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1 Data structures

1.1 Dsu

```cpp
struct DSU {
  vector<int> ps;
  vector<int> size;
  DSU(int N) : ps(N + 1), size(N + 1, 1) { iota(ps.begin(), ps.end(), 0); }
  int find_set(int x) { return ps[x] == x ? x : ps[x] = find_set(ps[x]); }
  bool same_set(int x, int y) { return find_set(x) == find_set(y); }
  void union_set(int x, int y) {
    if (same_set(x, y)) return;

    int px = find_set(x);
    int py = find_set(y);

    if (size[px] < size[py]) swap(px, py);

    ps[py] = px;
    size[px] += size[py];
  }
};
```

1.2 Dsu (Python)

```python
class DSU:
    def __init__(self, n):
        self.n = n
        self.p = [x for x in range(0, n + 1)]
        self.size = [0 for i in range(0, n + 1)]

    def find_set(self, x):  # log n
        if self.p[x] == x:
            return x
        else:
            self.p[x] = self.find_set(self.p[x])
            return self.p[x]

    def same_set(self, x, y):  # log n
        return bool(self.find_set(x) == self.find_set(y))

    def union_set(self, x, y):  # log n
        px = self.find_set(x)
        py = self.find_set(y)

        if px == py:
            return

        size_x = self.size[px]
        size_y = self.size[py]

        if size_x > size_y:
            self.p[py] = self.p[px]
            self.size[px] += self.size[py]
        else:
            self.p[px] = self.p[py]
            self.size[py] += self.size[px]
```

1.3 Ordered Set Gnu Pbds

```cpp
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
template <typename T>
// using ordered_set = tree<T, null_type, less<T>, rb_tree_tag,
// tree_order_statistics_node_update>;

// if you want to find the elements less or equal :p
using ordered_set = tree<T, null_type, less_equal<T>, rb_tree_tag,
                         tree_order_statistics_node_update>;
```

1.4 Segtree Rmaxq Rmaxu

```cpp
template <typename T = ll>
struct SegTree {
  int N;
  T nu, nq;
  vector<T> st, lazy;
  SegTree(const vector<T> &xs)
    : N(len(xs)),
      nu(numeric_limits<T>::min()),
      nq(numeric_limits<T>::min()),
      st(4 * N + 1, nu),
      lazy(4 * N + 1, nu) {
    for (int i = 0; i < len(xs); ++i) update(i, i, xs[i]);
  }

  void update(int l, int r, T value) { update(1, 0, N - 1, l, r, value); }

  T query(int l, int r) { return query(1, 0, N - 1, l, r); }

  void update(int node, int nl, int nr, int ql, int qr, T v) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return;

    st[node] = max(st[node], v);
    if (ql <= nl and nr <= qr) {
      if (nl < nr) {
        lazy[left(node)] = max(lazy[left(node)], v);
        lazy[right(node)] = max(lazy[right(node)], v);
      }
      return;
    }
    update(left(node), nl, mid(nl, nr), ql, qr, v);
    update(right(node), mid(nl, nr) + 1, nr, ql, qr, v);

    st[node] = max(st[left(node)], st[right(node)]);
  }

  T query(int node, int nl, int nr, int ql, int qr) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return nq;

    if (ql <= nl and nr <= qr) return st[node];
    T x = query(left(node), nl, mid(nl, nr), ql, qr);
    T y = query(right(node), mid(nl, nr) + 1, nr, ql, qr);

    return max(x, y);
  }

  void propagation(int node, int nl, int nr) {
    if (lazy[node] != nu) {
      st[node] = max(st[node], lazy[node]);

      if (nl < nr) {
        lazy[left(node)] = max(lazy[left(node)], lazy[node]);
        lazy[right(node)] = max(lazy[right(node)], lazy[node]);
      }

      lazy[node] = nu;
    }
  }

  int left(int p) { return p << 1; }
  int right(int p) { return (p << 1) + 1; }
  int mid(int l, int r) { return (r - l) / 2 + l; }
};
int main() {
  int n;
  cin >> n;
  vector<array<int, 3>> xs(n);
  for (int i = 0; i < n; ++i) {
    for (int j = 0; j < 3; ++j) {
      cin >> xs[i][j];
    }
  }
  vi aux(n, 0);
  SegTree<int> st(aux);
  for (int i = 0; i < n; ++i) {
    int a = min(i + xs[i][1], n);
    int b = min(i + xs[i][2], n);
    st.update(i, i, st.query(i, i) + xs[i][0]);
    int cur = st.query(i, i);
    st.update(a, b, cur);
  }

  cout << st.query(0, n) << '\n';
}
```

1.5 Segtree Rminq Pau

```
template <typename T = ll>
struct SegTree {
  int n;
  T nu, nq;
  vector<T> st;
  SegTree(const vector<T> &v)
    : n(len(v)), nu(0), nq(numeric_limits<T>::max()), st(n * 4 + 1, nu) {
    for (int i = 0; i < n; ++i) update(i, v[i]);
  }
  void update(int p, T v) { update(1, 0, n - 1, p, v); }
  T query(int l, int r) { return query(1, 0, n - 1, l, r); }

  void update(int node, int nl, int nr, int p, T v) {
    if (p < nl or p > nr) return;

    if (nl == nr) {
      st[node] = v;
      return;
    }

    update(left(node), nl, mid(nl, nr), p, v);
    update(right(node), mid(nl, nr) + 1, nr, p, v);

    st[node] = min(st[left(node)], st[right(node)]);
  }

  T query(int node, int nl, int nr, int ql, int qr) {
    if (ql <= nl and qr >= nr) return st[node];
    if (nl > qr or nr < ql) return nq;
    if (nl == nr) return st[node];

    return min(query(left(node), nl, mid(nl, nr), ql, qr),
               query(right(node), mid(nl, nr) + 1, nr, ql, qr));
  }

  int left(int p) { return p << 1; }
  int right(int p) { return (p << 1) + 1; }
  int mid(int l, int r) { return (r - l) / 2 + l; }
};
```

1.6 Segtree Rminq Rsu

```
template <typename t = ll>
struct SegTree {
  int n;
  t nu;
  t nq;
  vector<t> st, lazy;
  SegTree(const vector<t> &xs)
    : n(len(xs)),
      nu(0),
      nq(numeric_limits<t>::max()),
      st(4 * n, nu),
      lazy(4 * n, nu) {
    for (int i = 0; i < len(xs); ++i) update(i, i, xs[i]);
  }

  SegTree(int n) : n(n), st(4 * n, nu), lazy(4 * n, nu) {}

  void update(int l, int r, ll value) { update(1, 0, n - 1, l, r, value); }

  t query(int l, int r) { return query(1, 0, n - 1, l, r); }

  void update(int node, int nl, int nr, int ql, int qr, ll v) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return;
    if (ql <= nl and nr <= qr) {
      st[node] += (nr - nl + 1) * v;

      if (nl < nr) {
        lazy[left(node)] += v;
        lazy[right(node)] += v;
      }

      return;
    }

    update(left(node), nl, mid(nl, nr), ql, qr, v);
    update(right(node), mid(nl, nr) + 1, nr, ql, qr, v);

    st[node] = min(st[left(node)], st[right(node)]);
  }

  t query(int node, int nl, int nr, int ql, int qr) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return nq;

    if (ql <= nl and nr <= qr) return st[node];

    t x = query(left(node), nl, mid(nl, nr), ql, qr);
    t y = query(right(node), mid(nl, nr) + 1, nr, ql, qr);

    return min(x, y);
  }

  void propagation(int node, int nl, int nr) {
    if (lazy[node]) {
      st[node] += lazy[node];

      if (nl < nr) {
        lazy[left(node)] += lazy[node];
        lazy[right(node)] += lazy[node];
      }

      lazy[node] = nu;
    }
  }

  int left(int p) { return p << 1; }
  int right(int p) { return (p << 1) + 1; }
  int mid(int l, int r) { return (r - l) / 2 + l; }
};
```

1.7 Segtree Rsq Rsu

```
template <typename T = ll>
struct SegTree {
  int N;
  vector<T> st, lazy;
  T nu = 0;
  T nq = 0;
  SegTree(const vector<T> &xs) : N(len(xs)), st(4 * N, nu), lazy(4 * N, nu) {
    for (int i = 0; i < len(xs); ++i) update(i, i, xs[i]);
  }

  SegTree(int n) : N(n), st(4 * N, nu), lazy(4 * N, nu) {}

  void update(int l, int r, ll value) { update(1, 0, N - 1, l, r, value); }

  T query(int l, int r) { return query(1, 0, N - 1, l, r); }

  void update(int node, int nl, int nr, int ql, int qr, ll v) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return;

    if (ql <= nl and nr <= qr) {
      st[node] += (nr - nl + 1) * v;

      if (nl < nr) {
        lazy[left(node)] += v;
        lazy[right(node)] += v;
      }

      return;
    }

    update(left(node), nl, mid(nl, nr), ql, qr, v);
    update(right(node), mid(nl, nr) + 1, nr, ql, qr, v);

    st[node] = st[left(node)] + st[right(node)];
  }

  T query(int node, int nl, int nr, int ql, int qr) {
    propagation(node, nl, nr);

    if (ql > nr or qr < nl) return nq;

    if (ql <= nl and nr <= qr) return st[node];

    T x = query(left(node), nl, mid(nl, nr), ql, qr);
    T y = query(right(node), mid(nl, nr) + 1, nr, ql, qr);

    return x + y;
  }

  void propagation(int node, int nl, int nr) {
    if (lazy[node]) {
      st[node] += (nr - nl + 1) * lazy[node];

      if (nl < nr) {
        lazy[left(node)] += lazy[node];
        lazy[right(node)] += lazy[node];
      }

      lazy[node] = nu;
    }
  }

  int left(int p) { return p << 1; }
  int right(int p) { return (p << 1) + 1; }
  int mid(int l, int r) { return (r - l) / 2 + l; }
};
```

