Contents

1 Basic

1.1 bashrc

```
xmodmap -e 'clear Lock' -e 'keycode 0x42 = Escape'
```

1.2 vimrc

```
set nu rnu is ls=2 hls ts=4 sw=4 et sts=4 ai bs=2 sc
    acd mouse=a encoding=utf-8
syn on
filetype plugin indent on
colo desert
inoremap {<CR> {<CR>}<Esc>O
inoremap jj <Esc>
nnoremap <F8> :w <bar> !g++ -std=c++17 % -o %:r -O2<CR>
nnoremap <F9> :w <bar> !g++ -std=c++17 % -o %:r -Wall -
    Wextra -Wconversion -Wshadow -Wfatal-errors -
    fsanitize=undefined,address -g -Dgenshin <CR>
nnoremap <F10> :!./%:r <CR>
ca Hash w !cpp -dD -P -fpreprocessed \| tr -d '[:space
    :]' \| md5sum \| cut -c-6
```

1.3 Default [124900]

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

using ll = long long;
using ull = unsigned long long;
using ld = long double;
using uint = unsigned int;
const double EPS = 1e-8;
const int INF = 0x3F3F3F3F;
const ll LINF = 4611686018427387903;
const int MOD = 1e9+7;
const int maxn = 1e5 + 25;

signed main() { ios::sync_with_stdio(0); cin.tie(0);

}
```

1.4 Debug code [634e46]

```cpp
#ifdef genshin
#define debug(x) cerr << "\e[1;31m" << #x << " = " << (
    x) << "\e[0m\n"
#define print(x) _my_debug(#x, begin(x), end(x))
template<typename T, typename T2> ostream& operator<<(
    ostream &os, const pair<T, T2> &obj) {
  return os << '{' << obj.first << ',' << obj.second <<
      '}';
}
template<typename T> void _my_debug(const char *s, T l,
     T r) {
  cerr << "\e[1;33m" << s << " = [";
  while (l != r) {
    cerr << *l;
    cerr << (++l == r ? ']' : ',');
  }
  cerr << "\e[0m\n";
}
#else
#define debug(x) 48763
#define print(x) 48763
#endif
```

1.5 Pragma [d346d7]

```cpp
#pragma GCC optimize("Ofast,no-stack-protector")
#pragma GCC optimize("no-math-errno,unroll-loops")
#pragma GCC target("sse,sse2,sse3,ssse3,sse4")
#pragma GCC target("popcnt,abm,mmx,avx,tune=native")
```

2 Data Structure

2.1 Black Magic [68c435]

```cpp
template<typename T>
using pbds_tree = __gnu_pbds::tree<T, null_type, less<T
    >,
   rb_tree_tag, tree_order_statistics_node_update>;
// find_by_order: like array accessing, order_of_key
// join: (one should smaller than the other)
// split(v, b): <= v are a, > v are b
template<typename T, typename T2>
using hash_table = __gnu_pbds::gp_hash_table<T, T2>;
// ht.find(a) ht[a] = v
template<typename T>
using rope = __gnu_cxx::rope<T>;
// array stands for string &s, char *s or int *a
// push_back, pop_back, insert(pos, x)
```

```
// insert(pos, array, len): from pos, insert len elements of array
// append(array, pos, len): append len elements from pos of array
// substr(pos, len), at(pos), erase(pos, len)
// copy(pos, len, array): from pos, replace len elements from array
// Use = and + to concat substrs, += to append element
// O(log n) or O(1). Use pointer and new for persistent use:
vector<rope<int>*> r(n);
r[0] = new rope<int>();
r[i] = new rope<int>(*r[i - 1]);
r[i]->push_back(i);
```

2.2 Lazy Segment Tree [a46c93]

```
// 0-based, [l, r)
// Remember to call init
struct tag {
  // Construct identity element
  tag() { }
  // apply tag
  tag& operator+=(const tag &b) {
    return *this;
  }
};
struct node {
  // Construct identity element
  node() { }
  // Merge two nodes
  node operator+(const node &b) const {
    node res = node();
    return res;
  }
  // Apply tag to this node
  void operator()(const tag &t) {
  }
};
template<typename N, typename T>
struct lazy_segtree {
  N arr[maxn << 1];
  T tag[maxn];
  int n;
  void init(const vector<N> &a) {
    n = a.size();
    for (int i = 0; i < n; i++)
      arr[i + n] = a[i], tag[i] = T();
    for (int i = n - 1; i; i--)
      arr[i] = arr[i << 1] + arr[i << 1 | 1];
  }
  void upd(int p, T v) {
    if (p < n)
      tag[p] += v;
    arr[p](v);
  }
  void pull(int p) {
    for (p >>= 1; p; p >>= 1) {
      arr[p] = arr[p << 1] + arr[p << 1 | 1];
      arr[p](tag[p]);
    }
  }
  void push(int p) {
    for (int h = __lg(p); h; h--) {
      int i = p >> h;
      upd(i << 1, tag[i]);
      upd(i << 1 | 1, tag[i]);
      tag[i] = T();
    }
  }
  void edt(int l, int r, T v) {
    int tl = l + n, tr = r + n - 1;
    push(tl); push(tr);
    for (l += n, r += n; l < r; l >>= 1, r >>= 1) {
      if (l & 1)
        upd(l++, v);
      if (r & 1)
        upd(--r, v);
    }
    pull(tl); pull(tr);
  }
  N que(int l, int r) {
    N resl = N(), resr = N();
    int tl = l + n, tr = r + n - 1;
    push(tl); push(tr);
    for (l += n, r += n; l < r; l >>= 1, r >>= 1) {
      if (l & 1)
        resl = resl + arr[l++];
      if (r & 1)
        resr = arr[--r] + resr;
    }
    return resl + resr;
  }
};
```

2.3 Persistent BIT [3226a9]

```
// Remember to call init
struct fenwicktree {
  vector<int> arr[maxn], sum[maxn];
  void init() {
    for (int i = 0; i < maxn; i++) {
      arr[i].push_back(0);
      sum[i].push_back(0);
    }
  }
  // edit must be called with non-increasing t
  void edt(int p, int v, int t) {
    for (; p < maxn; p += p & -p) {
      arr[p].push_back(t);
      sum[p].push_back(sum[p].back() + v);
    }
  }
  inline int get(int i, int t) {
    return sum[i][(upper_bound(arr[i].begin(), arr[i].end(), t) - arr[i].begin()) - 1];
  }
  int que(int l, int r, int t) {
    if (r < l || l == 0)
      return 0;
    int res = 0;
    for (; r; r -= r & -r)
      res += get(r, t);
    for (l--; l; l -= l & -l)
      res -= get(l, t);
    return res;
  }
  // return the last p s.t. bit[dw..up][1..p] < v
  // maxn - 1 if v > sum and 0 if v = 0
  int bin(int v, int dw, int up) {
    int res = 0, p = 0;
    for (int i = 1 << 20; i; i>>= 1) {
      int g = get(p | i, up) - get(p | i, dw - 1);
      if ((p | i) < maxn && res + g < v) {
        res += g;
        p |= i;
      }
    }
    return p;
  }
} bit;
```

2.4 Treap [cbb731]

```
__gnu_cxx::sfmt19937 rnd(48763);
namespace Treap {
struct node {
  int size, pri;
  node *lc, *rc, *pa;
  node() : size(1), pri(rnd()), lc(0), rc(0), pa(0) {}
  void pull() {
    size = 1; pa = 0;
    if (lc) { size += lc->size; lc->pa = this; }
    if (rc) { size += rc->size; rc->pa = this; }
  }
};
int SZ(node *x) { return x ? x->size : 0; }
node *merge(node *L, node *R) {
  if (!L || !R) return L ? L : R;
  if (L->pri > R->pri)
    return L->rc = merge(L->rc, R), L->pull(), L;
  else
    return R->lc = merge(L, R->lc), R->pull(), R;
}
void splitBySize(node *o, int k, node *&L, node *&R) {
  if (!o) { L = R = 0; }
  else if (int s = SZ(o->lc) + 1; s <= k) {
```

```
    L = o, splitBySize(o->rc, k-s, L->rc, R);
    L->pull();
  }
  else {
    R = o, splitBySize(o->lc, k, L, R->lc);
    R->pull();
  }
} // SZ(L) == k
int getRank(node *o) { // 1-base
  int r = SZ(o->lc) + 1;
  for (; o->pa; o = o->pa)
    if (o->pa->rc == o) r += SZ(o->pa->lc) + 1;
  return r;
}
} // namespace Treap, not tested
```

2.5 DSU Undo [d41d8c]

```
// If undo is not needed, remove st, time() and
    rollback()
// e stands for size (roots) and parent
// int t = dsu.tim(); ...; uf.rollback(t);
struct dsu_undo {
  vector<int> e;
  vector<pair<int, int>> st;
  dsu_undo(int n) : e(n, -1) {}
  int size(int x) { return -e[find(x)]; }
  int find(int x) { return e[x] < 0 ? x : find(e[x]); }
  int time() { return st.size(); }
  void rollback(int t) {
    for (int i = time(); i-- > t;)
      e[st[i].first] = st[i].second;
    st.resize(t);
  }
  bool join(int a, int b) {
    a = find(a), b = find(b);
    if (a == b) return false;
    if (e[a] > e[b]) swap(a, b);
    st.push_back({a, e[a]});
    st.push_back({b, e[b]});
    e[a] += e[b]; e[b] = a;
    return true;
  }
};
```

2.6 Lichao Tree [ef9ec7]

```
struct lichao { // maxn: range
  struct line {
    ll a, b;
    line(): a(0), b(0) { } // or b(LINF) if min
    line(ll a, ll b): a(a), b(b) { }
    ll operator()(ll x) { return a * x + b; } // v[x]
    after li san hua
  } arr[maxn << 2];
  void insert(int l, int r, int id, line x) {
    int m = (l + r) >> 1;
    if (arr[id](m) < x(m))
      swap(arr[id], x);
    if (l == r - 1)
      return;
    if (arr[id].a < x.a)
      insert(m, r, id << 1 | 1, x);
    else
      insert(l, m, id << 1, x);
  } // change to > if query min
  // maxn -> v.size() after li san hua
  void insert(ll a, ll b) { insert(0, maxn, 1, line(a,
    b)); }
  ll que(int l, int r, int id, int p) {
    if (l == r - 1)
      return arr[id](p);
    int m = (l + r) >> 1;
    if (p < m)
      return max(arr[id](p), que(l, m, id << 1, p));
    return max(arr[id](p), que(m, r, id << 1 | 1, p));
  } // chnage to min if query min
  // maxn -> v.size() after li san hua
  ll que(int p) { return que(0, maxn, 1, p); }
} tree;
```

2.7 Linear Basis [3a3430]

