Содержание

1 Теория чисел

1.1 КТО

```cpp
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; }
```

1.2 Алгоритм Миллера — Рабина

```cpp
__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;
}
```

1.3 Алгоритм Берлекэмпа — Месси

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

```cpp
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;
}
```

2   Графы

2.1 $\mathcal{SCC}$ и 2-$\mathcal{SAT}$

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

В случае 2-$\mathcal{SAT}$ рёбра $i \Rightarrow j$ и $(j \oplus 1) \Rightarrow (i \oplus 1)$ должны быть добавлены одновременно.

```cpp
vector<vector<int>> g(2 * n);
vector<vector<int>> r(g.size());
for (int i = 0; i < g.size(); ++i) {
  for (int j : g[i]) r[j].push_back(i);
}
vector<int> used(g.size()), tout(g.size());
int time = 0;
auto dfs = [&](auto dfs, int cur) -> void {
  if (used[cur]) return;
  used[cur] = 1;
  for (int nxt : g[cur]) {
    dfs(dfs, nxt);
  }
  // used[cur] = 2;
  tout[cur] = time++;
};
for (int i = 0; i < g.size(); ++i) if (!used[i])
    dfs(dfs, i);
vector<int> ind(g.size());
iota(ind.begin(), ind.end(), 0);
sort(all(ind), [&](int i, int j){return tout[i] >
    tout[j];});
vector<int> scc(g.size(), -1);
auto go = [&](auto go, int cur, int color) -> void
    {
  if (scc[cur] != -1) return;
  scc[cur] = color;
  for (int nxt : r[cur]) {
    go(go, nxt, color);
  }
};
int color = 0;
for (int i : ind) {
  if (scc[i] == -1) go(go, i, color++);
}
for (int i = 0; i < g.size() / 2; ++i) {
  if (scc[2 * i] == scc[2 * i + 1]) "IMPOSSIBLE"
  if (scc[2 * i] < scc[2 * i + 1]) {
  // !i => i, assign i = true
  } else {
  // i => !i, assign i = false
  }
}
```

2.2   Эйлеров цикл

```cpp
vector<vector<pair<int, int>>> g(n); // pair{nxt,
    idx}
vector<pair<int, int>> e(p.size());
// build graph
vector<int> in(n), out(n);
for (auto [u, v] : e) in[v]++, out[u]++;
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);
  }
};
int cnt = 0, odd = -1;
for (int i = 0; i < n; ++i){
  if (out[i] && odd == -1) odd = i;
  if (in[i] != out[i]) {
    if (in[i] + 1 == out[i]) odd = i;
    if (abs(in[i] - out[i]) > 1) return {}; // must
     hold
```

```cpp
    cnt++;
  }
}
if (cnt != 0 && cnt != 2) return {}; // must hold
// for undirected find odd vertex (and count that #
     of odd is 0 or 2)
dfs(dfs, odd);
reverse(cycle.begin(), cycle.end());
if (cycle.size() != m) return {};
```

2.3   Компоненты рёберной двусвязности

```cpp
int n, m;
cin >> n >> m;
vector <vector <int> > g(n + 1);
map <pair <int, int>, int> comp, col;
for (int i = 0; i < m; ++i) {
  int u, v, c; cin >> u >> v >> c;c--;
  col[{u,v}]=col[{v,u}]=c;
  g[u].push_back(v);
  g[v].push_back(u);
}
vector <int> used(n + 1);
vector <int> newCompWithoutParent(n + 1), h(n + 1),
     up(n + 1);
auto findCutPoints = [&] (auto self, int u, int p)
     -> void {
  used[u] = 1;
  up[u] = h[u];
  for (int v : g[u]) {
    if (!used[v]) {
      h[v] = h[u] + 1;
      self(self, v, u);
      up[u] = min(up[u], up[v]);
      if (up[v] >= h[u]) {
        newCompWithoutParent[v] = 1;
      }
    }
    else {
      up[u] = min(up[u], h[v]);
    }
  }
};
for (int u = 1; u <= n; ++u) {
  if (!used[u]) {
    findCutPoints(findCutPoints, u, u);
  }
}
int ptr = 0;
vector <map <int, int> > colors(m);
auto markComponents = [&] (auto self, int u, int
    cur) -> void {
  used[u] = 1;
  for (int v : g[u]) {
    if (!used[v]) {
      if (newCompWithoutParent[v]) {
        ptr++;
        self(self, v, ptr - 1);
      }
      else {
        self(self, v, cur);
      }
    }
    else if (h[v] < h[u]) {
      comp[{u,v}]=comp[{v,u}]=cur;
      int c = col[{u,v}];
      colors[cur][u] |= 1 << c;
      colors[cur][v] |= 1 << c;
    }
  }
};
used.assign(n + 1, 0);
for (int u = 1; u <= n; ++u) {
  if (!used[u]) {
    markComponents(markComponents, u, -1);
  }
}
for (int comp = 0; comp < m; ++comp) {
  vector <int> cnt(4);
```

```
65   int tot = 0;
66   for (auto [u, mask] : colors[comp]) {
67     tot |= mask;
68     cnt[bp(mask)]++;
69   }
70   if (bp(tot)<3) {
71     continue;
72   }
73   if (cnt[2] || cnt[3]>2) {
74     cout << "Yes" << endl;
75     return;
76   }
77 }
78 cout << "No" << endl;
```