1.8 Sparse Table Rminq

```
/*
        Sparse table implementation for rmq.
        build: O(NlogN)
        query: O(1)
*/
int fastlog2(ll x) {
  ull i = x;
  return i ? __builtin_clzll(1) - __builtin_clzll(i) : -1;
}
template <typename T>
class SparseTable {
 public:
  int N;
  int K;
  vector<vector<T>> st;
  SparseTable(vector<T> vs)
    : N((int)vs.size()), K(fastlog2(N) + 1), st(K + 1, vector<T>(N + 1)) {
    copy(vs.begin(), vs.end(), st[0].begin());

    for (int i = 1; i <= K; ++i)
      for (int j = 0; j + (1 << i) <= N; ++j)
        st[i][j] = min(st[i - 1][j], st[i - 1][j + (1 << (i - 1))]);
  }
  T RMQ(int l, int r) {  // [l, r], 0 indexed
    int i = fastlog2(r - l + 1);
    return min(st[i][l], st[i][r - (1 << i) + 1]);
  }
};
```

2 Dynamic programming

2.1 Edit Distance

```
int edit_distance(const string &a, const string &b) {
  int n = a.size();
  int m = b.size();
  vector<vi> dp(n + 1, vi(m + 1, 0));

  int ADD = 1, DEL = 1, CHG = 1;
  for (int i = 0; i <= n; ++i) {
    dp[i][0] = i * DEL;
  }
  for (int i = 1; i <= m; ++i) {
    dp[0][i] = ADD * i;
  }

  for (int i = 1; i <= n; ++i) {
    for (int j = 1; j <= m; ++j) {
      int add = dp[i][j - 1] + ADD;
      int del = dp[i - 1][j] + DEL;
      int chg = dp[i - 1][j - 1] + (a[i - 1] == b[j - 1] ? 0 : 1) * CHG;
      dp[i][j] = min({add, del, chg});
    }
  }

  return dp[n][m];
}
```

2.2 Kadane

```
/*
 * Find the maximum sum subarray in a given array.
 * O(N)
 * */
int kadane(const vi &as) {
  vi s(len(as));
  s[0] = as[0];

  for (int i = 1; i < len(as); ++i) s[i] = max(as[i], s[i - 1] + as[i]);

  return *max_element(all(s));
}
```

2.3 Knapsack (value)

```
const int MAXN{2010}, MAXM{2010};

ll st[MAXN][MAXM];

ll dp(int i, int m, int M, const vii &cs) {
  if (i < 0) return 0;

  if (st[i][m] != -1) return st[i][m];

  auto res = dp(i - 1, m, M, cs);
  auto [w, v] = cs[i];

  if (w <= m) res = max(res, dp(i - 1, m - w, M, cs) + v);

  st[i][m] = res;
  return res;
}

ll knapsack(int M, const vii &cs) {
  memset(st, -1, sizeof st);

  return dp((int)cs.size() - 1, M, M, cs);
}
```

2.4 Knapsack With Elements

```
const int MAXN{2010}, MAXM{2010};
ll st[MAXN][MAXM];
char ps[MAXN][MAXM];

pair<ll, vi> knapsack(int M, const vii &cs) {
  int N = len(cs) - 1;

  for (int i = 0; i <= N; ++i) st[i][0] = 0;
  for (int m = 0; m <= M; ++m) st[0][m] = 0;

  for (int i = 1; i <= N; ++i) {
    for (int m = 1; m <= M; ++m) {
      st[i][m] = st[i - 1][m];
      ps[i][m] = 0;
      auto [w, v] = cs[i];

      if (w <= m and st[i - 1][m - w] + v > st[i][m]) {
        st[i][m] = st[i - 1][m - w] + v;
        ps[i][m] = 1;
      }
    }
  }

  int m = M;
  vi is;
  for (int i = N; i >= 1; --i) {
    if (ps[i][m]) {
      is.push_back(i);
      m -= cs[i].first;
    }
  }

  reverse(all(is));

  // max value, items
  return {st[N][M], is};
}
```

2.5 Longest Increasing Sequence

```
int LIS(int N, const vector<int> &as) {
  vector<int> lis(N + 1, oo);
  lis[0] = -oo;

  auto ans = 0;

  for (int i = 0; i < N; ++i) {
    auto it = lower_bound(lis.begin(), lis.end(), as[i]);
    auto pos = (int)(it - lis.begin());

    ans = max(ans, pos);
    lis[pos] = as[i];
  }

  return ans;
}
```

2.6 Money Sum Bottom Up

```
/*
   find every possible sum using
   the given values only once.
*/
set<int> money_sum(const vi &xs) {
  using vc = vector<char>;
  using vvc = vector<vc>;
  int _m = accumulate(all(xs), 0);
  int _n = xs.size();
  vvc _dp(_n + 1, vc(_m + 1, 0));
  set<int> _ans;
  _dp[0][xs[0]] = 1;
  for (int i = 1; i < _n; ++i) {
    for (int j = 0; j <= _m; ++j) {
      if (j == 0 or _dp[i - 1][j]) {
        _dp[i][j + xs[i]] = 1;
        _dp[i][j] = 1;
      }
    }
  }

  for (int i = 0; i < _n; ++i)
    for (int j = 0; j <= _m; ++j)
      if (_dp[i][j]) _ans.insert(j);
  return _ans;
}
```

2.7 Tsp

```
using vi = vector<int>;
vector<vi> dist;
vector<vi> memo;
/* O ( N^2 * 2^N )*/
int tsp(int i, int mask, int N) {
  if (mask == (1 << N) - 1) return dist[i][0];
  if (memo[i][mask] != -1) return memo[i][mask];
  int ans = INT_MAX << 1;
  for (int j = 0; j < N; ++j) {
    if (mask & (1 << j)) continue;
    auto t = tsp(j, mask | (1 << j), N) + dist[i][j];
    ans = min(ans, t);
  }
  return memo[i][mask] = ans;
}
```