```
template<int BITS>
struct linear_basis {
  array<uint64_t, BITS> basis;
  linear_basis() { basis.fill(0); }
  void insert(uint64_t x) {
    for (int i = BITS - 1; i >= 0; i--) if ((x >> i) &
    1) {
      if (basis[i] == 0) {
        basis[i] = x;
        return;
      }
      x ^= basis[i];
    }
  }
  bool valid(uint64_t x) {
    for (int i = BITS - 1; i >= 0; i--)
      if ((x >> i) & 1) x ^= basis[i];
    return x == 0;
  }
  uint64_t operator[](int i) { return basis[i]; }
}; // max xor sum: greedy from high bit
  // min xor sum: zero(if possible) or min_element
```

2.8 Heavy Light Decomposition [2c4577]

```
/* Requirements:
 * N := the count of nodes
 * edge[N] := the edges of the graph
 * Can be modified:
 * tree := Segment Tree or other data structure
 */
struct heavy_light_decomposition {
  int dep[N], pa[N], hea[N], hev[N], pos[N], t;
  int dfs(int u) {
    int mx = 0, sz = 1;
    hev[u] = -1;
    for(int v : edge[u]) {
      if(v == pa[u])
        continue;
      pa[v] = u;
      dep[v] = dep[u] + 1;
      int c = dfs(v);
      if(c > mx)
        mx = c, hev[u] = v;
      sz += c;
    }
    return sz;
  }
  void find_head(int u, int h) {
    hea[u] = h;
    pos[u] = t++; // 0-indexed !!!
    if(~hev[u])
      find_head(hev[u], h);
    for(int v : edge[u])
      if(v != pa[u] && v != hev[u])
        find_head(v, v);
  }
  void init(int rt) {
    dfs(rt, rt);
    find_head(rt, rt);
  }
  /* It is necessary to edit below for every use */
  void edt(int a, int b, int v) {

  }
  int query(int a, int b) { // query path sum
    int res = 0;
    for(; hea[a] != hea[b]; a = pa[hea[a]]) {
      if(dep[hea[a]] < dep[hea[b]])
        swap(a, b);
      res += tree.que(pos[hea[a]], pos[a] + 1);
    }
    if(dep[a] > dep[b])
      swap(a, b);
    return res + tree.que(pos[a], pos[b] + 1);
  }
} hld;
```

2.9 Link Cut Tree [d41d8c]

```
namespace LCT {
  const int N = 1e5 + 25;
  int pa[N], ch[N][2];
  ll dis[N], prv[N], tag[N];
```

```
  vector<pair<int, int>> edge[N];
  vector<pair<ll, ll>> eve;
  inline bool dir(int x) { return ch[pa[x]][1] == x; }
  inline bool is_root(int x) { return ch[pa[x]][0] != x
     && ch[pa[x]][1] != x; }
  inline void rotate(int x) {
    int y = pa[x], z = pa[y], d = dir(x);
    if(!is_root(y))
      ch[z][dir(y)] = x;
    pa[x] = z;
    ch[y][d] = ch[x][!d];
    if(ch[x][!d])
      pa[ch[x][!d]] = y;
    ch[x][!d] = y;
    pa[y] = x;
  }
  inline void push_tag(int x) {
    if(!tag[x])
      return;
    prv[x] = tag[x];
    if(ch[x][0])
      tag[ch[x][0]] = tag[x];
    if(ch[x][1])
      tag[ch[x][1]] = tag[x];
    tag[x] = 0;
  }
  void push(int x) {
    if(!is_root(x))
      push(pa[x]);
    push_tag(x);
  }
  inline void splay(int x) {
    push(x);
    while(!is_root(x)) {
      if(int y = pa[x]; !is_root(y))
        rotate(dir(y) == dir(x) ? y : x);
      rotate(x);
    }
  }
  inline void access(ll t, int x) {
    int lst = 0, tx = x;
    while(x) {
      splay(x);
      if(lst) {
        ch[x][1] = lst;
        eve.push_back({prv[x] + dis[x], t + dis[x]});
      }
      lst = x;
      x = pa[x];
    }
    splay(tx);
    if(ch[tx][0])
      tag[ch[tx][0]] = t;
  }
  void dfs(int u) {
    prv[u] = -LINF;
    for(const auto &[v, c] : edge[u]) {
      if(v == pa[u])
        continue;
      pa[v] = u;
      ch[u][1] = v;
      dis[v] = dis[u] + c;
      dfs(v);
    }
  }
};
```

3 Graph

3.1 Bridge CC [25b45e]

```
namespace bridge_cc {
  vector<int> tim, low;
  stack<int, vector<int>> st;
  int t, bcc_id;
  void dfs(int u, int p, const vector<vector<pair<int,
     int>>> &edge, vector<int> &pa) {
    tim[u] = low[u] = t++;
    st.push(u);
    for (const auto &[v, id] : edge[u]) {
      if (id == p)
        continue;
      if (tim[v])
        low[u] = min(low[u], tim[v]);
      else {
        dfs(v, id, edge, pa);
        if(low[v] > tim[u]) {
          int x;
          do {
            pa[x = st.top()] = bcc_id;
            st.pop();
          } while (x != v);
          bcc_id++;
        }
        else
          low[u] = min(low[u], low[v]);
      }
    }
  }
  vector<int> solve(const vector<vector<pair<int, int
    >>> &edge) { // (to, id)
    int n = edge.size();
    tim.resize(n);
    low.resize(n);
    t = bcc_id = 1;
    vector<int> pa(n);

    for (int i = 0; i < n; i++) {
      if (!tim[i]) {
        dfs(i, -1, edge, pa);
        while (!st.empty()) {
          pa[st.top()] = bcc_id;
          st.pop();
        }
        bcc_id++;
      }
    }
    return pa;
  } // return bcc id(start from 1)
};
```

3.2 Vertex BCC [6be52c]

```
class bicon_cc {
  private:
    int n, ecnt;
    vector<vector<pair<int, int>>> G;
    vector<int> bcc, dfn, low, st;
    vector<bool> ap, ins;
    void dfs(int u, int f) {
      dfn[u] = low[u] = dfn[f] + 1;
      int ch = 0;
      for (auto [v, t]: G[u]) if (v != f) {
        if (!ins[t]) {
          st.push_back(t);
          ins[t] = true;
        }
        if (dfn[v]) {
          low[u] = min(low[u], dfn[v]);
          continue;
        }
        ++ch;
        dfs(v, u);
        low[u] = min(low[u], low[v]);
        if (low[v] >= dfn[u]) {
          ap[u] = true;
          while (true) {
            int eid = st.back();
            st.pop_back();
            bcc[eid] = ecnt;
            if (eid == t) break;
          }
          ecnt++;
        }
      }
      if (ch == 1 && u == f) ap[u] = false;
    }
  public:
    void init(int n_) {
      G.clear(); G.resize(n = n_);
      ecnt = 0; ap.assign(n, false);
      low.assign(n, 0); dfn.assign(n, 0);
    }
    void add_edge(int u, int v) {
      G[u].emplace_back(v, ecnt);
      G[v].emplace_back(u, ecnt++);
```

```
  }
  void solve() {
    ins.assign(ecnt, false);
    bcc.resize(ecnt); ecnt = 0;
    for (int i = 0; i < n; ++i)
      if (!dfn[i]) dfs(i, i);
  }
  // The id of bcc of the x-th edge (0-indexed)
  int get_id(int x) { return bcc[x]; }
  // Number of bcc
  int count() { return ecnt; }
  bool is_ap(int x) { return ap[x]; }
}; // 0-indexed
```

3.3 Strongly Connected Component [ac4987]

```
namespace scc {
  vector<int> edge[maxn], redge[maxn];
  stack<int, vector<int>> st;
  bool vis[maxn];
  void dfs(int u) {
    vis[u] = true;
    for(int v : edge[u])
      if(!vis[v])
        dfs(v);
    st.push(u);
  }
  void dfs2(int u, vector<int> &pa) {
    for(int v : redge[u])
      if(!pa[v])
        pa[v] = pa[u], dfs2(v, pa);
  }
  void add_edge(int u, int v) {
    edge[u].push_back(v);
    redge[v].push_back(u);
  }
  // pa[i]: scc id of all nodes in topo order
  vector<int> solve(int n) {
    vector<int> pa(n + 1);
    for(int i = 1; i <= n; i++)
      if(!vis[i])
        dfs(i);
    int id = 1; // start from 1
    while(!st.empty()) {
      int u = st.top();
      st.pop();
      if(!pa[u])
        pa[u] = id++, dfs2(u, pa);
    }
    return pa;
  } // 1-based
};
```

3.4 Two SAT [0b5797]

```
// maxn >= 2 * n (n: number of variables)
// clauses: (x, y) = x V y, -x if neg, var are 1-based
// return empty is no solution
vector<bool> solve(int n, const vector<pair<int, int>>
    &clauses) {
  auto id = [&](int x) { return abs(x) + n * (x < 0);
    };
  for(const auto &[a, b] : clauses) {
    scc::add_edge(id(-a), id(b));
    scc::add_edge(id(-b), id(a));
  }
  auto pa = scc::solve(n * 2);
  vector<bool> ans(n + 1);
  for(int i = 1; i <= n; i++) {
    if(pa[i] == pa[i + n])
      return vector<bool>();
    ans[i] = pa[i] > pa[i + n];
  }
  return ans;
}
```

3.5 Virtual Tree [ad5cf5]

```
// dfn: the dfs order, vs: important points, r: root
vector<pair<int, int>> build(vector<int> vs, int r) {
  vector<pair<int, int>> res;
  sort(vs.begin(), vs.end(), [](int i, int j) {
      return dfn[i] < dfn[j]; });
  vector<int> s = {r};
  for (int v : vs) if (v != r) {
    if (int o = lca(v, s.back()); o != s.back()) {
      while (s.size() >= 2) {
        if (dfn[s[s.size() - 2]] < dfn[o]) break;
        res.emplace_back(s[s.size() - 2], s.back());
        s.pop_back();
      }
      if (s.back() != o) {
        res.emplace_back(o, s.back());
        s.back() = o;
      }
    }
    s.push_back(v);
  }
  for (size_t i = 1; i < s.size(); ++i)
    res.emplace_back(s[i - 1], s[i]);
  return res; // (x, y): x->y
} // The returned virtual tree contains r (root).
```

3.6 Dominator Tree [af4aab]

