Содержание

1 Настройка CLion

1. В файле `CMakeLists.txt` дописать строчку `add_compile_definitions(LOCAL)`. Нажать появившуюся опцию в правом верхнем углу `enable auto-reload`.

2. Вбить шаблон в `main.cpp`:

```
#ifdef LOCAL
#define _GLIBCXX_DEBUG
#endif
#include<bits/stdc++.h>

using namespace std;

#define int long long
#define app push_back
#define all(x) x.begin(), x.end()
#ifdef LOCAL
#define debug(...) [](auto...a){ ((cout << a << ' '), ...) << endl; }(#__VA_ARGS__, ":", __VA_ARGS__)
#define debugv(v) do { cout << #v << ": "; for (auto x : v) cout << x << ' '; cout << endl; } while(0)
#else
#define debug(...)
#define debugv(v)
#endif

int32_t main() {
  cin.tie(0);ios_base::sync_with_stdio(0);
  int n = 2; vector<int> a(n, n);
  debug(n); debugv(a);
}
//59124c
```

   Скомпилировать, чтобы проверить отсутствие опечаток.

3. Запустить терминал (crtl + alt + T)

```
$ cd workspace/CLionProjects
$ for c in {A..Z}; do cp main.cpp $c.cpp && echo "add_executable($c $c.cpp)" >> CMakeLists.txt ; done
```

Далее отключаем подсветку и форматирование в настройках (ctrl+alt+S)

- Editor → Code Style → Formatter → `Do not format` прописать *
- Editor → Inspections → C/C++ → static analysis tools → CLang-Tidy отключить
- Editor → Inlay Hints → отключаем всё (достаточно первых трёх — code vision, parameter names, types).

Тёмная тема отключается в Appearance & Behavior → Appearance.

Чтобы добавить санитайзеры, надо дописать в CMakeLists.txt `set(CMAKE_CXX_FLAGS "-fsanitize=address -fsanitize=undefined")`

2 Теория чисел

2.1 КТО

```
int gcd(int a, int b, int &x, int &y) {
  if (b==0) { x = 1; y = 0; return a; }
  int d = gcd(b,a%b,y,x);
  y-=a/b*x;
  return d;
}
int inv(int r, int m) {
  int x, y;
  gcd(r,m,x,y);
  return (x+m)%m;
}
int crt(int r, int n, int c, int m) { return r + ((c - r) % m + m) * inv(n, m) % m * n; }
//8ed8ed
```

2.2 Алгоритм Миллера — Рабина

```
__int128 one=1;
int po(int a,int b,int p)
{
  int res=1;
  while(b) {if(b & 1) {res=(res*one*a)%p;--b;} else {
    a=(a*one*a)%p;b>>=1;}} return res;
}
bool chprime(int n) ///miller-rabin
{
  if(n==2) return true;
  if(n<=1 || n%2==0) return false;
  int h=n-1;int d=0;while(h%2==0) {h/=2;++d;}
  for(int a:{2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31,
    37})
    {
    if(a==n) return true;
    int u=po(a,h,n);bool ok=0;
    if(u%n==1) continue;
    for(int c=0;c<d;++c)
      {
      if((u+1)%n==0) {ok=1;break;}
      u=(u*one*u)%n;
    }
    if(!ok) return false;
  }
  return true;
}
//86b2ed
```

2.3 Алгоритм Берлекэмпа — Месси

https://mzhang2021.github.io/cp-blog/berlekamp-massey/

```
template<typename T>
vector<T> berlekampMassey(const vector<T> &s) {
  int n = s.size(), l = 0, m = 1;
  vector<T> b(n), c(n);
  T ld = b[0] = c[0] = 1;
  for (int i=0; i<n; i++, m++) {
    T d = s[i];
    for (int j=1; j<=l; j++)
      d += c[j] * s[i-j];
    if (d == 0) continue;
    vector<T> temp = c;
    T coef = d / ld;
    for (int j=m; j<n; j++) c[j] -= coef * b[j-m];
    if (2 * l <= i) {
      l = i + 1 - l;
      b = temp;
      ld = d;
      m = 0;
    }
  }
  c.resize(l + 1);
  c.erase(c.begin());
  for (T &x : c)
    x = -x;
  return c;
}
//ff47ae
```

2.4 Линейное решето

```
const int C = 1e7+7;
vi pr, lp(C);
for (int i = 2; i < C; ++i) {
  if (lp[i] == 0) {
    lp[i] = i;
    pr.app(i);
  }
  for (int j = 0; j < (int)pr.size() && pr[j] <= lp[i
    ] && pr[j] * i < C; ++j) {
    lp[pr[j] * i] = pr[j];
  }
}
//36b3d1
```

2.5 Алгоритм Шенкса

```
#define T int
int mod;
int gcd(int a, int b, int &x, int &y) {
  if (b==0) { x = 1; y = 0; return a; }
  int d = gcd(b,a%b,y,x);
  y-=a/b*x;
  return d;
}
int inv(int r, int m) {
  int x, y;
  gcd(r,m,x,y);
  return (x+m)%m;
}
int crt(int r, int n, int c, int m) { return r + ((c
    - r) % m + m) * inv(n, m) % m * n; }
T inv(T a)
{
  return inv(a,mod);
}
T mul(T a,T b)
{
  return (a*b)%mod;
}
vector<int> rasl(int x)
{
  vector<int> v;
  if(x==1) {return v;}
  for(int i=2;i*i<=x;++i)
  {
    if(x%i==0)
    {
      v=rasl(x/i);v.app(i);return v;
    }
  }
  v.app(x);return v;
}
T po(T a,int b) ///b>=1
{
  if(b==1) {return a;}
  if(b%2==0)
  {
    T u=po(a,b/2);
    return mul(u,u);
  }
  else
  {
    T u=po(a,b-1);
    return mul(a,u);
  }
}
T getper(T a,T one,int per,vector<int> v)
{
  for(int p:v)
  {
    if(po(a,per/p)==one)
    {
      per/=p;
    }
  }
  return per;
}
vector<pair<int,int> > shanks(T a,vector<T> b,T one,
    int per) ///a^per=1 and b[i]^per=1 /// all right
    numbers in output are equal
{
  if(b.empty()) {return {};}
  int n=b.size();
  vector<int> vp=rasl(per);
  int pera=getper(a,one,per,vp);per=pera;
  vp=rasl(pera);
  vector<int> have(n,0);
  int cur2=per;T cura=a;T invcura=inv(a);
  int curad=1;
  vector<pair<T,int> > v;
  vector<bool> ok(n,true);
  vector<T> poinvzx;
  for(int p:vp)
  {
    T ca=po(cura,cur2/p);
    if(ca==one) {continue;}
    T invca=po(invcura,cur2/p);
    int step=sqrt(b.size()*p)+2;
    int wee=p/step+2;
    v.clear();poinvzx.clear();
    T zx=one;T invzx=one;T buba=one;
    vector<T> zhe;
    T lu=one;
    for(int i=0;i<step;++i)
    {
      v.app({zx,i});zhe.app(lu);
      zx=mul(zx,ca);invzx=mul(invzx,invca);buba=mul(
    buba,cura);lu=mul(lu,invcura);
    }
    poinvzx.app(one);
    for(int j=0;j<wee;++j)
    {
      poinvzx.app(mul(poinvzx.back(),buba));
```

```
    }
    sort(all(v));
    for(int i=0;i<n;++i)
    {
      if(!ok[i]) {continue;}
      T uu=po(b[i],cur2/p);
      bool okkk=false;
      for(int j=0;j<wee;++j)
      {
        auto it=lower_bound(all(v),make_pair(uu,0LL))
    ;
        if(it!=v.end() && (*it).first==uu)
        {
          okkk=true;
          have[i]-=(curad*step*j);
          have[i]+=(curad*(*it).second);
          have[i]%=pera;if(have[i]<0) {have[i]+=pera
    ;}
          b[i]=mul(b[i],poinvzx[j]);b[i]=mul(b[i],zhe
    [(*it).second]);
          assert(po(b[i],cur2/p)==one);
          break;
        }
        uu=mul(uu,zx);
      }
      if(!okkk) {ok[i]=false;}
    }
    cur2/=p;cura=po(cura,p);invcura=po(invcura,p);
    curad*=p;
  }
  vector<pair<int,int> > res;
  for(int i=0;i<n;++i)
  {
    if(ok[i] && b[i]==one)
    {
      res.app({(have[i]%pera+pera)%pera,pera});
    }
    else
    {
      res.app({-1,pera});
    }
  }
  return res;
}
int shanks2(int x,int y,int mod1) ///only for T=long
    long, 0^0 = 1 by default
{
  mod=mod1;
  vector<int> v=rasl(mod);sort(all(v));
  int per=1;for(int i=0;i<v.size();++i) {if(i==0 || v
    [i]!=v[i-1]) {per*=(v[i]-1);} else {per*=v[i];}}
  if(y==1 || mod==1) {return 0;}
  int C=61;
  for(int i=1;i<C;++i)
  {
    if(po(x,i)==y) {return i;}
  }
  if(y==0) {return (-1);}
  T h=po(x,C);
  int lc1=gcd(h,mod);int lc2=gcd(y,mod);
  if(lc1!=lc2) {return (-1);}
  mod/=lc2;T h1=h/lc2;T y1=y/lc2;
  vector<pair<int,int> > s=shanks(x%mod,{mul(y1,inv(
    h1))},1,per);
  if(s[0].first!=(-1))
  {
    return s[0].first+C;
  }
  else
  {
    return (-1);
  }
}
//a75596
```

3 Графы

3.1 SCC и 2-SAT

Алгоритм ищет сильносвязные компоненты в графе g, если есть путь $i \to j$, то $scc[i] \le scc[j]$

```
vector<int> find_scc(vector<vector<int>> g) {
  int n = g.size();
  vector<vector<int>> r(n);
  for (int i = 0; i < n; ++i) {
    for (int j : g[i]) r[j].push_back(i);
  }
  vector<int> used(n), tout(n);
  int time = 0;
  auto dfs = [&](auto dfs, int cur) -> void {
    used[cur] = 1;
    for (int nxt : g[cur]) {
      if (!used[nxt]) dfs(dfs, nxt);
    }
    tout[cur] = time++;
  };
  for (int i = 0; i < n; ++i) if (!used[i]) dfs(dfs,
    i);
  vector<int> ind(n);
  iota(all(ind), 0);
  sort(all(ind), [&](int i, int j){return tout[i] >
    tout[j];});
  vector<int> scc(n, -1);
  auto go = [&](auto go, int cur, int color) -> void
    {
    scc[cur] = color;
    for (int nxt : r[cur]) {
      if (scc[nxt] == -1) go(go, nxt, color);
    }
  };
  int color = 0;
  for (int i : ind) {
    if (scc[i] == -1) go(go, i, color++);
  }
  return scc;
}
//4fd51f
```

Чтобы решать 2-SAT, надо создать граф на $2n$ вершинах, рёбра $i \Rightarrow j$ и $(j \oplus 1) \Rightarrow (i \oplus 1)$ должны быть добавлены одновременно. После этого если `scc[2 * i] = scc[2 * i + 1]`, то решения нет; если `scc[2 * i + 0] < scc[2 * i + 1]`, то присутствует импликация $\neg i \Rightarrow i$, надо назначить i =`true`.

3.2 Эйлеров цикл

```
vector<int> euler(vector<vector<pair<int, int>>> g,
    int m, int src) {  // g[cur][i] = pair{nxt, idx}
  int n = g.size();
  vector<int> used(m), it(n), cycle;
  auto dfs = [&](auto dfs, int cur) -> void {
    while (true) {
      while (it[cur] < g[cur].size() && used[g[cur][
    it[cur]].second]) it[cur]++;
      if (it[cur] == g[cur].size()) return;
      auto [nxt, idx] = g[cur][it[cur]];
      used[idx] = true;
      dfs(dfs, nxt);
      cycle.push_back(idx); // or {cur, nxt}
    }
  };
  dfs(dfs, src);
  reverse(cycle.begin(), cycle.end());
  if (cycle.size() != m) return {}; // check that all
     edges are present in the cycle, fail otherwise
  return cycle;
}
//f6b9d4
```

3.3 Компоненты рёберной двусвязности

```
//n - number of vertices, m - number of edges,
    parallel edges -- ???, color of any edge is the
    color of its lower end
vector <vector <int> > dfstree(n);
vector <int> used(n), cut(n), h(n), up(n);
auto findCutPoints = [&] (auto self, int u) -> void {
  used[u] = 1;
  up[u] = h[u];
  for (int v : g[u]) {
    if (!used[v]) {
      dfstree[u].push_back(v);
      h[v] = h[u] + 1;
      self(self, v);
      up[u] = min(up[u], up[v]);
      if (up[v] >= h[u]) {
        cut[v] = 1;
      }
    }
    else {
      up[u] = min(up[u], h[v]);
    }
  }
};
findCutPoints(findCutPoints, 0);
vector <vector <int> > tree(n + m);
```

```
vector<int> color(n);color[0]=0;int ptr=n;
auto build = [&] (auto self, int u) -> void {
  for (int v : dfstree[u]) {
    if (cut[v]) {
      color[v]=ptr;++ptr;
      self(self, v);
    }
    else {
      color[v]=color[u];
      self(self, v);
    }
  }
};
build(build, 0);
for(int i=0;i<n;++i) {
  set<int> to;
  for(int j:g[i]) {
    int x=i,y=j;
    if(h[x]<h[y]) swap(x,y);
    to.insert(color[x]);
  }
  for(int j:to) {
    tree[i].app(j);tree[j].app(i);
  }
}
//2ebfbb
```

3.4 DCP offline

```
struct Dsu {
  int n;
  vector<pair<int &, int>> s;
  vector<int> p, sz;
  // other info

  Dsu(int n) : n(n), p(n), sz(n, 1){
    iota(all(p), 0);
  }

  int get(int u) {
    while (u != p[u]) u = p[u];
    return u;
  }

  bool merge(int u, int v) {
    u = get(u), v = get(v);
    if (u == v) return false;
    if (sz[v] < sz[u]) swap(u, v);
    s.app({p[u], p[u]});
    s.app({sz[v], sz[v]});
    // app other info like s.app({comp, comp});
    p[u] = v;
    sz[v] += sz[u];
    return true;
  }

  void rollback(int sz) {
    while (s.size() != sz) {
      s.back().first = s.back().second;
      s.pop_back();
    }
  }
};

struct DcpOffline {
  int n;
  vector<vector<pair<int, int>>> d;

  void addEdgeOnSegment(int l, int r, int a, int b) {
    for (l += n, r += n; l < r; l /= 2, r /= 2) {
      if (l & 1) d[l++].app({a, b});
      if (r & 1) d[--r].app({a, b});
    }
  }

  template<typename T>
  void dfs(Dsu &dsu, T act) {
    dfs(1, 0, n, dsu, act);
  }

  template<typename T>
  void dfs(int v, int l, int r, Dsu &dsu, T act) {
    int sz = dsu.s.size();
    for (auto [u, v]: d[v]) {
      dsu.merge(u, v);
    }
    if (l + 1 == r) {
      act(l, dsu);
    } else {
      int m = (l + r) / 2;
      dfs(v * 2, l, m, dsu, act);
      dfs(v * 2 + 1, m, r, dsu, act);
    }
    dsu.rollback(sz);
  }

  DcpOffline(int maxt) : n(2 << __lg(maxt + 1)), d(2
    * n) {}
};
//3c4e2d
```