3 Extras

3.1 Bigint

```
const int maxn = 1e2 + 14, lg = 15;
const int base = 1000000000;
const int base_digits = 9;
struct bigint {
  vector<int> a;
  int sign;

  int size() {
    if (a.empty()) return 0;
    int ans = (a.size() - 1) * base_digits;
    int ca = a.back();
    while (ca) ans++, ca /= 10;
    return ans;
  }
```

```cpp
bigint operator^(const bigint &v) {
  bigint ans = 1, a = *this, b = v;
  while (!b.isZero()) {
    if (b % 2) ans *= a;
    a *= a, b /= 2;
  }
  return ans;
}
string to_string() {
  stringstream ss;
  ss << *this;
  string s;
  ss >> s;
  return s;
}
int sumof() {
  string s = to_string();
  int ans = 0;
  for (auto c : s) ans += c - '0';
  return ans;
}
/*</arpa>*/
bigint() : sign(1) {}

bigint(long long v) { *this = v; }

bigint(const string &s) { read(s); }

void operator=(const bigint &v) {
  sign = v.sign;
  a = v.a;
}

void operator=(long long v) {
  sign = 1;
  a.clear();
  if (v < 0) sign = -1, v = -v;
  for (; v > 0; v = v / base) a.push_back(v % base);
}

bigint operator+(const bigint &v) const {
  if (sign == v.sign) {
    bigint res = v;

    for (int i = 0, carry = 0; i < (int)max(a.size(), v.a.size()) || carry;
         ++i) {
      if (i == (int)res.a.size()) res.a.push_back(0);
      res.a[i] += carry + (i < (int)a.size() ? a[i] : 0);
      carry = res.a[i] >= base;
      if (carry) res.a[i] -= base;
    }
    return res;
  }
  return *this - (-v);
}

bigint operator-(const bigint &v) const {
  if (sign == v.sign) {
    if (abs() >= v.abs()) {
      bigint res = *this;
      for (int i = 0, carry = 0; i < (int)v.a.size() || carry; ++i) {
        res.a[i] -= carry + (i < (int)v.a.size() ? v.a[i] : 0);
        carry = res.a[i] < 0;
        if (carry) res.a[i] += base;
      }
      res.trim();
      return res;
    }
    return -(v - *this);
  }
  return *this + (-v);
}

void operator*=(int v) {
  if (v < 0) sign = -sign, v = -v;
  for (int i = 0, carry = 0; i < (int)a.size() || carry; ++i) {
    if (i == (int)a.size()) a.push_back(0);
    long long cur = a[i] * (long long)v + carry;
    carry = (int)(cur / base);
    a[i] = (int)(cur % base);
    // asm("divl %%ecx" : "=a"(carry), "=d"(a[i]) :
    // "A"(cur), "c"(base));
  }
  trim();
}

bigint operator*(int v) const {
  bigint res = *this;
  res *= v;
  return res;
}

void operator*=(long long v) {
  if (v < 0) sign = -sign, v = -v;
  if (v > base) {
    *this = *this * (v / base) * base + *this * (v % base);
    return;
  }
  for (int i = 0, carry = 0; i < (int)a.size() || carry; ++i) {
    if (i == (int)a.size()) a.push_back(0);
    long long cur = a[i] * (long long)v + carry;
    carry = (int)(cur / base);
    a[i] = (int)(cur % base);
    // asm("divl %%ecx" : "=a"(carry), "=d"(a[i]) :
    // "A"(cur), "c"(base));
  }
  trim();
}

bigint operator*(long long v) const {
  bigint res = *this;
  res *= v;
  return res;
}

friend pair<bigint, bigint> divmod(const bigint &a1, const bigint &b1) {
  int norm = base / (b1.a.back() + 1);
  bigint a = a1.abs() * norm;
  bigint b = b1.abs() * norm;
  bigint q, r;
  q.a.resize(a.a.size());

  for (int i = a.a.size() - 1; i >= 0; i--) {
    r *= base;
    r += a.a[i];
    int s1 = r.a.size() <= b.a.size() ? 0 : r.a[b.a.size()];
    int s2 = r.a.size() <= b.a.size() - 1 ? 0 : r.a[b.a.size() - 1];
    int d = ((long long)base * s1 + s2) / b.a.back();
    r -= b * d;
    while (r < 0) r += b, --d;
    q.a[i] = d;
  }

  q.sign = a1.sign * b1.sign;
  r.sign = a1.sign;
  q.trim();
  r.trim();
  return make_pair(q, r / norm);
}

bigint operator/(const bigint &v) const { return divmod(*this, v).first; }

bigint operator%(const bigint &v) const { return divmod(*this, v).second; }

void operator/=(int v) {
  if (v < 0) sign = -sign, v = -v;
  for (int i = (int)a.size() - 1, rem = 0; i >= 0; --i) {
    long long cur = a[i] + rem * (long long)base;
    a[i] = (int)(cur / v);
    rem = (int)(cur % v);
  }
  trim();
}

bigint operator/(int v) const {
  bigint res = *this;
  res /= v;
  return res;
}

int operator%(int v) const {
  if (v < 0) v = -v;
  int m = 0;
  for (int i = a.size() - 1; i >= 0; --i)
    m = (a[i] + m * (long long)base) % v;
  return m * sign;
}

void operator+=(const bigint &v) { *this = *this + v; }
void operator-=(const bigint &v) { *this = *this - v; }
void operator*=(const bigint &v) { *this = *this * v; }
void operator/=(const bigint &v) { *this = *this / v; }

bool operator<(const bigint &v) const {
  if (sign != v.sign) return sign < v.sign;
  if (a.size() != v.a.size()) return a.size() * sign < v.a.size() * v.sign;
  for (int i = a.size() - 1; i >= 0; i--)
    if (a[i] != v.a[i]) return a[i] * sign < v.a[i] * sign;
  return false;
}

bool operator>(const bigint &v) const { return v < *this; }
bool operator<=(const bigint &v) const { return !(v < *this); }
bool operator>=(const bigint &v) const { return !(*this < v); }
bool operator==(const bigint &v) const {
  return !(*this < v) && !(v < *this);
}
bool operator!=(const bigint &v) const { return *this < v || v < *this; }

void trim() {
  while (!a.empty() && !a.back()) a.pop_back();
  if (a.empty()) sign = 1;
}

bool isZero() const { return a.empty() || (a.size() == 1 && !a[0]); }

bigint operator-() const {
  bigint res = *this;
  res.sign = -sign;
  return res;
}

bigint abs() const {
  bigint res = *this;
  res.sign *= res.sign;
  return res;
}

long long longValue() const {
  long long res = 0;
  for (int i = a.size() - 1; i >= 0; i--) res = res * base + a[i];
  return res * sign;
}

friend bigint gcd(const bigint &a, const bigint &b) {
  return b.isZero() ? a : gcd(b, a % b);
}
friend bigint lcm(const bigint &a, const bigint &b) {
  return a / gcd(a, b) * b;
}

void read(const string &s) {
  sign = 1;
  a.clear();
  int pos = 0;
  while (pos < (int)s.size() && (s[pos] == '-' || s[pos] == '+')) {
    if (s[pos] == '-') sign = -sign;
    ++pos;
  }
  for (int i = s.size() - 1; i >= pos; i -= base_digits) {
    int x = 0;
    for (int j = max(pos, i - base_digits + 1); j <= i; j++)
```

```
      x = x * 10 + s[j] - '0';
    a.push_back(x);
  }
  trim();
}

friend istream &operator>>(istream &stream, bigint &v) {
  string s;
  stream >> s;
  v.read(s);
  return stream;
}

friend ostream &operator<<(ostream &stream, const bigint &v) {
  if (v.sign == -1) stream << '-';
  stream << (v.a.empty() ? 0 : v.a.back());
  for (int i = (int)v.a.size() - 2; i >= 0; --i)
    stream << setw(base_digits) << setfill('0') << v.a[i];
  return stream;
}

static vector<int> convert_base(const vector<int> &a, int old_digits,
                                int new_digits) {
  vector<long long> p(max(old_digits, new_digits) + 1);
  p[0] = 1;
  for (int i = 1; i < (int)p.size(); i++) p[i] = p[i - 1] * 10;
  vector<int> res;
  long long cur = 0;
  int cur_digits = 0;
  for (int i = 0; i < (int)a.size(); i++) {
    cur += a[i] * p[cur_digits];
    cur_digits += old_digits;
    while (cur_digits >= new_digits) {
      res.push_back(int(cur % p[new_digits]));
      cur /= p[new_digits];
      cur_digits -= new_digits;
    }
  }
  res.push_back((int)cur);
  while (!res.empty() && !res.back()) res.pop_back();
  return res;
}

typedef vector<long long> vll;

static vll karatsubaMultiply(const vll &a, const vll &b) {
  int n = a.size();
  vll res(n + n);
  if (n <= 32) {
    for (int i = 0; i < n; i++)
      for (int j = 0; j < n; j++) res[i + j] += a[i] * b[j];
    return res;
  }

  int k = n >> 1;
  vll a1(a.begin(), a.begin() + k);
  vll a2(a.begin() + k, a.end());
  vll b1(b.begin(), b.begin() + k);
  vll b2(b.begin() + k, b.end());

  vll a1b1 = karatsubaMultiply(a1, b1);
  vll a2b2 = karatsubaMultiply(a2, b2);

  for (int i = 0; i < k; i++) a2[i] += a1[i];
  for (int i = 0; i < k; i++) b2[i] += b1[i];

  vll r = karatsubaMultiply(a2, b2);
  for (int i = 0; i < (int)a1b1.size(); i++) r[i] -= a1b1[i];
  for (int i = 0; i < (int)a2b2.size(); i++) r[i] -= a2b2[i];

  for (int i = 0; i < (int)r.size(); i++) res[i + k] += r[i];
  for (int i = 0; i < (int)a1b1.size(); i++) res[i] += a1b1[i];
  for (int i = 0; i < (int)a2b2.size(); i++) res[i + n] += a2b2[i];
  return res;
}

bigint operator*(const bigint &v) const {
  vector<int> a6 = convert_base(this->a, base_digits, 6);
  vector<int> b6 = convert_base(v.a, base_digits, 6);
  vll a(a6.begin(), a6.end());
  vll b(b6.begin(), b6.end());
  while (a.size() < b.size()) a.push_back(0);
  while (b.size() < a.size()) b.push_back(0);
  while (a.size() & (a.size() - 1)) a.push_back(0), b.push_back(0);
  vll c = karatsubaMultiply(a, b);
  bigint res;
  res.sign = sign * v.sign;
  for (int i = 0, carry = 0; i < (int)c.size(); i++) {
    long long cur = c[i] + carry;
    res.a.push_back((int)(cur % 1000000));
    carry = (int)(cur / 1000000);
  }
  res.a = convert_base(res.a, 6, base_digits);
  res.trim();
  return res;
}
};
```

3.2 Binary To Gray

```
string binToGray(string bin) {
  string gray(bin.size(), '0');
  int n = bin.size() - 1;
  gray[0] = bin[0];
  for (int i = 1; i <= n; i++) {
    gray[i] = '0' + (bin[i - 1] == '1') ^ (bin[i] == '1');
  }
  return gray;
}
```

3.3 Get Permutation Cicles

```
/*
 * receives a permutation [0, n-1]
 * returns a vector of cicles
 * for example: [ 1, 0, 3, 4, 2] -> [[0, 1], [2, 3, 4]]
 * */
vector<vll> getPermutationCicles(const vll &ps) {
  ll n = len(ps);
  vector<char> visited(n);
  vector<vll> cicles;
  for (int i = 0; i < n; ++i) {
    if (visited[i]) continue;

    vll cicle;
    ll pos = i;
    while (!visited[pos]) {
      cicle.pb(pos);
      visited[pos] = true;
      pos = ps[pos];
    }

    cicles.push_back(vll(all(cicle)));
  }
  return cicles;
}
```

