tree[n].second < x) return
            {tree[n].second, -1 };
        if (b == e) {
            deleted_idx = b;
            return tree[n];
        }
        int mid = (b + e) >> 1, l = n << 1,
            r = l + 1;
        pair<int, int> L = query(l, b, mid,
            x);
        if (L.second != -1) return L;
        pair<int, int> R = query(r, mid + 1,
            e, x - L.first);
        return R;
    }
} st;
void solve() {
    int id = n, end = n + q + 5;
    while (q--) {
        char c; cin >> c;
        if (c == 'a') {
            int p; cin >> p;
            st.upd(1, 1, end, ++id, p, 1);
        } else {
            int k; cin >> k;
            pair<int, int> ans = st.query(1,
                1, end, k);
            if (ans.second == -1) cout <<
                "none\n";
            else {
                cout << ans.first << '\n';
                st.upd(1, 1, end, deleted_idx,
                    0, 0);
            }
        }
    }
}

```

4.12 Merge Sort Tree with Point Upd

```

struct MST { // merge sort tree
    o_set<array<int, 2>> tree[4 * N]; //
        greater<T>
    o_set<array<int, 2>>
        merge(o_set<array<int, 2>> &a,
            o_set<array<int, 2>> &b) {

```

```

        int i = 0, j = 0;
        int n = a.size(), m = b.size();
        o_set<array<int, 2>> ans;
        for (auto x : a) ans.insert(x);
        for (auto x : b) ans.insert(x);
        return ans;
    }
    void build(int n, int b, int e) {
        if (b == e) {
            tree[n].insert({a[b], b});
            return;
        }
        int mid = (b + e) >> 1, l = n << 1,
            r = l + 1;
        build(l, b, mid);
        build(r, mid + 1, e);
        tree[n] = merge(tree[l], tree[r]);
    }
    void upd(int n, int b, int e, int i,
        int x) {
        if (b == e) {
            tree[n].erase({a[b], b});
            tree[n].insert({x, b});
            a[b] = x;
            return;
        }
        int mid = (b + e) >> 1, l = n << 1,
            r = l + 1;
        tree[n].erase({a[i], i});
        tree[n].insert({x, i});
        if (i <= mid) upd(l, b, mid, i, x);
        else upd(r, mid + 1, e, i, x);
    }
    int query(int n, int b, int e, int i,
        int j, int k) {
        if (b > j || e < i) return 0;
        if (b >= i && e <= j) {
            int idx = tree[n].order_of_key({k,
                inf});
            return idx;
        }
        int mid = (b + e) >> 1, l = n << 1,
            r = l + 1;
        int L = query(l, b, mid, i, j, k);
        int R = query(r, mid + 1, e, i, j, k);
        return (L + R);
    }
} mst;

```

4.13 Sparse Table

```

const int N = 2e5 + 9, K = 20; // change
here
int a[N], tree[N][K];
int log2_floor(unsigned long long i) {
    return i ? __builtin_clzll(1) -
        __builtin_clzll(i) : -1;
}
void build(int n) {
    for (int i = 1; i <= n; i++) {
        tree[i][0] = a[i];
    }
    for (int k = 1; k < K; k++) {
        for (int i = 1; i + (1 << k) - 1 <=
            n; i++) {

```

```

            tree[i][k] = min(tree[i][k - 1],
                tree[i + (1 << (k - 1))][k - 1]); // change here
        }
    }
    int query(int l, int r) {
        int k = log2_floor(r - l + 1);
        return min(tree[l][k], tree[r - (1 <<
            k) + 1][k]); // change here
    }
    build(n);
}

```

4.14 DSU

```

struct DSU {
    vector<int> par, sz;
    int c;
    DSU(int n) {
        par.resize(n + 1), sz.resize(n + 1,
            1);
        for (int i = 1; i <= n; i++) {
            par[i] = i;
        }
        c = n;
    }
    int find(int i) {
        return (i == par[i] ? i : par[i] =
            find(par[i]));
    }
    bool same(int i, int j) {
        return find(i) == find(j);
    }
    int get_size(int i) {
        return sz[find(i)];
    }
    int count() { // number of connected
        components
        return c;
    }
    int merge(int i, int j) {
        if ((i = find(i)) == (j = find(j)))
            return -1;
        c--;
        if (sz[i] < sz[j]) swap(i, j);
        par[j] = i;
        sz[i] += sz[j];
        return i;
    }
};
DSU dsu(n);

```

4.15 MOs Algorithm

```

const int N = 1e6 + 9, B = 440;
struct query {
    int l, r, id;
    bool operator < (const query &x) const {
        if (l / B == x.l / B) return ((l /
            B) & 1) ? r > x.r : r < x.r;
        return l / B < x.l / B;
    }
} Q[N];
int cnt[N], a[N];
long long sum;
inline void add_left(int i) {
    int x = a[i];
    sum += 1LL * (cnt[x] + cnt[x] + 1) * x;
    ++cnt[x];
}

```

```

    sum += 1LL * (cnt[x] + cnt[x] + 1) * x;
    ++cnt[x];
}
inline void add_right(int i) {
    int x = a[i];
    sum += 1LL * (cnt[x] + cnt[x] + 1) * x;
    ++cnt[x];
}
inline void rem_left(int i) {
    int x = a[i];
    sum -= 1LL * (cnt[x] + cnt[x] - 1) * x;
    --cnt[x];
}
inline void rem_right(int i) {
    int x = a[i];
    sum -= 1LL * (cnt[x] + cnt[x] - 1) * x;
    --cnt[x];
}
long long ans[N];
int32_t main() {
    int n, q; cin >> n >> q;
    for (int i = 1; i <= n; i++) cin >>
        a[i];
    for (int i = 1; i <= q; i++) {
        cin >> Q[i].l >> Q[i].r;
        Q[i].id = i;
    }
    sort(Q + 1, Q + q + 1);
    int l = 1, r = 0;
    for (int i = 1; i <= q; i++) {
        int L = Q[i].l, R = Q[i].r;
        if (R < l) {
            while (l > L) add_left(--l);
            while (l < L) rem_left(l++);
            while (r < R) add_right(++r);
            while (r > R) rem_right(r--);
        } else {
            while (r < R) add_right(++r);
            while (r > R) rem_right(r--);
            while (l > L) add_left(--l);
            while (l < L) rem_left(l++);
        }
        ans[Q[i].id] = sum;
    }
    for (int i = 1; i <= q; i++) cout <<
        ans[i] << '\n';
}

```

4.16 Wavelet Tree

```

struct wavelet_tree {
    int low, high;
    wavelet_tree *lft = NULL, *rgt = NULL;
    int *pref = NULL;
    long long *sum = NULL; // remove if no
        need
    wavelet_tree(int *l, int *r, int low,
        int high): low(low), high(high) {
        if (l >= r || low >= high) return;
        pref = new int[r - l + 2];
        sum = new long long[r - l + 2];
        pref[0] = 0;
        sum[0] = 0;
        int mid = (low + high) >> 1, cnt = 1;
        for (int *i = l; i != r; i++, cnt++) {

```

```

pref[cnt] = pref[cnt - 1] + ((*i)
    <= mid);
sum[cnt] = sum[cnt - 1] + (*i);
}
int *pivot = stable_partition(l, r,
    [&](int x) {return x <= mid;});
lft = new wavelet_tree(l, pivot,
    low, mid);
rgt = new wavelet_tree(pivot, r, mid
    + 1, high);
}

// swaps the elements at index 'idx'
// and 'idx+1'
void swap_adjacent(int idx) {
    if (low == high) return;
    int firstBit = pref[idx] - pref[idx
        - 1];
    sum[idx] = sum[idx - 1] + sum[idx +
        1] - sum[idx];
    if (firstBit == (pref[idx + 1] -
        pref[idx])) {
        if (firstBit)
            lft->swap_adjacent(pref[idx]);
        else rgt->swap_adjacent(idx -
            pref[idx]);
    } else {
        if (firstBit) pref[idx]--;
        else pref[idx]++;
    }
}

// count occurrences of 'k' in range
// [l,r]
int count(int l, int r, int k) {
    if (l > r || high < k || low > k)
        return 0;
    if (low == high) return r - l + 1;
    int mid = (low + high) >> 1;
    if (k <= mid) return
        lft->count(pref[l - 1] + 1,
            pref[r], k);
    return rgt->count(l - pref[l - 1], r
        - pref[r], k);
}

// returns the k'th smallest element in
// range [l,r] // act like multiset
int kth(int l, int r, int k) {
    if (l > r) return 0;
    if (low == high) return low;
    int lftCount = pref[r] - pref[l - 1];
    if (lftCount >= k) return
        lft->kth(pref[l - 1] + 1,
            pref[r], k);
    return rgt->kth(l - pref[l - 1], r -
        pref[r], k - lftCount);
}

// returns the count of elements that
// are less than or equal to 'k' in
// range [l,r]
int LTE(int l, int r, int k) {
    if (l > r || low > k) return 0;
    if (high <= k) return r - l + 1;
}

```

```

return lft->LTE(pref[l - 1] + 1,
    pref[r], k) + rgt->LTE(l -
        pref[l - 1], r - pref[r], k);
}

// returns the count of elements that
// are greater than or equal to 'k' in
// range [l,r]
int GTE(int l, int r, int k) {
    if (l > r || high < k) return 0;
    if (low >= k) return r - l + 1;
    return lft->GTE(pref[l - 1] + 1,
        pref[r], k) + rgt->GTE(l -
            pref[l - 1], r - pref[r], k);
}

// returns the sum of elements less
// than 'k' in range [l,r]
long long sum_query(int l, int r, int
    k) {
    if (l > r || low >= k) return 0;
    if (low == high) return 1LL * (r - l
        + 1) * low;
    if (high < k) return sum[r] - sum[l
        - 1];
    return lft->sum_query(pref[l - 1] +
        1, pref[r], k) +
        rgt->sum_query(l - pref[l - 1],
            r - pref[r], k);
}