3.5 Взвешенное паросочетание

https://judge.yosupo.jp/submission/201334

```
#define d(x) (lab[x.u] + lab[x.v] - 2 * e[x.u][x.v].w
    )
const int N = 403*2;
const int inf = 1e18;
struct Q{ int u, v, w; } e[N][N];
vector<int> p[N];
int n, m = 0, id, h, t, lk[N], sl[N], st[N], f[N], b[
    N][N], s[N], ed[N], q[N], lab[N];
void upd(int u, int v) { if (!sl[v] || d(e[u][v]) < d
    (e[sl[v]][v])) sl[v] = u; }
void ss(int v) {
  sl[v] = 0;
  for (int u = 1; u <= n; ++u) if (e[u][v].w > 0 &&
    st[u] != v && !s[st[u]]) upd(u, v);
}
void ins(int u){ if (u <= n) q[++t] = u; else for (
    int v : p[u]) ins(v); }
void ch(int u, int w) { st[u] = w; if (u > n) for (
    int v : p[u]) ch(v, w); }
int gr(int u, int v) {
  if ((v = find(all(p[u]), v) - p[u].begin()) & 1) {
    reverse(1 + all(p[u]));
    return (int)p[u].size() - v;
  }
  return v;
}
void stm(int u, int v) {
  lk[u] = e[u][v].v;
  if (u <= n) return; Q w = e[u][v];
  int x = b[u][w.u], y = gr(u,x);
  for (int i = 0; i < y; ++i) stm(p[u][i], p[u][i^1])
    ;
  stm(x, v); rotate(p[u].begin(), y+all(p[u]));
}
void aug(int u, int v) {
  int w = st[lk[u]];stm(u, v);if (!w) return;
  stm(w, st[f[w]]);
  aug(st[f[w]], w);
}
int lca(int u, int v) {
  for (id++; u|v; swap(u, v)) {
    if (!u) continue;if(ed[u] == id) return u;
    ed[u] = id; if (u = st[lk[u]]) u = st[f[u]]; //
    =, not ==
  }
  return 0;
}
//cf1d55



void add(int u, int a, int v) {
  int x = n + 1; while (x <= m && st[x]) ++x;
  if (x > m) ++m;
  lab[x] = s[x] = st[x] = 0;
  lk[x] = lk[a];
  p[x].clear();
  p[x].push_back(a);
#define op(q) for (int i = q, j = 0; i != a; i=st[f[j
    ]]) p[x].push_back(i), p[x].push_back(j=st[lk[i
    ]]), ins(j) // also not ==
  op(u); reverse(1+all(p[x]));op(v);
  ch(x, x); for (int i = 1; i <= m; ++i) e[x][i].w =
    e[i][x].w = 0;
  fill(b[x]+1, b[x]+n+1, 0);
  for (int u : p[x]) {
    for (int v = 1; v <= m; ++v) if (!e[x][v].w || d(
    e[u][v]) < d(e[x][v])) e[x][v] = e[u][v], e[v][x]
     = e[v][u];
    for (int v = 1; v <= n; ++v) if (b[u][v]) b[x][v]
     = u;
  }
  ss(x);
}
```

```
void ex(int u) {
  for (int x : p[u]) ch(x, x);
  int a = b[u][e[u][f[u]].u], r = gr(u, a);
  for (int i = 0; i < r; i += 2) {
    int x = p[u][i], y = p[u][i + 1];
    f[x] = e[y][x].u; s[x] = 1; s[y] = 0; sl[x] = 0;
    ss(y); ins(y);
  }
  s[a] = 1; f[a] = f[u];
  for (int i = r + 1; i < p[u].size(); ++i) s[p[u][i
    ]] = -1, ss(p[u][i]);
  st[u] = 0;
}
bool on(const Q &e) {
  int u = st[e.u], v = st[e.v], a;
  if (s[v] == -1) {
    f[v] = e.u, s[v] = 1, a = st[lk[v]], sl[v] = sl[a
    ] = s[a] = 0, ins(a);
  } else if (!s[v]) {
    a = lca(u, v); if (!a) return aug(u, v), aug(v, u
    ), 1; else add(u, a, v);
  }
  return 0;
}
//3f0f1d



bool bfs() {
  fill(s+1, s+m+1, -1);fill(sl+1, sl+m+1, 0); // s is
     filled with -1
  h = 1, t = 0; for (int i = 1; i <= m; ++i) if (st[i
    ] == i && !lk[i]) f[i] = s[i] = 0, ins(i);
  if (h > t) return 0;
  while (1) {
    while (h <= t) {
      int u = q[h++];
      if (s[st[u]] != 1) {
        for (int v = 1; v <= n; ++v) if (e[u][v].w >
    0 && st[u] != st[v]) {
          if (d(e[u][v])) upd(u, st[v]); else if (on(
    e[u][v])) return 1;
        }
      }
    }
    int x = inf;
    for (int i = n+1; i <= m; ++i) if (st[i] == i &&
    s[i] == 1) x = min(x, lab[i]/2);
    for (int i = 1; i <= m; ++i) if (st[i] == i && sl
    [i] && s[i] != 1) x = min(x, d(e[sl[i]][i])>>s[i
    ]+1);
    for (int i = 1; i <= n; ++i) if (~s[st[i]]) if ((
    lab[i] += (s[st[i]] * 2 - 1) * x) <=0) return 0;
    for (int i = n + 1; i <= m; ++i) if (st[i] == i
    && ~s[st[i]]) lab[i] += (2 - 4 * s[st[i]]) * x;
    h = 1, t = 0;
    for (int i = 1; i <= m; ++i) if (st[i] == i && sl
    [i] && st[sl[i]] != i && !d(e[sl[i]][i]) && on(e[
    sl[i]][i])) return 1;
    for (int i = n+1; i <= m; ++i) if (st[i] == i &&
    s[i] == 1 && !lab[i]) ex(i);
  }
}

pair<int, vector<array<int, 2>>> run(int N, vector<
    array<int, 3>> edges) {
  for (auto &[u, v, w] : edges) ++u, ++v;
  fill(ed+1, ed+m+1, 0);
  fill(lk+1, lk+m+1, 0);
  n = m = N;
  id = 0;
  iota(st + 1, st + n + 1, 1);
  int wm = 0, weight = 0;
  for (int i = 1; i <= n; ++i) for (int j = 1; j <= n
    ; ++j) e[i][j] = {i,j,0};
  for (auto [u, v, w] : edges) wm = max(wm, e[v][u].w
     = e[u][v].w = max(e[u][v].w, w));
  for (int i = 1; i <= n; ++i) p[i].clear();
  for (int i = 1; i <= n; ++i) for (int j = 1; j <= n
    ; ++j) b[i][j] = i==j?i:0;
  fill_n(lab+1, n, wm); while (bfs());
  vector<array<int, 2>> matching;
  for (int i = 1; i <= n; ++i) if (i < lk[i]) weight
    += e[i][lk[i]].w, matching.push_back({i - 1, lk[i
    ] - 1});
  return {weight, matching};
}
//be682f
```

3.6 Дерево доминаторов

```
struct DominatorTree{
  struct DSU{
    struct Vert{
      int p;
      pair<int, int> val;
    };

    vector<Vert> t;
    vector<int> ord;

    DSU(vector<int> &ord): ord(ord) { t.resize(ord.
    size()); for (int i = 0; i < ord.size(); i++) t[i
    ].p = i; }

    int get(int v){
      if (t[v].p == v) return v;
      int new_p = get(t[v].p);
      if (ord[t[v].val.first] > ord[t[t[v].p].val.
    first]) t[v].val = t[t[v].p].val;
      t[v].p = new_p;
      return t[v].p;
    }

    void merge(int a, int b){
      a = get(a); b = get(b);
      if (a != b){
        t[b].p = a;
      }
    }

    void setVal(int v, pair<int, int> val){
      t[v].val = val;
    }

    auto getVal(int v){
      get(v);
      return t[v].val;
    }
  };

  vector<vector<int> > g, gr, lg;
  vector<int> idom, sdom, was, tin;

  int timer;
  void dfs(int v){
    tin[v] = timer++;
    was[v] = 1;
    for (int to : g[v]) if (!was[to]) dfs(to);
  }

  vector<vector<int> > req;

  DominatorTree(int n, vector<pair<int, int> > &edges
    , int root){
    g.resize(n); gr.resize(n); lg.resize(n);
    idom.resize(n, -1); sdom.resize(n);
    was.resize(n, 0), tin.resize(n);
    req.resize(n);
    for (auto &&e : edges){
      g[e.first].push_back(e.second);
      gr[e.second].push_back(e.first);
    }
    timer = 0; dfs(root);
    vector<int> ord;
    for (int i = 0; i < n; i++) ord.push_back(i);
    sort(ord.begin(), ord.end(), [this](int w1, int
    w2){ return tin[w1] > tin[w2]; });
    DSU dsu(tin);
    for (int v : ord){
      sdom[v] = v;
      for (int to : gr[v]){
        if (v == to) continue;
        int val = tin[to] < tin[v] ? to : dsu.getVal(
    to).first;
        if (tin[val] < tin[sdom[v]]) sdom[v] = val;
      }

      req[sdom[v]].push_back(v);
      for (auto &&r : req[v]){
        auto val = dsu.getVal(r);
        if (tin[val.first] < tin[sdom[r]]){
          lg[val.second].push_back(r);
        } else {
          idom[r] = sdom[r];
        }
      }
```

```
      dsu.setVal(v, make_pair(sdom[v], v));
      for (int to : g[v]){
        if (tin[to] > tin[v] && dsu.t[to].p == to){
          dsu.merge(v, to);
        }
      }
    }

    for (int i = 0; i < n; i++) was[i] = 0;

    for (int i = 0; i < n; i++) if (!was[i] && idom[i
    ] != -1){
      vector<int> st;
      st.push_back(i);
      was[i] = 1;
      while(st.size()){
        int v = st.back(); st.pop_back();
        idom[v] = idom[i];
        for (int to : lg[v]) if (!was[to]) was[to] =
    1, st.push_back(to);
      }
    }
  }
};

/*
vector <pair <int, int> > e;
DominatorTree d(n,e,0);
auto par = d.idom;
*/
//839464
```

3.7 Венгерский алгоритм решения задачи о назначениях

```
//choose one element in each row to minimize sum of
    the chosen elements, n <= m, INF>max(abs(a[i][j])
    )
const int INF = 1e18;
vector<int> hungarian(int n, int m, vector<vector<int
    >> a, int &cost) { //1-indexed!, a.size()=n+1, a[
    i].size()=m+1
  vector<int> u(n+1), v(m+1), p(m+1), way(m+1);
  for (int i=1; i<=n; ++i) {
    p[0] = i;
    int j0 = 0;
    vector<int> minv(m+1, INF);
    vector<char> used(m+1, false);
    do {
      used[j0] = true;
      int i0 = p[j0],  delta = INF,  j1;
      for (int j=1; j<=m; ++j)
        if (!used[j]) {
          int cur = a[i0][j]-u[i0]-v[j];
          if (cur < minv[j])
            minv[j] = cur, way[j] = j0;
          if (minv[j] < delta)
            delta = minv[j], j1 = j;
        }
      for (int j=0; j<=m; ++j)
        if (used[j])
          u[p[j]] += delta, v[j] -= delta;
        else
          minv[j] -= delta;
      j0 = j1;
    } while (p[j0] != 0);
    do {
      int j1 = way[j0];
      p[j0] = p[j1];
      j0 = j1;
    } while (j0);
  }
  vector<int> ans(n+1);
  for (int j=1; j<=m; ++j) {
    if (p[j]!=0) {
      ans[p[j]] = j;
    }
  }
  cost = -v[0];
  return ans;
}
//6d564b
```

3.8 Алгоритм Чу-Лью

В ориентированном взвешенном графе ищет остовное дерево минимального веса (такое дерево, что все вершины достижимы из нуля, входящая степень любой ненулевой вершины равна 1, в нуль не входит ни одного ребра). Если `recover = true`, то восстанавливает ответ.

Предполагается, что все вершины достижимы из нуля.

```
using edge = array<int, 4>; // {from, to, w, i}

template<typename T, typename C>
using pq = priority_queue<T, vector<T>, C>;

pair<int, vector<int>> solve(int n, vector<edge> ed,
    bool recover) {
  auto cmp = [&](int i, int j) { return ed[i][2] > ed
    [j][2]; };
  vector r(n, pq<int, decltype(cmp)>(cmp));
  for (auto [u, v, w, i] : ed) r[v].push(i);
  vector<int> mod(n), p(n), color(n), take;
  iota(all(p), 0);
  auto get = [&](int u) {
    while (u != p[u]) u = p[u] = p[p[u]];
    return u;
  };
  auto unite = [&](int x, int y) {
    x = get(x), y = get(y);
    if (x == y) return;
    if (r[x].size() > r[y].size()) swap(x, y);
    p[x] = y;
    while (r[x].size()) {
      auto e = r[x].top();
      r[x].pop();
      ed[e][2] += mod[x] - mod[y];
      r[y].push(e);
    }
  };
  vector<vector<pair<int, int>>> g(n);
  int ans = 0;
  color[0] = 2;
  auto go = [&](int cur) {
    vector<pair<int, int>> stack;
    int time = 0;
    while (color[cur] < 2) {
      color[cur] = 1;
      edge e;
      do {
        e = ed[r[cur].top()];
        r[cur].pop();
      } while (get(e[0]) == cur);
      e[2] += mod[cur];
      ans += e[2];
      mod[cur] -= e[2];
      stack.push_back({cur, e[3]});
      int a = get(e[0]);
      if (color[a] == 1) {
        while (true) {
          auto [nxt, i] = stack.back();
          stack.pop_back();
          g[ed[i][0]].push_back({time++, i});
          unite(nxt, cur);
          if (nxt == a) break;
        }
      }
      cur = get(e[0]);
    }
    for (auto [x, i] : stack) {
      color[x] = 2;
    }
    if (recover) {
      pq<pair<int, int>, greater<>> dijkstra;
      for (auto [x, i] : stack) {
        dijkstra.emplace(x, i);
      }
      while (!dijkstra.empty()) {
        auto [t, i] = dijkstra.top();
        dijkstra.pop();
        if (color[ed[i][1]] == 3) {
          continue;
        }
        color[ed[i][1]] = 3;
        take.push_back(i);
        for (auto [t2, i2] : g[ed[i][1]]) {
          dijkstra.emplace(t2, i2);
        }
      }
    }
  };
  for (int i = 1; i < n; ++i) go(get(i));
  return {ans, take};
}
//f245b7
```