```
/* Find dominator tree with root s in O(n)
 * Return the father of each node, **-2 for unreachable
     ** */
struct dominator_tree { // 0-based
  int tk;
  vector<vector<int>> g, r, rdom;
  vector<int> dfn, rev, fa, sdom, dom, val, rp;
  dominator_tree(int n): tk(0), g(n), r(n), rdom(n),
  dfn(n, -1), rev(n, -1), fa(n, -1), sdom(n, -1),
  dom(n, -1), val(n, -1), rp(n, -1) {}
  void add_edge(int x, int y) { g[x].push_back(y); }
  void dfs(int x) {
    rev[dfn[x] = tk] = x;
    fa[tk] = sdom[tk] = val[tk] = tk;
    tk++;
    for (int u : g[x]) {
      if (dfn[u] == -1) dfs(u), rp[dfn[u]] = dfn[x];
      r[dfn[u]].push_back(dfn[x]);
    }
  }
  void merge(int x, int y) { fa[x] = y; }
  int find(int x, int c = 0) {
    if (fa[x] == x) return c ? -1 : x;
    if (int p = find(fa[x], 1); p != -1) {
      if (sdom[val[x]] > sdom[val[fa[x]]])
        val[x] = val[fa[x]];
      fa[x] = p;
      return c ? p : val[x];
    } else {
      return c ? fa[x] : val[x];
    }
  }
  vector<int> build(int s, int n) {
    dfs(s);
    for (int i = tk - 1; i >= 0; --i) {
      for (int u : r[i])
        sdom[i] = min(sdom[i], sdom[find(u)]);
      if (i) rdom[sdom[i]].push_back(i);
      for (int u : rdom[i]) {
        int p = find(u);
        dom[u] = (sdom[p] == i ? i : p);
      }
      if (i) merge(i, rp[i]);
    }
    vector<int> p(n, -2);
    p[s] = -1;
    for (int i = 1; i < tk; ++i)
      if (sdom[i] != dom[i]) dom[i] = dom[dom[i]];
    for (int i = 1; i < tk; ++i)
      p[rev[i]] = rev[dom[i]];
    return p;
  }
};
```

3.7 Dinic [a007ae]

```
// Return max flor from s to t. INF, LINF and maxn
    required
template<typename T> // maxn: edge/node counts
struct dinic { // T: int or ll, up to range of flow
  const T IN_INF = (is_same_v<T, int>) ? INF : LINF;
  struct E {
```

```
    int v; T c; int r;
    E(int v, T c, int r):
      v(v), c(c), r(r){}
  };
  vector<E> adj[maxn];
  pair<int, int> is[maxn]; // counts of edges
  void add_edge(int u, int v, T c, int i = 0) {
    is[i] = {u, adj[u].size()};
    adj[u].push_back(E(v, c, (int) adj[v].size()));
    adj[v].push_back(E(u, 0, (int) adj[u].size() - 1));
  }
  int n, s, t;
  void init(int nn, int ss, int tt) {
    n = nn, s = ss, t = tt;
    for (int i = 0; i <= n; ++i)
      adj[i].clear();
  }
  int le[maxn], it[maxn];
  int bfs() {
    fill(le, le + maxn, -1); le[s] = 0;
    queue<int> q; q.push(s);
    while (!q.empty()) {
      int u = q.front(); q.pop();
      for (auto [v, c, r] : adj[u]) {
        if (c > 0 && le[v] == -1)
          le[v] = le[u] + 1, q.push(v);
      }
    }
    return ~le[t];
  }
  T dfs(int u, T f) {
    if (u == t) return f;
    for (int &i = it[u]; i < (int) adj[u].size(); ++i)
    {
      auto &[v, c, r] = adj[u][i];
      if (c > 0 && le[v] == le[u] + 1) {
        T d = dfs(v, min(c, f));
        if (d > 0) {
          c -= d;
          adj[v][r].c += d;
          return d;
        }
      }
    }
    return 0;
  }
  T flow() {
    T ans = 0, d;
    while (bfs()) {
      fill(it, it + maxn, 0);
      while ((d = dfs(s, IN_INF)) > 0) ans += d;
    }
    return ans;
  }
  T rest(int i) {
    return adj[is[i].first][is[i].second].c;
  }
};
```

3.8 Min Cost Max Flow [56c624]

```
struct cost_flow { // maxn: node count
  static const int64_t INF = 102938475610293847LL;
  struct Edge {
    int v, r;
    int64_t f, c;
    Edge(int a,int b,int _c,int d):v(a),r(b),f(_c),c(d)
    { }
  };
  int n, s, t, prv[maxn], prvL[maxn], inq[maxn];
  int64_t dis[maxn], fl, cost;
  vector<Edge> E[maxn];
  void init(int _n, int _s, int _t) {
    n = _n; s = _s; t = _t;
    for (int i = 0; i < n; i++) E[i].clear();
    fl = cost = 0;
  }
  void add_edge(int u, int v, int64_t f, int64_t c) {
    E[u].push_back(Edge(v, E[v].size() , f, c));
    E[v].push_back(Edge(u, E[u].size()-1, 0, -c));
  }
  pair<int64_t, int64_t> flow() {
    while (true) {
      for (int i = 0; i < n; i++) {
        dis[i] = INF;
        inq[i] = 0;
      }
      dis[s] = 0;
      queue<int> que;
      que.push(s);
      while (!que.empty()) {
        int u = que.front(); que.pop();
        inq[u] = 0;
        for (int i = 0; i < E[u].size(); i++) {
          int v = E[u][i].v;
          int64_t w = E[u][i].c;
          if (E[u][i].f > 0 && dis[v] > dis[u] + w) {
            prv[v] = u; prvL[v] = i;
            dis[v] = dis[u] + w;
            if (!inq[v]) {
              inq[v] = 1;
              que.push(v);
            }
          }
        }
      }
      if (dis[t] == INF) break;
      int64_t tf = INF;
      for (int v = t, u, l; v != s; v = u) {
        u = prv[v]; l = prvL[v];
        tf = min(tf, E[u][l].f);
      }
      for (int v = t, u, l; v != s; v = u) {
        u = prv[v]; l = prvL[v];
        E[u][l].f -= tf;
        E[v][E[u][l].r].f += tf;
      }
      cost += tf * dis[t];
      fl += tf;
    }
    return {fl, cost};
  }
};
```

3.9 Stoer Wagner Algorithm [85ecf3]

```
// return global min cut in O(n^3)
struct SW { // 1-based
  int edge[maxn][maxn], wei[maxn], n;
  bool vis[maxn], del[maxn];
  void init(int _n) {
    n = _n; MEM(edge, 0); MEM(del, 0);
  }
  void add_edge(int u, int v, int w) {
    edge[u][v] += w; edge[v][u] += w;
  }
  void search(int &s, int &t) {
    MEM(wei, 0); MEM(vis, 0);
    s = t = -1;
    while(true) {
      int mx = -1;
      for(int i = 1; i <= n; i++) {
        if(del[i] || vis[i]) continue;
        if(mx == -1 || wei[mx] < wei[i])
          mx = i;
      }
      if(mx == -1) break;
      vis[mx] = true;
      s = t; t = mx;
      for(int i = 1; i <= n; i++)
        if(!vis[i] && !del[i])
          wei[i] += edge[mx][i];
    }
  }
  int solve() {
    int ret = INF;
    for(int i = 1; i < n; i++) {
      int x, y;
      search(x, y);
      ret = min(ret, wei[y]);
      del[y] = true;
      for(int j = 1; j <= n; j++) {
        edge[x][j] += edge[y][j];
        edge[j][x] += edge[y][j];
      }
    }
```

```
    return ret;
  }
} sw;
```

3.10 General Matching [5c9691]

```
// Find max matching on general graph in O(|V|^3)
vector<int> max_matching(vector<vector<int>> g) {
  int n = g.size();
  vector<int> match(n + 1, n), pre(n + 1, n), que;
  vector<int> s(n + 1), mark(n + 1), pa(n + 1);
  function<int(int)> fnd = [&](int x) {
    if(x == pa[x]) return x;
    return pa[x] = fnd(pa[x]);
  };
  auto lca = [&](int x, int y) {
    static int tk = 0;
    tk++;
    x = fnd(x);
    y = fnd(y);
    for(;; swap(x, y))
      if(x != n) {
        if(mark[x] == tk)
          return x;
        mark[x] = tk;
        x = fnd(pre[match[x]]);
      }
  };
  auto blossom = [&](int x, int y, int l) {
    while(fnd(x) != l) {
      pre[x] = y;
      y = match[x];
      if(s[y] == 1)
        que.push_back(y), s[y] = 0;
      if(pa[x] == x) pa[x] = l;
      if(pa[y] == y) pa[y] = l;
      x = pre[y];
    }
  };
  auto bfs = [&](int r) {
    fill(s.begin(), s.end(), -1);
    iota(pa.begin(), pa.end(), 0);
    que = {r}; s[r] = 0;
    for(int it = 0; it < que.size(); it++) {
      int x = que[it];
      for(int u : g[x]) {
        if(s[u] == -1) {
          pre[u] = x;
          s[u] = 1;
          if(match[u] == n) {
            for(int a = u, b = x, lst;
                b != n; a = lst, b = pre[a]) {
              lst = match[b];
              match[b] = a;
              match[a] = b;
            }
            return;
          }
          que.push_back(match[u]);
          s[match[u]] = 0;
        }
        else if(s[u] == 0 && fnd(u) != fnd(x)) {
          int l = lca(u, x);
          blossom(x, u, l);
          blossom(u, x, l);
        }
      }
    }
  };
  for(int i = 0; i < n; i++)
    if(match[i] == n) bfs(i);
  match.resize(n);
  for(int i = 0; i < n; i++)
    if(match[i] == n) match[i] = -1;
  return match;
} // 0-based
```

3.11 Hopcroft Karp Algorithm [01aa79]

```
// Find maximum bipartite matching in O(Esqrt(V))
// g: edges for all nodes at left side
vector<int> hopcroft_karp(vector<vector<int>> g, int l,
     int r) {
  vector<int> match_l(l, -1), match_r(r, -1);
  vector<int> dis(l);
  vector<bool> vis(l);
  while(true) {
    queue<int> que;
    for(int i = 0; i < l; i++) {
      if(match_l[i] == -1)
        dis[i] = 0, que.push(i);
      else
        dis[i] = -1;
      vis[i] = false;
    }
    while(!que.empty()) {
      int x = que.front();
      que.pop();
      for(int y : g[x])
        if(match_r[y] != -1 && dis[match_r[y]] == -1) {
          dis[match_r[y]] = dis[x] + 1;
          que.push(match_r[y]);
        }
    }
    auto dfs = [&](auto dfs, int x) {
      vis[x] = true;
      for(int y : g[x]) {
        if(match_r[y] == -1) {
          match_l[x] = y;
          match_r[y] = x;
          return true;
        }
        else if(dis[match_r[y]] == dis[x] + 1
            && !vis[match_r[y]]
            && dfs(dfs, match_r[y])) {
          match_l[x] = y;
          match_r[y] = x;
          return true;
        }
      }
      return false;
    };
    bool ok = true;
    for(int i = 0; i < l; i++)
      if(match_l[i] == -1 && dfs(dfs, i))
        ok = false;
    if(ok)
      break;
  }
  return match_l;
} // 0-based
```

3.12 Directed MST [f61898]