~wavelet_tree() {
    if (pref != NULL) delete []pref;
    if (sum != NULL) delete []sum;
    if (lft != NULL) delete lft;
    if (rgt != NULL) delete rgt;
}

int32_t main() {
    int n; cin >> n;
    for (int i = 1; i <= n; i++) cin >>
        a[i];
    wavelet_tree t = wavelet_tree(a + 1, a
        + n + 1, -MAXV, MAXV); // a[i] will
        change
}

```

4.17 Trie for bit

```

struct Trie {
    static const int B = 31;
    struct node {
        node* nxt[2];
        int sz;
        node() {
            nxt[0] = nxt[1] = NULL;
            sz = 0;
        }
    }*root;
    Trie() {
        root = new node();
    }
    void insert(int val) {
        node* cur = root;
        cur->sz++;
        for (int i = B - 1; i >= 0; i--) {
            int b = val >> i & 1;
            if (cur->nxt[b] == NULL) cur->
                nxt[b] = new node();
            cur = cur->nxt[b];
        }
    }
}

```

```

cur = cur->nxt[b];
cur->sz++;
}

int query(int x, int k) { // number
    of values s.t. val ⊕ x < k
    node* cur = root;
    int ans = 0;
    for (int i = B - 1; i >= 0; i--) {
        if (cur == NULL) break;
        int b1 = x >> i & 1, b2 = k >> i &
            1;
        if (b2 == 1) {
            if (cur->nxt[b1]) ans += cur
                ->nxt[b1]->sz;
            cur = cur->nxt[!b1];
        } else cur = cur->nxt[b1];
    }
    return ans;
}

int get_max(int x) { // returns
    maximum of val ⊕ x
    node* cur = root;
    int ans = 0;
    for (int i = B - 1; i >= 0; i--) {
        int k = x >> i & 1;
        if (cur->nxt[!k]) cur = cur->
            nxt[!k], ans <= 1, ans++;
        else cur = cur->nxt[k], ans <= 1;
    }
    return ans;
}

int get_min(int x) { // returns
    minimum of val ⊕ x
    node* cur = root;
    int ans = 0;
    for (int i = B - 1; i >= 0; i--) {
        int k = x >> i & 1;
        if (cur->nxt[k]) cur = cur->
            nxt[k], ans <= 1;
        else cur = cur->nxt[!k], ans <=
            1, ans++;
    }
    return ans;
}

void del(node* cur) {
    for (int i = 0; i < 2; i++) if (cur
        ->nxt[i]) del(cur->nxt[i]);
    delete(cur);
}
}

```

4.18 2D BIT

```

const int N = 2500 + 10;
int a[N][N], tree[N][N];
void update(int x, int y, int val) { // x
    and y is the coordinate from range
    update
    for (int i = x; i < N; i += i & (-i)) {
        for (int j = y; j < N; j += j &
            (-j)) {
            tree[i][j] += val;
        }
    }
}

```

```

int query(int x, int y) {
    int res = 0;
    for (int i = x; i < N; i += i & (-i)) {
        for (int j = y; j < N; j += j &
            (-j)) {
            res += tree[i][j];
        }
    }
    return res;
}

void range_add(int a, int b, int c, int
    d, int val) {
    update(a, b, val);
    update(a, d + 1, -val);
    update(c + 1, b, -val);
    update(c + 1, d + 1, val);
}

```

5 Dynamic Programming

5.1 Knapsack 2

Constraints: $N \leq 100$, $W \leq 1e9$, $\text{val}[i] \leq 1000$

$dp[i][\text{cur_val}]$ = min weight needed to achieve cur_val from i to n . **if** $dp[1][\text{val}] \leq W$ then val is a candidate ans. where val is all_possible_val (1 to $100*1000$)

5.2 LIS using Segment Tree

```

int32_t main() {
    int n; cin >> n;
    for (int i = 1; i <= n; i++) {
        cin >> a[i]; // a[i] must be >= 2
    }
    // dp[i] = LIS ending at pos i
    st.build(1, 1, M); // range max query,
    and upd idx with max(cur_val,
    new_val)
    for (int i = 1; i <= n; i++) {
        dp[i] = 1;
        if (a[i] != 1) {
            int mx = st.query(1, 1, M, 1, a[i]
                - 1);
            mx++;
            dp[i] = max(dp[i], mx);
        }
        st.upd(1, 1, M, a[i], dp[i]);
    }
    int ans = 0;
    for (int i = 1; i <= n; i++) ans =
        max(ans, dp[i]);
    cout << ans << '\n';
}

```

5.3 Digit DP

// Problem: How Many Zeroes? - LightOJ
// How many zeroes between n to m ($n \leq m$). 100 to 102 ans 4

```

11 fun2(int i, bool is_small) {
    if (i == sz) return 1;
    int l = 0, r = s[i] - '0';
    if (is_small) r = 9;
    ll &ans = dp2[i][is_small];
    if (ans != -1) return ans;
    ans = 0;
}

```

```

for (int x = 1; x <= r; x++) {
    ans += fun2(i + 1, (is_small | (x < r)));
}
return ans;
}

ll fun(int i, bool is_small, bool has_started) {
    if (i == sz) return 0;
    int l = 0, r = s[i] - '0';
    if (is_small) r = 9;
    ll &ans = dp1[i][is_small][has_started];
    if (ans != -1) return ans;
    ans = 0;
    for (int x = 1; x <= r; x++) {
        bool new_has_started = has_started | (x != 0);
        ans += fun(i + 1, (is_small | (x < r)), new_has_started);
        if (x == 0 and has_started) {
            ans += fun2(i + 1, (is_small | (x < r)));
        }
    }
    return ans;
}

void get(long long x) {
    if (x < 0) return; s = "";
    while (x > 0) {
        char c = (x % 10) + '0';
        s += c; x /= 10;
    }
    reverse(s.begin(), s.end());
    sz = s.size();
    memset(dp1, -1, sizeof(dp1));
    memset(dp2, -1, sizeof(dp2));
}

void solve() {
    ll n, m; cin >> n >> m;
    get(n - 1);
    memset(dp1, -1, sizeof(dp1));
    memset(dp2, -1, sizeof(dp2));
    ll ans1 = (n == 0) ? 0 : fun(0, false, false);
    get(m);
    ll ans2 = fun(0, false, false);
    cout << ans2 - ans1 + (n == 0) << '\n';
}

```

5.4 Bitmask DP

```

// Problem: DNA Sequence - LOJ
// Given n strings, find the shortest string that contains all the given strings as substrings and lexicographically smallest.
const int N = 17;
int n, tail[N][N], dp[(1 << N) + 2][N + 2];
string s[N + 2];
bool cmp(string a, string b) {
    if (a.size() < b.size()) {
        return true;
    }
    return false;
}

void solve() {
    cin >> n;
    string str[n + 1];
    for (int i = 1; i <= n; i++) {
        cin >> str[i]; // len <= 100
    }
    // remove duplicates and strings which is a subarray of others
    sort(str + 1, str + n + 1, cmp);
    vector<string> vec;
    for (int i = 1; i <= n; i++) {

```

```

        int fun(int mask, int last) {
            if (_builtin_popcount(mask) >= n)
                return 0;
            int &ans = dp[mask][last];
            if (ans != -1) return ans;
            ans = 1e9;
            for (int j = 1; j <= n; j++) {
                if (!(mask & (1 << j))) {
                    if (last == n + 1) {
                        int x = s[j].length() + fun(mask | (1 << j), j);
                        ans = min(ans, x);
                    } else {
                        int x = (s[j].length() - tail[last][j]) + fun(mask | (1 << j), j);
                        ans = min(ans, x);
                    }
                }
            }
            return ans;
        }

        void print(int mask, int last) {
            if (_builtin_popcount(mask) >= n)
                return;
            int ans = fun(mask, last), idx = -1;
            string str = "{";
            for (int j = 1; j <= n; j++) {
                if (!(mask & (1 << j))) {
                    if (last == n + 1) {
                        int x = s[j].length() + fun(mask | (1 << j), j);
                        if (x == ans) {
                            string d = s[j];
                            if (d <= str) str = d; idx = j;
                        }
                    } else {
                        int x = (s[j].length() - tail[last][j]) + fun(mask | (1 << j), j);
                        if (x == ans) {
                            string d =
                                s[j].substr(tail[last][j]);
                            if (d <= str) str = d; idx = j;
                        }
                    }
                }
            }
            cout << s[idx].substr(tail[last][idx]);
            print(mask | (1 << idx), idx);
        }

        void solve() {
            cin >> n;
            string str[n + 1];
            for (int i = 1; i <= n; i++) {
                cin >> str[i]; // len <= 100
            }
            // remove duplicates and strings which is a subarray of others
            sort(str + 1, str + n + 1, cmp);
            vector<string> vec;
            for (int i = 1; i <= n; i++) {

```

```

                bool ok = true;
                for (int j = i + 1; j <= n; j++) {
                    if (str[j].find(str[i]) != string::npos) {
                        ok = false;
                        break;
                    }
                }
                if (ok) vec.push_back(str[i]);
            }
            n = vec.size();
            int idx = 1;
            for (auto x : vec) s[idx++] = x;
            // maximum length that suffix of a[i] = prefix of a[j]
            memset(tail, 0, sizeof(tail));
            for (int i = 1; i <= n; i++) {
                string x = s[i];
                for (int j = 1; j <= n; j++) {
                    string y = s[j];
                    int cnt = 0;
                    for (int k = min(x.length(), y.length()); k >= 1; k--) {
                        if (x.substr(x.length() - k) == y.substr(0, k)) {
                            cnt = k;
                            break;
                        }
                    }
                    tail[i][j] = cnt;
                }
            }
            memset(dp, -1, sizeof(dp));
            fun(0, n + 1);
            print(0, n + 1);
        }
    }
}

5.5 MCM DP

```

// Problem: Slimes - Atcoder DP Contest
// Given n slimes. Choose two adjacent slimes, and combine them into a new slime. The new slime has a size of $x+y$, where x and y are the sizes of the slimes before combining them. Here, a cost of $x+y$ is incurred.
Example-
 $(10, 20, 30, 40) \rightarrow (30, 30, 40)$
 $(30, 30, 40) \rightarrow (60, 40)$
 $(60, 40) \rightarrow (100)$ ans = 190
// Solution: Think reverse. We are given the final sum, from i to j . Now we will cut any point between i to j and calculate the cost
// Time: $O(n^3)$