4 Geometry

4.1 Point Template

```
const ld EPS = 1e-6;

typedef ld T;
bool eq(T a, T b) { return abs(a - b) <= EPS; }
struct point {
  T x, y;
  int id;
  point(T x = 0, T y = 0) : x(x), y(y) {}
  point operator+(const point &o) const { return {x + o.x, y + o.y}; }
  point operator-(const point &o) const { return {x - o.x, y - o.y}; }
  point operator*(T t) const { return {x * t, y * t}; }
  point operator/(T t) const { return {x / t, y / t}; }
  T operator*(const point &o) const {
    return x * o.x + y * o.y;
  }  // dot product
  T operator^(const point &o) const {
    return x * o.y - y * o.x;
  }  // cross product
};

ld dist(point a, point b) {
  point d = a - b;
  return sqrt(d * d);
}
```

5 Graphs

5.1 2 SAT (struct)

```
struct SAT2 {
ll n;
vll2d adj, adj_t;
vc used;
vll order, comp;
vc assignment;
bool solvable;
SAT2(ll _n)
  : n(2 * _n),
    adj(n),
    adj_t(n),
    used(n),
    order(n),
    comp(n, -1),
    assignment(n / 2) {}
void dfs1(int v) {
  used[v] = true;
  for (int u : adj[v]) {
    if (!used[u]) dfs1(u);
  }
  order.push_back(v);
}

void dfs2(int v, int cl) {
  comp[v] = cl;
  for (int u : adj_t[v]) {
    if (comp[u] == -1) dfs2(u, cl);
  }
}

bool solve_2SAT() {
  // find and label each SCC
  for (int i = 0; i < n; ++i) {
    if (!used[i]) dfs1(i);
  }
  reverse(all(order));
  ll j = 0;
  for (auto &v : order) {
    if (comp[v] == -1) dfs2(v, j++);
  }

  assignment.assign(n / 2, false);
  for (int i = 0; i < n; i += 2) {
    // x and !x belong to the same SCC
    if (comp[i] == comp[i + 1]) {
      solvable = false;
      return false;
    }

    assignment[i / 2] = comp[i] > comp[i + 1];
  }
  solvable = true;
  return true;
}

void add_disjunction(int a, bool na, int b, bool nb) {
  a = (2 * a) ^ na;
  b = (2 * b) ^ nb;
  int neg_a = a ^ 1;
```

```
    int neg_b = b ^ 1;
    adj[neg_a].push_back(b);
    adj[neg_b].push_back(a);
    adj_t[b].push_back(neg_a);
    adj_t[a].push_back(neg_b);
  }
};
```

5.2 SCC (struct)

```
struct SCC {
  ll N;
  vll2d adj, tadj;
  vll todo, comps, comp;
  vector<set<ll>> sccadj;
  vchar vis;
  SCC(ll _N) : N(_N), adj(_N), tadj(_N), comp(_N, -1), sccadj(_N), vis(_N) {}

  void add_edge(ll x, ll y) { adj[x].eb(y), tadj[y].eb(x); }

  void dfs(ll x) {
    vis[x] = 1;
    for (auto &y : adj[x])
      if (!vis[y]) dfs(y);
    todo.pb(x);
  }
  void dfs2(ll x, ll v) {
    comp[x] = v;
    for (auto &y : tadj[x])
      if (comp[y] == -1) dfs2(y, v);
  }
  void gen() {
    for (ll i = 0; i < N; ++i)
      if (!vis[i]) dfs(i);
    reverse(all(todo));
    for (auto &x : todo)
      if (comp[x] == -1) {
        dfs2(x, x);
        comps.pb(x);
      }
  }

  void genSCCGraph() {
    for (ll i = 0; i < N; ++i) {
      for (auto &j : adj[i]) {
        if (comp[i] != comp[j]) {
          sccadj[comp[i]].insert(comp[j]);
        }
      }
    }
  }
};
```

5.3 SCC Nodes (kosajaru)

```
/*
 * O(n+m)
 * Returns a pair <a, b>
 *      a: number of SCCs
 *      b: vector of size n, where b[i] is the SCC id of node i
 * */
void dfs(ll u, vchar &visited, const vll2d &g, vll &scc, bool buildScc, ll id,
         vll &sccid) {
  visited[u] = true;
  sccid[u] = id;
  for (auto &v : g[u])
    if (!visited[v]) dfs(v, visited, g, scc, buildScc, id, sccid);

  // if it's the first pass, add the node to the scc
  if (buildScc) scc.eb(u);
}

pair<ll, vll> kosajaru(vll2d &g) {
  ll n = len(g);
  vll scc;
  vchar vis(n);
  vll sccid(n);
  for (ll i = 0; i < n; i++)
    if (!vis[i]) dfs(i, vis, g, scc, true, 0, sccid);

  // build the transposed graph
  vll2d gt(n);
  for (int i = 0; i < n; ++i)
    for (auto &v : g[i]) gt[v].eb(i);

  // run the dfs on the previous scc order
  ll id = 1;
  vis.assign(n, false);
  for (ll i = len(scc) - 1; i >= 0; i--)
    if (!vis[scc[i]]) {
      dfs(scc[i], vis, gt, scc, false, id++, sccid);
    }
  return {id - 1, sccid};
}
```

5.4 Bellman Ford

```
bool bellman_ford(const vector<vector<pair<int, ll>>> &g, int s,
                  vector<ll> &dist) {
  int n = (int)g.size();
  dist.assign(n, LLONG_MAX);

  vector<int> count(n);
  vector<char> in_queue(n);
  queue<int> q;

  dist[s] = 0;
  q.push(s);
  in_queue[s] = true;

  while (not q.empty()) {
    int cur = q.front();
    q.pop();
    in_queue[cur] = false;
    for (auto [to, w] : g[cur]) {
      if (dist[cur] + w < dist[to]) {
        dist[to] = dist[cur] + w;
        if (not in_queue[to]) {
          q.push(to);
          in_queue[to] = true;
          count[to]++;
          if (count[to] > n) return false;
        }
      }
    }
  }

  return true;
}
```

5.5 Check Bipartite

```
// O(V)
bool checkBipartite(const ll n, const vector<vll> &adj) {
  ll s = 0;
  queue<ll> q;
  q.push(s);
  vll color(n, INF);
  color[s] = 0;
  bool isBipartite = true;
  while (!q.empty() && isBipartite) {
    ll u = q.front();
    q.pop();
    for (auto &v : adj[u]) {
      if (color[v] == INF) {
        color[v] = 1 - color[u];
        q.push(v);
      } else if (color[v] == color[u]) {
        return false;
      }
    }
  }
  return true;
}
```

5.6 Count SCC (kosajaru)

```
void dfs(ll u, vchar &visited, const vll2d &g, vll &scc, bool buildScc) {
  visited[u] = true;
  for (auto &v : g[u])
    if (!visited[v]) dfs(v, visited, g, scc, buildScc);

  // if it's the first pass, add the node to the scc
  if (buildScc) scc.eb(u);
}

ll kosajaru(vll2d &g) {
  ll n = len(g);
  vll scc;
  vchar vis(n);
  for (ll i = 0; i < n; i++)
    if (!vis[i]) dfs(i, vis, g, scc, true);

  // build the transposed graph
  vll2d gt(n);
  for (int i = 0; i < n; ++i)
    for (auto &v : g[i]) gt[v].eb(i);

  // run the dfs on the previous scc order
  ll scccnt = 0;
  vis.assign(n, false);
  for (ll i = len(scc) - 1; i >= 0; i--)
    if (!vis[scc[i]]) dfs(scc[i], vis, gt, scc, false), scccnt++;
  return scccnt;
}
```

5.7 Dijkstra

```
ll __inf = LLONG_MAX >> 5;
vll dijkstra(const vector<vector<pll>> &g, ll n) {
  priority_queue<pll, vector<pll>, greater<pll>> pq;
  vll dist(n, __inf);
  vector<char> vis(n);
  pq.emplace(0, 0);
  dist[0] = 0;
  while (!pq.empty()) {
    auto [d1, v] = pq.top();
    pq.pop();
    if (vis[v]) continue;
    vis[v] = true;

    for (auto [d2, u] : g[v]) {
      if (dist[u] > d1 + d2) {
        dist[u] = d1 + d2;
        pq.emplace(dist[u], u);
      }
    }
  }
  return dist;
}
```

5.8 Floyd Warshall

```
vector<vll> floyd_warshall(const vector<vll> &adj, ll n) {
  auto dist = adj;

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

5.9 Kruskal (Python)

```
class DSU:
    def __init__(self, n):
        self.n = n
        self.p = [x for x in range(0, n + 1)]
        self.size = [0 for i in range(0, n + 1)]

    def find_set(self, x):
        if self.p[x] == x:
            return x
        else:
            self.p[x] = self.find_set(self.p[x])
            return self.p[x]

    def same_set(self, x, y):
        return bool(self.find_set(x) == self.find_set(y))

    def union_set(self, x, y):
        px = self.find_set(x)
        py = self.find_set(y)

        if px == py:
            return

        size_x = self.size[px]
        size_y = self.size[py]

        if size_x > size_y:
            self.p[py] = self.p[px]
            self.size[px] += self.size[py]
        else:
            self.p[px] = self.p[py]
            self.size[py] += self.size[px]


def kruskal(gv, n):
    """
    Receives te list of edges as a list of tuple in the form:
        d, u, v
        d: distance between u  and v
    And also n as the total of verties.
    """
    dsu = DSU(n)

    c = 0
    for e in gv:
        d, u, v = e
        if not dsu.same_set(u, v):
            c += d
            dsu.union_set(u, v)

    return c
```

5.10 Lowest Common Ancestor Sparse Table

```
int fastlog2(ll x) {
  ull i = x;
  return i ? __builtin_clzll(1) - __builtin_clzll(i) : -1;
}
template <typename T>
class SparseTable {
 public:
  int N;
  int K;
  vector<vector<T>> st;
  SparseTable(vector<T> vs)
    : N((int)vs.size()), K(fastlog2(N) + 1), st(K + 1, vector<T>(N + 1)) {
    copy(vs.begin(), vs.end(), st[0].begin());

    for (int i = 1; i <= K; ++i)
      for (int j = 0; j + (1 << i) <= N; ++j)
        st[i][j] = min(st[i - 1][j], st[i - 1][j + (1 << (i - 1))]);
  }
  SparseTable() {}
  T RMQ(int l, int r) {
    int i = fastlog2(r - l + 1);
    return min(st[i][l], st[i][r - (1 << i) + 1]);
  }
};
class LCA {
 public:
  int p;
  int n;
  vi first;
  vector<char> visited;
  vi vertices;
  vi height;
  SparseTable<int> st;