```
// Find minimum directed minimum spanning tree in O(
    Elog V)
// DSU rollback is reuqired
// Return parent of all nodes, -1 for unreachable ones
    and root
struct dmst_edge { int a, b; ll w; };
struct dmst_node { // lazy skew heap node
  dmst_edge key;
  dmst_node *l, *r;
  ll delta;
  void prop() {
    key.w += delta;
    if (l) l->delta += delta;
    if (r) r->delta += delta;
    delta = 0;
  }
  dmst_edge top() { prop(); return key; }
};
dmst_node *dmst_merge(dmst_node *a, dmst_node *b) {
  if (!a || !b) return a ?: b;
  a->prop();
  b->prop();
  if (a->key.w > b->key.w) swap(a, b);
  swap(a->l, (a->r = dmst_merge(b, a->r)));
  return a;
}
void dmst_pop(dmst_node*& a) {
  a->prop();
  a = dmst_merge(a->l, a->r);
}
pair<ll, vector<int>> dmst(int n, int r, const vector<
    dmst_edge>& g) {
  dsu_undo uf(n);
```

```cpp
  vector<dmst_node*> heap(n);
  vector<dmst_node*> tmp;
  for (dmst_edge e : g) {
    tmp.push_back(new dmst_node {e});
    heap[e.b] = dmst_merge(heap[e.b], tmp.back());
  }
  ll res = 0;
  vector<int> seen(n, -1), path(n), par(n);
  seen[r] = r;
  vector<dmst_edge> Q(n), in(n, {-1, -1}), comp;
  deque<tuple<int, int, vector<dmst_edge>>> cycs;
  for (int s = 0; s < n; s++) {
    int u = s, qi = 0, w;
    while (seen[u] < 0) {
      if (!heap[u]) return {-1, {}};
      dmst_edge e = heap[u]->top();
      heap[u]->delta -= e.w;
      dmst_pop(heap[u]);
      Q[qi] = e;
      path[qi++] = u;
      seen[u] = s;
      res += e.w;
      u = uf.find(e.a);
      if (seen[u] == s) { // found cycle, contract
        dmst_node* cyc = 0;
        int end = qi, time = uf.time();
        do {
          cyc = dmst_merge(cyc, heap[w = path[--qi]]);
        } while (uf.join(u, w));
        u = uf.find(u);
        heap[u] = cyc;
        seen[u] = -1;
        cycs.push_front({u, time, {&Q[qi], &Q[end]}});
      }
    }
    for (int i = 0; i < qi; i++)
      in[uf.find(Q[i].b)] = Q[i];
  }

  for (auto& [u, t, comp] : cycs) { // restore sol (
    optional)
    uf.rollback(t);
    dmst_edge indmst_edge = in[u];
    for (auto& e : comp) in[uf.find(e.b)] = e;
    in[uf.find(indmst_edge.b)] = indmst_edge;
  }
  for (int i = 0; i < n; i++)
    par[i] = in[i].a;
  for (auto &a : tmp)
    delete a;
  return {res, par};
}
```

3.13 Edge Coloring [6d0f61]

```cpp
/* Find a edge coloring using at most d+1 colors, where
     d is the max deg, in O(V^3)
 * mat[i][j] is the color between i, j in 1-based (0
     for no edge)
 * use recolor() to add edge. Calculation is done in
     every recolor */
struct edge_coloring { // 0-based
  int n;
  int mat[maxn][maxn];
  bool vis[maxn], col[maxn];
  void init(int _n) { n = _n; } // remember to init
  int check_conflict(int x, int loc) {
    for (int i = 0; i < n; i++)
      if (mat[x][i] == loc)
        return i;
    return n;
  }
  int get_block(int x) {
    memset(col, 0, sizeof col);
    for (int i = 0; i < n; i++) col[mat[x][i]] = 1;
    for (int i = 1; i < n; i++) if (!col[i]) return i;
    return n;
  }
  void recolor(int x, int y) {
    int pre_mat = get_block(y);
    int conflict = check_conflict(x, pre_mat);
    memset(vis, 0, sizeof vis);
    vis[y] = 1;
    vector<pair<int, int>> mat_line;
    mat_line.push_back({y, pre_mat});
    while (conflict != n && !vis[conflict]) {
      vis[conflict] = 1;
      y = conflict;
      pre_mat = get_block(y);
      mat_line.push_back({y, pre_mat});
      conflict = check_conflict(x, pre_mat);
    }
    if (conflict == n) {
      for (auto t : mat_line) {
        mat[x][t.first] = t.second;
        mat[t.first][x] = t.second;
      }
    }
    else {
      int pre_mat_x = get_block(x);
      int conflict_x = check_conflict(conflict,
   pre_mat_x);
      mat[x][conflict] = pre_mat_x;
      mat[conflict][x] = pre_mat_x;
      while (conflict_x != n) {
        int tmp = check_conflict(conflict_x, pre_mat);
        mat[conflict][conflict_x] = pre_mat;
        mat[conflict_x][conflict] = pre_mat;
        conflict = conflict_x;
        conflict_x = tmp;
        swap(pre_mat_x, pre_mat);
      }
      recolor(x, mat_line[0].first);
    }
  }
} mg;
```

4 Geometry

4.1 Basic [e546a6]

```cpp
template<typename T>
struct point {
  T x, y;
  point(): x(0), y(0) { }
  point(T a, T b): x(a), y(b) { }
  template<typename V>
  explicit point(point<V> p): x(p.x), y(p.y) { }
  point operator-(const point &b) const {
    return point(x - b.x, y - b.y);
  }
  point operator+(const point &b) const {
    return point(x + b.x, y + b.y);
  }
  point<ld> operator*(ld r) const {
    return point<ld>(x * r, y * r);
  }
  point<ld> operator/(ld r) const {
    return point<ld>(x / r, y / r);
  }
  point operator-() const { return point(-x, -y); }
  bool operator<(const point &b) const {
    return x == b.x ? y < b.y : x < b.x; }
  T dis2() const { return x * x + y * y; }
  ld dis() const { return sqrt(dis2()); }
  point perp() const { return point(-y, x); }
  point norm() const {
    ld d = dis();
    return *this / d;
  }
  point rot(double o) const {
    double c = cos(o), s = sin(o);
    return point(c * a.x - s * a.y, s * a.x + c * a.y);
  }
};
using ptld = point<ld>;
using ptll = point<ll>;
template<typename T>
T cross(const point<T> &a, const point<T> &b, const
    point<T> &c) {
  auto x = b - a, y = c - a;
  return x.x * y.y - y.x * x.y;
}
template<typename T>
T cross2(const point<T> &x, const point<T> &y) {
  return x.x * y.y - y.x * x.y;
```

```cpp
}
template<typename T>
T dot(const point<T> &a, const point<T> &b, const point
    <T> &c) {
  auto x = b - a, y = c - a;
  return x.x * y.x + x.y * y.y;
}
template<typename T>
ld area(const point<T> &a, const point<T> &b, const
    point<T> &c) {
  return ld(cross(a, b, c)) / 2;
}
int sgn(ld v) {
  if (abs(v) < EPS)
    return 0;
  return v > 0 ? 1 : -1;
}
int sgn(ll v) { return (v > 0 ? 1 : (v < 0 ? -1 : 0));
    }
template<typename T>
int ori(point<T> a, point<T> b, point<T> c) {
  return sgn(cross(a, b, c));
}
template<typename T>
bool collinearity(point<T> a, point<T> b, point<T> c) {
  return ori(a, b, c) == 0;
}
template<typename T>
bool btw(point<T> p, point<T> a, point<T> b) {
  return collinearity(p, a, b) && sgn(dot(p, a, b)) <=
    0;
}
template<typename T>
point<ld> projection(point<T> p1, point<T> p2, point<T>
     p3) {
  return (p2 - p1) * dot(p1, p2, p3) / (p2 - p1).dis2()
    ;
}
template<typename T>
int quad(point<T> a) {
  if (a.x == 0 && a.y == 0) // change this for ld
    return -1;
  if (a.x > 0)
    return a.y > 0 || a.y == 0 ? 0 : 3;
  if (a.x < 0)
    return a.y > 0 ? 1 : 2;
  return a.y > 0 ? 1 : 3;
}
template<typename T>
bool cmp_by_polar(const point<T> &a, const point<T> &b)
     {
  // start from positive x-axis
  // Undefined if a or b is the origin
  if (quad(a) != quad(b))
    return quad(a) < quad(b);
  if (ori(point<T>(), a, b) == 0)
    return a.dis2() < b.dis2();
  return ori(point<T>(), a, b) > 0;
}
int arg_quad(ptll p) {
  return (p.y == 0) // use sgn for ptld
    ? (p.x < 0 ? 3 : 1) : (p.y < 0 ? 0 : 2);
}
template<typename T>
int arg_cmp(point<T> a, point<T> b) {
 // returns 0/+-1, starts from theta = -PI
 int qa = arg_quad(a), qb = arg_quad(b);
 if (qa != qb) return sgn(ll(qa - qb));
 return sgn(cross2(b, a));
}
using Line = pair<ptll, ptll>;
bool seg_intersect(Line a, Line b) {
  auto [p1, p2] = a;
  auto [p3, p4] = b;
  tie(p1, p2) = a;
  tie(p3, p4) = b;
  if (btw(p1, p3, p4) || btw(p2, p3, p4) || btw(p3, p1,
     p2) || btw(p4, p1, p2))
    return true;
  return ori(p1, p2, p3) * ori(p1, p2, p4) < 0 &&
    ori(p3, p4, p1) * ori(p3, p4, p2) < 0;
}
ptld intersect(Line a, Line b) {
  ptll p1, p2, p3, p4;
  tie(p1, p2) = a;
  tie(p3, p4) = b;
  ld a123 = cross(p1, p2, p3);
  ld a124 = cross(p1, p2, p4);
  return (p4 * a123 - p3 * a124) / (a123 - a124);
}
```

4.2 2D Convex Hull [5346ef]

```cpp
// returns a convex hull in counterclockwise order
// for a non-strict one, change cross >= to >
// Be careful of n <= 2
vector<point> convex_hull(vector<point> p) {
  sort(p.begin(), p.end());
  if (p[0] == p.back()) return { p[0] };
  int s = 1, t = 0;
  vector<point> h(p.size() + 1);
  for (int _ = 2; _--; s = t--, reverse(p.begin(), p.
    end()))
    for (point i : p) {
      while (t > s && ori(i, h[t - 1], h[t - 2]) >= 0)
        t--;
      h[t++] = i;
    }
  return h.resize(t), h;
}
```

4.3 Farthest Pair [9117eb]