```

ll fun(int i, int j) {
    if (i == j) return 0;
    ll &ans = dp[i][j];
    if (ans != -1) return ans;
    ll cur = 0;
    for (int x = i; x <= j; x++) {
        cur += a[x];
    }
    ans = inf;
    for (int x = i; x < j; x++) {

```

```

        ans = min(ans, cur + fun(i, x) + fun(x + 1, j));
    }
    return ans;
}
cout << fun(1, n) << '\n';

5.6 Number of Unique Subsequence
int nxt[N][26], dp[N];
int f(int i) {
    if (i > n) return 0;
    int &ans = dp[i];
    if (ans != -1) return ans;
    ans = 1;
    for (int c = 0; c < 26; c++) {
        ans = (ans + f(nxt[i][c])) % mod;
    }
    return ans;
}
// nxt[i][c] = nxt c strictly after i
void solve() {
    cin >> s; s = '.' + s;
    cout << f(0) << '\n';
}

5.7 [Problem] Rose Land - SUST 24
// Given a complete binary tree,  $i$ -th node grows  $a_i$  roses per day and deliver to  $u$  in  $dis(u, i)$  days. Alice at node  $u$ , How many roses he will get within  $t$  days?  $u$  and  $t$  for  $Q$  queries.
// Idea: as it is a complete binary tree, max dis is  $2 * \log n$ . We can do DP on Tree for ~40 days.
ll dp[N][45], dp2[N][45];
void dfs(int u, int p) {
    for (int i = 1; i <= 40; i++) {
        dp[u][i] = i * a[u];
    }
    for (auto v : g[u]) {
        if (v != p) {
            dfs(v, u);
            for (int i = 1; i <= 40; i++) {
                dp[u][i] += dp[v][i - 1];
            }
        }
    }
}
void dfs2(int u, int p) {
    for (int i = 2; u != 1 and i <= 40; i++) {
        dp2[u][i] = (dp[p][i - 1] + dp2[p][i - 1]) - dp[u][i - 2];
    }
    for (auto v : g[u]) {
        if (v != p) {
            dfs2(v, u);
        }
    }
}
int32_t main() {
    cin >> n; ll sum = 0;
    for (int i = 1; i <= n; i++) {

```

```

    cin >> a[i]; sum += a[i];
}
dfs(1, 0); // rose from subtree
dfs2(1, 0); // rose from par
int q; cin >> q;
while (q--) {
    int u, t; cin >> u >> t;
    int extra = t - 40;
    t = min(40, t);
    ll ans = dp[u][t] + dp2[u][t];
    if (extra > 0) ans += 1ll * extra *
        sum;
    cout << ans << '\n';
}



---



### 5.8 [Problem] Sub-Palindromic Tree



---



```

// Given a tree, each node has a char.
// Print max len subsequence any path
// which is a palindrome. (CF/1777/D)
// Time: O(N^2)
int nxt[N][N], dp[N][N];
vector<int> vec;
void dfs(int u, int p) {
 vec.push_back(u);
 for (auto v : g[u]) {
 if (v != p) dfs(v, u);
 }
 int f(int u, int v) {
 if (v == u) return 1;
 int &ans = dp[u][v];
 if (ans != -1) return ans;
 ans = 0;
 if (s[u] == s[v]) ans = 2 + (nxt[u][v]
 == v ? 0 : f(nxt[u][v],
 nxt[v][u]));
 else ans = max(f(nxt[u][v], v), f(u,
 nxt[v][u]));
 return ans;
 }
 void solve() {
 cin >> n >> s; s = '.' + s;
 for (int i = 1; i < n; i++) {
 int u, v; cin >> u >> v;
 g[u].push_back(v);
 g[v].push_back(u);
 }
 // nxt[u][v] = next node after u
 // if I want to go from u to v
 for (int u = 1; u <= n; u++) {
 for (auto x : g[u]) {
 vec.clear();
 dfs(x, u);
 for (auto v : vec) nxt[u][v] = x;
 }
 }
 memset(dp, -1, sizeof dp);
 int ans = 0;
 for (int u = 1; u <= n; u++) {
 for (int v = 1; v <= n; v++) {
 ans = max(ans, f(u, v));
 }
 }
 cout << ans << '\n';
 }
}

```


```

}

6 Graph Theory

6.1 Binary Lifting and LCA

```

const int N = 2e5 + 9, LOG = 20;
vector<int> g[N];
int par[N][LOG], depth[N];
void dfs(int u, int p) {
    par[u][0] = p;
    tree_mx[u][0] = dis;
    depth[u] = depth[p] + 1;
    for (int i = 1; i < LOG; i++) {
        par[u][i] = par[par[u][i - 1]][i - 1];
    }
    for (auto v : g[u]) {
        if (v != p) {
            dfs(v, u);
        }
    }
}
int lca(int u, int v) {
    if (depth[u] < depth[v]) {
        swap(u, v);
    }
    int k = depth[u] - depth[v];
    for (int i = 0; i < LOG; i++) {
        if (CHECK(k, i)) u = par[u][i];
    }
    if (u == v) return u;
    for (int i = LOG - 1; i >= 0; i--) {
        if (par[u][i] != par[v][i]) {
            u = par[u][i];
            v = par[v][i];
        }
    }
    return par[u][0];
}
int kth(int u, int k) { // kth parent of
    assert(k >= 0);
    for (int i = 0; i < LOG; i++) {
        if (CHECK(k, i)) u = par[u][i];
    }
    return u;
}
int dist(int u, int v) { // distance from
    u to v
    int l = lca(u, v);
    return (depth[u] - depth[l]) +
        (depth[v] - depth[l]);
}
int kth(int u, int v, int k) {
    int l = lca(u, v);
    int d = dist(u, v);
    assert(k <= d);
    if (depth[l] + k <= depth[u]) {
        return kth(u, k);
    }
    k -= depth[u] - depth[l];
    return kth(v, depth[v] - depth[l] - k);
}

```

6.2 LCA and Sparse Table on Tree

// max and min weights of a path

```

const int N = 1e5 + 9, LOG = 20, inf =
    1e9; // change here
vector<array<int, 2>> g[N];
int par[N][LOG], tree_mx[N][LOG],
    depth[N];
void dfs(int u, int p, int dis) {
    par[u][0] = p;
    tree_mx[u][0] = dis;
    depth[u] = depth[p] + 1;
    for (int i = 1; i < LOG; i++) {
        par[u][i] = par[par[u][i - 1]][i - 1];
        tree_mx[u][i] = max(tree_mx[u][i - 1],
            tree_mx[par[u][i - 1]][i - 1]);
    }
    for (auto [v, w] : g[u]) {
        if (v != p) {
            dfs(v, u, w);
        }
    }
}
int query_max(int u, int v) { // max
    weight on path u to v
    int l = lca(u, v);
    int d = dist(l, u);
    int ans = 0;
    for (int i = 0; i < LOG; i++) {
        if (CHECK(d, i)) {
            ans = max(ans, tree_mx[u][i]);
            u = par[u][i];
        }
    }
    d = dist(l, v);
    for (int i = 0; i < LOG; i++) {
        if (CHECK(d, i)) {
            ans = max(ans, tree_mx[v][i]);
            v = par[v][i];
        }
    }
    return ans;
}

```

6.3 Dijkstra

```

vector<int> dijkstra(int s) {
    vector<int> dis(n + 1, inf);
    vector<bool> vis(n + 1, false);
    dis[s] = 0;
    priority_queue<array<int, 2>,
        vector<array<int, 2>>, greater<array<int, 2>>> pq;
    pq.push({0, s});
    while (!pq.empty()) {
        auto [d, u] = pq.top(); pq.pop();
        if (vis[u]) continue;
        vis[u] = true;
        for (auto [v, w] : g[u]) {
            if (dis[v] > d + w) {
                dis[v] = d + w;
                pq.push({dis[v], v});
            }
        }
    }
    return dis;
}

```

6.4 Bellman Ford

```

// works for neg edge, can detect neg
cycle
// Time: O(n^2)
const ll inf = 1e18;
vector<ll> dis(N, inf);
bool bellman_ford(int s) {
    dis[s] = 0;
    bool has_cycle = false;
    for (int i = 1; i <= n; i++) {
        for (int u = 1; u <= n; u++) {
            for (auto [v, w] : g[u]) {
                if (dis[v] > dis[u] + w) {
                    if (i == n) has_cycle = true;
                    dis[v] = dis[u] + w;
                }
            }
        }
    }
    return has_cycle;
}

```

6.5 Floyd Warshall

```

// dis[i][j] = min distance to reach i to
j, works for neg edge (no neg cycle)
// Time: O(n^3)
vector<int> construct_path(int u, int v)
{
    if (nxt[u][v] == -1) return {};
    vector<int> path = {u};
    while (u != v) {
        u = nxt[u][v];
        path.push_back(u);
    }
    return path;
}
void floyd_marshall() {
    for (int i = 1; i <= n; i++) {
        for (int j = 1; j <= n; j++) {
            if (i == j) dis[i][j] = 0;
            else if (g[i][j] == 0) dis[i][j] =
                inf;
            else dis[i][j] = g[i][j];
        }
    }
    for (int k = 1; k <= n; ++k) {
        for (int i = 1; i <= n; ++i) {
            for (int j = 1; j <= n; ++j) {
                if (dis[i][k] < inf and
                    dis[k][j] < inf)
                    dis[i][j] = min(dis[i][j],
                        dis[i][k] + dis[k][j]);
                nxt[i][j] = nxt[i][k];
            }
        }
    }
}
int32_t main() {
    int q; cin >> n >> m >> q;
    memset(nxt, -1, sizeof nxt);
    while (m--) {
        int u, v, w; cin >> u >> v >> w;
        g[u][v] = (g[u][v] != 0 ?
            min(g[u][v], w) : w);
    }
}

```

```

g[v][u] = (g[v][u] != 0 ?
    min(g[v][u], w) : w;
nxt[u][v] = v;
nxt[v][u] = u;
}
floyd_marshall();
while (q--) {
    int u, v; cin >> u >> v;
    cout << (dis[u][v] == inf ? -1 :
        dis[u][v]) << '\n';
}
return 0;
}

```

6.6 Strongly Connected Components