  LCA(const vector<vi> &g)
    : p(0), n((int)g.size()), first(n + 1), visited(n + 1, 0), height(n + 1) {
    build_dfs(g, 1, 1);
    st = SparseTable<int>(vertices);
  }

  void build_dfs(const vector<vi> &g, int u, int hi) {
    visited[u] = true;
    height[u] = hi;
    first[u] = vertices.size();
    vertices.push_back(u);
    for (auto uv : g[u]) {
      if (!visited[uv]) {
        build_dfs(g, uv, hi + 1);
        vertices.push_back(u);
      }
    }
  }

  int lca(int a, int b) {
    int l = min(first[a], first[b]);
    int r = max(first[a], first[b]);
    return st.RMQ(l, r);
  }
};
```

5.11 Topological Sorting

```
/*
```

```
 * O(V)
 * assumes:
 *       * vertices have index [0, n-1]
 * if is a DAG:
 *      * returns a topological sorting
 * else:
 *     * returns an empty vector
 * */
enum class state { not_visited, processing, done };
bool dfs(const vector<vll> &adj, ll s, vector<state> &states, vll &order) {
  states[s] = state::processing;
  for (auto &v : adj[s]) {
    if (states[v] == state::not_visited) {
      if (not dfs(adj, v, states, order)) return false;
    } else if (states[v] == state::processing)
      return false;
  }
  states[s] = state::done;
  order.pb(s);
  return true;
}
vll topologicalSorting(const vector<vll> &adj) {
  ll n = len(adj);
  vll order;
  vector<state> states(n, state::not_visited);
  for (int i = 0; i < n; ++i) {
    if (states[i] == state::not_visited) {
      if (not dfs(adj, i, states, order)) return {};
    }
  }
  reverse(all(order));
  return order;
}
```

6 Math

6.1 Arithmetic Progression Sum

```
/*
 * s: first term
 * d: common difference
 * n: number of terms
 */
ll arithmeticProgressionSum(ll s, ll d, ll n) {
  return (s + (s + d * (n - 1))) * n / 2ll;
}
```

6.2 Combinatorics With Repetitions

```
void combinations_with_repetition(int n, int k,
                                  function<void(const vector<int> &)> process)
     {
  vector<int> v(k, 1);
  int pos = k - 1;

  while (true) {
    process(v);
    v[pos]++;

    while (pos > 0 and v[pos] > n) {
      --pos;
      v[pos]++;
    }

    if (pos == 0 and v[pos] > n) break;

    for (int i = pos + 1; i < k; ++i) v[i] = v[pos];

    pos = k - 1;
  }
}
```

6.3 Count Divisors Memo

```
const ll mod = 1073741824;
const ll maxd = 100 * 100 * 100 + 1;
vector<ll> memo(maxd, -1);
ll countdivisors(ll x) {
  ll ox = x;
  ll ans = 1;
  for (ll i = 2; i <= x; ++i) {
    if (memo[x] != -1) {
      ans *= memo[x];
      break;
    }
    ll count = 0;
    while (x and x % i == 0) {
      x /= i;
      count++;
    }
    ans *= (count + 1);
  }
  memo[ox] = ans;
  return ans;
}
```

6.4 Euler Phi

```
const ll MAXN = 1e5;
vll list_primes(ll n) {  // Nlog * log N
  vll ps;
  bitset<MAXN> sieve;
  sieve.set();
  sieve.reset(1);
  for (ll i = 2; i <= n; ++i) {
    if (sieve[i]) ps.push_back(i);
    for (ll j = i * 2; j <= n; j += i) {
      sieve.reset(j);
    }
  }
  return ps;
}

vector<pll> factorization(ll n, const vll &primes) {
  vector<pll> ans;
  for (auto &p : primes) {
    if (n == 1) break;
    ll cnt = 0;
    while (n % p == 0) {
      cnt++;
      n /= p;
    }
    if (cnt) ans.emplace_back(p, cnt);
  }
  return ans;
}

ll phi(ll n, vector<pll> factors) {
  if (n == 1) return 1;
  ll ans = n;

  for (auto [p, k] : factors) {
    ans /= p;
    ans *= (p - 1);
  }

  return ans;
}
```

6.5 Factorial Factorization

```
// O(logN) greater k that p^k | n
ll E(ll n, ll p) {
  ll k = 0, b = p;
  while (b <= n) {
    k += n / b;
    b *= p;
  }
  return k;
}

// lsit every prime until MAXN O(Nlog * log N)
const ll MAXN = 1e5;
vll list_primes(ll n) {
  vll ps;
  bitset<MAXN> sieve;
  sieve.set();
  sieve.reset(1);
  for (ll i = 2; i <= n; ++i) {
    if (sieve[i]) ps.push_back(i);
    for (ll j = i * 2; j <= n; j += i) sieve.reset(j);
  }
  return ps;
}

// O(pi(N)*logN)
map<ll, ll> factorial_factorization(ll n, const vll &primes) {
  map<ll, ll> fs;
  for (const auto &p : primes) {
    if (p > n) break;
    fs[p] = E(n, p);
  }
  return fs;
}
```

6.6 Factorial

```
const ll MAX = 18;
vll fv(MAX, -1);
ll factorial(ll n) {
  if (fv[n] != -1) return fv[n];
  if (n == 0) return 1;
  return n * factorial(n - 1);
}
```

6.7 Factorization With Primes

```
// Nlog * log N
const ll MAXN = 1e5;
vll list_primes(ll n) {
  vll ps;
  bitset<MAXN> sieve;
  sieve.set();
  sieve.reset(1);
  for (ll i = 2; i <= n; ++i) {
    if (sieve[i]) ps.push_back(i);
    for (ll j = i * 2; j <= n; j += i) sieve.reset(j);
  }
  return ps;
}

// O(pi(sqrt(n)))
map<ll, ll> factorization(ll n, const vll &primes) {
  map<ll, ll> ans;
  for (auto p : primes) {
    if (p * p > n) break;
    ll count = 0;
    for (; n % p == 0; count++, n /= p)
      ;
    if (count) ans[p] = count;
  }
  return ans;
}
```

6.8 Factorization

```
// O(sqrt(n))
map<ll, ll> factorization(ll n) {
  map<ll, ll> ans;
  for (ll i = 2; i * i <= n; i++) {
    ll count = 0;
    for (; n % i == 0; count++, n /= i)
      ;
    if (count) ans[i] = count;
  }
  if (n > 1) ans[n]++;
  return ans;
}
```

6.9 Fast Fourrier Transform

```
template <bool invert = false>
void fft(vector<complex<double>>& xs) {
  int N = (int)xs.size();

  if (N == 1) return;

  vector<complex<double>> es(N / 2), os(N / 2);

  for (int i = 0; i < N / 2; ++i) es[i] = xs[2 * i];

  for (int i = 0; i < N / 2; ++i) os[i] = xs[2 * i + 1];

  fft<invert>(es);
  fft<invert>(os);

  auto signal = (invert ? 1 : -1);
  auto theta = 2 * signal * acos(-1) / N;
  complex<double> S{1}, S1{cos(theta), sin(theta)};

  for (int i = 0; i < N / 2; ++i) {
    xs[i] = (es[i] + S * os[i]);
    xs[i] /= (invert ? 2 : 1);

    xs[i + N / 2] = (es[i] - S * os[i]);
    xs[i + N / 2] /= (invert ? 2 : 1);

    S *= S1;
  }
}
```

6.10 Fast Exp

```
/*
  Fast exponentiation algorithm,
  compute a^n in O(log(n))
*/
ll fexp(ll a, int n) {
  if (n == 0) return 1;
  if (n == 1) return a;
  ll x = fexp(a, n / 2);
  return x * x * (n & 1 ? a : 1);
}
```

6.11 Gauss Elimination

```
template <size_t Dim>
struct GaussianElimination {
  vector<ll> basis;
  size_t size;