3   xor, and, or-свёртки

```
1  const int p = 998244353;
2  vector<int> band(vector<int> a,vector<int> b)
3  {
4    int n=0;while((1<<n)<a.size()) ++n;
5    a.resize(1<<n);b.resize(1<<n);
6    for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(mask & (1<<i)) {a[mask-(1<<i)]+=a[
       mask];a[mask-(1<<i)]%=p;}
7    for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(mask & (1<<i)) {b[mask-(1<<i)]+=b[
       mask];b[mask-(1<<i)]%=p;}
8    vector<int> c(1<<n,0);
9    for(int mask=0;mask<(1<<n);++mask) {c[mask]=a[
       mask]*b[mask];c[mask]%=p;}
10   for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(!(mask & (1<<i))) {c[mask]-=c[mask
       +(1<<i)];c[mask]%=p;}
11   return c;
12 }
13 vector<int> bor(vector<int> a,vector<int> b)
14 {
15   int n=0;while((1<<n)<a.size()) ++n;
16   a.resize(1<<n);b.resize(1<<n);
17   for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(!(mask & (1<<i))) {a[mask+(1<<i)]+=
       a[mask];a[mask+(1<<i)]%=p;}
18   for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(!(mask & (1<<i))) {b[mask+(1<<i)]+=
       b[mask];b[mask+(1<<i)]%=p;}
19   vector<int> c(1<<n,0);
20   for(int mask=0;mask<(1<<n);++mask) {c[mask]=a[
       mask]*b[mask];c[mask]%=p;}
21   for(int i=0;i<n;++i) for(int mask=0;mask<(1<<n)
       ;++mask) if(mask & (1<<i)) {c[mask]-=c[mask
       -(1<<i)];c[mask]%=p;}
22   return c;
23 }
24 vector<int> bxor(vector<int> a,vector<int> b)
25 {
26   assert(p%2==1);int inv2=(p+1)/2;
27   int n=0;while((1<<n)<a.size()) ++n;
28   a.resize(1<<n);b.resize(1<<n);
29   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;}
30   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;}
31   vector<int> c(1<<n,0);
32   for(int mask=0;mask<(1<<n);++mask) {c[mask]=a[
       mask]*b[mask];c[mask]%=p;}
33   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;}
34   return c;
35 }
```

4   Структуры данных

4.1   Дерево Фенвика

```
1 int fe[maxn]; /// fenwick tree
2 void pl(int pos,int val) {while(pos<maxn) {fe[pos
    ]+=val;pos|=(pos+1);}}
3 int get(int pos) {int ans=0;while(pos>=0) {ans+=fe[
    pos];pos&=(pos+1);--pos;} return ans;} /// [0,
    pos] - vkluchitelno!!!
4 int get(int l,int r) {return get(r-1)-get(l-1);} //
    / summa na [l,r)
```

4.2   Дерево отрезков

```
1  template<typename Data, typename Mod, typename
     UniteData, typename UniteMod, typename Apply>
2  struct MassSegmentTree {
3    int h, n;
4    Data zd;
5    Mod zm;
6    vector<Data> data;
7    vector<Mod> mod;
8
9    UniteData ud; // Data (Data, Data)
10   UniteMod um; // Mod (Mod, Mod);
11   Apply a; // Data (Data, Mod, int); last argument
       is the length of current segment (could be used
        for range += and sum counting, for instance)
12
13   template<typename I>
14   MassSegmentTree(int sz, Data zd, Mod zm,
       UniteData ud, UniteMod um, Apply a, I init) : h
       (__lg(sz > 1 ? sz - 1 : 1) + 1), n(1 << h), zm(
       zm), zd(zd), data(2 * n, zd), mod(n, zm), ud(ud
       ), um(um), a(a) {
15     for (int i = 0; i < sz; ++i) data[i + n] = init
       (i);
16     for (int i = n - 1; i > 0; --i) data[i] = ud(
       data[2 * i], data[2 * i + 1]);
17   }
18
19   MassSegmentTree(int sz, Data zd, Mod zm,
       UniteData ud, UniteMod um, Apply a) : h(__lg(sz
        > 1 ? sz - 1 : 1) + 1), n(1 << h), zm(zm), zd(
       zd), data(2 * n, zd), mod(n, zm), ud(ud), um(um
       ), a(a) {}
20
21   void push(int i) {
22     if (mod[i] == zm) return;
23     apply(2 * i, mod[i]);
24     apply(2 * i + 1, mod[i]);
25     mod[i] = zm;
26   }
27
28   // is used only for apply
29   int length(int i) { return 1 << (h - __lg(i)); }
30
31   // is used only for descent
32   int left(int i) {
33     int lvl = __lg(i);
34     return (i & ((1 << lvl) - 1)) * (1 << (h - lvl)
       );
35   }
36
37   // is used only for descent
38   int right(int i) {
39     int lvl = __lg(i);
40     return ((i & ((1 << lvl) - 1)) + 1) * (1 << (h
       - lvl));
41   }
42
43   template<typename S>
44   void apply(int i, S x) {
45     data[i] = a(data[i], x, length(i));
46     if (i < n) mod[i] = um(mod[i], x);
47   }
48
49   void update(int i) {
```