```

// Time: O(n + m)
const int N = 1e5 + 9;
vector<int> g[N], gT[N], G[N];
vector<bool> vis(N, false);
vector<vector<int>> components;
vector<int> order;
int n, roots[N], sz[N];
void dfs(int u) {
    vis[u] = true;
    for (auto v : g[u]) {
        if (!vis[v]) dfs(v);
    }
    order.push_back(u);
}
void dfs2(int u, vector<int> &component) {
    vis[u] = true;
    component.push_back(u);
    for (auto v : gT[u]) {
        if (!vis[v]) dfs2(v, component);
    }
}
void scc() {
    // get order sorted by end time
    order.clear();
    for (int u = 1; u <= n; u++) {
        if (!vis[u]) dfs(u);
    }
    reverse(order.begin(), order.end());
    // transpose the graph
    for (int u = 1; u <= n; u++) {
        for (auto v : g[u]) {
            gT[v].push_back(u);
        }
    }
    // get all components
    components.clear();
    for (int i = 1; i <= n; i++) vis[i] =
        false;
    for (auto u : order) {
        if (!vis[u]) {
            vector<int> component;
            dfs2(u, component);
            sort(component.begin(),
                component.end());
            components.push_back(component);
            for (auto v : component) {
                roots[v] = component.front();
                sz[v] = component.size();
            }
        }
    }
}

```

```

    }
    // add edges to condensation graph
    for (int u = 1; u <= n; u++) {
        for (auto v : g[u]) {
            if (roots[u] != roots[v]) {
                G[roots[u]].push_back(roots[v]);
            }
        }
    }
    // when you need to use condensed graph,
    // use it carefully (Specially g->G,
    // i->roots[i])
}

```

6.7 Articulation Points

```

int disc[N], low[N], timer, n;
vector<bool> vis(N, false), is_ap(N,
    false);
void ap_dfs(int u, int p) {
    disc[u] = low[u] = ++timer;
    vis[u] = true;
    int children_cnt = 0;
    for (auto v : g[u]) {
        if (v == p) continue;
        if (vis[v]) low[u] = min(low[u],
            disc[v]);
        else {
            ap_dfs(v, u);
            low[u] = min(low[u], low[v]);
            if (disc[u] <= low[v] and p != -1)
                is_ap[u] = true;
            children_cnt++;
        }
    }
    if (p == -1 and children_cnt > 1)
        is_ap[u] = true;
}
void find_articulation_points() {
    for (int u = 1; u <= n; u++) {
        if (!vis[u]) {
            timer = 0;
            ap_dfs(u, -1);
        }
    }
}

```

6.8 Find Bridges

```

map<pair<int, int>, int> bridges;
void bridges_dfs(int u, int p) { // find
    bridges
    disc[u] = low[u] = ++timer;
    vis[u] = true;
    for (auto v : g[u]) {
        if (v == p) continue;
        if (vis[v]) low[u] = min(low[u],
            disc[v]);
        else {
            bridges_dfs(v, u);
            low[u] = min(low[u], low[v]);
            if (disc[u] < low[v]) {
                bridges[{min(u, v),
                    max(u, v)}]++;
            }
        }
    }
}

```

```

    }
    void find_bridges() {
        for (int u = 1; u <= n; u++) {
            if (!vis[u]) {
                timer = 0;
                bridges_dfs(u, -1);
            }
        }
    }

```

6.9 DSU on Tree

```

// Problem: Distinct Colors CSES (Number
// of distinct color in a subtree)
// Complexity: O(n(logn)^2)
set<int> se[N];
int col[N], ans[N], par[N]; // par[i] = i
initially
int find(int i) {
    return (i == par[i] ? i : par[i] =
        find(par[i]));
}
void merge(int u, int v) {
    if ((u = find(u)) == (v = find(v)))
        return;
    if (se[u].size() > se[v].size())
        swap(u, v);
    for (auto x : se[u]) {
        se[v].insert(x);
    }
    se[u].clear();
    par[u] = v;
}
void dfs(int u, int p) {
    se[find(u)].insert(col[u]);
    for (auto v : g[u]) {
        if (v != p) {
            dfs(v, u);
            merge(u, v);
        }
    }
    ans[u] = se[find(u)].size();
}

```

6.10 Heavy-Light Decomposition

```

// Per Query Complexity: O(logn^2)
// Path and subtree updates and queries.
const int N = 2e5 + 9, LOG = 20, inf =
    1e9; // change here
vector<int> g[N];
int par[N][LOG], depth[N], sz[N];
int disc[N], finish[N], timer, head[N];
int n;
void dfs(int u, int p = 0) {
    par[u][0] = p;
    depth[u] = depth[p] + 1;
    sz[u] = 1;
    for (int i = 1; i < LOG; i++) {
        par[u][i] = par[par[u][i - 1]][i - 1];
    }
    if (p) g[u].erase(find(g[u].begin(),
        g[u].end(), p));
    for (auto &v : g[u]) {
        if (v != p) {
            dfs(v, u);
            sz[u] += sz[v];
        }
    }
}

```

```

    if (sz[v] > sz[g[u][0]]) swap(v,
        g[u][0]);
}
}
void dfs_hld(int u) {
    disc[u] = ++timer;
    for (auto v : g[u]) {
        head[v] = (v == g[u][0] ? head[u] :
            v);
        dfs_hld(v);
    }
    finish[u] = timer;
}
int kth(int u, int k) {
    assert(k >= 0);
    for (int i = 0; i < LOG; i++) {
        if (CHECK(k, i)) u = par[u][i];
    }
    return u;
}
int query_up(int u, int v) {
    int ans = -inf; // change here
    while (head[u] != head[v]) {
        ans = max(ans, st.query(1, 1, n,
            disc[head[u]], disc[u])); // //
        change here
        u = par[head[u]][0];
    }
    ans = max(ans, st.query(1, 1, n,
        disc[v], disc[u])); // change here
    return ans;
}
int query(int u, int v) {
    int lc = lca(u, v);
    int ans = query_up(u, lc);
    if (v != lc) {
        ans = max(ans, query_up(v, kth(v,
            depth[v] - depth[lc] - 1))); // //
        change here
    }
    return ans;
}
void solve() {
    cin >> n;
    for (int i = 2; i <= n; i++) {
        int u, v; cin >> u >> v;
        g[u].push_back(v);
        g[v].push_back(u);
    }
    dfs(1);
    head[1] = 1;
    dfs_hld(1);
    st.build(1, 1, n);
}

```

6.11 Inverse Graph

```

// Problem: CF/0-1 MST
// A Complete Graph. m edges have
// weight 1, rest have 0. MST?
const int N = 200000 + 9;
set<int> g[N], non_vis;
void dfs(int u) {

```

```

non_vis.erase(u);
for (int v = 1; v <= n; v++) {
    if (v == u) continue;
    auto it = non_vis.lower_bound(v);
    if (it == non_vis.end()) break;
    v = *it;
    if (g[u].find(v) != g[u].end())
        continue;
    dfs(v);
}
int32_t main() {
    int m; cin >> n >> m;
    while (m--) {
        int u, v; cin >> u >> v;
        g[u].insert(v);
        g[v].insert(u);
    }
    for (int i = 1; i <= n; i++)
        non_vis.insert(i);
    int component_cnt = 0;
    for (int i = 1; i <= n; i++) {
        if (non_vis.find(i) != non_vis.end())
            component_cnt++;
        dfs(i);
    }
    cout << component_cnt - 1 << '\n';
}

```

6.12 [Problem] Rooted Tree - Hackerrank

Given a rooted tree, Upd: Add $d * k$ on v (subtree nodes of u), where k will be given and d is distance of v from u . Query: Node Value/Subtree Sum (using ETT) or Path Value Sum (using HLD). **Idea:** $d_i = \text{dis from root to } i$. Then, $\text{ans} = k \cdot \sum_{v \in \text{subtree}(u)} d_v$. It's hard to find d_v for each u , rather we can find $d_v = \text{dis of } v \text{ from root}$. Although some extra value added on each v of subtree u because of d_v from root (not u), we can easily subtract them ($\text{depth}[u] * k$).

6.13 Dinic

```

const int N = 105, inf = 1e9;
int n, m, st, en;
// Edges should be added in both
// direction separately if the graph is
// undirected
const int INF = 2000000000;
struct Edge {
    int from, to, cap, flow, index;
    Edge(int from, int to, int cap, int
        flow, int index) :
        from(from), to(to), cap(cap),
        flow(flow), index(index) {}
};
struct Dinic {
    int N;
    vector<vector<Edge>> G;
    vector<Edge*> dad;

```

```

vector<int> Q;
Dinic(int N) : N(N), G(N), dad(N),
    Q(N) {}
void AddEdge(int from, int to, int
    cap) {
    G[from].emplace_back(from, to, cap,
        0, G[to].size());
    if (from == to)
        G[from].back().index++;
    G[to].emplace_back(to, from, 0, 0,
        G[from].size() - 1);
}
long long BlockingFlow(int s, int t) {
    fill(dad.begin(), dad.end(), (Edge
        *)NULL);
    dad[s] = &G[0][0] - 1;
    int head = 0, tail = 0;
    Q[tail++] = s;
    while (head < tail) {
        int x = Q[head++];
        for (int i = 0; i < G[x].size(); i++) {
            Edge &e = G[x][i];
            if (!dad[e.to] && e.cap - e.flow
                > 0) {
                dad[e.to] = &G[x][i];
                Q[tail++] = e.to;
            }
        }
    }
    if (!dad[t]) return 0;
    long long totflow = 0;
    for (int i = 0; i < G[t].size(); i++) {
        Edge *start =
            &G[G[t][i].to][G[t][i].index];
        int amt = INF;
        for (Edge *e = start; amt && e != dad[s]; e = dad[e->from]) {
            if (!e) { amt = 0; break; }
            amt = min(amt, e->cap - e->flow);
        }
        if (amt == 0) continue;
        for (Edge *e = start; amt && e != dad[s]; e = dad[e->from]) {
            e->flow += amt;
            G[e->to][e->index].flow -= amt;
        }
        totflow += amt;
    }
    return totflow;
}
long long GetMaxFlow(int s, int t) {
    long long totflow = 0;
    while (long long flow =
        BlockingFlow(s, t))
        totflow += flow;
    return totflow;
}
void solve() {
    cin >> n >> st >> en >> m;
    Dinic *dinic = new Dinic(n + 1);
    while (m--) {

```