```cpp
// p is CCW convex hull w/o colinear points
void farthest_pair(vecotr<point> p) {
  int n = p.size(), pos = 1; lld ans = 0;
  for (int i = 0; i < n; i++) {
    P e = p[(i + 1) % n] - p[i];
    while (cross(e, p[(pos + 1) % n] - p[i]) >
        cross(e, p[pos] - p[i]))
      pos = (pos + 1) % n;
    for (int j: {i, (i + 1) % n})
      ans = max(ans, norm(p[pos] - p[j]));
  } // tested @ AOJ CGL_4_B
}
```

4.4 Minkowski Sum [d97584]

```cpp
// If we want to calculate the minkowski sum of vectors
    ,
// sort <v_i, -v_i, v_{i + 1}, -v_{i + 1}, ...> by
    polar angle order
// The prefix sum of vectors is a convex polygon and
    is the minkowski sum
// To get the new origin, compare the max (x, y) of the
     convex and the sum of positive (x, y) of the
    vectors

// A, B are convex hull rotated to min by (X, Y)
// i.e. rotate(A.begin(), min_element(all(A)), A.end())
vector<point> Minkowski(vector<point> A, vector<point>
    B) {
  vector<point> C(1, A[0] + B[0]), s1, s2;
  const int N = (int) A.size(), M = (int) B.size();
  for(int i = 0; i < N; ++i)
    s1.push_back(A[(i + 1) % N] - A[i]);
  for(int i = 0; i < M; i++)
    s2.push_back(B[(i + 1) % M] - B[i]);
  for(int i = 0, j = 0; i < N || j < M;)
    if (j >= N || (i < M && cross(s1[i], s2[j]) >= 0))
      C.push_back(C.back() + s1[i++]);
    else
      C.push_back(C.back() + s2[j++]);
  return convex_hull(C);
}
```

4.5 Circle [11ff47]

```cpp
struct Circle {
  point c;
  double r;
};

// Calculate intersection between given circle and line
vector<point> inter_circle_line(Circle cir, Line l) {
  const auto &[c, r] = cir;
  const auto &[a, b] = l;
```

```
  point p = a + (b - a) * dot(a, b, c) / (b - a).dis2()
    ;
  double s = cross(a, b, c), h2 = r * r - s * s / (b -
    a).dis2();
  if (h2 < 0) return {};
  if (h2 == 0) return {p};
  point h = (b - a) / (b - a).dis() * sqrt(h2);
  return {p - h, p + h};
} // no tested

// return p4 is strictly in circumcircle of tri(p1,p2,
    p3)
inline ll sqr(ll x) { return x * x; }
bool in_cc(const point& p1, const point& p2, const
    point& p3, const point& p4) {
  ll u11 = p1.x - p4.x; ll u12 = p1.y - p4.y;
  ll u21 = p2.x - p4.x; ll u22 = p2.y - p4.y;
  ll u31 = p3.x - p4.x; ll u32 = p3.y - p4.y;
  ll u13 = sqr(p1.x) - sqr(p4.x) + sqr(p1.y) - sqr(p4.y
    );
  ll u23 = sqr(p2.x) - sqr(p4.x) + sqr(p2.y) - sqr(p4.y
    );
  ll u33 = sqr(p3.x) - sqr(p4.x) + sqr(p3.y) - sqr(p4.y
    );
  __int128 det = (__int128)-u13 * u22 * u31 + (__int128
    )u12 * u23 * u31 + (__int128)u13 * u21 * u32 - (
    __int128)u11 * u23 * u32 - (__int128)u12 * u21 *
    u33 + (__int128)u11 * u22 * u33;
  return det > EPS;
} // not tested

// Return the area of intersection of poly and circle
double _area(point pa, point pb, double r) {
  if (pa.dis2() < pb.dis2())
    swap(pa, pb);
  if (pb.dis() < EPS)
    return 0;
  double S, h, theta;
  double a = pb.dis(), b = pa.dis(), c = (pb - pa).dis
    ();
  double cosB = dot2(pb, pb - pa) / a / c, B = acos(
    cosB);
  double cosC = dot2(pa, pb) / a / b, C = acos(cosC);
  if (a > r) {
    S = (C / 2) * r * r;
    h = a * b * sin(C) / c;
    if (h < r && B < PI / 2)
      S -= (acos(h / r) * r * r - h * sqrt(r * r - h *
    h));
  }
  else if (b > r) {
    theta = PI - B - asin(sin(B) / r * a);
    S = 0.5 * a * r * sin(theta) + (C - theta) / 2 * r
    * r;
  }
  else S = 0.5 * sin(C) * a * b;
  return S;
}
double area_poly_circle(const vector<point> poly, const
     Circle c) {
  const auto &[O, r] = c;
  double S = 0;
  for (int i = 0; i < poly.size(); ++i)
    S +=_area(poly[i] - O, poly[(i + 1) % poly.size()]
    - O, r) * ori(O, poly[i], poly[(i + 1) % poly.size
    ()]);
  return abs(S);
} // not tested

// Return intersection of two circles in p1 and p2
bool CCinter(Circle &a, Circle &b, point &p1, point &p2
    ) {
  point o1 = a.O, o2 = b.O;
  double r1 = a.r, r2 = b.r, d2 = (o1 - o2).dis2(), d =
     sqrt(d2);
  if (d < max(r1, r2) - min(r1, r2) || d > r1 + r2)
    return 0;
  point u = (o1 + o2) * 0.5 + (o1 - o2) * ((r2 * r2 -
    r1 * r1) / (2 * d2));
  double A = sqrt((r1 + r2 + d) * (r1 - r2 + d) * (r1 +
     r2 - d) * (-r1 + r2 + d));
  point v = point(o1.Y - o2.Y, -o1.X + o2.X) * A / (2 *
     d2);
  p1 = u + v, p2 = u - v;
  return 1;
} // not tested
```

4.6 Tangent Lines of Circle and Point [003418]

```
vector<Line> tangent(Circle c, point p) {
  vector<Line> z;
  double d = (p - c.c).dis();
  if (sign(d - c.r) == 0) {
    point i = (p - c.c)rot(PI / 2);
    z.push_back({p, p + i});
  } else if (d > c.r) {
    double o = acos(c.r / d);
    point i = (p - c.c).norm(), j = i.rot(o) * c.r, k =
     i.rot(-o) * c.r;
    z.push_back({c.c + j, p});
    z.push_back({c.c + k, p});
  }
  return z;
} // not tested
```

4.7 Tangent Lines of Cricles [d4f0a6]

```
vector <Line> tangent(Circle c1, Circle c2, int sign1)
    {
  // sign1 = 1 for outer tang, -1 for inter tang
  vector <Line> ret;
  double d_sq = abs2(c1.c - c2.c);
  if (sgn(d_sq) == 0) return ret;
  double d = sqrt(d_sq);
  point v = (c2.c - c1.c) / d;
  double c = (c1.r - sign1 * c2.r) / d;
  if (c * c > 1) return ret;
  double h = sqrt(max(0.0, 1.0 - c * c));
  for (int sign2 = 1; sign2 >= -1; sign2 -= 2) {
    point n = point(v.x * c - sign2 * h * v.y, v.y * c
    + sign2 * h * v.x);
    point p1 = c1.c + n * c1.r;
    point p2 = c2.c + n * (c2.r * sign1);
    if (sign(p1.x - p2.x) == 0 && sign(p1.y - p2.y) ==
    0)
      p2 = p1 + (c2.c - c1.c).perp();
    ret.push_back({p1, p2});
  }
  return ret;
} // not tested
```

4.8 Delaunay Triangular [f3d422]

```
/* please ensure input points are unique */
/* A triangulation such that no points will strictly
  inside circumcircle of any triangle.
  find(root, p) : return a triangle contain given point
add_point : add a point into triangulation
Region of triangle u: iterate each u.e[i].tri,
each points are u.p[(i+1)%3], u.p[(i+2)%3]
Voronoi diagram: for each triangle in `res`,
the bisector of all its edges will split the region. */
#define L(i) ((i) == 0 ? 2 : (i) - 1)
#define R(i) ((i) == 2 ? 0 : (i) + 1)
#define F3 for (int i = 0; i < 3; i++)
bool in_cc(const array<ptll, 3> &p, ptll q) {
  __int128 det = 0;
  F3 det += __int128(p[i].dis2() - q.dis2()) * cross2(p
    [R(i)] - q, p[L(i)] - q);
  return det > 0;
}
struct Tri;
struct E {
  Tri *t; int side; E() : t(0), side(0) { }
  E(Tri *t_, int side_) : t(t_), side(side_){ }
};
struct Tri {
  bool vis;
  array<ptll, 3> p;
  array<Tri*, 3> ch;
  array<E, 3> e;
  Tri(ptll a = ptll(), ptll b = ptll(), ptll c = ptll()
    ) : vis(0), p{a,b,c}, ch{} {}
  bool has_chd() const { return ch[0] != nullptr; }
```

```cpp
  bool contains(ptll q) const {
    F3 if (ori(p[i], p[R(i)], q) < 0) return false;
    return true;
  }
} pool[maxn * 10], *it;
void link(E a, E b) {
  if (a.t) a.t->e[a.side] = b;
  if (b.t) b.t->e[b.side] = a;
}
const int C = 100 * 1007 * 1007;
struct Trigs {
  Tri *root;
  Trigs() { // should at least contain all points
    root = // C = 100*MAXC^2 or just MAXC?
      new(it++) Tri(ptll(-C, -C), ptll(C * 2, -C), ptll
    (-C, C * 2));
  }
  void add_point(ptll p) { add_point(find(p, root), p);
    }
  static Tri* find(ptll p, Tri *r) {
    while (r->has_chd()) for (Tri *c: r->ch)
      if (c && c->contains(p)) { r = c; break; }
    return r;
  }
  void add_point(Tri *r, ptll p) {
    array<Tri*, 3> t; /* split into 3 triangles */
    F3 t[i] = new (it++) Tri(r->p[i], r->p[R(i)], p);
    F3 link(E(t[i], 0), E(t[R(i)], 1));
    F3 link(E(t[i], 2), r->e[L(i)]);
    r->ch = t;
    F3 flip(t[i], 2);
  }
  void flip(Tri* A, int a) {
    auto [B, b] = A->e[a]; /* flip edge between A,B */
    if (!B || !in_cc(A->p, B->p[b])) return;
    Tri *X = new(it++) Tri(A->p[R(a)], B->p[b], A->p[a
    ]);
    Tri *Y = new(it++) Tri(B->p[R(b)], A->p[a], B->p[b
    ]);
    link(E(X, 0), E(Y, 0));
    link(E(X, 1), A->e[L(a)]);
    link(E(X, 2), B->e[R(b)]);
    link(E(Y, 1), B->e[L(b)]);
    link(E(Y, 2), A->e[R(a)]);
    A->ch = B->ch = {X, Y, nullptr};
    flip(X, 1); flip(X, 2); flip(Y, 1); flip(Y, 2);
  }
};
vector<Tri*> res;
void go(Tri *now) { // store all tri into res
  if (now->vis) return;
  now->vis = true;
  if (!now->has_chd()) res.push_back(now);
  for (Tri *c : now->ch) if (c) go(c);
}
vector<Directed_Line> frame;
vector<vector<ptld>> build_voronoi_cells(const vector<
    ptll> &p, const vector<Tri*> &res); // Only need
    for voronoi
// !!! The order is shuffled !!!
vector<vector<ptld>> build(vector<ptll> &ps) {
  it = pool; res.clear();
  shuffle(ps.begin(), ps.end(), mt19937(487638763));
  Trigs tr; for (point p : ps) tr.add_point(p);
  go(tr.root); // use `res` afterwards
  return build_voronoi_cells(ps, res); // Only needed
    for voronoi
  // res is the result otherwise
}
```

4.9 Half Plane Intersection [ced799]