4 Свёртки

4.1 XOR свёртка

```
vector<int> bxor(vector<int> a,vector<int> b)
{
  assert(p%2==1);int inv2=(p+1)/2;
  int n=0;while((1<<n)<a.size()) ++n;
  a.resize(1<<n);b.resize(1<<n);
  for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++
    mask) if(!(mask & (1<<i))) {int u=a[mask],v=a[
    mask+(1<<i)];a[mask+(1<<i)]=(u+v)%p;a[mask]=(u-v)
    %p;}
  for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++
    mask) if(!(mask & (1<<i))) {int u=b[mask],v=b[
    mask+(1<<i)];b[mask+(1<<i)]=(u+v)%p;b[mask]=(u-v)
    %p;}
  vector<int> c(1<<n,0);
  for(int mask=0;mask<(1<<n);++mask) {c[mask]=a[mask
    ]*b[mask];c[mask]%=p;}
  for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n);++
    mask) if(!(mask & (1<<i))) {int u=c[mask],v=c[
    mask+(1<<i)];c[mask+(1<<i)]=((v-u)*inv2)%p;c[mask
    ]=((u+v)*inv2)%p;}
  return c;
}
//20cc50
```

4.2 FFT & co

```
typedef long long ll;
const int p=998244353;
int po(int a,int b) {if(b==0) return 1; if(b==1)
    return a; if(b%2==0) {int u=po(a,b/2);return (u*1
    LL*u)%p;} else {int u=po(a,b-1);return (a*1LL*u)%
    p;}}
int inv(int x) {return po(x,p-2);}
template<int M, int K, int G> struct Fft {
  // 1, 1/4, 1/8, 3/8, 1/16, 5/16, 3/16, 7/16, ...
  int g[1 << (K - 1)];
  Fft() : g() { //if tl constexpr...
    // static_assert(K >= 2, "Fft: K >= 2 must hold")
    ;
    g[0] = 1;
    g[1 << (K - 2)] = G;
    for (int l = 1 << (K - 2); l >= 2; l >>= 1) {
      g[l >> 1] = (g[l] * 1LL* g[l]) % M;
    }
    assert((g[1]*1LL * g[1]) % M == M - 1);
    for (int l = 2; l <= 1 << (K - 2); l <<= 1) {
      for (int i = 1; i < l; ++i) {
        g[l + i] = (g[l] * 1LL * g[i]) % M;
      }
    }
  }
  void fft(vector<int> &x) const {
    const int n = x.size();
    assert(n <= 1 << K);
    for (int h = __builtin_ctz(n); h--; ) {
      const int l = (1 << h);
      for (int i = 0; i < n >> (h+1); ++i) {
        for (int j = i << (h+1); j < (((i << 1) + 1)
    << h); ++j) {
          const int t = (g[i] * 1LL* x[j | l]) % M;
          x[j | l] = x[j] - t;
          if (x[j|l] < 0) x[j | l] += M;
          x[j]+=t;
          if (x[j] >= M) x[j] -= M;
        }
      }
    }
    for (int i = 0, j = 0; i < n; ++i) {
      if (i < j) std::swap(x[i], x[j]);
      for (int l = n; (l >>= 1) && !((j ^= l) & l); )
      {}
    }
  }
  vector<int> convolution(vector<int> a, vector<int>
    b) const {
    if(a.empty() || b.empty()) return {};
    for(int& x:a) {x%=p;if(x>=p) x-=p; if(x<0) x+=p;}
     for(int& x:b) {x%=p;if(x>=p) x-=p; if(x<0) x+=p
    ;}
    const int na = a.size(), nb = b.size();
    int n, invN = 1;
    for (n = 1; n < na + nb - 1; n <<= 1) invN = ((
    invN & 1) ? (invN + M) : invN) >> 1;
    vector<int> x(n, 0), y(n, 0);
    std::copy(a.begin(), a.end(), x.begin());
    std::copy(b.begin(), b.end(), y.begin());
    fft(x);
    fft(y);
    for (int i = 0; i < n; ++i) x[i] = (((static_cast
    <long long>(x[i]) * y[i]) % M) * invN) % M;
    std::reverse(x.begin() + 1, x.end());
    fft(x);
    x.resize(na + nb - 1);
    return x;
  }
};
Fft<998244353,23,31> muls;
//a1b591



vector<int> form(vector<int> v,int n)
{
  while(v.size()<n) v.push_back(0);
  while(v.size()>n) v.pop_back();
  return v;
}
vector<int> operator *(vector<int> v1,vector<int> v2)
{
  return muls.convolution(v1,v2);
}
vector<int> operator +(vector<int> v1,vector<int> v2)
{
  while(v2.size()<v1.size()) v2.push_back(0); while(
    v1.size()<v2.size()) v1.push_back(0);
  for(int i=0;i<v1.size();++i) {v1[i]+=v2[i];if(v1[i
    ]>=p) v1[i]-=p; else if(v1[i]<0) v1[i]+=p;}
  return v1;
}
vector<int> operator -(vector<int> v1,vector<int> v2)
{
  int sz=max(v1.size(),v2.size());while(v1.size()<sz)
     v1.push_back(0); while(v2.size()<sz) v2.
    push_back(0);
  for(int i=0;i<sz;++i) {v1[i]-=v2[i];if(v1[i]<0) v1[
    i]+=p; else if(v1[i]>=p) v1[i]-=p;} return v1;
}
vector<int> trmi(vector<int> v)
{
  for(int i=1;i<v.size();i+=2) {if(v[i]>0) v[i]=p-v[i
    ]; else v[i]=(-v[i]);}
  return v;
}
vector<int> deriv(vector<int> v)
{
  if(v.empty()) return{};
  vector<int> ans(v.size()-1);
  for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)%p
    ;
  return ans;
}
vector<int> integ(vector<int> v)
{
  vector<int> ans(v.size()+1);ans[0]=0;
  for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)%p
    ;
  return ans;
}
vector<int> mul(vector<vector<int> > v)
{
  if(v.size()==1) return v[0];
  vector<vector<int> > v1,v2;for(int i=0;i<v.size()
    /2;++i) v1.push_back(v[i]); for(int i=v.size()/2;
    i<v.size();++i) v2.push_back(v[i]);
  return muls.convolution(mul(v1),mul(v2));
}
vector<int> inv1(vector<int> v,int n)
{
  assert(v[0]!=0);
  int sz=1;v=form(v,n);vector<int> a={inv(v[0])};
  while(sz<n)
  {
    vector<int> vsz;for(int i=0;i<min(n,2*sz);++i)
    vsz.push_back(v[i]);
    vector<int> b=((vector<int>) {1})-muls.
    convolution(a,vsz);
    for(int i=0;i<sz;++i) assert(b[i]==0);
    b.erase(b.begin(),b.begin()+sz);
    vector<int> c=muls.convolution(b,a);
    for(int i=0;i<sz;++i) a.push_back(c[i]);
    sz*=2;
  }
  return form(a,n);
}
```

```
//12aa4e
```

4.3 Быстрое FFT

- Solution based on https://codeforces.com/blog/entry/117947
- Iterative and in-place version.
- Uses signed montgomery
- Optimized to minimize memory usage

```
const int MOD = 998244353;
const long long MOD2 = (long long) MOD * MOD;
const int root = 3;
const int alim = 64; // Bound for using O(n^2)
    polynomial mult

int modpow(int b, int e) {
  int ans = 1;
  for (; e; b = (long long) b * b % MOD, e /= 2)
    if (e & 1) ans = (long long) ans * b % MOD;
  return ans;
}

const int MODinv = 2 - MOD; // pow(-MOD, -1, 2**32)
inline int m_reduce(long long x) {
  int m = x * MODinv;
  return (x>>32) - (((long long) m * MOD) >> 32);
}

const int r2 = modpow(2, 64);
inline int m_transform(int x) {
  return m_reduce((long long)x * r2);
}

inline int m_add(int x, int y) {
  int z = x + y;
  return z < 0 ? z + MOD : z - MOD;
}

inline int m_sub(int x, int y) {
  int z = x - y;
  return z < 0 ? z + MOD : z - MOD;
}

inline int m_mult(int x, int y) {
  return m_reduce((long long) x * y);
}

vector<int> rt = {1};
vector<int> transformed_rt;
vector<int> transformed_rt2;

template<int a>
void transform(vector<int> &P) {
  int m = P.size();
  int n = m / a;

  int size = rt.size();
  while (2 * size < n) {
    rt.resize(n / 2);
    int r = modpow(root, MOD / (4 * size));
    for (int i = 0; i < size; ++i)
      rt[i + size] = (long long) r * rt[i] % MOD;
    size *= 2;
  }

  // For montgomery
  for (int i = transformed_rt.size(); i < rt.size();
    ++i) {
    transformed_rt.resize(rt.size());
    transformed_rt[i] = m_transform(rt[i]);
    transformed_rt2.resize(rt.size());
    transformed_rt2[i] = (unsigned int) MODinv *
    transformed_rt[i];
  }

  int k = n;
  while (k >= 4) k /= 4;

  if (k == 2) {
    int step = n * a;
    int half_step = step / 2;
    for (int j1 = 0; j1 < half_step; ++j1) {
      int j2 = j1 + half_step;

      int diff = m_sub(P[j1], P[j2]);
      P[j1] = m_add(P[j1], P[j2]);
      P[j2] = diff;
    }
    k = n/2;
  } else {
    k = n;
  }

  for (; k > 1; k /= 4) {
    for (int i = 0; i < n/k; ++i) {
      int step = k * a;
      int half_step = step / 2;
      int quarter_step = half_step / 2;

      int R20  = transformed_rt2[2 * i];
      int RR0 = transformed_rt[2 * i];

      int R21 = transformed_rt2[2 * i + 1];
      int RR1 = transformed_rt[2 * i + 1];

      int R2 = transformed_rt2[i];
      int RR = transformed_rt[i];

      int j1 = i * step;
      int j2 = j1 + quarter_step;
      int j3 = j2 + quarter_step;
      int j4 = j3 + quarter_step;

      for (int j = 0; j < quarter_step; ++j, ++j1, ++
    j2, ++j3, ++j4) {
        int z0;
        {
          int z = P[j3];
          int m = (unsigned int) R2 * z;
          z0 = ((long long) z * RR - (long long) m *
    MOD) >> 32;
        }

        int z1;
        {
          int z = P[j4];
          int m = (unsigned int) R2 * z;
          z1 = ((long long) z * RR - (long long) m *
    MOD) >> 32;
        }

        int sum0 = m_add(P[j1], z0);
        int diff0 = m_sub(P[j1], z0);
        int sum1 = P[j2] + z1;
        int diff1 = P[j2] - z1;

        // [sum0, sum1, diff0, diff1]

        int zz0;
        {
          int z = sum1;
          int m = (unsigned int) R20 * z;
          zz0 = ((long long) z * RR0 - (long long) m
    * MOD) >> 32;
        }

        int zz1;
        {
          int z = diff1;
          int m = (unsigned int) R21 * z;
          zz1 = ((long long) z * RR1 - (long long) m
    * MOD) >> 32;
        }

        P[j1]  = m_add(sum0, zz0);
        P[j2]  = m_sub(sum0, zz0);
        P[j3]  = m_add(diff0, zz1);
        P[j4]  = m_sub(diff0, zz1);
      }
    }
  }

  for (int i = 0; i < m; ++i)
    if (P[i] < 0) P[i] += MOD;
}

template<int a>
void inverse_transform(vector<int> &P) {
  int m = P.size();
  int n = m / a;
  int n_inv = m_transform(modpow(n, MOD - 2));

  vector<int> rev(n);
  for (int i = 1; i < n; ++i) {
    rev[i] = rev[i / 2] / 2 + (i & 1) * n / 2;
```

```
  }

  // P = [p * n_inv for p in P]
  for (int i = 0; i < m; ++i)
    P[i] = m_mult(n_inv, P[i]);

  // P = [P[a * rev[i // a] + (i % a)] for i in range
    (m)]
  for (int i = 1; i < n; ++i)
    if (i < rev[i])
      swap_ranges(P.begin() + a * i, P.begin() + a *
    i + a, P.begin() + a * rev[i]);

  // P = [P[-a * (i // a) + (i % a)] for i in range(m
    )]
  for (int i = 1; i < n/2; ++i)
    swap_ranges(P.begin() + a * i, P.begin() + a * i
    + a, P.begin() + a * (n - i));

  transform<a>(P);

  // P = [P[a * rev[i // a] + (i % a)] for i in range
    (m)]
  for (int i = 1; i < n; ++i)
    if (i < rev[i])
      swap_ranges(P.begin() + a * i, P.begin() + a *
    i + a, P.begin() + a * rev[i]);
}

template<int a>
void fast_polymult_mod(vector<int> &P, vector<int> &Q
    ) {
  int m = P.size();
  int n = m / a;

  transform<a>(P);
  transform<a>(Q);

  vector<int> &PQ = P;
  for (int i = 0; i < n; ++i) {
    vector<unsigned long long> res(2 * a);
    for (int j = 0; j < a; ++j) {
      if (j >= 10 && j % 9 == 8)
        for (int k = j; k < j + a - 10; ++k)
          res[k] -= (res[k] >> 63) * 9 * MOD2;
      for (int k = 0; k < a; ++k)
        res[j + k] += (long long) P[i * a + j] * Q[i
    * a + k];
    }

    int c = rt[i/2];
    if (i & 1) c = MOD - c;
    for (int j = 0; j < a; ++j)
      PQ[i * a + j] = (res[j] + c * (res[j + a] % MOD
    )) % MOD;
  }

  inverse_transform<a>(PQ);
}

template <size_t... N>
void work(std::index_sequence<N...>, int x, std::
    vector<int>& a, std::vector<int>& b) {
  static void (*ptrs[])(std::vector<int>&, std::
    vector<int>&) = {&fast_polymult_mod<N+1>...};
  ptrs[x - 1](a, b);
}

void fast_polymult(vector<int> &P, vector<int> &Q) {
  int m1 = P.size();
  int m2 = Q.size();
  int res_len = m1 + m2 - 1;

  int b = 1;
  while ((alim << b) < res_len) ++b;
  int a = ((res_len - 1) >> b) + 1;
  int m = a << b;

  P.resize(m);
  Q.resize(m);

  // Call fast_polymult_mod<a>(P, Q);
  work(std::make_index_sequence<alim>{}, a, P, Q);

  P.resize(res_len);
}
//239b3e
```

4.4 FFT в double'ах

```
using cd = complex<double>;
const double PI = acos(-1);

void fft(vector<cd> & a, bool invert) {
  int n = a.size();

  for (int i = 1, j = 0; i < n; i++) {
    int bit = n >> 1;
    for (; j & bit; bit >>= 1)
      j ^= bit;
    j ^= bit;

    if (i < j)
      swap(a[i], a[j]);
  }

  for (int len = 2; len <= n; len <<= 1) {
    double ang = 2 * PI / len * (invert ? -1 : 1);
    cd wlen(cos(ang), sin(ang));
    for (int i = 0; i < n; i += len) {
      cd w(1);
      for (int j = 0; j < len / 2; j++) {
        cd u = a[i+j], v = a[i+j+len/2] * w;
        a[i+j] = u + v;
        a[i+j+len/2] = u - v;
        w *= wlen;
      }
    }
  }

  if (invert) {
    for (cd & x : a)
      x /= n;
  }
}
vector<int> multiply(vector<int> const& a, vector<int
    > const& b) {
  vector<cd> fa(a.begin(), a.end()), fb(b.begin(), b.
    end());
  int n = 1;
  while (n < a.size() + b.size())
    n <<= 1;
  fa.resize(n);
  fb.resize(n);

  fft(fa, false);
  fft(fb, false);
  for (int i = 0; i < n; i++)
    fa[i] *= fb[i];
  fft(fa, true);

  vector<int> result(n);
  for (int i = 0; i < n; i++)
    result[i] = round(fa[i].real());
  while(!result.empty() && !result.back()) result.
    pop_back();
  return result;
}
//35d9d0
```