```

        int u, v, w; cin >> u >> v >> w;
        dinic->AddEdge(u, v, w);
        dinic->AddEdge(v, u, w);
    }
    cout << dinic->GetMaxFlow(st, en) <<
        '\n';
    delete(dinic);
}


```

7 String

7.1 Hashing

```

const int N = 1e6 + 9; // change here
const int MOD1 = 127657753, MOD2 =
    987654319;
const int p1 = 137, p2 = 277; // change
// here
int ip1, ip2;
pair<int, int> pw[N], ipw[N];
void prec() {
    pw[0] = {1, 1};
    for (int i = 1; i < N; i++) {
        pw[i].first = 1ll * pw[i - 1].first
            * p1 % MOD1;
        pw[i].second = 1ll * pw[i - 1].second
            * p2 % MOD2;
    }
    ip1 = power(p1, MOD1 - 2, MOD1);
    ip2 = power(p2, MOD2 - 2, MOD2);
    ipw[0] = {1, 1};
    for (int i = 1; i < N; i++) {
        ipw[i].first = 1ll * ipw[i - 1].first
            * ip1 % MOD1;
        ipw[i].second = 1ll * ipw[i - 1].second
            * ip2 % MOD2;
    }
}


```

```

pair<int, int> get_hash() { // 1
    indexed
    return get_hash(1, n);
}
bool is_palindrome(int l, int r) {
    return get_hash(l, r) == rev_hash(l,
        r);
}


```

```

    p.second = (rev_hash_val[i].second
        + 1ll * s[i] * pw[j].second %
            MOD2) % MOD2;
    rev_hash_val.push_back(p);
}
pair<int, int> get_hash(int l, int r) {
    { // 1 indexed
    pair<int, int> ans;
    ans.first = (hash_val[r].first -
        hash_val[l - 1].first + MOD1) *
        1ll * ipw[l - 1].first % MOD1;
    ans.second = (hash_val[r].second -
        hash_val[l - 1].second + MOD2) *
        1ll * ipw[l - 1].second % MOD2;
    return ans;
}
pair<int, int> rev_hash(int l, int r) {
    { // 1 indexed
    pair<int, int> ans;
    ans.first = (rev_hash_val[r].first -
        rev_hash_val[l - 1].first +
        MOD1) * 1ll * ipw[n - r].first %
            MOD1;
    ans.second = (rev_hash_val[r].second -
        rev_hash_val[l - 1].second +
        MOD2) * 1ll * ipw[n - r].second %
            MOD2;
    return ans;
}
pair<int, int> get_hash() { // 1
    indexed
    return get_hash(1, n);
}
bool is_palindrome(int l, int r) {
    return get_hash(l, r) == rev_hash(l,
        r);
}


```

7.2 Hashing with Updates

```

using T = array<int, 2>;
const T MOD = {127657753, 987654319};
const T p = {137, 277}; // change here
T operator + (T a, int x) {return {(a[0]
    + x) % MOD[0], (a[1] + x) % MOD[1]};}
T operator - (T a, int x) {return {(a[0]
    - x + MOD[0]) % MOD[0], (a[1] - x +
    MOD[1]) % MOD[1]};}
T operator * (T a, int x) {return
    {(int)((long long) a[0] * x %
        MOD[0]), (int)((long long) a[1] * x %
        MOD[1])};}
T operator + (T a, T x) {return {(a[0] +
    x[0]) % MOD[0], (a[1] + x[1]) %
        MOD[1]};}
T operator - (T a, T x) {return {(a[0] -
    x[0] + MOD[0]) % MOD[0], (a[1] -
    x[1] + MOD[1]) % MOD[1]};}
T operator * (T a, T x) {return
    {(int)((long long) a[0] * x[0] %
        MOD[0]), (int)((long long) a[1] * x[1] %
        MOD[1])};}


```

```

ostream& operator << (ostream& os, T
hash) {return os << "(" << hash[0]
<< ", " << hash[1] << ")");}

T pw[N], ipw[N];
void prec() {
    pw[0] = {1, 1};
    for (int i = 1; i < N; i++) {
        pw[i] = pw[i - 1] * p;
    }
    ipw[0] = {1, 1};
    T ip = {power(p[0], MOD[0] - 2,
MOD[0]), power(p[1], MOD[1] - 2,
MOD[1])};
    for (int i = 1; i < N; i++) {
        ipw[i] = ipw[i - 1] * ip;
    }
}

struct Hashing {
    int n;
    string s; // 1 - indexed
    vector<array<T, 2>> t; // (normal, rev)
    hash
    array<T, 2> merge(array<T, 2> l,
array<T, 2> r) {
        l[0] = l[0] + r[0];
        l[1] = l[1] + r[1];
        return l;
    }
    void build(int node, int b, int e) {
        if (b == e) {
            t[node][0] = pw[b] * s[b];
            t[node][1] = pw[n - b + 1] * s[b];
            return;
        }
        int mid = (b + e) >> 1, l = node <<
        1, r = l | 1;
        build(l, b, mid);
        build(r, mid + 1, e);
        t[node] = merge(t[l], t[r]);
    }
    void upd(int node, int b, int e, int
i, char x) {
        if (b > i || e < i) return;
        if (b == e && b == i) {
            t[node][0] = pw[b] * x;
            t[node][1] = pw[n - b + 1] * x;
            return;
        }
        int mid = (b + e) >> 1, l = node <<
        1, r = l | 1;
        upd(l, b, mid, i, x);
        upd(r, mid + 1, e, i, x);
        t[node] = merge(t[l], t[r]);
    }
    array<T, 2> query(int node, int b, int
e, int i, int j) {
        if (b > j || e < i) return {T({0,
0}), T({0, 0})};
        if (b >= i && e <= j) return t[node];
        int mid = (b + e) >> 1, l = node <<
        1, r = l | 1;
        return merge(query(l, b, mid, i, j),
query(r, mid + 1, e, i, j));
    }
}

```

```

Hashing() {}
Hashing(string _s) {
    n = _s.size();
    s = '.' + _s;
    t.resize(4 * n + 1);
    build(1, 1, n);
}
void upd(int i, char c) {
    upd(1, 1, n, i, c);
    s[i] = c;
}
T get_hash(int l, int r) { // 1 -
    indexed
    return query(1, 1, n, l, r)[0] *
ipw[l - 1];
}
T rev_hash(int l, int r) { // 1 -
    indexed
    return query(1, 1, n, l, r)[1] *
ipw[n - r];
}
T get_hash() {
    return get_hash(1, n);
}
bool is_palindrome(int l, int r) {
    return get_hash(l, r) == rev_hash(l,
r);
}

```

7.3 Hashing with Upd and Deletes

// update or delete a char in the string
or check whether a range [l,r] is a
palindrome or not (Palindromic Query I
- Top)

```

#define int long long
const int N = 1e5 + 9;
int en;
struct ST {
    pair<int, int> tree[4 * (N + N)];
    void build(int n, int b, int e) {
        if (b == e) {
            tree[n].first = b;
            tree[n].second = 1;
            return;
        }
        int mid = (b + e) >> 1, l = n << 1,
        r = l + 1;
        build(l, b, mid);
        build(r, mid + 1, e);
        tree[n].second = tree[l].second +
tree[r].second;
    }
    void upd(int n, int b, int e, int i,
        int x1, int x2) {
        if (b > i || e < i) return;
        if (b == e && b == i) {
            tree[n].first = x1;
            tree[n].second = x2;
            return;
        }
        int mid = (b + e) >> 1, l = node <<
        1, r = l + 1;
        upd(l, b, mid, i, x1);
        upd(r, mid + 1, e, i, x2);
        tree[n].second = tree[l].second +
tree[r].second;
    }
}

```

```

tree[n].second = tree[l].second +
tree[r].second;
}
pair<int, int> query(int n, int b, int
e, int x) {
    if (b > e) return {-1, -1};
    if (tree[n].second < x) return
{tree[n].second, -1};
    if (b == e) return tree[n];
    int mid = (b + e) >> 1, l = n << 1,
    r = l + 1;
    pair<int, int> L = query(l, b, mid,
x);
    if (L.second != -1) return L;
    pair<int, int> R = query(r, mid + 1,
e, x - L.first);
    return R;
}
int st, st2;
using T = array<int, 2>;
const T MOD = {127657753, 987654319};
const T p = {137, 277};
// add operators overloading of T (from
only upd) + prec()
int get(int i, int n) {
    return n - i + 1;
}
struct Hashing {
    int n; string s;
    vector<T> tree, lazy;
    void push(int node, int b, int e) {
        if (lazy[node][0] == 1) return;
        tree[node] = tree[node] * lazy[node];
        if (b != e) {
            int l = node << 1, r = l + 1;
            lazy[l] = lazy[l] * lazy[node];
            lazy[r] = lazy[r] * lazy[node];
        }
        lazy[node] = T{1, 1};
    }
    void build(int node, int b, int e) {
        lazy[node] = T{1, 1};
        if (b == e) {
            tree[node] = pw[b] * s[b];
            return;
        }
        int mid = (b + e) >> 1, l = node <<
        1, r = l + 1;
        build(l, b, mid);
        build(r, mid + 1, e);
        tree[node] = tree[l] + tree[r];
    }
    void upd(int i, char c, int cur) {
        T x = pw[i] * c;
        if (cur == 1) i = st.query(1, 1, en,
i).first;
        else i = st2.query(1, 1, en, i).first;
        upd(1, 1, n, i, x);
    }
    void del(int i, int cur) {
        int orgi = i;
        T x = pw[i] * 011;
        if (cur == 1) i = st.query(1, 1, en,
i).first;
        else i = st2.query(1, 1, en, i).first;
        upd(1, 1, n, i, x);
        del(1, 1, n, i + 1, n);
        if (cur == 1) st.upd(1, 1, en, i, i,
0);
        else st2.upd(1, 1, en, i, i, 0);
    }
}

```