```cpp
// O(NLogN), undefined if the result has area INF (not
    enclosed)
struct Directed_Line {
  ptll st, ed, dir;
  Directed_Line(ptll s, ptll e) : st(s), ed(e), dir(e -
     s) {}
};
using LN = const Directed_Line &;
ptld intersect(LN A, LN B) {
  ld t = cross2(B.st - A.st, B.dir) / ld(cross2(A.dir,
    B.dir));
  return ptld(A.st) + A.dir * t; // C^3 / C^2
}
int sgn(__int128 v) { return (v > 0 ? 1 : (v < 0 ? -1 :
     0)); }
bool cov(LN l, LN A, LN B) {
  __int128 u = cross2(B.st - A.st, B.dir);
  __int128 v = cross2(A.dir, B.dir);
  // ori(l.st, l.ed, A.st + A.dir*(u/v)) <= 0?
  __int128 x = (A.dir).x * u + (A.st - l.st).x * v;
  __int128 y = (A.dir).y * u + (A.st - l.st).y * v;
  return sgn(x * (l.dir).y - y * (l.dir).x) * sgn(v) >=
     0;
} // x, y are C^3
bool operator<(LN a, LN b) {
  if (int c = arg_cmp(a.dir, b.dir)) return c == -1;
  return ori(a.st, a.ed, b.st) < 0;
}
// cross(pt-line.st, line.dir)<=0 <-> pt in half plane
// the half plane is the LHS when going from st to ed
vector<ptld> HPI(vector<Directed_Line> &q) {
  sort(q.begin(), q.end());
  int n = (int)q.size(), l = 0, r = -1;
  for (int i = 0; i < n; i++) {
    if (i && !arg_cmp(q[i].dir, q[i - 1].dir)) continue
    ;
    while (l < r && cov(q[i], q[r-1], q[r])) --r;
    while (l < r && cov(q[i], q[l], q[l + 1])) ++l;
    q[++r] = q[i];
  }
  while (l < r && cov(q[l], q[r-1], q[r])) --r;
  while (l < r && cov(q[r], q[l], q[l+1])) ++l;
  n = r - l + 1; // q[l .. r] are the lines
  if (n <= 1 || !arg_cmp(q[l].dir, q[r].dir)) return {
    };
  vector<ptld> pt(n);
  for (int i = 0; i < n; i++)
    pt[i] = intersect(q[i + l], q[(i + 1) % n + l]);
  return pt;
}
```

4.10 Point In Convex [324eed]

```cpp
bool in_convex(const vector<point> &convex, point p,
    bool strict = true) {
  if (convex.empty())
    return false;
  int a = 1, b = convex.size() - 1, r = !strict;
  if (b < 2)
    return r && btw(p, convex[0], convex.back());
  if (ori(convex[0], convex[a], convex[b]) > 0) swap(a,
     b);
  if (ori(convex[0], convex[a], p) >= r || ori(convex
    [0], convex[b], p) <= -r)
    return false;
  while (abs(a - b) > 1) {
    int c = (a + b) / 2;
    (ori(convex[0], convex[c], p) > 0 ? b : a) = c;
  }
  return ori(convex[a], convex[b], p) < r;
} // no tested
```

4.11 Voronoi Diagram [519adb]

```cpp
vector<Directed_Line> frame;
vector<vector<ptld>> build_voronoi_cells(const vector<
    ptll> &p, const vector<Tri*> &res) {
  // O(nlogn)
  vector<vector<int>> adj(p.size());
  map<ptll, int> mp;
  for (size_t i = 0; i < p.size(); ++i)
    mp[p[i]] = i;
  const auto Get = [&](ptll z) {
    auto it = mp.find(z);
    return it == mp.end() ? -1 : it->second;
  };
  for (Tri *t : res) F3 {
    ptll A = t->p[i], B = t->p[R(i)];
    int a = Get(A), b = Get(B);
    if (a == -1 || b == -1) continue;
    adj[a].emplace_back(b);
  }
  // use `adj` and `p` and HPI to build cells
  vector<vector<ptld>> owo;
  for (size_t i = 0; i < p.size(); i++) {
```

```
    assert(!frame.empty());
    vector<Directed_Line> ls = frame; // the frame, a
    rectangle closing all points
    // coordinates of frame should be doubled
    for (int j : adj[i]) {
      point m = p[i] + p[j], d = (p[j] - p[i]).perp();
      assert(d.dis2() != 0);
      ls.emplace_back(m, m + d); // doubled coordinate
    }
    // use HPI(ls) to get the convex hull closing point
     i
    owo.push_back(HPI(ls));
  }
  return owo;
}
```

5 String

5.1 KMP [647790]

```
vector<int> kmp(const string &s) {
  int n = s.size();
  vector<int> dp(n);
  for (int i = 1, j = 0; i < n; i++) {
    while (j && s[i] != s[j])
      j = dp[j - 1];
    if (s[i] == s[j])
      j++;
    dp[i] = j;
  }
  return dp;
}
```

5.2 Z Value [f762e6]

```
// Return Z value of string s in O(|S|)
// Note that z[0] = |S|
vector<int> Zalgo(const string &s) {
 vector<int> z(s.size(), (int) s.size());
 for (int i = 1, l = 0, r = 0; i < z[0]; ++i) {
  int j = clamp(r - i, 0, z[i - l]);
  while (i + j < z[0] && s[i + j] == s[j])
    j++;
  if (i + (z[i] = j) > r)
    r = i + z[l = i];
 }
 return z;
}
```

5.3 Suffix Array [fb97cc]

```
int sa[maxn], tmp[2][maxn], c[maxn];
void get_sa(const string &s) { // m: char set
  int *x = tmp[0], *y = tmp[1], m = 256, n = s.size();
  for (int i = 0; i < m; i++) c[i] = 0;
  for (int i = 0; i < n; i++) c[x[i] = s[i]]++;
  for (int i = 1; i < n; i++) c[i] += c[i - 1];
  for (int i = n - 1; i >= 0; --i) sa[--c[x[i]]] = i;
  for (int k = 1; k < n; k <<= 1) {
    for (int i = 0; i < m; i++) c[i] = 0;
    for (int i = 0; i < n; i++) c[x[i]]++;
    for (int i = 1; i < m; i++) c[i] += c[i - 1];
    int p = 0;
    for (int i = n - k; i < n; i++) y[p++] = i;
    for (int i = 0; i < n; i++)
      if (sa[i] >= k) y[p++] = sa[i] - k;
    for (int i = n - 1; i >= 0; --i) sa[--c[x[y[i]]]] =
     y[i];
    y[sa[0]] = p = 0;
    for (int i = 1; i < n; i++) {
      int a = sa[i], b = sa[i - 1];
      if (x[a] == x[b] && a + k < n && b + k < n && x[a
     + k] == x[b + k]) { }
      else p++;
      y[sa[i]] = p;
    }
    if (n == p + 1)
      break;
    swap(x, y);
    m = p + 1;
  }
} // sa[i]: index which ranks i
int rk[maxn], lcp[maxn]; // lcp[i] : lcp with i-1
void get_lcp(const string &s) {
  int n = s.size(), val = 0;
  for (int i = 0; i < n; i++) rk[sa[i]] = i;
  for (int i = 0; i < n; i++) {
    if (rk[i] == 0) lcp[rk[i]] = 0;
    else {
      if (val) val--;
      int p = sa[rk[i] - 1];
      while (val + i < n && val + p < n && s[val + i]
    == s[val + p])
        val++;
      lcp[rk[i]] = val;
    }
  }
}
```

5.4 AC Automaton [971e58]

```
// Remember to call init then compile
class AhoCorasick {
  private:
    static constexpr int Z = 26;
    struct node {
      node *nxt[Z], *fail;
      vector<int> data;
      node(): fail(nullptr) {
        memset(nxt, 0, sizeof(nxt));
        data.clear();
      }
    } *rt;
    inline int Idx(char c) { return c - 'a'; }
  public:
    void init() { rt = new node(); }
    void add(const string &s, int d) { // d is index,
    etc
      node* cur = rt;
      for (auto c : s) {
        if (!cur->nxt[Idx(c)])
          cur->nxt[Idx(c)] = new node();
        cur = cur->nxt[Idx(c)];
      }
      cur->data.push_back(d);
    }
    void compile() {
      vector<node*> bfs;
      size_t ptr = 0;
      for (int i = 0; i < Z; i++) {
        if (!rt->nxt[i]) {
          // uncomment 2 lines to make it DFA
          // rt->nxt[i] = rt;
          continue;
        }
        rt->nxt[i]->fail = rt;
        bfs.push_back(rt->nxt[i]);
      }
      while (ptr < bfs.size()) {
        node* u = bfs[ptr++];
        // More code here to record information...
        // rt is NOT in bfs
        for (int i = 0; i < Z; i++) {
          if (!u->nxt[i]) {
            // u->nxt[i] = u->fail->nxt[i];
            continue;
          }
          node* u_f = u->fail;
          while (u_f) {
            if (!u_f->nxt[i]) {
              u_f = u_f->fail;
              continue;
            }
            u->nxt[i]->fail = u_f->nxt[i];
            break;
          }
          if (!u_f) u->nxt[i]->fail = rt;
          bfs.push_back(u->nxt[i]);
        }
      }
    }
    void match(const string &s, vector<int> &ret) {
      node* u = rt;
      for (auto c : s) {
        while (u != rt && !u->nxt[Idx(c)])
          u = u->fail;
        u = u->nxt[Idx(c)];
```

```
      if (!u) u = rt;
      node* tmp = u;
      while (tmp != rt) {
        for (auto d : tmp->data)
          ret.push_back(d);
        tmp = tmp->fail;
      }
    }
  }
} ac;
```

5.5 Booth Algorithm [e7cb5d]

```
// return start index of minimum rotation in O(|s|)
int min_rotation(string s) {
  s += s;
  int k = 0;
  vector<int> f(s.size(), -1);
  for(int j = 1; j < s.size(); j++) {
    int i = f[j - k - 1];
    for(i = f[j - k - 1];
        i != -1 && s[j] != s[i + k + 1]; i = f[i])
      if(s[k + i + 1] > s[j])
        k = j - i - 1;
    if(i == -1 && s[j] != s[k + i + 1]) {
      if(s[j] < s[k + i + 1])
        k = j;
      f[j - k] = -1;
    }
    else
      f[j - k] = i + 1;
  }
  return k;
}
```

5.6 Manacher Algorithm [5cc8bc]