5 Структуры данных

5.1 Дерево Фенвика

```
int fe[maxn];
void pl(int pos,int val) {while(pos<maxn) {fe[pos]+=
    val;pos|=(pos+1);}}
int get(int pos) {int ans=0;while(pos>=0) {ans+=fe[
    pos];pos&=(pos+1);--pos;} return ans;} /// [0,pos
    ] - vkluchitelno!!!
int get(int l,int r) {return get(r-1)-get(l-1);} ///
    sum of [l,r)
//2991a1
```

5.2 Дерево отрезков в точке

```
template<typename T, typename U>
struct SegmentTree {
  int h, n;
  T neutral;
  U unite;
  vector<T> data;

  template<typename I>
```

```
SegmentTree(int sz, T neutral, U unite, I init) : h
  (__lg(sz) + 1), n(1 << h), neutral(neutral),
  unite(unite), data(2 * n) {
  for (int i = 0; i < sz; ++i) data[i + n] = init(i
  );
  for (int i = n - 1; i > 0; --i) data[i] = unite(
  data[2 * i], data[2 * i + 1]);
}

SegmentTree(int sz, T neutral, U unite) : h(__lg(sz
  ) + 1), n(1 << h), neutral(neutral), unite(unite)
  , data(2 * n, neutral) {}

void set(int i, T x) {
  data[i += n] = x;
  for (i /= 2; i > 0; i /= 2) data[i] = unite(data
  [2 * i], data[2 * i + 1]);
}

T get(int l, int r) {
  T leftRes = neutral, rightRes = neutral;
  for (l += n, r += n; l < r; l /= 2, r /= 2) {
    if (l & 1) leftRes = unite(leftRes, data[l++]);
    if (r & 1) rightRes = unite(data[--r], rightRes
  );
  }
  return unite(leftRes, rightRes);
}
int left(int i) {
  int lvl = __lg(i);
  return (i & ((1 << lvl) - 1)) * (1 << (h - lvl));
}
int right(int i) {
  int lvl = __lg(i);
  return ((i & ((1 << lvl) - 1)) + 1) * (1 << (h -
  lvl));
}

// l \in [0; n) && ok(get(l, l), l);
// returns last r: ok(get(l, r), r)
template<typename C>
int lastTrue(int l, C ok) {
  T cur = neutral;
  l += n;
  do {
    l >>= __builtin_ctz(l);
    T with1 = unite(cur, data[l]);
    if (ok(with1, right(l))) {
      cur = with1;
      ++l;
    } else {
      while (l < n) {
        T with2 = unite(cur, data[2 * l]);
        if (ok(with2, right(2 * l))) {
          cur = with2;
          l = 2 * l + 1;
        } else {
          l = 2 * l;
        }
      }
      return l - n;
    }
  } while (l & (l - 1));
  return n;
}

// r \in [0; n) && ok(get(r, r), r);
// returns first l: ok(get(l, r), l)
template<typename C>
int firstTrue(int r, C ok) {
  T cur = neutral;
  r += n;
  while (r & (r - 1)) {
    r >>= __builtin_ctz(r);
    T with1 = unite(data[--r], cur);
    if (ok(with1, left(r))) {
      cur = with1;
    } else {
      while (r < n) {
        T with2 = unite(data[2 * r + 1], cur);
        if (ok(with2, left(2 * r + 1))) {
          cur = with2;
          r = 2 * r;
        } else {
          r = 2 * r + 1;
        }
      }
      return r - n + 1;
    }
    }
    return 0;
  }
};
//64190d
```

5.3 Массовое дерево отрезков

```
template<typename T, typename M, typename Ud,
    typename Um, typename A>
struct MassSegmentTree {
  int h, n;
  T zd;
  M zm;
  vector<T> data;
  vector<M> mod;

  Ud ud; // T (T, T)
  Um um; // M (M, M);
  A a; // T (T, M, int); last argument is the length
    of current segment (could be used for range +=
    and sum counting, for instance)

  template<typename I>
  MassSegmentTree(int sz, T zd, M zm, Ud ud, Um um, A
     a, I init) : h(__lg(sz) + 1), n(1 << h), zm(zm),
     zd(zd), data(2 * n, zd), mod(n, zm), ud(ud), um(
    um), a(a) {
    for (int i = 0; i < sz; ++i) data[i + n] = init(i
    );
    for (int i = n - 1; i > 0; --i) data[i] = ud(data
    [2 * i], data[2 * i + 1]);
  }

  MassSegmentTree(int sz, T zd, M zm, Ud ud, Um um, A
     a) : h(__lg(sz) + 1), n(1 << h), zm(zm), zd(zd),
     data(2 * n, zd), mod(n, zm), ud(ud), um(um), a(a
    ) {}

  void push(int i) {
    if (mod[i] == zm) return;
    apply(2 * i, mod[i]);
    apply(2 * i + 1, mod[i]);
    mod[i] = zm;
  }

  // is used only for apply
  int length(int i) { return 1 << (h - __lg(i)); }

  // used only for descent
  int left(int i) {
    int lvl = __lg(i);
    return (i & ((1 << lvl) - 1)) * (1 << (h - lvl));
  }
  // used only for descent
  int right(int i) {
    return left(i) + length(i);
  }

  template<typename S>
  void apply(int i, S x) {
    data[i] = a(data[i], x, length(i));
    if (i < n) mod[i] = um(mod[i], x);
  }

  void update(int i) {
    if (mod[i] != zm) return;
    data[i] = ud(data[2 * i], data[2 * i + 1]);
  }

  template<typename S>
  void update(int l, int r, S x) { // [l; r)
    l += n, r += n;
    for (int shift = h; shift > 0; --shift) {
      push(l >> shift);
      push((r - 1) >> shift);
    }
    for (int lf = l, rg = r; lf < rg; lf /= 2, rg /=
    2) {
      if (lf & 1) apply(lf++, x);
      if (rg & 1) apply(--rg, x);
    }
    for (int shift = 1; shift <= h; ++shift) {
      update(l >> shift);
      update((r - 1) >> shift);
    }
  }

  T get(int l, int r) { // [l; r)
```

```
    l += n, r += n;
    for (int shift = h; shift > 0; --shift) {
      push(l >> shift);
      push((r - 1) >> shift);
    }
    T leftRes = zd, rightRes = zd;
    for (; l < r; l /= 2, r /= 2) {
      if (l & 1) leftRes = ud(leftRes, data[l++]);
      if (r & 1) rightRes = ud(data[--r], rightRes);
    }
    return ud(leftRes, rightRes);
  }

  // l \in [0; n) && ok(get(l, l), l);
  // returns last r: ok(get(l, r), r)
  template<typename C>
  int lastTrue(int l, C ok) {
    l += n;
    for (int shift = h; shift > 0; --shift) push(l >>
     shift);
    T cur = zd;
    do {
      l >>= __builtin_ctz(l);
      T with = ud(cur, data[l]);
      if (ok(with, right(l))) {
        cur = with;
        ++l;
      } else {
        while (l < n) {
          push(l);
          l = 2 * l;
          with = ud(cur, data[l]);
          if (ok(with, left(l + 1))) {
            cur = with;
            ++l;
          }
        }
        return l - n;
      }
    } while (l & (l - 1));
    return n;
  }

  // r \in [0; n) && ok(get(r, r), r);
  // returns first l: ok(get(l, r), l)
  template<typename C>
  int firstTrue(int r, C ok) {
    r += n;
    for (int shift = h; shift > 0; --shift) push((r -
     1) >> shift);
    auto cur = zd;
    while (r & (r - 1)) {
      r >>= __builtin_ctz(r);
      T with = ud(data[--r], cur);
      if (ok(with, left(r))) {
        cur = with;
      } else {
        while (r < n) {
          push(r);
          r = 2 * r;
          with = ud(data[r + 1], cur);
          if (ok(with, left(r + 1))) {
            cur = with;
          } else {
            ++r;
          }
        }
        return r - n + 1;
      }
    }
    return 0;
  }
};
//fc0cde
```

5.4 Битовый бор

```
template<unsigned int sz,typename T=int>
struct binarytrie{
  using Bit=typename conditional<sz<=32,unsigned int,
    unsigned long long>::type;
  struct node{
    T cnt;
    array<int,2>nxt;
    node():cnt(0),nxt({-1,-1}){}
  };
  vector<node>v;
  binarytrie(){v.emplace_back();}
  void insert(Bit x){add(x,1);}
  void erase(Bit x){add(x,-1);}
  void add(Bit x,T k)
  {
    assert(0<=x&&(x>>sz)==0);
    int p=0;
    v[p].cnt+=k;
    for(int i=sz;i--;)
    {
      int j=x>>i&1;
      if(v[p].nxt[j]==-1)
      {
        v[p].nxt[j]=v.size();
        v.emplace_back();
      }
      p=v[p].nxt[j];
      v[p].cnt+=k;
    }
  }
  T count(Bit x,Bit xor_val=0)const//[0,x)
  {
    assert(0<=xor_val&&(xor_val>>sz)==0);
    if(x<0)return 0;
    else if(x>>sz)return v[0].cnt;
    T ret=0;
    int p=0;
    for(int i=sz;i--;)
    {
      int j=x>>i&1,k=xor_val>>i&1;
      if(j==0)p=v[p].nxt[k];
      else
      {
        if(v[p].nxt[k]>=0)ret+=v[v[p].nxt[k]].cnt;
        p=v[p].nxt[!k];
      }
      if(p==-1)break;
    }
    return ret;
  }
  Bit max(Bit xor_val=0)const
  {
    assert(0<=xor_val&&(xor_val>>sz)==0);
    int p=0;
    Bit ret=0;
    if(v[p].cnt==0)return ret;
    for(int i=sz;i--;)
    {
      ret<<=1;
      int k=xor_val>>i&1;
      if(v[p].nxt[!k]>=0&&v[v[p].nxt[!k]].cnt>0)
      {
        p=v[p].nxt[!k];
        ret|=1;
      }
      else p=v[p].nxt[k];
    }
    return ret;
  }
  Bit min(Bit xor_val=0)const
  {
    assert(0<=xor_val&&(xor_val>>sz)==0);
    int p=0;
    Bit ret=0;
    for(int i=sz;i--;)
    {
      ret<<=1;
      int k=xor_val>>i&1;
      if(v[p].nxt[k]>=0&&v[v[p].nxt[k]].cnt>0)p=v[p].
    nxt[k];
      else
      {
        p=v[p].nxt[!k];
        ret|=1;
      }
    }
    return ret;
  }
  Bit find_by_order(T ord,Bit xor_val=0)const
  {
    assert(0<=xor_val&&(xor_val>>sz)==0);
    assert(0<=ord&&ord<v[0].cnt);
    int p=0;
    Bit ret=0;
    for(int i=sz;i--;)
    {
      ret<<=1;
      int k=xor_val>>i&1;
      if(v[p].nxt[k]>=0)
      {
        if(ord>=v[v[p].nxt[k]].cnt)
```

```
        {
          ord-=v[v[p].nxt[k]].cnt;
          p=v[p].nxt[!k];
          ret|=1;
        }
        else p=v[p].nxt[k];
      }
      else
      {
        p=v[p].nxt[!k];
        ret|=1;
      }
    }
    return ret;
  }
  T order_of_key(Bit x,Bit xor_val=0)const{return
    count(x,xor_val);}
};
binarytrie<32>bt;
//0b3855
```

5.5 Ordered set

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>

using namespace __gnu_pbds;
using namespace std;

using ordered_set = tree<int, null_type, less<>,
    rb_tree_tag, tree_order_statistics_node_update>;
//f589b9
```

5.6 Динамический битсет

```
#include <tr2/dynamic_bitset>
using namespace tr2;
using bs=dynamic_bitset<>;
//26f8b6
```

5.7 Convex hull trick

```
int div_up(int a, int b) { return a/b+((a^b)>0&&a%b);
     } // divide a by b rounded up
const int LQ = ..., RQ = ...; //leftmost query,
    rightmost query
int in(ii L, int x) {
  return L.x * x + L.y;
}
struct Hull {
vector <pair <int, int> > lines;
vector <int> borders;
void push(ii L) {
  while (lines.size() && in(L,borders.back()) < in(
    lines.back(),borders.back())) {
    lines.pop_back();
    borders.pop_back();
  }
  if (lines.empty()) {
    lines = {L};
    borders = {LQ};
  }
  else if (lines.back().x > L.x) {
    int x = div_up(L.y - lines.back().y, lines.back()
    .x - L.x);
    if (x <= RQ) {
      lines.app(L);
      borders.app(x);
    }
  }
}
Hull (){}
Hull (vector <ii> a) {
  auto comp = [&] (ii u, ii v) {
    return u.x > v.x || (u.x == v.x && u.y < v.y);
  };
  sort(all(a), comp);
  for (auto L : a) {
    push(L);
  }
}
int get(int x) {
  int pos = upper_bound(all(borders), x) - borders.
    begin();
  assert(pos>0);
  pos--;
  return in(lines[pos],x);
}
};
//04555a
```

5.8 Центроиды

```
vector<int> sz(n), lvl(n, -1);
auto dfs = [&](auto dfs, int cur, int prev) -> int {
  if (lvl[cur] != -1) return 0;
  sz[cur] = 1;
  for (auto [nxt, w] : g[cur]) {
    if (nxt != prev) sz[cur] += dfs(dfs, nxt, cur);
  }
  return sz[cur];
};
auto find = [&](auto find, int cur, int prev, int tot
    ) -> int {
  int bch = -1, bsz = 0;
  for (auto [nxt, w] : g[cur]) {
    if (nxt == prev || lvl[nxt] != -1) continue;
    if (sz[nxt] > bsz) {
      bch = nxt;
      bsz = sz[nxt];
    }
  }
  if (bsz + bsz <= tot) return cur;
  return find(find, bch, cur, tot);
};
dfs(dfs, 0, 0);
auto c = find(find, 0, 0, sz[0]);
vector<pair<int, int>> stack{{c, 0}};
while (!stack.empty()) {
  auto [centroid, l] = stack.back();
  stack.pop_back();
  lvl[centroid] = l;
  for (auto [nxt, w] : g[centroid]) {
    if (lvl[nxt] != -1) continue;
    dfs(dfs, nxt, centroid);
    int new_centroid = find(find, nxt, centroid, sz[
    nxt]);
    stack.push_back({new_centroid, lvl[centroid] +
    1});
  }
}
//0e1e52
```

5.9 Дерево Ли Чао