```

T get_hash(int l, int r, int cur) { // 1 -
    indexed
    int ll = st.query(1, 1, en, l).first;
    int rr = st.query(1, 1, en, r).first;
    if (cur == 2) {
        ll = st2.query(1, 1, en, l).first;
        rr = st2.query(1, 1, en, r).first;
    }
    tree[node] = tree[l] + tree[r];
}
void del(int node, int b, int e, int
i, int j) {
    push(node, b, e);
    if (b > j || e < i) return;
    if (b >= i && e <= j) {
        lazy[node] = lazy[node] * ipw[1];
        push(node, b, e);
        return;
    }
    int mid = (b + e) >> 1, l = node <<
    1, r = l + 1;
    del(l, b, mid, i, j);
    del(r, mid + 1, e, i, j);
    tree[node] = tree[l] + tree[r];
}
T query(int node, int b, int e, int i,
int j) {
    push(node, b, e);
    if (b > j || e < i) return {0, 0};
    if (b >= i && e <= j) return
tree[node];
    int mid = (b + e) >> 1, l = node <<
    1, r = l + 1;
    T L = query(l, b, mid, i, j);
    T R = query(r, mid + 1, e, i, j);
    return L + R;
}
Hashing() {}
Hashing(string _s) {
    s = _s;
    n = s.size();
    s = '.' + s;
    tree.resize(4 * n + 1);
    lazy.resize(4 * n + 1);
    build(1, 1, n);
}

```

```

    }
    return query(1, 1, n, 11, rr) *
        ipw[l - 1];
}
int32_t main() {
    prec(); // must include
    string s; cin >> s;
    int n = s.size();
    int q; cin >> q;
    string t = s;
    reverse(t.begin(), t.end());
    Hashing hs(s), hs2(t);
    en = n + q + 5;
    st.build(1, 1, en);
    st2.build(1, 1, en);
    while (q--) {
        char c; cin >> c;
        if (c == 'C') {
            int l, r; cin >> l >> r;
            int l2 = get(l, n);
            int r2 = get(r, n);
            if (hs.get_hash(l, r, 1) ==
                hs2.get_hash(r2, l2, 2)) cout
                << "Yes!\n";
            else cout << "No!\n";
        } else if (c == 'U') {
            int i; char x; cin >> i >> x;
            int i2 = get(i, n);
            hs.upd(i, x, 1);
            hs2.upd(i2, x, 2);
        } else {
            int i; cin >> i;
            int i2 = get(i, n);
            hs.del(i, 1);
            hs2.del(i2, 2);
            --n;
        }
    }
}

```

7.4 Hashing on Tree

```

// Given a tree, Check whether it is
// symmetrical or not. Problem - CF G.
// Symmetree
// The value for each node is its
// subtree size and position is the
// level (ordered). But the order of
// child's doesn't matter (unordered)
const int N = 2e5 + 9;
vector<int> g[N];
vector<array<int, 3>> hassh[N]; // hash1,
// hash2, node
int n, sz[N];
const int MOD1 = 1e9 + 9, MOD2 = 1e9 + 21;
const int p1 = 1e5 + 19, p2 = 1e5 + 43;
void dfs2(int u, int p, int lvl) {
    array<int, 3> my_hash;
    my_hash[0] = 1ll * sz[u] *
        pw[lvl].first % MOD1;
    my_hash[1] = 1ll * sz[u] *
        pw[lvl].second % MOD2;
    my_hash[2] = u;
}

```

```

bool leaf = true;
for (auto v : g[u]) {
    if (v != p) {
        dfs2(v, u, lvl + 1);
        leaf = false;
    }
}
if (!leaf) {
    int sum1 = 1, sum2 = 1;
    for (auto here : hassh[u]) {
        auto [x, y, _] = here;
        sum1 = (sum1 * x) % MOD1;
        sum2 = (sum2 * y) % MOD2;
    }
    my_hash[0] = power(my_hash[0], sum1,
        MOD1);
    my_hash[1] = power(my_hash[1], sum2,
        MOD2);
}
hassh[p].push_back(my_hash);
}
bool ok(int u) {
    map<pair<int, int>, int> mp;
    for (auto [x, y, who] : hassh[u]) {
        mp[{x, y}]++;
    }
    int odd = 0;
    pair<int, int> val;
    for (auto [here, cnt] : mp) {
        odd += cnt & 1;
        if (cnt & 1) val = here;
    }
    if (odd == 0) return true;
    if (odd > 1) return false;
    int node;
    for (auto [x, y, who] : hassh[u]) {
        pair<int, int> here = {x, y};
        if (here == val) node = who;
    }
    return ok(node);
}
void solve() {
    cin >> n; clr(n);
    for (int i = 2; i <= n; i++) {
        int u, v; cin >> u >> v;
        g[u].push_back(v);
        g[v].push_back(u);
    }
    dfs(1, 0); // calc. subtree size
    dfs2(1, 0, 1);
    if (ok(0)) cout << "YES\n";
    else cout << "NO\n";
}

```

7.5 Compare 2 strings Lexicographically

```

// Time: O(logn)
string s;
Hashing hs;
// return 0 if both equal
// return 1 if first substring greater
// return -1 if second substring greater
// here lcp() provides the len of longest
// common prefix
int compare(int i, int j, int x, int y) {
    int common_prefix = lcp(i, j, x, y);

```

```

    int len1 = j - i + 1, len2 = y - x + 1;
    if (common_prefix == len1 and len1 == len2) return 0;
    else if (common_prefix == len1) return -1;
    else if (common_prefix == len2) return 1;
    else return (s[i + common_prefix - 1]
        < s[x + common_prefix - 1]) ? -1 :
        1;
}

```

7.6 KMP

```

vector<int> build_lps(string &pat) {
    int n = pat.size();
    vector<int> lps(n, 0);
    for (int i = 1; i < n; i++) {
        int j = lps[i - 1];
        while (j > 0 and pat[i] != pat[j]) {
            j = lps[j - 1];
        }
        if (pat[i] == pat[j]) j++;
        lps[i] = j;
    }
    return lps;
}
int kmp(string &txt, string &pat) {
    string s = pat + '#' + txt;
    vector<int> lps = build_lps(s);
    int ans = 0;
    for (auto x : lps) {
        if (x == pat.size()) ans++;
    }
    return ans;
}
int kmp(string &txt, string &pat) {
    vector<int> lps = build_lps(pat);
    int n = txt.size(), m = pat.size();
    int ans = 0;
    int j = 0;
    for (int i = 0; i < n; i++) {
        while (j > 0 and txt[i] != pat[j]) {
            j = lps[j - 1];
        }
        if (txt[i] == pat[j]) j++;
        if (j == m) {
            ans++;
            j = lps[j - 1];
        }
    }
    return ans;
}

```

7.7 KMP Automata

```

// like DFA. if string is "abcdeabg",
// aut[7]['c'] = 3. Means 7th index e
// 'c' bosaile LPS koto, aut[7]['g'] = 8
void compute_automaton(string s,
    vector<vector<int>>& aut) {
    s += '#';
    int n = s.size();
    vector<int> pi = build_lps(s);
    aut.assign(n, vector<int>(26));
    for (int i = 0; i < n; i++) {
        for (int c = 0; c < 26; c++) {

```

```

            if (i > 0 && 'a' + c != s[i])
                aut[i][c] = aut[pi[i - 1]][c];
            else
                aut[i][c] = i + ('a' + c == s[i]);
        }
    }
}

```

7.8 Prefix Occurrence Count

```

// Count the number of occurrences of each
// prefix
vector<int> ans(n + 1);
for (int i = 0; i < n; i++) ans[lps[i]]++;
for (int i = n - 1; i > 0; i--)
    ans[lps[i - 1]] += ans[i];
for (int i = 0; i <= n; i++) ans[i]++;

```

7.9 Number of palindromic substring in L to R using Wavelet Tree

```

// Problem - Kattis palindromes
11 f(int x) {
    return (1ll * x * (x + 1)) / 2;
}
11 f(int l, int r) {
    if (l > r) return 0;
    return f(r) - f(l - 1);
}
bool ok(int l, int r) {
    return hash_s.is_palindrome(l, r);
}
int32_t main() {
    cin >> s;
    n = s.size();
    hash_s = Hashing(s);
    for (int i = 1; i <= n; i++) {
        int l = 0, r = min(n - i, i - 1),
            cnt = 1;
        while (l <= r) {
            int mid = (l + r) >> 1;
            if (ok(i - mid, i + mid)) {
                cnt = mid;
                l = mid + 1;
            } else r = mid - 1;
        }
        pi1[i] = cnt + 1;
        pi1_left[i] = pi1[i] - i;
        pi1_right[i] = i + pi1[i];
    }
    for (int i = 2; i <= n; i++) {
        if (s[i - 1] == s[i - 2]) {
            int l = 0, r = min(n - i, i - 1),
                cnt = 2;
            while (l <= r) {
                int mid = (l + r) >> 1;
                if (ok(i - 1 - mid, i + mid)) {
                    cnt = mid;
                    l = mid + 1;
                } else r = mid - 1;
            }
            pi2[i] = cnt + 1;
        }
    }
}

```