3

```
50      if (mod[i] != zm) return;
51      data[i] = ud(data[2 * i], data[2 * i + 1]);
52    }
53
54    template<typename S>
55    void update(int l, int r, S x) { // [l; r)
56      l += n, r += n;
57      for (int shift = h; shift > 0; --shift) {
58        push(l >> shift);
59        push((r - 1) >> shift);
60      }
61      for (int lf = l, rg = r; lf < rg; lf /= 2, rg
      /= 2) {
62        if (lf & 1) apply(lf++, x);
63        if (rg & 1) apply(--rg, x);
64      }
65      for (int shift = 1; shift <= h; ++shift) {
66        update(l >> shift);
67        update((r - 1) >> shift);
68      }
69    }
70
71    Data get(int l, int r) { // [l; r)
72      l += n, r += n;
73      for (int shift = h; shift > 0; --shift) {
74        push(l >> shift);
75        push((r - 1) >> shift);
76      }
77      Data leftRes = zd, rightRes = zd;
78      for (; l < r; l /= 2, r /= 2) {
79        if (l & 1) leftRes = ud(leftRes, data[l++]);
80        if (r & 1) rightRes = ud(data[--r], rightRes)
      ;
81      }
82      return ud(leftRes, rightRes);
83    }
84
85    // l \in [0; n) && ok(get(l, l), l);
86    // returns last r: ok(get(l, r), r)
87    template<typename C>
88    int lastTrue(int l, C ok) {
89      l += n;
90      for (int shift = h; shift > 0; --shift) push(l
      >> shift);
91      Data cur = zd;
92      do {
93        l >>= __builtin_ctz(l);
94        Data with1;
95        with1 = ud(cur, data[l]);
96        if (ok(with1, right(l))) {
97          cur = with1;
98          ++l;
99        } else {
100          while (l < n) {
101            push(l);
102            Data with2;
103            with2 = ud(cur, data[2 * l]);
104            if (ok(with2, right(2 * l))) {
105              cur = with2;
106              l = 2 * l + 1;
107            } else {
108              l = 2 * l;
109            }
110          }
111          return l - n;
112        }
113      } while (l & (l - 1));
114      return n;
115    }
116
117    // r \in [0; n) && ok(get(r, r), r);
118    // returns first l: ok(get(l, r), l)
119    template<typename C>
120    int firstTrue(int r, C ok) {
121      r += n;
122      for (int shift = h; shift > 0; --shift) push((r
       - 1) >> shift);
123      Data cur = zd;
124      while (r & (r - 1)) {
125        r >>= __builtin_ctz(r);
```

```
126        Data with1;
127        with1 = ud(data[--r], cur);
128        if (ok(with1, left(r))) {
129          cur = with1;
130        } else {
131          while (r < n) {
132            push(r);
133            Data with2;
134            with2 = ud(data[2 * r + 1], cur);
135            if (ok(with2, right(2 * r))) {
136              cur = with2;
137              r = 2 * r;
138            } else {
139              r = 2 * r + 1;
140            }
141          }
142          return r - n + 1;
143        }
144      }
145      return 0;
146    }
147  };
```

4.2.1   Примеры использования

- Взятие максимума и прибавление константы

```
1  MassSegmentTree segtree(n, 0LL, 0LL,
2  [](int x, int y) { return max(x, y); },
3  [](int x, int y) { return x + y; },
4  [](int x, int y, int len) { return x + y; });
```

- Взятие суммы и прибавление константы

```
1  MassSegmentTree segtree(n, 0LL, 0LL,
2  [](int x, int y) { return x + y; },
3  [](int x, int y) { return x + y; },
4  [](int x, int y, int len) { return x + y * len;
   });
```