```
struct Line{
  int a, b;
  Line(){}
  Line (int a, int b) : a(a), b(b) {}
  int get(int x) { return a + b * x;}
};

struct Lichao {
  int n;
  vector <int> x;
  vector <Line> t;
  Lichao(){}
  Lichao (int n, vector<int> x) : n(n), t(n << 2,
    Line(inf, 0)), x(x) {}

  void put(int v, int l, int r, Line L) {
    if (l + 1 == r) {
      if (L.get(x[l]) < t[v].get(x[l])) {
        t[v] = L;
      }
      return;
    }
    int m = (l + r) / 2;
    if (L.get(x[m]) < t[v].get(x[m])) {
      swap(L, t[v]);
    }
    if (L.b > t[v].b) {
      put(2 * v + 1, l, m, L);
    }
    else {
      put(2 * v + 2, m, r, L);
    }
  }

  int get(int v, int l, int r, int i) {
    if (l + 1 == r) {
      return t[v].get(x[l]);
    }
    int m = (l + r) / 2;
    int ans = t[v].get(x[i]);
```

```
    if (i < m) {
      ans = min(ans, get(2 * v + 1, l, m, i));
    } else {
      ans = min(ans, get(2 * v + 2, m, r, i));}
    return ans;
  }

  void put(Line L) {
    put(0, 0, n, L);
  }

  int get(int i) {
    return get(0, 0, n, i);
  }
};
//99f5fa
```

5.10 Min-Kinetic Segment Tree

I guess the source is https://koosaga.com/307

```
using lint = long long;
const lint inf = 4e18;
const int MAXT = 4100000;
using pi = array<lint, 2>;

struct line {
  lint A, B;
  int idx;

  lint eval(lint x) { return A * x + B; }

  // returns the x-intercept of intersection "
    strictly" larger than T
  lint cross_after(line &x, lint T) {
    if (x.A == A) {
      return inf;
    }
    lint up = x.B - B;
    lint dn = A - x.A;
    if (dn < 0) {
      dn *= -1;
      up *= -1;
    }
    lint incep = (up <= 0 ? -((-up) / dn) : (up + dn
    - 1) / dn);
    if (incep > T)
      return incep;
    return inf;
  }
};

struct kst { // min kinetic segment tree
  line tree[MAXT];
  lint melt[MAXT], T;
  pi lazy[MAXT];
  int n;

  bool cmp(line &a, line &b) {
    lint l = a.eval(T), r = b.eval(T);
    if (l != r)
      return l > r;
    return a.A > b.A;
  }

  void pull(int p) {
    tree[p] = cmp(tree[2 * p], tree[2 * p + 1]) ?
    tree[2 * p + 1] : tree[2 * p];
    melt[p] = min({melt[2 * p], melt[2 * p + 1], tree
    [2 * p].cross_after(tree[2 * p + 1], 0)});
  }

  void init(int s, int e, int p, vector<line> &l) {
    if (s == e) {
      tree[p] = l[s];
      melt[p] = inf;
      lazy[p] = {0, 0};
      return;
    }
    lazy[p] = {0, 0};
    int m = (s + e) / 2;
    init(s, m, 2 * p, l);
    init(m + 1, e, 2 * p + 1, l);
    pull(p);
  }

  void lazydown(int p) {
    for (int i = 2 * p; i < 2 * p + 2; i++) {
      lazy[i][0] += lazy[p][0];
      lazy[i][1] += lazy[p][1];
      tree[i].B += lazy[p][0] * tree[i].A + lazy[p
    ][1];
      melt[i] -= lazy[p][0];
    }
    lazy[p][0] = lazy[p][1] = 0;
  }

  void propagate(int p) {
    if (melt[p] > 0)
      return;
    lazydown(p);
    propagate(2 * p);
    propagate(2 * p + 1);
    pull(p);
  }

  lint query(int s, int e, int ps, int pe, int p = 1)
     {
    if (e < ps || pe < s)
      return inf;
    if (s <= ps && pe <= e)
      return tree[p].eval(0);
    int pm = (ps + pe) / 2;
    lazydown(p);
    return min(query(s, e, ps, pm, 2 * p), query(s, e
    , pm + 1, pe, 2 * p + 1));
  }

  void heaten(int s, int e, int ps, int pe, int p,
    lint v) {
    if (e < ps || pe < s)
      return;
    if (s <= ps && pe <= e) {
      lazy[p][0] += v;
      tree[p].B += v * tree[p].A;
      melt[p] -= v;
      propagate(p);
      return;
    }
    lazydown(p);
    int pm = (ps + pe) / 2;
    heaten(s, e, ps, pm, 2 * p, v);
    heaten(s, e, pm + 1, pe, 2 * p + 1, v);
    pull(p);
  }

  void add(int s, int e, int ps, int pe, int p, lint
    v) {
    if (e < ps || pe < s)
      return;
    if (s <= ps && pe <= e) {
      lazy[p][1] += v;
      tree[p].B += v;
      return;
    }
    lazydown(p);
    int pm = (ps + pe) / 2;
    add(s, e, ps, pm, 2 * p, v);
    add(s, e, pm + 1, pe, 2 * p + 1, v);
    pull(p);
  }

  void init(vector<line> &l, lint _T) {
    n = l.size();
    T = _T;
    init(0, n - 1, 1, l);
  }
};
//66f9a9
```

5.11 Декартово дерево

5.11.1 Декартово дерево по явному ключу. Multiset

```
mt19937 rng(0);

using ptr = int32_t;

struct vertex {
  ptr lf = 0, rg = 0;
  int32_t heap = rng(), rnd = rng(), sz = 1;
  int val, sum = 0;

  vertex(int x = 0) : val(x), sum(x) {}
};

vector <vertex> mem;
```

```
ptr new_vertex(int x) {
  mem.app(vertex(x));
  return (int)mem.size()-1;
}

ptr update(ptr v) {
  mem[v].sz = mem[mem[v].lf].sz + 1 + mem[mem[v].rg].
    sz;
  mem[v].sum = mem[mem[v].lf].sum + mem[v].val + mem[
    mem[v].rg].sum;
  return v;
}

ptr merge(ptr l, ptr r) {
  if (!l || !r) return l ^ r;
  if (mem[l].heap > mem[r].heap) {
    mem[l].rg = merge(mem[l].rg, r);
    return update(l);
  } else {
    mem[r].lf = merge(l, mem[r].lf);
    return update(r);
  }
}

pair<ptr, ptr> splitkey(ptr v, int x, int32_t rnd) {
  if (!v) return {v, v};
  if (pair{mem[v].val, mem[v].rnd} < pair{x, rnd}) {
    auto [lf, rg] = splitkey(mem[v].rg, x, rnd);
    mem[v].rg = lf;
    return {update(v), rg};
  } else {
    auto [lf, rg] = splitkey(mem[v].lf, x, rnd);
    mem[v].lf = rg;
    return {lf, update(v)};
  }
}

void insert(ptr &a, ptr b) {
  if (!a) {
    a = b;
    return;
  }
  if (mem[a].heap > mem[b].heap) {
    if (pair{mem[a].val, mem[a].rnd} < pair{mem[b].
    val, mem[b].rnd}) {
      insert(mem[a].rg, b);
    } else {
      insert(mem[a].lf, b);
    }
    update(a);
  } else {
    auto [lf, rg] = splitkey(a, mem[b].val, mem[b].
    rnd);
    mem[b].lf = lf;
    mem[b].rg = rg;
    a = update(b);
  }
}

void join(ptr &a, ptr b) {
  auto dfs = [&](auto dfs, ptr b) -> void {
    if (!b) return;
    ptr lf = mem[b].lf;
    ptr rg = mem[b].rg;
    mem[b].lf = mem[b].rg = 0;
    insert(a, update(b));
    dfs(dfs, lf);
    dfs(dfs, rg);
  };
  dfs(dfs, b);
}

pair <ptr, ptr> splitsz(ptr v, int k) {
  if (!v) return {v, v};
  if (k <= mem[mem[v].lf].sz) {
    auto [l, r] = splitsz(mem[v].lf, k);
    mem[v].lf = r;
    return {l, update(v)};
  } else {
    auto [l, r] = splitsz(mem[v].rg, k - mem[mem[v].
    lf].sz - 1);
    mem[v].rg = l;
    return {update(v), r};
  }
}

int32_t main() {
  mem = {vertex()};
  mem[0].sz = 0;
}
//54a637
```

6 Строковые алгоритмы

6.1 Префикс-функция

```
vector<int> prefix_function(string s) {
  int n = s.size();
  vector<int> p(n);
  for (int i = 1; i < n; ++i) {
    p[i] = p[i - 1];
    while (p[i] && s[p[i]] != s[i]) p[i] = p[p[i] -
    1];
    p[i] += s[i] == s[p[i]];
  }
  return p;
}
//91103c
```

6.2 Z-функция

```
vector<int> z_function (string s) { // z[i] - lcp of
    s and s[i:]
  int n = s.size();
  vector<int> z(n);
  for (int i=1, l=0, r=0; i<n; ++i) {
    if (i <= r) z[i] = min(r-i+1, z[i-l]);
    while (i+z[i] < n && s[z[i]] == s[i+z[i]]) ++z[i
    ];
    if (i+z[i]-1 > r) {
      l = i,  r = i+z[i]-1;
    }
  }
  return z;
}
//48cccd
```

6.3 Алгоритм Манакера

```
vector<int> manacher(const string &s, int even) {
  int l = 0, r = 0, n = s.size();
  vector<int> man(n, 0);
  for (int i = 1; i < n; i++) {
    int j = i - even;
    if (j <= r) {
      man[i] = min(r - j, man[l + r - j]);
    }
    while (j + man[i] + 1 < n && i - man[i] > 0 && s[
    j + man[i] + 1] == s[i - man[i] - 1]) {
      man[i]++;
    }
    if (j + man[i] > r) {
      l = i - man[i];
      r = j + man[i];
    }
  }
  return man;
}

// abacaba : odd : (0 1 0 3 0 1 0); even : (0 0 0 0 0
     0 0)
// abbaa : odd : (0 0 0 0 0); even : (0 0 2 0 1)
bool pal(int from, int len) {
    if (len == 0) {
        return true;
    }
    int m = len/2;
    if (len & 1) {
        return odd[from + m] >= m;
    }
    else {
        return even[from + m] >= m;
    }
}
//8a64d6
```

6.4 Суфмассив

Переработанный китайский суффмассив

```
const int inf = 1e9;
struct rmq {
  int n;
  vector<int> a;
```

```
  void build(const vector<int> &x) {
    assert(x.size() == n);
    for (int i = 0; i < n; ++i) a[n + i] = x[i];
    for (int i = n - 1; i > 0; --i) a[i] = min(a[2 *
    i], a[2 * i + 1]);
  }
  rmq(int n) : n(n), a(2 * n, inf) {}
  void put(int i, int x) {
    a[i + n] = min(a[i + n], x);
    for (i = (i + n) / 2; i > 0; i /= 2) {
      a[i] = min(a[i * 2], a[i * 2 + 1]);
    }
  }
  int getMin(int l, int r) { //[l;r)
    assert(l < r);
    int res = inf;
    for (l += n, r += n; l < r; l /= 2, r /= 2) {
      if (l & 1) res = min(res, a[l++]);
      if (r & 1) res = min(res, a[--r]);
    }
    return res;
  }
};
template <typename T>
vector <int> SA(const T &a) {
  int m = *max_element(all(a)) + 1, n = a.size();
  vector <int> sa(n), nsa(n), pre(max(n, m)), x(a.
    begin(), a.end()), y(n);
  for (int e : x) pre[e]++;
  for (int i = 1; i < m; ++i) pre[i] += pre[i - 1];
  for (int i = 0; i < n; ++i) sa[--pre[x[i]]]=i;
  int dif = 1;
  y[sa.front()]=0;
  for (int i = 1; i < n; ++i) {
    dif += x[sa[i]]!=x[sa[i-1]];
    y[sa[i]] = dif - 1;
  }
  x = y;
  for (int h = 1; dif < n; h *= 2) {
    fill(all(pre), 0);
    for (int e : x) pre[e]++;
    for (int i = 1; i < dif; ++i) pre[i] += pre[i -
    1];
    for (int t = n; t--; ) {
      int i = sa[t];
      if (i>=h) {
        nsa[--pre[x[i-h]]]=i-h;
      }
      else if (i + 1 != h) {
        nsa[--pre[x[i-h+n+1]]]=i-h+n+1;
      }
    }
    nsa[--pre[x[n - h]]]=n-h;
    sa = nsa;
    auto getr = [&] (int i) {
      if (i + h < n) {
        return x[i + h];
      }
      else {
        return x[i + h - n - 1];
      }
    };
    dif = 1;
    y[sa.front()]=0;
    for (int i = 1; i < n; ++i) {
      if (x[sa[i]]!=x[sa[i-1]] || sa[i-1]+h==n) {
        dif++;
      }
      else {
        dif += getr(sa[i]) != getr(sa[i-1]);
      }
      y[sa[i]]=dif-1;
    }
    x = y;
  }
  return sa;
}

template <typename T>
struct suar {
  vector <int> sa, lcp, pos; rmq t;
  suar (const T &a) : t((int)a.size() - 1) {
    sa = SA(a);
    int n = (int)a.size(), k = 0;
    lcp.resize(n - 1);
    pos.resize(n);
    for (int i = 0; i < n; ++i) pos[sa[i]] = i;
    for (int i = 0; i < n; ++i) {
      if (pos[i]+1<n) {
        int j = sa[pos[i]+1];
        while (i+k<n&&j+k<n&&a[i+k]==a[j+k])k++;
        lcp[pos[i]]=k;
      }
      if (k) {
        k--;
      }
    }
    t.build(lcp);
  }
  int getLcp(int i, int j) {
    i = pos[i]; j = pos[j];
    if (j < i) {
      swap(i, j);
    }
    if (i == j) {
      return inf;
    }
    else {
      return t.getMin(i, j);
    }
  }
};
//6327c9
```

6.5 Алгоритм Ахо — Корасик

```
const int alpha = 26;
const char a = 'a';

struct node{
  int next[alpha] = {}, link[alpha] = {};
  int suf = 0;
  int visited = 0, ans = 0;
  int bad = 0; // any term is reachable by suf links
  vector<int> term;
  node() {
    fill(next, next + alpha, -1);
  }
};

vector<node> mem;

int get_next_or_create(int nd, char c) {
  if (mem[nd].next[c - a] == -1) { mem[nd].next[c - a
    ] = mem.size(); mem.emplace_back(); }
  return mem[nd].next[c - a];
}

void build(vector<string> t) {
  mem.reserve(1e6 + 100);mem.clear();
  mem.emplace_back();
  // 0th element is nullptr, 1st is the root
  for (int j = 0; j < t.size(); ++j) {
    int cur = 0;
    for (char c : t[j]) cur = get_next_or_create(cur,
     c);
    mem[cur].term.push_back(j);
  }
  vector<int> bfs_order;
  queue<int> bfs;
  {
    node &root = mem[0];
    root.suf = 0;
    for (char c = a; c < a + alpha; ++c) {
      root.link[c - a] = (root.next[c - a] == -1 ? 0
    : root.next[c - a]);
    }
    bfs.push(0);
  }
  while (!bfs.empty()) {
    int cur_idx = bfs.front();
    bfs.pop();
    node &cur = mem[cur_idx];
    cur.bad = cur.term.size() > 0 || mem[cur.suf].bad
    ;
    bfs_order.push_back(cur_idx);
    for (char c = a; c < a + alpha; ++c) {
      int nxt_idx = cur.next[c - a];
      if (nxt_idx == -1) continue;
      node &nxt = mem[nxt_idx];
      nxt.suf = (cur_idx ? mem[cur.suf].link[c - a] :
     0);
      for (char c = a; c < a + alpha; ++c) {
        nxt.link[c - a] = (nxt.next[c - a] == -1 ?
    mem[nxt.suf].link[c - a] : nxt.next[c - a]);
      }
```