  GaussianElimination() : basis(Dim + 1), size(0) {}

  void insert(ll x) {
    for (ll i = Dim; i >= 0; i--) {
      if ((x & 1ll << i) == 0) continue;

      if (!basis[i]) {
        basis[i] = x;
        size++;
        break;
      }

      x ^= basis[i];
    }
  }

  void normalize() {
    for (ll i = Dim; i >= 0; i--)
      for (ll j = i - 1; j >= 0; j--)
        if (basis[i] & 1ll << j) basis[i] ^= basis[j];
  }

  bool check(ll x) {
    for (ll i = Dim; i >= 0; i--) {
      if ((x & 1ll << i) == 0) continue;

      if (!basis[i]) return false;

      x ^= basis[i];
    }

    return true;
  }

  auto operator[](ll k) { return at(k); }

  ll at(ll k) {
    ll ans = 0;
    ll total = 1ll << size;
    for (ll i = Dim; ~i; i--) {
      if (!basis[i]) continue;

      ll mid = total >> 1ll;
      if ((mid < k and (ans & 1ll << i) == 0) ||
          (k <= mid and (ans & 1ll << i)))
        ans ^= basis[i];

      if (mid < k) k -= mid;

      total >>= 1ll;
    }
    return ans;
  }

  ll at_normalized(ll k) {
    ll ans = 0;
    k--;
    for (size_t i = 0; i <= Dim; i++) {
      if (!basis[i]) continue;
      if (k & 1) ans ^= basis[i];
      k >>= 1;
    }
    return ans;
  }
};
```

6.12 Gcd Using Factorization

```
// O(sqrt(n))
map<ll, ll> factorization(ll n) {
  map<ll, ll> ans;
  for (ll i = 2; i * i <= n; i++) {
    ll count = 0;
    for (; n % i == 0; count++, n /= i)
      ;
    if (count) ans[i] = count;
  }
  if (n > 1) ans[n]++;
  return ans;
}

ll gcd_with_factorization(ll a, ll b) {
  map<ll, ll> fa = factorization(a);
  map<ll, ll> fb = factorization(b);
  ll ans = 1;
  for (auto fai : fa) {
    ll k = min(fai.second, fb[fai.first]);
    while (k--) ans *= fai.first;
  }
  return ans;
}
```

6.13 Gcd

```
ll gcd(ll a, ll b) { return b ? gcd(b, a % b) : a; }
```

6.14 Integer Mod

```
const ll INF = 1e18;
const ll mod = 998244353;
template <ll MOD = mod>
struct Modular {
  ll value;
  static const ll MOD_value = MOD;

  Modular(ll v = 0) {
    value = v % MOD;
    if (value < 0) value += MOD;
  }
  Modular(ll a, ll b) : value(0) {
    *this += a;
    *this /= b;
  }

  Modular& operator+=(Modular const& b) {
    value += b.value;
    if (value >= MOD) value -= MOD;
    return *this;
  }
  Modular& operator-=(Modular const& b) {
    value -= b.value;
    if (value < 0) value += MOD;
    return *this;
  }
  Modular& operator*=(Modular const& b) {
    value = (ll)value * b.value % MOD;
    return *this;
  }

  friend Modular mexp(Modular a, ll e) {
    Modular res = 1;
    while (e) {
      if (e & 1) res *= a;
      a *= a;
      e >>= 1;
    }
    return res;
  }
  friend Modular inverse(Modular a) { return mexp(a, MOD - 2); }

  Modular& operator/=(Modular const& b) { return *this *= inverse(b); }
  friend Modular operator+(Modular a, Modular const b) { return a += b; }
  Modular operator++(int) { return this->value = (this->value + 1) % MOD; }
  Modular operator++() { return this->value = (this->value + 1) % MOD; }
  friend Modular operator-(Modular a, Modular const b) { return a -= b; }
  friend Modular operator-(Modular const a) { return 0 - a; }
  Modular operator--(int) {
    return this->value = (this->value - 1 + MOD) % MOD;
  }

  Modular operator--() { return this->value = (this->value - 1 + MOD) % MOD; }
  friend Modular operator*(Modular a, Modular const b) { return a *= b; }
  friend Modular operator/(Modular a, Modular const b) { return a /= b; }
  friend std::ostream& operator<<(std::ostream& os, Modular const& a) {
    return os << a.value;
  }
  friend bool operator==(Modular const& a, Modular const& b) {
    return a.value == b.value;
  }
  friend bool operator!=(Modular const& a, Modular const& b) {
    return a.value != b.value;
  }
};
```

6.15 Is Prime

```
bool isprime(ll n) {  // O(sqrt(n))
  if (n < 2) return false;
  if (n == 2) return true;
  if (n % 2 == 0) return false;
  for (ll i = 3; i * i < n; i += 2)
    if (n % i == 0) return false;
  return true;
}
```

6.16 Lcm Using Factorization

```
map<ll, ll> factorization(ll n) {
  map<ll, ll> ans;
  for (ll i = 2; i * i <= n; i++) {
    ll count = 0;
    for (; n % i == 0; count++, n /= i)
      ;
    if (count) ans[i] = count;
  }
  if (n > 1) ans[n]++;
  return ans;
}

ll lcm_with_factorization(ll a, ll b) {
  map<ll, ll> fa = factorization(a);
  map<ll, ll> fb = factorization(b);
  ll ans = 1;
  for (auto fai : fa) {
    ll k = max(fai.second, fb[fai.first]);
    while (k--) ans *= fai.first;
  }
  return ans;
}
```

6.17 Lcm

```
ll gcd(ll a, ll b) { return b ? gcd(b, a % b) : a; }
ll lcm(ll a, ll b) { return a / gcd(a, b) * b; }
```

6.18 Modular Inverse Using Phi

```
map<ll, ll> factorization(ll n) {
  map<ll, ll> ans;
  for (ll i = 2; i * i <= n; i++) {
    ll count = 0;
    for (; n % i == 0; count++, n /= i)
      ;
    if (count) ans[i] = count;
  }
  if (n > 1) ans[n]++;
  return ans;
}

ll phi(ll n) {
  if (n == 1) return 1;

  auto fs = factorization(n);
  auto res = n;

  for (auto [p, k] : fs) {
    res /= p;
    res *= (p - 1);
  }

  return res;
}

ll fexp(ll a, ll n, ll mod) {
  if (n == 0) return 1;
  if (n == 1) return a;
  ll x = fexp(a, n / 2, mod);
  return x * x * (n & 1 ? a : 1) % mod;
}
```

```
ll inv(ll a, ll mod) { return fexp(a, phi(mod) - 1, mod); }
```

6.19 N Choose K Count

```
/*
 * O(nm) time, O(m) space
 * equal to n choose k
 * */
ll binom(ll n, ll k) {
  if (k > n) return 0;
  vll dp(k + 1, 0);
  dp[0] = 1;
  for (ll i = 1; i <= n; i++)
    for (ll j = k; j > 0; j--) dp[j] = dp[j] + dp[j - 1];
  return dp[k];
}
```

6.20 Permutation Count

```
const ll MAX = 18;
vll fv(MAX, -1);
ll factorial(ll n) {
  if (fv[n] != -1) return fv[n];
  if (n == 0) return 1;
  return n * factorial(n - 1);
}

template <typename T>
ll permutation_count(vector<T> xs) {
  map<T, ll> h;
  for (auto xi : xs) h[xi]++;
  ll ans = factorial((ll)xs.size());
  dbg(ans);
  for (auto [v, cnt] : h) {
    dbg(cnt);
    ans /= cnt;
  }

  return ans;
}
```

6.21 Polynomial

```
using polynomial = vector<ll>;
int degree(const polynomial &xs) { return xs.size() - 1; }
ll horner_evaluate(const polynomial &xs, ll x) {
  ll ans = 0;
  ll n = degree(xs);
  for (int i = n; i >= 0; --i) {
    ans *= x;
    ans += xs[i];
  }
  return ans;
}
polynomial operator+(const polynomial &a, const polynomial &b) {
  int n = degree(a);
  int m = degree(b);
  polynomial r(max(n, m) + 1, 0);

  for (int i = 0; i <= n; ++i) r[i] += a[i];
  for (int j = 0; j <= m; ++j) r[j] += b[j];
  while (!r.empty() and r.back() == 0) r.pop_back();
  if (r.empty()) r.push_back(0);
  return r;
}
polynomial operator*(const polynomial &p, const polynomial &q) {
  int n = degree(p);
  int m = degree(q);
  polynomial r(n + m + 1, 0);
  for (int i = 0; i <= n; ++i)
    for (int j = 0; j <= m; ++j) r[i + j] += (p[i] * q[j]);
  return r;
}
```

6.22 Power Sum

```
// calculates K^0 + K^1 ... + K^n
ll fastpow(ll a, int n) {
  if (n == 1) return a;
  ll x = fastpow(a, n / 2);
  return x * x * (n & 1 ? a : 1);
}
ll powersum(ll n, ll k) { return (fastpow(n, k + 1) - 1) / (n - 1); }
```

6.23 Sieve List Primes

```
// lsit every prime until MAXN
const ll MAXN = 1e5;
vll list_primes(ll n) {  // Nlog * log N
  vll ps;
  bitset<MAXN> sieve;
  sieve.set();
  sieve.reset(1);
  for (ll i = 2; i <= n; ++i) {
    if (sieve[i]) ps.push_back(i);
    for (ll j = i * 2; j <= n; j += i) {
      sieve.reset(j);
    }
  }
  return ps;
}
```

7 Searching

7.1 Ternary Search Recursive

```
const double eps = 1e-6;

// IT MUST BE AN UNIMODAL FUNCTION
double f(int x) { return x * x + 2 * x + 4; }

double ternary_search(double l, double r) {
  if (fabs(f(l) - f(r)) < eps) return f((l + (r - l) / 2.0));

  auto third = (r - l) / 3.0;
  auto m1 = l + third;
  auto m2 = r - third;