```

else pi2[i] = 0;
pi2_left[i] = pi2[i] - i;
pi2_right[i] = i + pi2[i];
}
// wavelet trees (odd_len_left,
// odd_len_right, even_len_left,
// even_len_right)
t1.init(pi1_left + 1, pi1_left + n +
    1, -N, N);
t2.init(pi1_right + 1, pi1_right + n +
    1, -N, N);
t3.init(pi2_left + 1, pi2_left + n +
    1, -N, N);
t4.init(pi2_right + 1, pi2_right + n +
    1, -N, N);

int q; cin >> q;
while (q--) {
    int l, r; cin >> l >> r;
    // define k, find cnt > k and
    // summation whose are <= k;
    int m = (l + r) / 2;
    int k = l - 1;
    ll ans = f(l, m);
    ans += t1.sum(l, m, k);
    int cnt = t1.GT(l, m, k);
    ans += 1ll * k * cnt;
    k = l + r;
    ans -= -f(m + 1, r);
    ans += t2.sum(m + 1, r, k);
    cnt = t2.GT(m + 1, r, k);
    ans += 1ll * k * cnt;
    if (l + 1 <= m) { // a bit different
        than others
        k = -1;
        ans += f(l + 1, m);
        ans += t3.sum(l + 1, m, k);
        cnt = t3.GT(l + 1, m, k);
        ans += 1ll * k * cnt;
    }
    k = l + r;
    ans += -f(m + 1, r);
    ans += t4.sum(m + 1, r, k);
    cnt = t4.GT(m + 1, r, k);
    ans += 1ll * k * cnt;
    cout << ans << '\n';
}

```

It is easier to explain by considering only palindromes centered at indices (so, odd length), the idea is the same anyway. For each index i , r_i will be the longest radius of a palindrome centered there (in other words, the amount of palindromes centered at index i). Directly from manacher, this takes $\mathcal{O}(n)$ to calculate.

For a query $[l, r]$, we first compute $m = \frac{l+r}{2}$. Now we want to calculate

$$\sum_{i=l}^m \min(i-l+1, r_i) + \sum_{i=m+1}^r \min(r-i+1, r_i)$$

$$\sum_{i=l}^m \min(i-l+1, r_i) = \sum_{i=l}^m i + \min(1-l, r_i - i).$$

The sum over i can be found in constant time. As for the other term, if we create some array $r'_i = r_i - i$ during the preprocessing, then the queries are asking for some over range of $\min(C, r'_i)$ where C is constant. You can solve this in $\mathcal{O}(\log n)$ per query using wavelet tree.

7.10 Trie

```

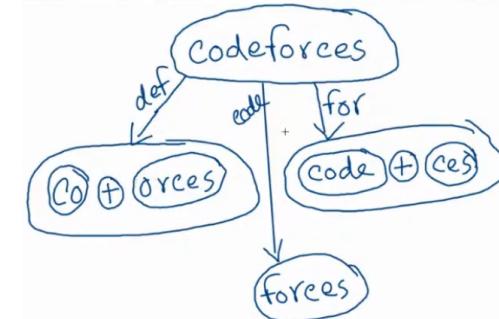
const int N = 10; // change here
const char base_char = '0'; // change
here
struct TrieNode {
    int cnt;
    TrieNode *nxt[N];
    TrieNode() {
        cnt = 0;
        for (int i = 0; i < N; i++) nxt[i] =
            NULL;
    }
    *root;
    void insert(const string &s) {
        TrieNode *cur = root;
        int n = (int)s.size();
        for (int i = 0; i < n; i++) {
            int idx = s[i] - base_char;
            if (cur -> nxt[idx] == NULL) cur ->
                nxt[idx] = new TrieNode();
            cur = cur -> nxt[idx];
            cur -> cnt++;
        }
    }
    void rem(TrieNode *cur, string &s, int
        pos) { // free :: De Alloactes Memory
        if (pos == s.size()) return;
        int idx = s[pos] - base_char;
        rem(cur -> nxt[idx], s, pos + 1);
        cur -> nxt[idx] -> cnt--;
        if (cur -> nxt[idx] -> cnt == 0) {
            free(cur -> nxt[idx]);
            cur -> nxt[idx] = NULL;
        }
    }
    int query(const string &s) { // "s" is a
        prefix of some element or not
        int n = (int)s.size();
        TrieNode *cur = root;
        for (int i = 0; i < n; i++) {
            int idx = s[i] - base_char;
            if (cur -> nxt[idx] == NULL) return 0;
            cur = cur -> nxt[idx];
        }
        return cur -> cnt;
    }
    void del(TrieNode *cur) {
        for (int i = 0; i < N; i++) if (cur ->
            nxt[i]) del(cur -> nxt[i]);
        delete(cur);
    }
    int32_t main() {
        root = new TrieNode(); // init new trie
        del(root); // clear trie
    }
}

```

8 Game Theory

8.1 Notes

- First Write a Bruteforce Solution
- If game is not impartial. Greedy, DP may work
- Nim = All XOR
- Misere Nim (Last player who took a stone loses) = Nim + (Corner Case: if all (odd) piles are 1 you lose)
- Bogus Nim = Nim
- Staircase Nim (Given an array where $a[i]$ is the number of stones at index i . Move: Choose any stones (> 1) from index i ($i > 1$) and move them to index $i-1$.) = Odd indexed pile Nim (Even indexed pile doesn't matter, as one player can give bogus moves to drop all even piles to ground)
- Sprague-Grundy:** Every impartial game under the normal play convention is equivalent to a ONE-HEAP GAME of NIM.
Grundy value can be calculate by DP/Pattern.



9 Misc.

9.1 [Trick] Median of Medians

Problem: Median of All Sub-Array Medians

Idea: Total Subarray, $k = \frac{n(n+1)}{2}$. We need all subarray medians, sort them and get $\frac{k}{2} + 1$. Now, Binary Search on Answer. `ok()` will return true if $cnt \geq \frac{k}{2} + 1$, where cnt = count of subarrays whose median is $\leq mid$. If true, $r = mid - 1$

9.2 Ternary Search

```

// Problem: Pyramid-ICPC Dhaka 2023
// Given the surface area of a square
// base pyramid, Need to maximize
// volume.
double suface_area;
double fun(double square_area) {
    double base = sqrt(square_area);
    double triangle_area = suface_area -
        square_area;
    double per_triangle_area =
        triangle_area / 4;
    double triangle_height =
        (per_triangle_area * 2) / base;
}

```

```

double x = base / 2;
double height = sqrt((triangle_height *
    triangle_height) - (x * x));
double volume = (base * base * height) /
    3;
if (x > triangle_height) volume = 0;
return volume;
}

int32_t main() {
    cin >> suface_area;
    double l = 0, r = suface_area, ans = -1;
    int it = 100;
    while (it--) {
        double mid1 = l + (r - l) / 3;
        double mid2 = r - (r - l) / 3;
        double x = fun(mid1);
        double y = fun(mid2);
        if (x > y) {
            ans = x;
            r = mid2;
        } else l = mid1;
    }
}

```

9.3 Pigeonhole Principle

- At least 1 subarray of an array of length N must be divisible by N .
- Build all possible sequences of length 10 whose value is between 1 to 100. At least any two sequences will be same.
- For $N \geq 100$, at least one 4-tuples XOR is 0.
- For $N > 20$ and $a_i \leq 10^6$, at least two subsets has same XOR. Because distinct XOR count can be 10^6 and Total Subset $2^{20} > 10^6$. Means there is a subset whose XOR is 0.

9.4 Matrix Expo

```

struct Mat {
    int n, m;
    vector<vector<int>> a;
    Mat() {}
    Mat(int _n, int _m) {n = _n; m = _m;
        a.assign(n, vector<int>(m, 0)); }
    Mat(vector<vector<int>> v) {n =
        v.size(); m = n ? v[0].size() : 0;
        a = v; }
    inline void make_unit() {
        assert(n == m);
        for (int i = 0; i < n; i++) {
            for (int j = 0; j < n; j++) {
                a[i][j] = i == j;
            }
        }
    }
    inline Mat operator + (const Mat &b) {
        assert(n == b.n && m == b.m);
        Mat ans = Mat(n, m);
        for (int i = 0; i < n; i++) {
            for (int j = 0; j < m; j++) {
                ans.a[i][j] = (a[i][j] +
                    b.a[i][j]) % mod;
            }
        }
    }
}

```

```

    }
    return ans;
}

inline Mat operator - (const Mat &b) {
    assert(n == b.n && m == b.m);
    Mat ans = Mat(n, m);
    for(int i = 0; i < n; i++) {
        for(int j = 0; j < m; j++) {
            ans.a[i][j] = (a[i][j] -
                b.a[i][j] + mod) % mod;
        }
    }
    return ans;
}

inline Mat operator * (const Mat &b) {
    assert(m == b.n);
    Mat ans = Mat(n, b.m);
    for(int i = 0; i < n; i++) {
        for(int j = 0; j < b.m; j++) {
            for(int k = 0; k < m; k++) {
                ans.a[i][j] = (ans.a[i][j] +
                    1LL * a[i][k] * b.a[k][j]
                    % mod) % mod;
            }
        }
    }
    return ans;
}

inline Mat pow(long long k) {
    assert(n == m);
    Mat ans(n, n), t = a; ans.make_unit();
    while (k) {
        if (k & 1) ans = ans * t;
        t = t * t;
        k >>= 1;
    }
    return ans;
}

inline Mat& operator += (const Mat& b)
    { return *this = (*this) + b; }

inline Mat& operator -= (const Mat& b)
    { return *this = (*this) - b; }

inline Mat& operator *= (const Mat& b)
    { return *this = (*this) * b; }

inline bool operator == (const Mat& b)
    { return a == b.a; }

inline bool operator != (const Mat& b)
    { return a != b.a; }

int32_t main() {
    int n; long long k; cin >> n >> k;
    Mat a(n, n); // then assign value
    Mat ans = a.pow(k);
}

```

9.5 2D Prefix Sum

```

const int N = 1e3 + 9;
int a[N][N];
ll pref[N][N];
void query(int x1, int y1, int x2, int
y2) {
    return pref[x2][y2] - pref[x1 -
    1][y2] - pref[x2][y1 - 1] +
    pref[x1 - 1][y1 - 1]
}

```

```

    }
    int32_t main() {
        int n, m; cin >> n >> m;
        for (int i = 1; i <= n; i++) {
            for (int j = 1; j <= m; j++) {
                pref[i][j] = pref[i - 1][j] +
                    pref[i][j - 1] - pref[i - 1][j - 1] +
                    a[i][j];
            }
        }
        int q; cin >> q;
        while (q--) {
            int x1, y1, x2, y2; cin >> x1 >> y1
                >> x2 >> y2;
            cout << query(x1, y1, x2, y2) << '\n';
        }
    }
}