```
      bfs.push(nxt_idx);
    }
  }
  // do something
}
//be16ed
```

6.6 Дерево палиндромов

```
const int alpha = 26;
const char a = 'a';
struct palindromic{
  int n;
  vector<int> p, suf{0, 0}, len{-1, 0};
  //d[u] is a difference of lengths of u and suf[u],
    go is jump by chain constant d
  vector<array<int, alpha>> to{{}, {}};
  int sz = 2;
  palindromic(const string &s) : n(s.size()), p(n +
    1, 0) {
    suf.reserve(n);
    len.reserve(n);
    for (int i = 0; i < n; ++i) {
      auto check = [&] (int l) {
        return i > l && s[i] == s[i - 1 - l];
      };
      int par = p[i];
      while (!check(len[par])) {
        par = suf[par];
      }
      if (to[par][s[i]-a] == 0) {
        p[i+1]=to[par][s[i]-a]=sz++;
        to.emplace_back();
        len.emplace_back(len[par]+2);
        if (par == 0) {
          suf.emplace_back(1);
        }
        else {
          do {
            par = suf[par];
          } while (!check(len[par]));
          suf.emplace_back(to[par][s[i]-a]);
        }
      }
      else {
        p[i+1]=to[par][s[i]-a];
      }
    }
  }
  int partition() {
    vector <int> d(sz), up(sz, 1); //d[1] = 0 sic
    for (int i = 2; i < sz; ++i) {
      d[i] = len[i] - len[suf[i]];
      if (d[i] == d[suf[i]]) {
        up[i] = up[suf[i]];
      }
      else {
        up[i] = suf[i];
      }
    }
    vector <int> dp(n + 1, n), last(sz);
    dp[0] = 0;
    for (int i = 1; i <= n; ++i) {
      int u = p[i];
      while (u != 1) {
        if (suf[u] == up[u]) {
          last[u] = dp[i - len[u]];
        }
        else {
          last[u] = min(last[suf[u]], dp[i - len[up[u
    ]] - d[u]]);
        }
        dp[i] = min(dp[i], last[u] + 1);
        u = up[u];
      }
    }
    return dp.back();
  }
};
//acac02
```

7 Потоки

7.1 Алгоритм Диница

```
#define pb push_back
struct Dinic{
  struct edge{
    int to, flow, cap;
  };

  const static int N = 555; //count of vertices

  vector<edge> e;
  vector<int> g[N + 7];
  int dp[N + 7];
  int ptr[N + 7];

  void clear(){
    for (int i = 0; i < N + 7; i++) g[i].clear();
    e.clear();
  }

  void addEdge(int a, int b, int cap){
    g[a].pb(e.size());
    e.pb({b, 0, cap});
    g[b].pb(e.size());
    e.pb({a, 0, 0});
  }

  int minFlow, start, finish;

  bool bfs(){
    for (int i = 0; i < N; i++) dp[i] = -1;
    dp[start] = 0;
    vector<int> st;
    int uk = 0;
    st.pb(start);
    while(uk < st.size()){
      int v = st[uk++];
      for (int to : g[v]){
        auto ed = e[to];
        if (ed.cap - ed.flow >= minFlow && dp[ed.to] ==
       -1){
          dp[ed.to] = dp[v] + 1;
          st.pb(ed.to);
        }
      }
    }
    return dp[finish] != -1;
  }

  int dfs(int v, int flow){
    if (v == finish) return flow;
    for (; ptr[v] < g[v].size(); ptr[v]++){
      int to = g[v][ptr[v]];
      edge ed = e[to];
      if (ed.cap - ed.flow >= minFlow && dp[ed.to] ==
      dp[v] + 1){
        int add = dfs(ed.to, min(flow, ed.cap - ed.flow
      ));
        if (add){
          e[to].flow += add;
          e[to ^ 1].flow -= add;
          return add;
        }
      }
    }
    return 0;
  }

  int dinic(int start, int finish){
    Dinic::start = start;
    Dinic::finish = finish;
    int flow = 0;
    for (minFlow = (1 << 30); minFlow; minFlow >>= 1){
      while(bfs()){
        for (int i = 0; i < N; i++) ptr[i] = 0;
        while(int now = dfs(start, (int)2e9 + 7)) flow
      += now;
      }
    }
    return flow;
  }
} dinic;
//15c079
```

7.2 Mincost k-flow

```
struct edge {
  int next, capacity, cost, flow = 0;

  edge() = default;

  edge(int next, int capacity, int cost) : next(next)
    , capacity(capacity), cost(cost) {}
```

```
  int rem() const { return capacity - flow; }

  int operator+=(int f) { return flow += f; }

  int operator-=(int f) { return flow -= f; }
};
auto addEdge = [&](auto from, auto next, auto
    capacity, int cost) {
  g[from].push_back(e.size());
  e.emplace_back(next, capacity, cost);
  g[next].push_back(e.size());
  e.emplace_back(from, 0, -cost);
};
/* in case of undirected graph use this:
addEdge(u, v, capacity, cost);
addEdge(v, u, capacity, cost);
*/
vector<ll> phi(n, 0);
auto fordBellman = [&](int s, int t) {
  phi.assign(n, 0);
  for (int iter = 0; iter < n; ++iter) {
    bool changed = false;
    for (int u = 0; u < n; ++u) {
      for (auto index : g[u]) {
        auto edge = e[index];
        if (edge.rem() > 0 && phi[edge.next] > phi[u]
     + edge.cost) {
          phi[edge.next] = phi[u] + edge.cost;
          changed = true;
        }
      }
    }
    if (!changed) break;
  }
};
fordBellman(s, t);
// now shortest path using dijkstra with potentials
vector<ll> dist;
vector<int> from;
vector<bool> cnt;
auto dijkstra = [&](int s, int t) {
  dist.assign(n, 1e18);
  from.assign(n, -1);
  cnt.assign(n, false);
  dist[s] = 0;
  set <pair <int, int> > se;
  se.insert({0, s});
  while ((int)(se.size())) {
    int cur = se.begin()->y;
    se.erase(se.begin());
    cnt[cur] = true;
    for (int index : g[cur]) {
      auto &edge = e[index];
      if (edge.rem() == 0) continue;
      ll weight = edge.cost + phi[cur] - phi[edge.
    next];
      if (dist[edge.next] > dist[cur] + weight) {
        se.erase({dist[edge.next], edge.next});
        dist[edge.next] = dist[cur] + weight;
        se.insert({dist[edge.next], edge.next});
        from[edge.next] = cur;
      }
    }
  }
  if (dist[t] == (ll) 1e18) return -1LL;
  ll cost = 0;
  for (int p = t; p != s; p = from[p]) {
    for (auto index : g[from[p]]) {
      auto &edge = e[index];
      ll weight = edge.cost + phi[from[p]] - phi[edge
    .next];
      if (edge.rem() > 0 && edge.next == p && dist[
    edge.next] == dist[from[p]] + weight) {
        edge += 1;
        e[index ^ 1] -= 1;
        cost += edge.cost;
        break;
      }
    }
  }
  for (int i = 0; i < n; ++i) {
    phi[i] += dist[i];
  }
  return cost;
};
ll cost = 0;
for (int flow = 0; flow < k; ++flow) {
  ll a = dijkstra(s, t);
  if (a == -1) {
    cout << "-1\n";
    return;
  }
  cost += a;
}
// now recover answer
auto findPath = [&](int s, int t) {
  vector<int> ans;
  int cur = s;
  while (cur != t) {
    for (auto index : g[cur]) {
      auto &edge = e[index];
      if (edge.flow <= 0) continue;
      edge -= 1;
      e[index ^ 1] += 1;
      ans.push_back(index / 4);
// index / 4 because each edge has 4 copies
      cur = edge.next;
      break;
    }
  }
  return ans;
};
for (int flow = 0; flow < k; ++flow) {
  auto p = findPath(s, t);
  cout << p.size() << ' ';
  for (int x : p) cout << x + 1 << ' ';
  cout << '\n';
}
//94b9cb


template <typename T, typename C>
class mcmf {
  public:
  static constexpr T eps = (T) 1e-9;

  struct edge {
    int from;
    int to;
    T c;
    T f;
    C cost;
  };

  vector< vector<int> > g;
  vector<edge> edges;
  vector<C> d;
  vector<int> q;
  vector<bool> in_queue;
  vector<int> pe;
  int n;
  int st, fin;
  T flow;
  C cost;

  mcmf(int _n, int _st, int _fin) : n(_n), st(_st),
    fin(_fin) {
    assert(0 <= st && st < n && 0 <= fin && fin < n
    && st != fin);
    g.resize(n);
    d.resize(n);
    in_queue.resize(n);
    pe.resize(n);
    flow = 0;
    cost = 0;
  }

  void clear_flow() {
    for (const edge &e : edges) {
      e.f = 0;
    }
    flow = 0;
  }

  void add(int from, int to, T forward_cap, T
    backward_cap, C cost) {
    assert(0 <= from && from < n && 0 <= to && to < n
    );
    g[from].push_back((int) edges.size());
    edges.push_back({from, to, forward_cap, 0, cost})
    ;
    g[to].push_back((int) edges.size());
    edges.push_back({to, from, backward_cap, 0, -cost
    });
  }

  bool expath() {
    fill(d.begin(), d.end(), numeric_limits<C>::max()
```

```
    );
    q.clear();
    q.push_back(st);
    d[st] = 0;
    in_queue[st] = true;
    int beg = 0;
    bool found = false;
    while (beg < (int) q.size()) {
      int i = q[beg++];
      if (i == fin) {
        found = true;
      }
      in_queue[i] = false;
      for (int id : g[i]) {
        const edge &e = edges[id];
        if (e.c - e.f > eps && d[i] + e.cost < d[e.to
    ]) {
          d[e.to] = d[i] + e.cost;
          pe[e.to] = id;
          if (!in_queue[e.to]) {
            q.push_back(e.to);
            in_queue[e.to] = true;
          }
        }
      }
    }
    if (found) {
      T push = numeric_limits<T>::max();
      int v = fin;
      while (v != st) {
        const edge &e = edges[pe[v]];
        push = min(push, e.c - e.f);
        v = e.from;
      }
      v = fin;
      while (v != st) {
        edge &e = edges[pe[v]];
        e.f += push;
        edge &back = edges[pe[v] ^ 1];
        back.f -= push;
        v = e.from;
      }
      flow += push;
      cost += push * d[fin];
    }
    return found;
  }

  pair<T, C> max_flow_min_cost() {
    while (expath()) {
    }
    return make_pair(flow, cost);
  }
};
//b7bbb2
```

8 Алгоритм Гаусса

8.1 Решение $Av = b$

```
optional<vector<int> > gauss(vector<vector<int> > A,
    vector<int> b) ///returns v such that Av=b
{
    int n=A.size();assert(b.size()==n);int m=A[0].
    size();
    for(int &x:b) {x%=p;x+=p;x%=p;}
    for(int i=0;i<n;++i) {for(int &x:A[i]) {x%=p;x+=p
    ;x%=p;}}
    int bi=0;
    for(int i=0;i<n;++i)
    {
        if(bi==m) break;
        for(int j=i;j<n;++j)
        {
            if(A[j][bi])
            {
                if(j!=i) {swap(A[i],A[j]);swap(b[i],b
    [j]);}
                break;
            }
        }
        if(A[i][bi])
        {
            int o=inv(A[i][bi]);
            for(int j=i+1;j<n;++j)
            {
                int we=(A[j][bi]*o)%p;
                b[j]-=we*b[i];b[j]%=p;if(b[j]<0) b[j
    ]+=p;
                for(int k=bi;k<m;++k)
                {
                    A[j][k]-=we*A[i][k];A[j][k]%=p;if
    (A[j][k]<0) A[j][k]+=p;
                }
            }
        }
        else
        {
            ++bi;--i;continue;
        }
    }
    vector<int> v(m);
    for(int i=n-1;i>=0;--i)
    {
        int bi=0;
        while(bi<m && !A[i][bi]) {++bi;}
        if(bi==m)
        {
            if(b[i]) {return nullopt;}
            else {continue;}
        }
        {
        int cur=b[i];
        for(int j=bi+1;j<m;++j)
        {
            cur-=A[i][j]*v[j];cur%=p;
        }
        v[bi]=cur*inv(A[i][bi]);v[bi]%=p;if(v[bi]<0)
    v[bi]+=p;
        }
    }
    return v;
}
//bcc622
```

8.2 Базис $Av = 0$

```
vector<vector<int> > gaussbasis(vector<vector<int> >
    A,int m) ///returns basis of Av=0
{
    int n=A.size();if(n) assert(m==A[0].size());
    for(int i=0;i<n;++i) {for(int &x:A[i]) {x%=p;x+=p
    ;x%=p;}}
    int bi=0;
    for(int i=0;i<n;++i)
    {
        if(bi==m) break;
        for(int j=i;j<n;++j)
        {
            if(A[j][bi])
            {
                if(j!=i) {swap(A[i],A[j]);}
                break;
            }
        }
        if(A[i][bi])
        {
            int o=inv(A[i][bi]);
            for(int j=i+1;j<n;++j)
            {
                int we=(A[j][bi]*o)%p;
                for(int k=bi;k<m;++k)
                {
                    A[j][k]-=we*A[i][k];A[j][k]%=p;if
    (A[j][k]<0) A[j][k]+=p;
                }
            }
        }
        else
        {
            ++bi;--i;continue;
        }
    }
    vector<int> indices(m);iota(all(indices),0);
    for(int i=n-1;i>=0;--i)
    {
        int bi=0;
        while(bi<m && !A[i][bi]) {++bi;}
        if(bi<m)
        {
            indices.erase(find(all(indices),bi));
        }
    }
    vector<vector<int> > v(indices.size(),vector<int
    >(m,0));
    for(int i=0;i<indices.size();++i)
```

```
    {
        v[i][indices[i]]=1;
    }
    for(int i=n-1;i>=0;--i)
    {
        int bi=0;
        while(bi<m && !A[i][bi]) {++bi;}
        if(bi==m) continue;
        for(int k=0;k<indices.size();++k) {
        int cur=0;
        for(int j=bi+1;j<m;++j)
        {
            cur-=A[i][j]*v[k][j];cur%=p;
        }
        v[k][bi]=cur*inv(A[i][bi]);v[k][bi]%=p;if(v[k
    ][bi]<0) v[k][bi]+=p;
        }
    }
    return v;
}
//ef40f3
```

9 Гамильтоновы путь и цикл

https://codeforces.com/blog/entry/90513,
https://codeforces.com/blog/entry/90743.

9.1 Link-cut tree