```
vector<int> manacher_algorithm(string s) {
  int n = 2 * s.size() + 1;
  string t(n, 0);
  vector<int> len(n);//len[i]: max length when mid at i
  for(int i = 0; i < n; i++) {
    if(i & 1)
      t[i] = s[i / 2];
  }
  for(int i = 0, l = 0, r = -1; i < n; i++) {
    len[i] = (i <= r ? min(len[2 * l - i], r - i) : 0);
    while(i - len[i] >= 0 && i + len[i] < n && t[i -
        len[i]] == t[i + len[i]])
      len[i]++;
    len[i]--;
    if(i + len[i] > r)
      l = i, r = i + len[i];
  }
  return len;
}
```

5.7 Palindromic Tree [0673ee]

```
struct PalindromicTree {
  struct node {
    // len: length of max palindromic at i
    // next[c]: next id if add c at front & back
    int nxt[26], f, len; // num = depth of fail link
    int cnt, num;    // = #pal_suffix of this node
    node(int l = 0) : nxt{}, f(0), len(l), cnt(0), num
    (0) {}
  };
  vector<node> st; vector<char> s; int last, n;
  void init() {
    st.clear(); s.clear();
    last = 1; n = 0;
    st.push_back(0); st.push_back(-1);
    st[0].f = 1; s.push_back(-1);
  }
  int getFail(int x) {
    while (s[n - st[x].len - 1] != s[n]) x = st[x].f;
    return x;
  }
  void add(int c) {
    s.push_back(c -= 'a'); ++n;
    int cur = getFail(last);
    if (!st[cur].nxt[c]) {
      int now = st.size();
      st.push_back(st[cur].len + 2);
      st[now].f = st[getFail(st[cur].f)].nxt[c];
      st[cur].nxt[c] = now;
      st[now].num = st[st[now].f].num + 1;
    }
    last = st[cur].nxt[c]; ++st[last].cnt;
  }
  void dpcnt() { // cnt = #occurence in whole str
    for (int i = st.size() - 1; i >= 0; i--)
      st[st[i].f].cnt += st[i].cnt;
  }
  int size() { return st.size() - 2; }
} pt; // not tested
/* usage
string s; cin >> s; pt.init();
for (int i = 0; i < SZ(s); i++) {
  int prvsz = pt.size(); pt.add(s[i]);
  if (prvsz != pt.size()) {
    int r = i, l = r - pt.st[pt.last].len + 1;
    // pal @ [l,r]: s.substr(l, r-l+1)
  }
} */
```

6 Math

6.1 Lemma And Theory

6.1.1 Pick's Theorem

For a simple polygon, its area A can be written as $A = i + \frac{b}{2} - 1$ in which i is the number of points that are strictly interior to the polygon and b is the number of points that are on the polygon's boundary.

6.1.2 Euler's Planar Graph Theorem

F: number of regions bounded by edges.
$V - E + F = C + 1, E \le 3V - 6$

6.1.3 Modular inversion recurrence

For some prime p,

$$inv_i = \begin{cases} 1 & i = 1 \\ p - \lfloor \frac{p}{i} \rfloor \times inv_{(p \bmod i)} & 1 < i < p \end{cases}$$

6.2 Numbers

6.2.1 Catalan number

Start from $n = 0 : 1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796, 58786, \ldots$

$$C_n = \frac{1}{n+1}\binom{2n}{n} = \frac{(2n)!}{(n+1)!n!} = \prod_{k=2}^{n} \frac{n+k}{k}$$

$$C_n = \binom{2n}{n} - \binom{2n}{n+1}$$

Recurrence

$$C_0 = 1$$

$$C_{n+1} = \sum_{i=0}^{n} C_i C_{n-i}$$

$$C_{n+1} = \frac{2(2n+1)}{n+2} C_n$$

6.2.2 Primes

$$12721, 13331, 14341, 75577$$
$$999997771, 999991231, 1000000007, 1000000009, 1000696969$$
$$10^{12} + 39, 10^{15} + 37$$

6.3 Extgcd [d8844c]

```
// return (d, x, y) s.t. ax+by=d=gcd(a,b)
template<typename T>
tuple<T, T, T> extgcd(T a, T b) {
  if(!b) return make_tuple(a, 1, 0);
  auto [d, x, y] = extgcd(b, a % b);
  return make_tuple(d, y, x - (a / b) * y);
}
```

6.4 Chinese Remainder Theorem [69f820]

```
// x % m1 = x1, x % m2 = x2
ll chre(ll x1, ll m1, ll x2, ll m2){
  ll g = __gcd(m1, m2);
  if ((x2 - x1) % g) return -1; // no solution
  m1 /= g; m2 /= g;
  ll p = get<1>(extgcd(m1, m2));
  ll lcm = m1 * m2 * g;
  ll res = p * (x2 - x1) * m1 + x1;
  // might overflow for above two lines, be cautious
  return (res % lcm + lcm) % lcm;
}
```

6.5 Linear Sieve [59dc40]

```
int least_prime_divisor[maxn];
vector<int> pr;
void linear_sieve() {
  for(int i = 2; i < maxn; i++) {
    if(!least_prime_divisor[i]) {
      pr.push_back(i);
      least_prime_divisor[i] = i;
    }
    for(int p : pr) {
      if(1LL * i * p >= maxn) break;
      least_prime_divisor[i * p] = p;
      if(i % p == 0) break;
    }
  }
}
```

6.6 Fast Walsh Transform [239248]

```
/* do not move ta,tb, default for xor
 * remove last 2 lines for non-xor
 * or convolution:
 * x[i]=ta,x[j]=ta+tb; x[i]=ta,x[j]=tb-ta for inv
 * and convolution:
 * x[i]=ta+tb,x[j]=tb; x[i]=ta-tb,x[j]=tb for inv */
void fwt(int x[], int N, bool inv = false) {
  for(int d = 1; d < N; d <<= 1) {
    for(int s = 0, d2 = d * 2; s < N; s += d2)
      for(int i = s, j = s + d; i < s + d; i++, j++) {
        int ta = x[i], tb = x[j];
        x[i] = modadd(ta, tb);
        x[j] = modsub(ta, tb);
      }
  }
  if(inv) for(int i = 0, invn = modinv(N); i < N; i++)
    x[i] = modmul(x[i], invn);
} // N: array len
```

6.7 Floor Sum [5e4ea5]

```
// @param n `n < 2^32`
// @param m `1 <= m < 2^32`
// @return sum_{i=0}^{n-1} floor((ai + b)/m) mod 2^64
ull floor_sum_unsigned(ull n, ull m, ull a, ull b) {
 ull ans = 0;
 while (true) {
  if (a >= m) {
   ans += n * (n - 1) / 2 * (a / m); a %= m;
  }
  if (b >= m) {
   ans += n * (b / m); b %= m;
  }
  ull y_max = a * n + b;
  if (y_max < m) break;
  // y_max < m * (n + 1)
  // floor(y_max / m) <= n
  n = (ull)(y_max / m), b = (ull)(y_max % m);
  swap(m, a);
 }
 return ans;
}
ll floor_sum(ll n, ll m, ll a, ll b) {
 ull ans = 0;
 if (a < 0) {
  ull a2 = (a % m + m) % m;
  ans -= 1ULL * n * (n - 1) / 2 * ((a2 - a) / m);
  a = a2;
 }
 if (b < 0) {
  ull b2 = (b % m + m) % m;
  ans -= 1ULL * n * ((b2 - b) / m);
  b = b2;
 }
 return ans + floor_sum_unsigned(n, m, a, b);
}
```

6.8 Linear Programming [e03738]

```
/* M constraints, i-th constraint is:
  \sum_{j=0}^{n-1} A[i][j] * x_j <= B[i]
  Let v = \sum_{j=0} C[j] * x_j
  maximize v satisfying constraints
  sol[i] = x_i
  remind the precision error */
struct Simplex { // 0-based
  using T = long double;
  static const int N = 410, M = 30010;
  const T eps = 1e-7;
  int n, m;
  int Left[M], Down[N];
  T a[M][N], b[M], c[N], v, sol[N];
  bool eq (T a, T b) { return fabs(a - b) < eps; }
  bool ls (T a, T b) { return a < b && !eq(a, b); }
  void init(int _n, int _m) {
    n = _n, m = _m, v = 0;
    for (int i = 0; i < m; ++i) for (int j = 0; j < n;
    ++j) {
      a[i][j] = 0;
    }
    for (int i = 0; i < m; ++i) b[i] = 0;
    for (int i = 0; i < n; ++i) c[i] = sol[i] = 0;
  }
  void pivot (int x, int y) {
    swap(Left[x], Down[y]);
    T k = a[x][y]; a[x][y] = 1;
    vector <int> nz;
    for (int i = 0; i < n; ++i) {
      a[x][i] /= k;
      if(!eq(a[x][i], 0)) nz.push_back(i);
    }
    b[x] /= k;
    for (int i = 0; i < m; ++i) {
      if (i == x || eq(a[i][y], 0)) continue;
      k = a[i][y], a[i][y] = 0;
      b[i] -= k * b[x];
      for (int j : nz) a[i][j] -= k * a[x][j];
    }
    if (eq(c[y], 0)) return;
    k = c[y], c[y] = 0, v += k * b[x];
    for (int i : nz) c[i] -= k * a[x][i];
  }
  // 0: found solution, 1: no feasible solution, 2:
    unbounded
  int solve() {
    for (int i = 0; i < n; ++i) Down[i] = i;
    for (int i = 0; i < m; ++i) Left[i] = n + i;
    while (1) {
      int x = -1, y = -1;
      for (int i = 0; i < m; ++i) if (ls(b[i], 0) && (x
     == -1 || b[i] < b[x])) x = i;
      if (x == -1) break;
      for (int i = 0; i < n; ++i) if (ls(a[x][i], 0) &&
     (y == -1 || a[x][i] < a[x][y])) y = i;
      if (y == -1) return 1;
      pivot(x, y);
    }
    while (1) {
      int x = -1, y = -1;
      for (int i = 0; i < n; ++i) if (ls(0, c[i]) && (y
     == -1 || c[i] > c[y])) y = i;
      if (y == -1) break;
      for (int i = 0; i < m; ++i) if (ls(0, a[i][y]) &&
     (x == -1 || b[i] / a[i][y] < b[x] / a[x][y])) x =
     i;
      if (x == -1) return 2;
      pivot(x, y);
    }
    for (int i = 0; i < m; ++i) if(Left[i] < n) sol[
    Left[i]] = b[i];
    return 0;
  }
} LP;
```

6.9 Miller Rabin [f458b0]