  // change the signal to find the maximum point.
  return m1 < m2 ? ternary_search(m1, r) : ternary_search(l, m2);
}
```

8 Strings

8.1 Hash Range Query

```
struct Hash {
  const ll P = 31;
  int n;
  string s;
  vll h, hi, p;
  Hash() {}
  Hash(string s) : s(s), n(s.size()), h(n), hi(n), p(n) {
    for (int i = 0; i < n; i++) p[i] = (i ? P * p[i - 1] : 1) % MOD;
    for (int i = 0; i < n; i++) h[i] = (s[i] + (i ? h[i - 1] : 0) * P) % MOD;
    for (int i = n - 1; i >= 0; i--)
      hi[i] = (s[i] + (i + 1 < n ? hi[i + 1] : 0) * P) % MOD;
  }
  ll query(int l, int r) {
    ll hash = (h[r] - (l ? h[l - 1] * p[r - l + 1] % MOD : 0));
    return hash < 0 ? hash + MOD : hash;
  }
  ll query_inv(int l, int r) {
    ll hash = (hi[l] - (r + 1 < n ? hi[r + 1] * p[r - l + 1] % MOD : 0));
    return hash < 0 ? hash + MOD : hash;
  }
};
```

8.2 Longest Palindrome

```
string longest_palindrome(const string &s) {
  int n = (int)s.size();
  vector<array<int, 2>> dp(n);

  pii odd(0, -1), even(0, -1);
  pii ans;
  for (int i = 0; i < n; i++) {
    int k = 0;
    if (i > odd.second)
      k = 1;
    else
      k = min(dp[odd.first + odd.second - i][0], odd.second - i + 1);
    while (i - k >= 0 and i + k < n and s[i - k] == s[i + k]) k++;
    dp[i][0] = k--;
    if (i + k > odd.second) odd = {i - k, i + k};
    if (2 * dp[i][0] - 1 > ans.second) ans = {i - k, 2 * dp[i][0] - 1};

    k = 0;
    if (i <= even.second)
    k = min(dp[even.first + even.second - i + 1][1], even.second - i + 1);
    while (i - k - 1 >= 0 and i + k < n and s[i - k - 1] == s[i + k]) k++;
    dp[i][1] = k--;
    if (i + k > even.second) even = {i - k - 1, i + k};
    if (2 * dp[i][1] > ans.second) ans = {i - k - 1, 2 * dp[i][1]};
  }
  return s.substr(ans.first, ans.second);
}
```

8.3 Rabin Karp

```
size_t rabin_karp(const string &s, const string &p) {
  if (s.size() < p.size()) return 0;

  auto n = s.size(), m = p.size();
  const ll p1 = 31, p2 = 29, q1 = 1e9 + 7, q2 = 1e9 + 9;
  const ll p1_1 = fpow(p1, q1 - 2, q1), p1_2 = fpow(p1, m - 1, q1);
  const ll p2_1 = fpow(p2, q2 - 2, q2), p2_2 = fpow(p2, m - 1, q2);

  pair<ll, ll> hs, hp;
  for (int i = (int)m - 1; ~i; --i) {
    hs.first = (hs.first * p1) % q1;
    hs.first = (hs.first + (s[i] - 'a' + 1)) % q1;
    hs.second = (hs.second * p2) % q2;
    hs.second = (hs.second + (s[i] - 'a' + 1)) % q2;

    hp.first = (hp.first * p1) % q1;
    hp.first = (hp.first + (p[i] - 'a' + 1)) % q1;
    hp.second = (hp.second * p2) % q2;
    hp.second = (hp.second + (p[i] - 'a' + 1)) % q2;
  }

  size_t occ = 0;
  for (size_t i = 0; i < n - m; i++) {
    occ += (hs == hp);

    int fi = s[i] - 'a' + 1;
    int fm = s[i + m] - 'a' + 1;

    hs.first = (hs.first - fi + q1) % q1;
    hs.first = (hs.first * p1_1) % q1;
    hs.first = (hs.first + fm * p1_2) % q1;
    hs.second = (hs.second - fi + q2) % q2;
    hs.second = (hs.second * p2_1) % q2;
    hs.second = (hs.second + fm * p2_2) % q2;
  }
  occ += hs == hp;

  return occ;
}
```

8.4 String Psum

```
struct strPsum {
  ll n;
  ll k;
  vector<vll> psum;
  strPsum(const string &s) : n(s.size()), k(100), psum(k, vll(n + 1)) {
    for (ll i = 1; i <= n; ++i) {
      for (ll j = 0; j < k; ++j) {
        psum[j][i] = psum[j][i - 1];
      }
      psum[s[i - 1]][i]++;
    }
  }

  ll qtd(ll l, ll r, char c) {  // [0,n-1]
    return psum[c][r + 1] - psum[c][l];
  }
}
```

8.5 Suffix Automaton (complete)

```
struct state {
  int len, link, cnt;
  // this can be optimized using a vector with the alphabet size
  map<char, int> next;
};

struct SuffixAutomaton {
  vector<state> st;
  int sz = 0;
  int last;
  vc cloned;

  SuffixAutomaton(const string &s, int maxlen)
    : st(maxlen * 2), cloned(maxlen * 2) {
    st[0].len = 0;
    st[0].link = -1;
    sz++;
    last = 0;
    for (auto &c : s) add_char(c);

    // precompute for count occurences
    for (int i = 1; i < sz; i++) {
      st[i].cnt = !cloned[i];
    }
    vector<pair<state, int>> aux;
    for (int i = 0; i < sz; i++) {
      aux.push_back({st[i], i});
    }

    sort(all(aux), [](const pair<state, int> &a, const pair<state, int> &b) {
      return a.fst.len > b.fst.len;
    });

    for (auto &[stt, id] : aux) {
      if (stt.link != -1) {
        st[stt.link].cnt += st[id].cnt;
      }
    }
  }

  void add_char(char c) {
    int cur = sz++;
    st[cur].len = st[last].len + 1;
    int p = last;
    // follow the suffix link until find a transition to c
    while (p != -1 and !st[p].next.count(c)) {
      st[p].next[c] = cur;
      p = st[p].link;
    }
    // there was no transition to c so create and leave
    if (p == -1) {
      st[cur].link = 0;
      last = cur;
      return;
    }

    int q = st[p].next[c];
    if (st[p].len + 1 == st[q].len) {
      st[cur].link = q;
    } else {
      int clone = sz++;
      cloned[clone] = true;
      st[clone].len = st[p].len + 1;
      st[clone].next = st[q].next;
      st[clone].link = st[q].link;
      while (p != -1 and st[p].next[c] == q) {
        st[p].next[c] = clone;
        p = st[p].link;
      }
      st[q].link = st[cur].link = clone;
    }
    last = cur;
  }

  bool checkOccurrence(const string &t) {  // O(len(t))
    int cur = 0;
    for (auto &c : t) {
      if (!st[cur].next.count(c)) return false;
      cur = st[cur].next[c];
      int cur = 0;
      for (auto &c : t) {
        if (!st[cur].next.count(c)) return 0;
        cur = st[cur].next[c];
      }
      return st[cur].cnt;
    }
  };
```

8.6 Trie Naive

```
//  time: O(n^2) memory: O(n^2)
using Node = map<char, int>;
using vi = vector<int>;
using Trie = vector<Node>;

Trie build(const string &s) {
  int n = (int)s.size();
  Trie trie(1);
  string suffix;

  for (int i = n - 1; i >= 0; --i) {
    suffix = s.substr(i) + '#';

    int v = 0;  // root
    for (auto c : suffix) {
      if (c == '#') {  // makrs the poistion of an occurence
        trie[v][c] = i;
        break;
      }
      if (trie[v][c])
        v = trie[v][c];
      else {
        trie.push_back({});
        trie[v][c] = trie.size() - 1;
        v = trie.size() - 1;
      }
    }
  }
  return trie;
}

vi search(Trie &trie, string s) {
  int p = 0;
  vi occ;
  for (auto &c : s) {
    p = trie[p][c];
    if (!p) return occ;
  }

  queue<int> q;
  q.push(0);
  while (!q.empty()) {
    auto cur = q.front();
    q.pop();
    for (auto [c, v] : trie[cur]) {
      if (c == '#')
        occ.push_back(v);
      else
        q.push(v);
    }
  }
  return occ;
}

ll distinct_substr(const Trie &trie) {
  ll cnt = 0;
  queue<int> q;
  q.push(0);
  while (!q.empty()) {
    auto u = q.front();
    q.pop();

    for (auto [c, v] : trie[u]) {
      if (c != '#') {
        cnt++;
        q.push(v);
      }
    }
  }
  return cnt;
}
```

8.7 Z Function Get Occurence Positions

```
/*
 * ans[i] = a position where p matchs
 * with s perfectly starting
 * O(len(s)+len(p))
 * */
vi getOccPos(string &s, string &p) {
  // Z-function
  char delim = '#';
  string t{p + delim + s};
  vi zs(len(t));

  int l = 0, r = 0;
  for (int i = 1; i < len(t); i++) {
    if (i <= r) zs[i] = min(zs[i - l], r - i + 1);
    while (zs[i] + i < len(t) and t[zs[i]] == t[i + zs[i]]) zs[i]++;
    if (r < i + zs[i] - 1) l = i, r = i + zs[i] - 1;
  }