```
namespace LCT {
  vector<vi> ch;
  vi fa, rev;
  void init(int n) {
    ch.resize(n + 1);
    fa.resize(n + 1);
    rev.resize(n + 1);
    for (int i = 0; i <= n; i++)
      ch[i].resize(2),
      ch[i][0] = ch[i][1] = fa[i] = rev[i] = 0;
  }
  bool isr(int a)
  {
    return !(ch[fa[a]][0] == a || ch[fa[a]][1] == a);
  }
  void pushdown(int a)
  {
    if(rev[a])
    {
      rev[ch[a][0]] ^= 1, rev[ch[a][1]] ^= 1;
      swap(ch[a][0], ch[a][1]);
      rev[a] = 0;
    }
  }
  void push(int a)
  {
    if(!isr(a)) push(fa[a]);
    pushdown(a);
  }
  void rotate(int a)
  {
    int f = fa[a], gf = fa[f];
    int tp = ch[f][1] == a;
    int son = ch[a][tp ^ 1];
    if(!isr(f))
      ch[gf][ch[gf][1] == f] = a;
    fa[a] = gf;

    ch[f][tp] = son;
    if(son) fa[son] = f;

    ch[a][tp ^ 1] = f, fa[f] = a;
  }
  void splay(int a)
  {
    push(a);
    while(!isr(a))
    {
      int f = fa[a], gf = fa[f];
      if(isr(f)) rotate(a);
      else
      {
        int t1 = ch[gf][1] == f, t2 = ch[f][1] == a;
        if(t1 == t2) rotate(f), rotate(a);
        else rotate(a), rotate(a);
      }
    }
  }
  void access(int a)
  {
    int pr = a;
    splay(a);
    ch[a][1] = 0;
    while(1)
    {
      if(!fa[a]) break;
      int u = fa[a];
      splay(u);
      ch[u][1] = a;
      a = u;
    }
    splay(pr);
  }
  void makeroot(int a)
  {
    access(a);
    rev[a] ^= 1;
  }
  void link(int a, int b)
  {
    makeroot(a);
    fa[a] = b;
  }
  void cut(int a, int b)
  {
    makeroot(a);
    access(b);
    fa[a] = 0, ch[b][0] = 0;
  }
  int fdr(int a)
  {
    access(a);
    while(1)
    {
      pushdown(a);
      if (ch[a][0]) a = ch[a][0];
      else {
        splay(a);
        return a;
      }
    }
  }
}
//647cca
```

9.2 Undirected case

```
#include <bits/stdc++.h>
using namespace std;
namespace hamil {
  template <typename T> bool chkmax(T &x,T y){return
    x<y?x=y,true:false;}
  template <typename T> bool chkmin(T &x,T y){return
    x>y?x=y,true:false;}
  #define vi vector<int>
  #define pb push_back
  #define mp make_pair
  #define pi pair<int, int>
  #define fi first
  #define se second
  #define ll long long
  using namespace LCT;
  vector<vi> used;
  unordered_set<int> caneg;
  void cut(int a, int b) {
    LCT::cut(a, b);
    for (int s = 0; s < 2; s++) {
      for (int i = 0; i < used[a].size(); i++)
        if (used[a][i] == b) {
          used[a].erase(used[a].begin() + i);
          break;
        }
      if (used[a].size() == 1) caneg.insert(a);
      swap(a, b);
    }
  }
  void link(int a, int b) {
    LCT::link(a, b);
    for (int s = 0; s < 2; s++) {
      used[a].pb(b);
      if (used[a].size() == 2) caneg.erase(a);
      swap(a, b);
    }
  }
  vi work(int n, vector<pi> eg, ll mx_ch = -1) {
    // mx_ch : max number of adding/replacing
    default is (n + 100) * (n + 50)
```

```
    // n : number of vertices. 1-indexed.
    // eg: vector<pair<int, int> > storing all the
    edges.
    // return a vector<int> consists of all indices
    of vertices on the path. return empty list if
    failed to find one.

    LCT::init(n);
    if (mx_ch == -1) mx_ch = 1ll * (n + 100) * (n +
    50); //default
    used.resize(n + 1);
    caneg.clear();
    for (int i = 1; i <= n; i++) used[i].clear();

    vector<vi> edges(n + 1);
    for (auto v : eg)
      edges[v.fi].pb(v.se),
      edges[v.se].pb(v.fi);

    for (int i = 1; i <= n; i++)
      caneg.insert(i);

    mt19937 x(chrono::steady_clock::now().
    time_since_epoch().count());
    int tot = 0;
    while (mx_ch >= 0) {
    //  cout << tot << ' ' << mx_ch << endl;
      vector<pi> eg;
      for (auto v : caneg)
        for (auto s : edges[v])
          eg.pb(mp(v, s));

      shuffle(eg.begin(), eg.end(), x);
      if (eg.size() == 0) break;
      for (auto v : eg) {
        mx_ch--;
        int a = v.fi, b = v.se;
        if (used[a].size() < used[b].size()) swap(a,
    b);
        if (used[b].size() >= 2) continue;
        if (x() & 1) continue;
        if (LCT::fdr(a) == LCT::fdr(b)) continue;
        if (used[a].size() < 2 && used[b].size() < 2)
          tot++;
        if (used[a].size() == 2) {
          int p = used[a][x() % 2];
          cut(a, p);
        }
        link(a, b);
      }
      if (tot == n - 1) {
        vi cur;
        for (int i = 1; i <= n; i++)
          if (used[i].size() <= 1) {
            int pl = i, ls = 0;
            while (pl) {
              cur.pb(pl);
              int flag = 0;
              for (auto v : used[pl])
                if (v != ls) {
                  ls = pl;
                  pl = v;
                  flag = 1;
                  break;
                }
              if (!flag) break;
            }
            break;
          }
        return cur;
      }
    }
    //failed to find a path
    return vi();
  }
}
//c35638
```

9.3 Directed case

```
namespace hamil {
  template <typename T> bool chkmax(T &x,T y){return
    x<y?x=y,true:false;}
  template <typename T> bool chkmin(T &x,T y){return
    x>y?x=y,true:false;}
  #define vi vector<int>
  #define pb push_back
  #define mp make_pair
  #define pi pair<int, int>
  #define fi first
  #define se second
  #define ll long long
  using namespace LCT;
  vi out, in;
  vi work(int n, vector<pi> eg, ll mx_ch = -1) {
    // mx_ch : max number of adding/replacing
    default is (n + 100) * (n + 50)
    // n : number of vertices. 1-indexed.
    // eg: vector<pair<int, int> > storing all the
    edges.
    // return a vector<int> consists of all indices
    of vertices on the path. return empty list if
    failed to find one.
    out.resize(n + 1), in.resize(n + 1);
    LCT::init(n);
    for (int i = 0; i <= n; i++) in[i] = out[i] = 0;
    if (mx_ch == -1) mx_ch = 1ll * (n + 100) * (n +
    50); //default
    vector<vi> from(n + 1), to(n + 1);
    for (auto v : eg)
      from[v.fi].pb(v.se),
      to[v.se].pb(v.fi);
    unordered_set<int> canin, canout;
    for (int i = 1; i <= n; i++)
      canin.insert(i),
      canout.insert(i);
    mt19937 x(chrono::steady_clock::now().
    time_since_epoch().count());
    int tot = 0;
    while (mx_ch >= 0) {
    //  cout << tot << ' ' << mx_ch << endl;
      vector<pi> eg;
      for (auto v : canout)
        for (auto s : from[v])
          if (in[s] == 0) {
            assert(canin.count(s));
            continue;
          }
          else eg.pb(mp(v, s));
      for (auto v : canin)
        for (auto s : to[v])
          eg.pb(mp(s, v));
      shuffle(eg.begin(), eg.end(), x);
      if (eg.size() == 0) break;
      for (auto v : eg) {
        mx_ch--;
        if (in[v.se] && out[v.fi]) continue;
        if (LCT::fdr(v.fi) == LCT::fdr(v.se))
    continue;
        if (in[v.se] || out[v.fi])
          if (x() & 1) continue;
        if (!in[v.se] && !out[v.fi])
          tot++;
        if (in[v.se]) {
          LCT::cut(in[v.se], v.se);
          canin.insert(v.se);
          canout.insert(in[v.se]);
          out[in[v.se]] = 0;
          in[v.se] = 0;
        }
        if (out[v.fi]) {
          LCT::cut(v.fi, out[v.fi]);
          canin.insert(out[v.fi]);
          canout.insert(v.fi);
          in[out[v.fi]] = 0;
          out[v.fi] = 0;
        }
        LCT::link(v.fi, v.se);
        canin.erase(v.se);
        canout.erase(v.fi);
        in[v.se] = v.fi;
        out[v.fi] = v.se;
      }
      if (tot == n - 1) {
        vi cur;
        for (int i = 1; i <= n; i++)
          if (!in[i]) {
            int pl = i;
            while (pl) {
              cur.pb(pl),
              pl = out[pl];
            }
            break;
          }
        return cur;
      }
    }
    //failed to find a path
```

```
    return vi();
  }
}
//43ae60
```

10 Геома

10.1 Примитивы

```
struct Point {
  int x, y;
  Point(){}
  Point (int x_, int y_) {
    x = x_; y = y_;
  }
  Point operator + (Point p) {
    return Point(x+p.x,y+p.y);
  }
  Point operator - (Point p) {
    return Point(x - p.x, y - p.y);
  }
  int operator * (Point p) {
    return x * p.y - y * p.x;
  }
  int operator % (Point p) {
    return x * p.x + y * p.y;
  }
  bool operator < (Point v) {
    return (*this) * v > 0;
  }
  bool operator > (Point v) {
    return v < (*this);
  };
  bool operator <= (Point v) {
    return (*this) * v >= 0;
  }
};
bool line(Point a, Point b, Point c) {
  return (b - a) * (c - b)==0;
}
bool ord(Point a, Point p, Point b) {
  return (p - a)%(p - b)<0;
}

int hp(Point a) {
  if (a.y == 0) return a.x >= 0;
  return a.y > 0;
}

bool comp(Point a, Point b) {
  if (hp(a) != hp(b)) return hp(a) < hp(b);
  return a.x * b.y - a.y * b.x > 0;
}
//a48b68
```

10.2 Выпуклая оболочка

```
using pt = pair<int, int>;
#define x first
#define y second

int cross(pt p, pt q) { return p.x * q.y - p.y * q.x;
    }
pt operator-(pt a, pt b) { return {a.x - b.x, a.y - b
    .y}; }

vector<point> convex(vector<point> a) {
  sort(all(a));
  a.erase(unique(all(a)), a.end());
  vector<point> h;
  for (int t = 0; t < 2; ++t) {
    int sz = h.size() - t;
    for (auto p: a) {
      while (h.size() >= sz + 2 && cross(p - h.end()
    [-1], h.end()[-2] - h.end()[-1]) <= 0) h.pop_back
    ();
      h.push_back(p);
    }
    reverse(all(a));
  }
  return h; // h is circular: h.empty() || h.front()
    == h.back()
}
//ef9132
```

10.3 Точка внутри многоугольника

```
auto inT = [&] (Point a, Point b, Point c, Point p) {
  a = a-p; b = b-p; c = c-p;
  int ab = a * b, bc = b * c, ca = c * a;
  return abs(ab)+abs(bc)+abs(ca) == abs(ab+bc+ca);
};
auto inP = [&] (Point p) {
//a must be in counterclockwise order!
//assuming no three points of a are collinear
  if (n == 1) return p == a[0];
  if (n == 2) return (p-a[0]) * (a[1]-a[0]) == 0 && (
    p-a[0]) % (p-a[1]) <= 0;
  int l = 1, r = n - 1;
  while (l < r - 1) {
    int m = (l + r) / 2;
    if ((a[m] - a[0]) < (p - a[0])) {
      l = m;
    } else {
      r = m;
    }
  }
  return inT(a[l], a[0], a[r], p);
};
//9e04bc
```

10.4 Касательные

```
auto max = [&] (auto cmp) {
  int k = 0;
  for (int lg = 18; lg >= 0; --lg) {
    int i = k + (1 << lg), j = k - (1 << lg);
    i = (i % n + n) % n;
    j = (j % n + n) % n;
    array<int, 3> ind{i, j, k};
    sort(all(ind), cmp);
    k = ind[2];
  }
  return k;
};
auto uppert = [&](Point p) { //last vertex in
    counterclockwise order about p
  auto cmp = [&] (int i, int j) {return (a[i] - p) <
    (a[j] - p); };
  return max(cmp);
};
auto lowert = [&](Point p) { //first vertex in
    counterclockwise order about p
  auto cmp = [&] (int i, int j) {return (a[i] - p) >
    (a[j] - p); };
  return max(cmp);
};
auto uppertinf = [&](Point p) { //upper tangent line
    parallel to vector p
  swap(p.x, p.y);
  p.x = -p.x;
  auto cmp = [&] (int i, int j) { return a[i] % p < a
    [j] % p; };
  return max(cmp);
};
auto lowertinf = [&](Point p) { //lower tangent line
    parallel to vector p
  swap(p.x, p.y);
  p.x = -p.x;
  auto cmp = [&] (int i, int j) { return a[i] % p > a
    [j] % p; };
  return max(cmp);
};
//90f89d
```

10.5 Пересечение многоугольника и полуплоскости

```
template<typename Check>
vector<point> intersect(vector<point> h, Check value)
    {
  int n = h.size();
  vector<int> pos(n);
  for (int i = 0; i < n; ++i) {
    pos[i] = value(h[i]) >= 0;
  }
  if (count(all(pos), 0) == 0) return h;
  if (count(all(pos), 1) == 0) return {};
  auto intersect = [&](point p, point q) {
    auto s = value(p);
    auto t = value(q);
    assert(s < 0 && t >= 0);
    return q + (p - q) * (t / (t - s));
  };
  int t01 = -1, t10 = -1;
```

```
  for (int i = 0; i < n; ++i) {
    h.push_back(h[i]);
    pos.push_back(pos[i]);
    if (pos[i] == 0 && pos[i + 1] == 1) t01 = i;
    if (pos[i] == 1 && pos[i + 1] == 0) t10 = i;
  }
  if (t10 < t01) t10 += n;
//for (int i = t01 + 1; i <= t10; ++i) assert(pos[i]
    == 1);
//for (int i = t10 + 1; i <= t01 + n; ++i) assert(pos
    [i] == 0);
  vector<point> res{intersect(h[t01], h[t01 + 1])};
  for (int i = t01 + 1; i <= t10; ++i) {
    res.push_back(h[i]);
  }
  res.push_back(intersect(h[t10 + 1], h[t10]));
  return res;
}

// Usage example:
void solve() {
    vector<point> p, q;
    // ... q must be in counterclockwise order; q[0]
    == q[m]
    for (int i = 0; i < m; ++i) {
        p = intersect(p, [&](point pt) { return cross
    (q[i + 1] - q[i], pt - q[i]); });
    }
}
//bd15f0
```

10.6 События для прямой