---



## 9.6 2D Static Range Update



```

// Add x on a rectangle q times,
// Finally print the array
const int N = 1e3 + 9;
int a[N][N];
ll d[N][N]; // difference array
int32_t main() {
 int n, m; cin >> n >> m;
 int q; cin >> q;
 while (q--) {
 int x1, y1, x2, y2, x; cin >> x1 >>
 y1 >> x2 >> y2 >> x; // add x on
 this rectangle
 d[x1][y1] += x;
 d[x1][y2 + 1] -= x;
 d[x2 + 1][y1] -= x;
 d[x2 + 1][y2 + 1] += x;
 }
 for (int i = 1; i <= n; i++) {
 for (int j = 1; j <= m; j++) {
 d[i][j] += d[i - 1][j] + d[i][j - 1] -
 d[i - 1][j - 1];
 }
 }
 // new updated array
 for (int i = 1; i <= n; i++) {
 for (int j = 1; j <= m; j++) {
 cout << d[i][j] + a[i][j] << ' ';
 }
 cout << '\n';
 }
}

```


```

9.7 CHECK SET CLR

```

bool CHECK(int N, int pos) { return
    (bool)(N & (1ll << pos)); }
void SET(int &N, int pos) { (N |= (1ll
    << pos)); }
void CLR(int &N, int pos) { (N &= ~(1ll
    << pos)); }

```

9.8 Graph Directions

```

int dx[] = {+0, +0, +1, -1, -1, +1, -1,
    +1};
int dy[] = {-1, +1, +0, +0, +1, +1, -1,
    -1};

```

9.9 Custom Hash

```

struct custom_hash {
    static uint64_t splitmix64(uint64_t x) {
        x += 0x9e377f9b7f4a7c15;
        x = (x ^ (x >> 30)) *
            0xb58476d1ce4e5b9;
        x = (x ^ (x >> 27)) *
            0x94d049bb133111eb;
        return x ^ (x >> 31);
    }
    size_t operator()(uint64_t x) const {
        static const uint64_t FIXED_RANDOM =
            chrono::steady_clock::now().time_
            _since_epoch().count();
        return splitmix64(x + FIXED_RANDOM);
    }
}

```

9.10 Coordinate Compression

```

int32_t main() {
    vector<int> a({100, 9, 10, 10, 9});
    vector<int> v = a;
    sort(v.begin(), v.end());
    v.resize(unique(v.begin(), v.end()) -
        v.begin());
    for (int i = 0; i < a.size(); i++) {
        a[i] = lower_bound(v.begin(),
            v.end(), a[i]) - v.begin() + 1;
    }
}

```

9.11 Submask Generator

```

int mask = 0; // any value
for (int submask = mask; submask;
    submask = (submask - 1) & mask) {}

```

9.12 Custom Comparators

```

bool cmp(pair<int, int> a, pair<int,
        int> b) { // for vector, arr...
    if (a.first != b.first) return a.first
        > b.first;
    return a.second < b.second; // must
        return false for equal elements
}
struct cmp { // for set, map, pq...
    bool operator()(const int& a, const
        int& b) const {
        return a > b;
    }
}

```

9.13 MOD Operations

```

inline ll modAdd(ll a, ll b, ll MOD) {ll
    res = a + b; res += ((res >> 63) &
    MOD); if (res >= MOD) res -= MOD;
    return res;}
inline ll modSub(ll a, ll b, ll MOD) {ll
    res = a - b; res += ((res >> 63) &
    MOD); if (res >= MOD) res -= MOD;
    return res;}
inline ll modMul(ll a, ll b, ll MOD) {a
    %= MOD; b %= MOD; a += ((a >> 63) &
    MOD); b += ((b >> 63) & MOD); return
    (a * b) % MOD;}
inline ll modInverse(ll a, ll MOD)
    {return modPow(a, MOD - 2, MOD);}

```

```

inline ll modDiv(ll a, ll b, ll MOD)
    {return modMul(a, modInverse(b,
        MOD), MOD);}
inline ll modMulBigMod(ll a, ll b, ll
    MOD) {a %= MOD; b %= MOD; a += ((b >> 63) &
    MOD); b += ((b >> 63) & MOD); return
    (ll)((__int128)a * b % MOD);}

```

9.14 Mex with Array Updates

```

int32_t main() {
    int n, q; cin >> n >> q;
    set<int> missing_numbers;
    for (int i = 0; i <= n + 200; i++) {
        missing_numbers.insert(i);
    }
    int a[n + 1];
    map<int, int> freq;
    for (int i = 1; i <= n; i++) {
        cin >> a[i];
        freq[a[i]]++;
        missing_numbers.erase(a[i]);
    }
    while (q--) {
        int i, x; cin >> i >> x; // Set
        a[i] = x;
        int y = a[i]; a[i] = x;
        missing_numbers.erase(x);
        freq[y]--;
        freq[x]++;
        if (freq[y] == 0) {
            freq.erase(y);
            missing_numbers.insert(y);
        }
        cout << *missing_numbers.begin() <<
            '\n'; // mex after upd
    }
}

```

10 Geometry

10.1 Convex Hull

```

typedef vector<long long> vll;
typedef long double ld;
#define int long long
struct point {
    int x, y;
    point() {}
    point( int x, int y ) { this->x = x;
        this->y = y; }
    bool operator< ( const point &other ) {
        if ( x == other.x ) return y <
            other.y;
        return x < other.x;
    }
    int crossProduct( point &a, point &b,
        point &c ) {
        return (b.x - a.x) * (c.y - a.y) -
            (b.y - a.y) * (c.x - a.x);
    }
    vector<point> hull( vector<point> a ) {
        vector<point> v = a;
        sort(v.begin(), v.end());
    }
}

```

```

vector<point> lower, upper;
for ( auto& p : v ) {
    while ( lower.size() >= 2 &&
            crossProduct(lower[lower.size() - 2], lower.back(), p) < 0 ) //<= for colinear
        lower.pop_back();
    lower.push_back(p);
}
for ( int i = v.size() - 1; i >= 0;
      i-- ) {
    point p = v[i];
    while ( upper.size() >= 2 &&
            crossProduct(upper[upper.size() - 2], upper.back(), p) < 0 ) //<= for colinear
        upper.pop_back();
    upper.push_back(p);
}
lower.pop_back();
upper.pop_back();
lower.insert(lower.end(),
             upper.begin(), upper.end());
return lower;
}

void senritsu() {
    int n; cin >> n;
    vector<point> a(n); for ( int i = 0; i < n; i++ ) cin >> a[i].x >> a[i].y;
    a = hull(a);
    n = a.size();
    cout << n << endl;
    for ( auto c : a ) cout << c.x << ' '
                                << c.y << endl;
}

```

10.2 Area of 2 polygon intersection

```

typedef vector<long long> vll;
typedef long double ld;
#define int long long
struct point {
    ld x, y;
    point() {}
    point( ld x, ld y ) { this->x = x;
                           this->y = y; }
    bool operator<( const point &other ) {
        if ( x == other.x ) return y <
                               other.y;
        return x < other.x;
    }
    bool operator==( const point &other ) {
        return ( x == other.x && y ==
                  other.y );
    }
    bool operator!=( const point &other ) {
        return ( x != other.x || y !=
                  other.y );
    }
    point operator-( const point &other ) {
        return {x - other.x, y - other.y};
    }
};

ld crossProduct( point &a, point &b,
                 point &c ) {

```

```

    return (b.x - a.x) * (c.y - a.y) -
           (b.y - a.y) * (c.x - a.x);
}
ld crossProduct( point &a, point &b ) {
    return a.x * b.y - a.y * b.x;
}
bool inside( point &a, point &b, point
             &c ) {
    return crossProduct(a, b, c) >= 0;
}
bool intersection( point &a, point &b,
                    point &c, point &d, point &ans ) { //< 2 line intersection point
    point ab = b - a;
    point cd = d - c;
    ld det = crossProduct( ab, cd );
    if ( det == 0 ) return false; //parallel or collinear
    ld z1 = crossProduct( a, b );
    ld z2 = crossProduct( c, d );
    ans.x = (ld)(z1 * (c.x - d.x) - z2 *
                (a.x - b.x)) / det;
    ans.y = (ld)(z1 * (c.y - d.y) - z2 *
                (a.y - b.y)) / det;
    return true;
}
vector<point> innerhull( vector<point>
                        a, vector<point> b ) {
    int n = a.size();
    vector<point> ans = b;
    for ( int i = 0; i < n; i++ ) {
        point x = a[i], y = a[(i + 1) % n];
        vector<point> temp = ans; ans.clear();
        int m = temp.size();
        if ( m == 0 ) break;
        for ( int j = 0; j < m; j++ ) {
            point p = temp[j], q = temp[(j +
                1) % m];
            int pIn = inside(x, y, p);
            int qIn = inside(x, y, q);
            if ( pIn ) ans.push_back(p);
            if ( pIn != qIn ) {
                point cur;
                if ( intersection(x, y, p, q,
                                  cur) ) {
                    ans.push_back(cur);
                }
            }
        }
        if ( !ans.empty() ) {
            vector<point> temp;
            temp.push_back(ans[0]);
            for ( int j = 1; j < ans.size();
                  j++ ) {
                if ( ans[j] != ans[j - 1] ) {
                    temp.push_back(ans[j]);
                }
            }
            ans = temp;
        }
    }
    return ans;
}
ld areaOfPolygon( vector<point> a ) {
    if ( a.size() < 3 ) return 0.0;
    a.push_back(a[0]);
    int n = a.size();
    ld ans = 0;
    for ( int i = 0; i < n - 1; i++ ) {
        ans += a[i].x * a[i + 1].y;
        ans -= a[i].y * a[i + 1].x;
    }
    if ( ans < 0 ) ans = -ans;
    return ans / 2.0;
}
void senritsu() {
    int n, m; cin >> n >> m;
    vector<point> a(n), b(m);
    for ( int i = 0; i < n; i++ ) {
        cin >> a[i].x >> a[i].y;
    }
    for ( int i = 0; i < m; i++ ) {
        cin >> b[i].x >> b[i].y;
    }
    vector<point> in = innerhull(a, b);
    cout << fixed << setprecision(4) <<
        areaOfPolygon(in) << endl;
}

```