```
ull mpow(__uint128_t a, ull b, ull m);
bool is_prime(ull x) {
  static auto witn = [](ull a, ull n, int t) {
    if (!a) return false;
    while (t--) {
      ull a2 = __uint128_t(a) * a % n;
      if (a2 == 1 && a != 1 && a != n - 1) return true;
      a = a2;
    }
    return a != 1;
  };
  if (x < 2) return false;
  if (!(x & 1)) return x == 2;
  int t = __builtin_ctzll(x - 1);
  ull odd = (x - 1) >> t;
  for (ull m:
      {2, 325, 9375, 28178, 450775, 9780504,
    1795265022})
    if (witn(mpow(m % x, odd, x), x, t))
      return false;
  return true;
}
```

6.10 Pollard's Rho [5f80a7]

```
ull f(ull x, ull k, ull m) {
  return (__uint128_t(x) * x + k) % m;
}
// does not work when n is prime
// return any non-trivial factor (NOT necessary be a
    prime)
ull pollard_rho(ull n) {
  if (!(n & 1)) return 2;
  mt19937_64 rnd(120821011);
  while (true) {
    ull y = 2, yy = y, x = rnd() % n, t = 1;
    for (ull sz = 2; t == 1; sz <<= 1, y = yy) {
      for (ull i = 0; t == 1 && i < sz; ++i) {
        yy = f(yy, x, n);
        t = __gcd(yy > y ? yy - y : y - yy, n);
      }
    }
    if (t != 1 && t != n) return t;
  }
}
```

6.11 Gauss Elimination [93d9bd]

```
// Returns n - rank
int gauss_elimination(vector<vector<double>> &d) {
  int n = d.size(), m = d[0].size();
  for (int i = 0, r = 0; i < m; ++i) {
    int p = -1;
    for (int j = r; j < n; ++j) {
      if (fabs(d[j][i]) < eps) continue;
      if (p == -1 || fabs(d[j][i]) > fabs(d[p][i])) p =
     j;
    }
    if (p == -1) continue;
    swap(d[p], d[r]);
    for (int j = 0; j < n; ++j) {
      if (r == j) continue;
      double z = d[j][i] / d[r][i];
      for (int k = 0; k < m; ++k) d[j][k] -= z * d[r][k
    ];
    }
    r++;
  }
  return r;
}
```

6.12 Determinant [bb39ae]

```
ll Det(vector<vector<ll>> a) {
  int n = a.size();
  ll det = 1;
  for (int i = 0; i < n; ++i) {
    if (!a[i][i]) {
      det = -det;
      if (det < 0) det += MOD;
      for (int j = i + 1; j < n; ++j) if (a[j][i]) {
        swap(a[j], a[i]);
        break;
      }
      if (!a[i][i]) return 0;
    }
    det = det * a[i][i] % MOD;
    ll mul = mpow(a[i][i], MOD - 2);
    for (int j = 0; j < n; ++j)
      a[i][j] = a[i][j] * mul % MOD;
    for (int j = 0; j < n; ++j) if (i ^ j) {
      ll mul = a[j][i];
      for (int k = 0; k < n; ++k) {
        a[j][k] -= a[i][k] * mul % MOD;
        if (a[j][k] < 0) a[j][k] += MOD;
      }
    }
  }
  return det;
} // not tested
```

6.13 Fast Fourier Transform [8389ae]

```
using cplx = complex<double>;
const double pi = acos(-1);
cplx omega[maxn * 4];
void prefft(int n) {
 for(int i = 0; i <= n; i++)
  omega[i] = cplx(cos(2 * pi * i / n),
     sin(2 * pi * i / n));
}
void fft(vector<cplx> &v, int n) {
  int z = __builtin_ctz(n) - 1;
  for(int i = 0; i < n; i++) {
    int x = 0, j = 0;
    for(; (1 << j) < n; j++) x ^= (i >> j & 1) << (z -
    j);
    if(x > i) swap(v[x], v[i]);
  }
  for(int s = 2; s <= n; s <<= 1) {
    int z = s >> 1;
    for(int i = 0; i < n; i += s) {
      for(int k = 0; k < z; k++) {
        cplx x = v[i + z + k] * omega[n / s * k];
        v[i + z + k] = v[i + k] - x;
        v[i + k] = v[i + k] + x;
      }
    }
  }
}
void ifft(vector<cplx> &v, int n) {
  fft(v, n); reverse(v.begin() + 1, v.end());
  for(int i = 0; i < n; i++) v[i] = v[i] * cplx(1.0 / n
    , 0);
}
vl convolution(const vl &a, const vl &b) {
  // Should be able to handle N <= 10^5, C <= 10^4
  int sz = 1, tot = a.size() + b.size() - 1;
  while(sz < tot) sz <<= 1;
  prefft(sz);
  vector<cplx> v(sz);
  for(int i = 0; i < sz; i++) {
    double re = i < a.size() ? a[i] : 0;
    double im = i < b.size() ? b[i] : 0;
    v[i] = cplx(re, im);
  }
  fft(v, sz);
  for(int i = 0; i <= sz / 2; i++) {
    int j = (sz - i) & (sz - 1);
    cplx x = (v[i] + conj(v[j])) * (v[i] - conj(v[j]))
    * cplx(0, -0.25);
    if(j != i) v[j] = (v[j] + conj(v[i])) * (v[j] -
    conj(v[i])) * cplx(0, -0.25);
    v[i] = x;
  }
  ifft(v, sz);
  vl c(sz);
  for(int i = 0; i < sz; i++)c[i] = round(v[i].real());
  c.resize(tot);
  return c;
}
```

6.14 3 Primes NTT [8f0997]

```
// MOD: arbitrary prime
const int M1 = 998244353;
const int M2 = 1004535809;
```

```cpp
const int M3 = 2013265921;
int super_big_crt(int64_t A, int64_t B, int64_t C) {
  static_assert(M1 <= M2 && M2 <= M3);
  ll r12 = mpow(M1, M2 - 2, M2);
  ll r13 = mpow(M1, M3 - 2, M3);
  ll r23 = mpow(M2, M3 - 2, M3);
  ll M1M2 = 1LL * M1 * M2 % MOD;
  B = (B - A + M2) * r12 % M2;
  C = (C - A + M3) * r13 % M3;
  C = (C - B + M3) * r23 % M3;
  return (A + B * M1 + C * M1M2) % MOD;
} // return ans % MOD
```

6.15 Number Theory Transform [c79a7e]

```cpp
/* mod | g | maxn possible values:
998244353 | 3 | 8388608
1004535809 | 3 | 2097152
2013265921 | 31 | 134217728 */
template <int mod, int G, int maxn>
struct NTT {
  ll mpow(ll a, ll b) {
    ll res = 1;
    for (; b; b >>= 1, a = a * a % mod)
      if (b & 1)
        res = res * a % mod;
    return res;
  }
  static_assert(maxn == (maxn & -maxn));
  int roots[maxn];
  NTT() {
    ll r = mpow(G, (mod - 1) / maxn);
    for (int i = maxn >> 1; i; i >>= 1) {
      roots[i] = 1;
      for (int j = 1; j < i; j++)
        roots[i + j] = roots[i + j - 1] * r % mod;
      r = r * r % mod;
    }
  }
  // n = f.size() must be 2^k, and 0 <= f[i] < mod
  // n >= the size after convolution
  // practical:
  // int sz = 1;
  // while(sz < n + m - 1) sz <<= 1;
  void operator()(vector<ll> &f, int n, bool inv =
    false) {
    for (int i = 0, j = 0; i < n; i++) {
      if (i < j) swap(f[i], f[j]);
      for (int k = n >> 1; (j ^= k) < k; k >>= 1) { }
    }
    for (int s = 1; s < n; s *= 2) {
      for (int i = 0; i < n; i += s * 2) {
        for (int j = 0; j < s; j++) {
          ll a = f[i + j];
          ll b = f[i + j + s] * roots[s + j] % mod;
          f[i + j] = (a + b) % mod;
          f[i + j + s] = (a - b + mod) % mod;
        }
      }
    }
    if (inv) {
      int invn = mpow(n, mod - 2);
      for (int i = 0; i < n; i++)
        f[i] = f[i] * invn % mod;
      reverse(f.begin() + 1, f.end());
    }
  }
};
```

6.16 Berlekeamp Massey [73b3cc]

```cpp
// need add, sub, mul
vector <ll> BerlekampMassey(vector <ll> a) {
  // find min |c| such that a_n = sum c_j * a_{n - j -
    1}, 0-based
  // O(N^2), if |c| = k, |a| >= 2k sure correct
  auto f = [&](vector<ll> v, ll c) {
    for (ll &x : v) x = mul(x, c);
    return v;
  };
  vector <ll> c, best;
  int pos = 0, n = a.size();
  for (int i = 0; i < n; ++i) {
    ll error = a[i];
    for (int j = 0; j < c.size(); ++j)
      error = sub(error, mul(c[j], a[i - 1 - j]));
    if (error == 0) continue;
    ll inv = mpow(error, mod - 2);
    if (c.empty()) {
      c.resize(i + 1), pos = i, best.pb(inv);
    } else {
      vector <ll> fix = f(best, error);
      fix.insert(fix.begin(), i - pos - 1, 0);
      if (fix.size() >= c.size()) {
        best = f(c, sub(0, inv));
        best.insert(best.begin(), inv);
        pos = i, c.resize(fix.size());
      }
      for (int j = 0; j < fix.size(); ++j)
        c[j] = add(c[j], fix[j]);
    }
  }
  return c;
}
```

6.17 Fraction [5c3898]

```cpp
struct fraction {
  ll n, d;
  fraction(const ll _n=0, const ll _d=1): n(_n), d(_d)
    {
    ll t = gcd(n, d);
    n /= t, d /= t;
    if (d < 0) n = -n, d = -d;
  }
  fraction operator-() const
  { return fraction(-n, d); }
  fraction operator+(const fraction &b) const
  { return fraction(n * b.d + b.n * d, d * b.d); }
  fraction operator-(const fraction &b) const
  { return fraction(n * b.d - b.n * d, d * b.d); }
  fraction operator*(const fraction &b) const
  { return fraction(n * b.n, d * b.d); }
  fraction operator/(const fraction &b) const
  { return fraction(n * b.d, d * b.n); }
  void print() {
    cout << n;
    if (d != 1) cout << "/" << d;
  }
}; // not tested
```

7 Misc

7.1 Josephus Problem [f4494f]

```cpp
// n people kill m for each turn
int f(int n, int m) {
 int s = 0;
 for (int i = 2; i <= n; i++)
  s = (s + m) % i;
 return s;
}
// died at kth
int kth(int n, int m, int k){
 if (m == 1) return n-1;
 for (k = k*m+m-1; k >= n; k = k-n+(k-n)/(m-1));
 return k;
} // both not tested
```