```
int cross(point p, point q) { return p.x * q.y - q.x
    * p.y; }
point operator-(point p, point q) { return {p.x - q.x
    , p.y - q.y}; }
int sgn(int x) { return x < 0 ? -1 : (x > 0); }
double dist(point p) { return sqrt(p.x * p.x + p.y *
    p.y); }
const __int128 one = 1;

double solve(vector<point> a, point p, point q) {
  int n = a.size();
  a.push_back(a[0]);
  point pq = q - p;
  vector<array<int, 3>> ev;
  for (int i = 0; i < n; ++i) {
    point u = a[i], v = a[i + 1];
    int s = sgn(cross(u - p, pq)), t = sgn(cross(v -
    p, pq));
    if (s == t) continue;
    int top = cross(u - p, v - u), bot = cross(pq, v
    - u);
    ev.push_back({sgn(bot) * top, abs(bot), t - s});
  }
  sort(all(ev), [](auto e, auto f) {
    return e[0] * one * f[1] < f[0] * one * e[1];
  });
  int bal = 0;
  for (int i = 0; i + 1 < ev.size(); ++i) {
    if (bal + ev[i][2] < 0 || bal + ev[i][2] > 2) {
      assert(ev[i][0] * ev[i+1][1] == ev[i+1][0] * ev
    [i][1]);
      swap(ev[i], ev[i + 1]);
    }
    bal += ev[i][2];
  }
  // example usage: now calculating length of longest
     segment inside
  bal = 0;
  double from = 0, ans = 0;
  for (auto [t, b, w] : ev) {
    double x = t * 1.0 / b;
    if (bal == 0) from = x;
    bal += w;
    assert(0 <= bal && bal <= 2);
    if (bal == 0) ans = max(ans, x - from);
  }
  return ans * dist(pq);
}
//fe0649
```

10.7 Кривая Гильберта для алгоритма Мо

```
const int logn = 30; // any number, such that maxn is
     greater than coordinates. 20 is ok.
const int maxn = 1 << logn;
int hilbertorder(int x, int y) { // returns long long
    int d = 0; // long long
    for (int s = 1 << (logn - 1); s; s >>= 1)
    {
        bool rx = x & s, ry = y & s;
        d = (4 * d) | ((3 * rx) ^ ry);
        if (!ry) {
            if (rx) {
                x = maxn - x;
                y = maxn - y;
            }
            swap(x, y);
        }
    }
    return d;
}
// Usage example:
vector<int> sort_indices(int q, vector<pair<int, int
    >> &qs) {
    vector<int> ind(q), ord(q);
    iota(all(ind), 0);
    for (int i = 0; i < q; ++i) ord[i] = hilbertorder
    (qs[i].first, qs[i].second);
    sort(all(ind), [&](int i, int j) { return ord[i]
    < ord[j]; });
    return ind;
}
//134578
```

10.8 Симплекс

```
#define int long long
using namespace std;

typedef double ld;

const ld EPS = 1e-9;

struct LPSolver {
  int m, n;
  vector <int> B, N;
  vector <vector <ld> > D;

  LPSolver(const vector <vector <ld> > &A, const
    vector <ld> &b, const vector <ld> &c) :
    m(b.size()), n(c.size()), N(n + 1), B(m), D(m +
    2, vector <ld>(n + 2)) {
    for (int i = 0; i < m; i++) for (int j = 0; j < n
    ; j++) D[i][j] = A[i][j];
    for (int i = 0; i < m; i++) { B[i] = n + i; D[i][
    n] = -1; D[i][n + 1] = b[i]; }
    for (int j = 0; j < n; j++) { N[j] = j; D[m][j] =
     -c[j]; }
    N[n] = -1; D[m + 1][n] = 1;
  }

  void pivot(int r, int s) {
    double inv = 1.0 / D[r][s];
    for (int i = 0; i < m + 2; i++) if (i != r)
      for (int j = 0; j < n + 2; j++) if (j != s)
        D[i][j] -= D[r][j] * D[i][s] * inv;
    for (int j = 0; j < n + 2; j++) if (j != s) D[r][
    j] *= inv;
    for (int i = 0; i < m + 2; i++) if (i != r) D[i][
    s] *= -inv;
    D[r][s] = inv;
    swap(B[r], N[s]);
  }

  bool simplex(int phase) {
    int x = phase == 1 ? m + 1 : m;
    while (true) {
      int s = -1;
      for (int j = 0; j <= n; j++) {
        if (phase == 2 && N[j] == -1) continue;
        if (s == -1 || D[x][j] < D[x][s] || D[x][j]
    == D[x][s] && N[j] < N[s]) s = j;
      }
      if (D[x][s] > -EPS) return true;
      int r = -1;
      for (int i = 0; i < m; i++) {
        if (D[i][s] < EPS) continue;
        if (r == -1 || D[i][n + 1] / D[i][s] < D[r][n
     + 1] / D[r][s] ||
            (D[i][n + 1] / D[i][s]) == (D[r][n + 1] / D
    [r][s]) && B[i] < B[r]) r = i;
      }
      if (r == -1) return false;
```

```
      pivot(r, s);
    }
  }

  ld solve(vector <ld> &x) {
    int r = 0;
    for (int i = 1; i < m; i++) if (D[i][n + 1] < D[r
    ][n + 1]) r = i;
    if (D[r][n + 1] < -EPS) {
      pivot(r, n);
      if (!simplex(1) || D[m + 1][n + 1] < -EPS)
    return -numeric_limits<ld>::infinity();
      for (int i = 0; i < m; i++) if (B[i] == -1) {
        int s = -1;
        for (int j = 0; j <= n; j++)
          if (s == -1 || D[i][j] < D[i][s] || D[i][j]
     == D[i][s] && N[j] < N[s]) s = j;
        pivot(i, s);
      }
    }
    if (!simplex(2)) return numeric_limits<ld>::
    infinity();
    x = vector<ld>(n);
    for (int i = 0; i < m; i++) if (B[i] < n) x[B[i]]
     = D[i][n + 1];
    return D[m][n + 1];
  }
};
/*
//     maximize     c^T x
//     subject to   Ax <= b
//                  x >= 0
vector <vector <ld> > A(m, vector <ld> (n))
vector <ld> b(m), c(n)
LPSolver solver(A, b, c);
vector <ld> x;
ld value = solver.solve(x);
// OUTPUT: value of the optimal solution (infinity if
     unbounded above, -infinity if infeasible)
*/
//31e155
```

11 Цепные дроби

https://cp-algorithms.com/algebra/continued-fractions.html

11.1 Поиск нижней огибающей, сумма и минимум по модулю

```
int floor(int a, int b) {
  return a / b - ((a ^ b) < 0 && a % b);
}
vector<int> decompose(int p, int q) {
  vector<int> f;
  while (q != 0) {
    f.push_back(floor(p, q));
    p -= q * f.back();
    swap(p, q);
  }
  return f;
}

using matrix = array<int, 4>;

matrix operator*(matrix a, matrix b) {
  matrix c{0,0,0,0};
  for (int i = 0; i < 2; ++i) {
    for (int j = 0; j < 2; ++j) {
      for (int k = 0; k < 2; ++k) {
        c[2 * i + k] += a[2 * i + j] * b[2 * j + k];
      }
    }
  }
  return c;
}

#define x first
#define y second

// computes lower convex hull for 0 <= x <= N, 0 <= y
     <= (ax + b) / c
vector<pair<int, int>> lower_convex_hull(int a, int b
    , int c, int n) {
  matrix m = {1, 0, 0, 1};
  auto f = decompose(a, c);
  vector<pair<int, int>> conv{{1, 0}, {0, 1}};
  for (int x : f) {
    m = m * matrix{x, 1, 1, 0};
    conv.emplace_back(m[2], m[0]);
    if (m[2] > n) break; // there should be one (if
    any) with .x > n
  }
  auto diff = [&](int x, int y) {
    return c * y - a * x;
  };
  int x = 0, y = b / c;
  vector<pair<int, int>> res{{x, y}};
  int i;
  for (i = 2; i + 1 < conv.size(); i += 2) {
    while (diff(x + conv[i + 1].x, y + conv[i + 1].y)
     <= b) {
      int t = 1 + (diff(x + conv[i - 1].x, y + conv[i
     - 1].y) - b - 1) / abs(diff(conv[i].x, conv[i].y
    ));
      auto [dx, dy] = tuple{conv[i - 1].x + t * conv[
    i].x, conv[i - 1].y + t * conv[i].y};
      int k = (n - x) / dx;
      if (k == 0) break;
      if (diff(dx, dy)) k = min(k, (b - diff(x, y)) /
     diff(dx, dy));
      x += k * dx, y += k * dy;
      res.push_back({x, y});
    }
  }
  if (i >= conv.size()) i -= 2;
  for (; i > 0; i -= 2) {
    auto [dx1, dy1] = conv[i];
    if (x + dx1 > n) continue;
    x += dx1, y += dy1;
    if (i + 1 < conv.size()) {
      auto [dx2, dy2] = conv[i + 1];
      int k = (n - x) / dx2;
      x += k * dx2;
      y += k * dy2;
    }
    res.emplace_back(x, y);
    int k = (n - x) / dx1;
    if (k == 0) continue;
    x += k * dx1;
    y += k * dy1;
    res.emplace_back(x, y);
  }
  return res;
}

// number of (x, y) under pq line such that p.x <= x
    < q.x && 0 < y
int area(auto p, auto q) {
  int integers = gcd(q.x - p.x, q.y - p.y);
  return ((p.y + q.y - 1) * (q.x - p.x + 1) +
    integers + 1) / 2 - q.y;
}

// sum of (ax + b) / c for 0 <= x < n
int get_area(int a, int b, int c, int n) { // SUM (ax
     + b) / c for 0 <= x <= n
  auto ch = lower_convex_hull(a, b, c, n + 1);
  int sum = 0;
  for (int i = 0; i + 1 < ch.size(); ++i) {
    sum += area(ch[i], ch[i + 1]);
  }
  return sum;
}

// min of (ax + b) % c for 0 <= x <= n
int get_min(int a, int b, int c, int n) {
  auto ch = lower_convex_hull(a, b, c, n);
  // in fact, here we need only the last point of the
     first half of the algo (that is going up)
  int mn = c;
  for (auto [x, y] : ch) mn = min(mn, (a * x + b) % c
    );
  return mn;
}
//87941e
```

11.2 Простая рекурсия

Число точек $(x, y) : 0 \leqslant x < n, 0 < y \leqslant (kx+b)/d$. То есть $\sum_{x=0}^{n-1} \lfloor \frac{kx+b}{d} \rfloor$.

```
int cnt (int n, int k, int b, int d)
{
  if (k == 0) return (b / d) * n;
  if (k >= d || b >= d) {
```

```
    return (k / d) * n * (n - 1) / 2 + (b / d) * n +
    cnt(n, k % d, b % d, d);
  }
  return cnt((k * n + b) / d, d, (k * n + b) % d, k);
}
//11a6a0
```

12 Разное

12.1 Компараторы

```
bool cmp1(int x, int y) { return x > y; }

struct cmp2{
  bool operator()(int x, int y) const { return x > y;
     }
};

int32_t main() {
  set<int, decltype(cmp1)*> s1({1, 2, 3}, cmp1);
  for (int x : s1) cout << x << ' '; cout << '\n';
  set<int, cmp2> s2({4, 5, 6});
  for (int x : s2) cout << x << ' '; cout << '\n';
  auto cmp3 = [&](int x, int y) { return x > y; };
  set<int, decltype(cmp3)> s3({7, 8, 9}, cmp3); //
    second cmp3 could be omitted if cmp3 = [](...) {
    ... }
  for (int x : s3) cout << x << ' '; cout << '\n';

  vector<int> v{3, 2, 1};
  cout << lower_bound(all(v), 2, cmp1) - v.begin();
  cout << lower_bound(all(v),2,cmp2()) - v.begin();
  cout << lower_bound(all(v), 2, cmp3) - v.begin();
}
//adea08
```

12.2 Трюки от Сергея Копелиовича

12.2.1 Быстрый ввод

https://acm.math.spbu.ru/~sk1/algo/input-output

```
const int buf_size = 4096;

int getChar() {
  static char buf[buf_size];
  static int len = 0, pos = 0;
  if (pos == len)
    pos = 0, len = fread(buf, 1, buf_size, stdin);
  if (pos == len)
    return -1;
  return buf[pos++];
}

int readChar() {
  while (1) {
    int c = getChar();
    if (c > 32) return c;
  }
}

int readInt() {
  int s = 1, c = readChar(), x = 0;
  if (c == '-')
    s = -1, c = getChar();
  while (isdigit(c))
    x = x * 10 + c - '0', c = getChar();
  return s * x;
}
//dc0a77

double read_double() {
  string s;
  cin >> s;
  double sgn = 1, p10 = 0, num = 0;
  for (char c : s) {
    if (c == '-') {
      sgn = -1;
    } else if (c == '.') {
      p10 = 1;
    } else {
      p10 *= 10;
      num = (num * 10 + c - '0');
    }
  }
  if (p10 < 0.5) p10 = 1;
  return sgn * num / p10;
}
//b77b67
```

https://acm.math.spbu.ru/~sk1/algo/memory.cpp.html

12.2.2 Быстрый аллокатор

```
const int MAX_MEM = 1e8;
int mpos = 0;
char mem[MAX_MEM];
inline void * operator new (size_t n) {
  assert((mpos += n) <= MAX_MEM);
  return (void *)(mem + mpos - n);
}
void operator delete (void *) noexcept { }
void operator delete (void *, size_t) noexcept { }
//8726b1
```

12.3 Редукция Барретта

```
using u64 = unsigned long long;
using u128 = __uint128_t;
struct barrett{
  u64 p, m;
  barrett() {}
  barrett(u64 p) : p(p), m(-1ULL / p) {}
  int reduce(u64 x) {
    u64 q = (u128(m) * x) >> 64, r = x - q * p;
    return r - p * (r >= p);
  }
} ba;

// Usage example:
void solve() {
  int p = ...;
  ba = barrett(p);
  int x = ..., y = ...;
  int prod = ba.reduce(x * y);
}
//a8b4c7
```

12.4 Флаги компияции

```
-DLOCAL -Wall -Wextra -pedantic -Wshadow -Wformat=2
-Wfloat-equal -Wconversion -Wlogical-op -Wshift-
overflow=2 -Wduplicated-cond -Wcast-qual -Wcast-
align -D_GLIBCXX_DEBUG -D_GLIBCXX_DEBUG_PEDANTIC
-D_FORTIFY_SOURCE=2 -fsanitize=address -
fsanitize=undefined -fno-sanitize-recover -fstack-
protector -std=c++2a
```

12.5 Что сделать на пробном туре

- Послать клар
- Распечатать что-то
- Получить ML (stack & heap)
- Максимальный размер отправляемого файла?
- Убедиться, что чекер регистронезависимый (yes/YES)
- Позапускать Флойда — Варшалла
- Посмотреть, насколько быстр быстрый ввод
- Перебить что-то, проверить хеш
- Проверить санитайзеры

12.6 Хеш файла без комментариев

Хеш файла, игнорирующий переводы строк и комментарии:

```
$ cpp -dD -P -fpreprocessed "$filename" | tr -d '[:
    space:]' | md5sum | cut -c-6
```