  // Iterate over the results of Z-function to get ranges
  vi ans;
  int start = len(p) + 1 + 1 - 1;
  for (int i = start; i < len(zs); i++) {
    if (zs[i] == len(p)) {
      int l = i - start;
      ans.emplace_back(l);
    }
  }
  return ans;
}
```

9 Trees

9.1 Binary Lifting

```
/*
 * far[h][i] = the node that 2^h far from node i
 * sometimes is useful invert the order of loops
 * time : O(nlogn)
 * */
const int maxlog = 20;
int far[maxlog + 1][n + 1];
int n;
for (int h = 1; h <= maxlog; h++) {
  for (int i = 1; i <= n; i++) {
    far[h][i] = far[h - 1][far[h - 1][i]];
  }
}
```

9.2 Maximum Distances

```
/*
 * Returns the maximum distance from every node to any other node in the tree.
 * */
pll mostDistantFrom(const vector<vll> &adj, ll n, ll root) {
  // 0 indexed
  ll mostDistantNode = root;
  ll nodeDistance = 0;
  queue<pll> q;
  vector<char> vis(n);
  q.emplace(root, 0);
  vis[root] = true;
  while (!q.empty()) {
    auto [node, dist] = q.front();
    q.pop();
    if (dist > nodeDistance) {
      nodeDistance = dist;
      mostDistantNode = node;
    }
    for (auto u : adj[node]) {
      if (!vis[u]) {
        vis[u] = true;
        q.emplace(u, dist + 1);
      }
    }
  }
  return {mostDistantNode, nodeDistance};
}

ll twoNodesDist(const vector<vll> &adj, ll n, ll a, ll b) {
  queue<pll> q;
  vector<char> vis(n);
  q.emplace(a, 0);
  while (!q.empty()) {
    auto [node, dist] = q.front();
    q.pop();
    if (node == b) return dist;
    for (auto u : adj[node]) {
      if (!vis[u]) {
        vis[u] = true;
        q.emplace(u, dist + 1);
      }
    }
  }
  return -1;
}

tuple<ll, ll, ll> tree_diameter(const vector<vll> &adj, ll n) {
  // returns two points of the diameter and the diameter itself
  auto [node1, dist1] = mostDistantFrom(adj, n, 0);
  auto [node2, dist2] = mostDistantFrom(adj, n, node1);
  auto diameter = twoNodesDist(adj, n, node1, node2);
  return make_tuple(node1, node2, diameter);
}

vll everyDistanceFromNode(const vector<vll> &adj, ll n, ll root) {
  // Single Source Shortest Path, from a given root
  queue<pair<ll, ll>> q;
  vll ans(n, -1);
  ans[root] = 0;
  q.emplace(root, 0);
  while (!q.empty()) {
    auto [u, d] = q.front();
    q.pop();

    for (auto w : adj[u]) {
      if (ans[w] != -1) continue;
      ans[w] = d + 1;
      q.emplace(w, d + 1);
    }
  }
  return ans;
}

vll maxDistances(const vector<vll> &adj, ll n) {
  auto [node1, node2, diameter] = tree_diameter(adj, n);
  auto distances1 = everyDistanceFromNode(adj, n, node1);
  auto distances2 = everyDistanceFromNode(adj, n, node2);
  vll ans(n);
  for (int i = 0; i < n; ++i) ans[i] = max(distances1[i], distances2[i]);
  return ans;
}
```

9.3 Tree Diameter

```
pll mostDistantFrom(const vector<vll> &adj, ll n, ll root) {
  // 0 indexed
  ll mostDistantNode = root;
  ll nodeDistance = 0;
  queue<pll> q;
  vector<char> vis(n);
  q.emplace(root, 0);
  vis[root] = true;
  while (!q.empty()) {
    auto [node, dist] = q.front();
    q.pop();
    if (dist > nodeDistance) {
      nodeDistance = dist;
      mostDistantNode = node;
    }
    for (auto u : adj[node]) {
      if (!vis[u]) {
        vis[u] = true;
        q.emplace(u, dist + 1);
      }
    }
  }
  return {mostDistantNode, nodeDistance};
}
ll twoNodesDist(const vector<vll> &adj, ll n, ll a, ll b) {
  // 0 indexed
  queue<pll> q;
  vector<char> vis(n);
  q.emplace(a, 0);
  while (!q.empty()) {
    auto [node, dist] = q.front();
    q.pop();
    if (node == b) {
      return dist;
    }
    for (auto u : adj[node]) {
      if (!vis[u]) {
        vis[u] = true;
        q.emplace(u, dist + 1);
      }
    }
  }
  return -1;
}
ll tree_diameter(const vector<vll> &adj, ll n) {
  // 0 indexed !!!
  auto [node1, dist1] = mostDistantFrom(adj, n, 0);
  auto [node2, dist2] = mostDistantFrom(adj, n, node1);
  auto diameter = twoNodesDist(adj, n, node1, node2);
  return diameter;
}
```

10 Settings and macros

10.1 .vimrc

```
set ts=4 sw=4 sta nu rnu sc cindent
set bg=dark ruler clipboard=unnamed,unnamedplus, timeoutlen=100
colorscheme default

nnoremap <C-j> :botright belowright term bash <CR>
syntax on
```

10.2 degug.cpp

```
#include <bits/stdc++.h>
using namespace std;
/******** Debug Code *******/
template <typename T>
concept Printable = requires(T t) {
    { std::cout << t } -> std::same_as<std::ostream &>;
};
template <Printable T>
void __print(const T &x) {
    cerr << x;
}
template <size_t T>
void __print(const bitset<T> &x) {
    cerr << x;
}
template <typename A, typename B>
void __print(const pair<A, B> &p);
template <typename... A>
void __print(const tuple<A...> &t);
template <typename T>
void __print(stack<T> s);
template <typename T>
void __print(queue<T> q);
template <typename T, typename... U>
void __print(priority_queue<T, U...> q);
```

```cpp
template <typename A>
void __print(const A &x) {
    bool first = true;
    cerr << '{';
    for (const auto &i : x) {
        cerr << (first ? "" : ","), __print(i);
        first = false;
    }
    cerr << '}';
}
template <typename A, typename B>
void __print(const pair<A, B> &p) {
    cerr << '(';
    __print(p.first);
    cerr << ',';
    __print(p.second);
    cerr << ')';
}
template <typename... A>
void __print(const tuple<A...> &t) {
    bool first = true;
    cerr << '(';
    apply(
        [&first](const auto &...args) {
            ((cerr << (first ? "" : ","), __print(args), first = false), ...);
        },
        t);
    cerr << ')';
}
template <typename T>
void __print(stack<T> s) {
    vector<T> debugVector;
    while (!s.empty()) {
        T t = s.top();
        debugVector.push_back(t);
        s.pop();
    }
    reverse(debugVector.begin(), debugVector.end());
    __print(debugVector);
}
template <typename T>
void __print(queue<T> q) {
    vector<T> debugVector;
    while (!q.empty()) {
        T t = q.front();
        debugVector.push_back(t);
        q.pop();
    }
    __print(debugVector);
}
template <typename T, typename... U>
void __print(priority_queue<T, U...> q) {
    vector<T> debugVector;
    while (!q.empty()) {
        T t = q.top();
        debugVector.push_back(t);
        q.pop();
    }
    __print(debugVector);
}
void _print() { cerr << "]\n"; }
template <typename Head, typename... Tail>
void _print(const Head &H, const Tail &...T) {
    __print(H);
    if (sizeof...(T)) cerr << ", ";
    _print(T...);
}

#define dbg(x...)                    \
    cerr << "[" << #x << "] = ["; \
    _print(x)
```

10.3 .bashrc

```bash
cpp() {
  echo ">> COMPILING <<" 1>&2
  g++ -std=c++17 \
      -O2 \
      -g \
      -g3 \
      -Wextra \
      -Wshadow \
      -Wformat=2 \
      -Wconversion \
      -fsanitize=address,undefined \
      -fno-sanitize-recover \
      -Wfatal-errors  \

  if [ $? -ne 0 ]; then
      echo ">> FAILED <<" 1>&2
      return 1
  fi
  echo ">> DONE << " 1>&2
  time  ./a.out ${@:2}
}

prepare() {
    for i in {a..z}
    do
        cp macro.cpp $i.cpp
        touch $i.py
    done

    for i in {1..10}
    do
        touch in${i}
        touch out${i}
        touch ans${i}
    done
}
```

10.4 macro.cpp

```cpp
#include <bits/stdc++.h>
using namespace std;
#define endl '\n'
```

```cpp
#define fastio                         \
  ios_base::sync_with_stdio(false); \
  cin.tie(0);                       \
  cout.tie(0);
#define len(__x) (ll) __x.size()
using ll = long long;
using vll = vector<ll>;
using pll = pair<ll, ll>;
using vll2d = vector<vll>;
using vi = vector<int>;
using vi2d = vector<vi>;
using pii = pair<int, int>;
using vii = vector<pii>;
using vc = vector<char>;
#define all(a) a.begin(), a.end()
#define snd second
#define fst first
#define pb(___x) push_back(___x)
#define mp(___a, ___b) make_pair(___a, ___b)
#define eb(___x) emplace_back(___x)

const ll INF = 1e18;

void run() {}
int32_t main(void) {
  fastio;
  int t;
  t = 1;
  // cin >> t;
  while (t--) run();
}
```