- Взятие суммы и присовение

```
1  MassSegmentTree segtree(n, 0LL, -1LL,
2  [](int x, int y) { return x + y; },
3  [](int x, int y) { return y; },
4  [](int x, int y, int len) { return y * len; });
```

4.3   Ordered set

```
1  #include <ext/pb_ds/assoc_container.hpp>
2  #include <ext/pb_ds/tree_policy.hpp>
3
4  using namespace __gnu_pbds;
5  using namespace std;
6
7  using ordered_set = tree<int, null_type, less<>,
   rb_tree_tag, tree_order_statistics_node_update
   >;
```

4.4   Convex hull trick

```
1  ll div_up(ll a, ll b) { return a/b+((a^b)>0&&a%b);
   } // divide a by b rounded up
2
3  struct Line {
4      ll k, b;
5
6      Line() : k(), b() {}
7      Line (ll _k, ll _b) : k(_k), b(_b) {}
8
9      ll getVal(ll x) {
10          return k * x + b;
11      }
12  };
13  struct Hull {
14      vector<Line> lines;
15      vector<ll> borders;
16
```

4

```
17      Hull() : lines(), borders() {}
18
19      void addLine(Line L) {
20          while(!lines.empty()) {
21              if (lines.back().getVal(borders.back())
    >= L.getVal(borders.back())) {
22                  lines.pop_back();
23                  borders.pop_back();
24              } else break;
25          }
26          if (lines.empty()) {
27              lines.push_back(L);
28              borders.push_back(0LL); //leftmost
    query
29              return;
30          }
31          if (lines.back().k <= L.k) return;
32          ll x = div_up(L.b - lines.back().b, lines.
    back().k - L.k); //must work for negative!
33          lines.push_back(L);
34          borders.push_back(x);
35      }
36      ll getMinVal(ll x) {
37          int pos = upper_bound(borders.begin(),
    borders.end(), x) - borders.begin();
38          if (pos == 0) throw;
39          pos--;
40          return lines[pos].getVal(x);
41      }
42 };
```

4.5 Центроидная декомпозиция

```
1 vector<int> sz(n), lvl(n, -1);
2 auto dfs = [&](auto dfs, int cur, int prev) -> int
    {
3      if (lvl[cur] != -1) return 0;
4      sz[cur] = 1;
5      for (auto [nxt, w] : g[cur]) {
6          if (nxt != prev) sz[cur] += dfs(dfs, nxt,
    cur);
7      }
8      return sz[cur];
9 };
10 auto find = [&](auto find, int cur, int prev, int
    tot) -> int {
11     int bch = -1, bsz = 0;
12     for (auto [nxt, w] : g[cur]) {
13         if (nxt == prev || lvl[nxt] != -1) continue
    ;
14         if (sz[nxt] > bsz) {
15             bch = nxt;
16             bsz = sz[nxt];
17         }
18     }
19     if (bsz + bsz <= tot) return cur;
20     return find(find, bch, cur, tot);
21 };
22 dfs(dfs, 0, 0);
23 auto c = find(find, 0, 0, sz[0]);
24 vector<pair<int, int>> stack{{c, 0}};
25 int ans = INF;
26 while (!stack.empty()) {
27     auto [centroid, l] = stack.back();
28     stack.pop_back();
29     lvl[centroid] = l;
30     for (auto [nxt, w] : g[centroid]) {
31         if (lvl[nxt] != -1) continue;
32         dfs(dfs, nxt, centroid);
33         int new_centroid = find(find, nxt, centroid
    , sz[nxt]);
34         stack.push_back({new_centroid, lvl[centroid
    ] + 1});
35     }
36 }
```

5 Строковые алгоритмы

5.1 Префикс-функция

```
1 vector<int> prefix_function(string s) {
```

```
2     vector<int> p(s.size());
3     for (int i = 1; i < s.size(); ++i) {
4         p[i] = p[i - 1];
5         while (p[i] && s[p[i]] != s[i]) p[i] = p[p[i] -
    1];
6         p[i] += s[i] == s[p[i]];
7     }
8     return p;
9 }
```

5.2 Z-функция

```
1 vector<int> z_function (string s) { // z[i] - lcp
    of s and s[i:]
2   int n = (int) s.length();
3   vector<int> z (n);
4   for (int i=1, l=0, r=0; i<n; ++i) {
5     if (i <= r)
6       z[i] = min (r-i+1, z[i-l]);
7     while (i+z[i] < n && s[z[i]] == s[i+z[i]])
8       ++z[i];
9     if (i+z[i]-1 > r)
10      l = i,  r = i+z[i]-1;
11  }
12  return z;
13 }
```

5.3 Алгоритм Манакера

```
1 vector<int> manacher_odd(const string &s) {
2     vector<int> man(s.size(), 0);
3     int l = 0, r = 0;
4     int n = s.size();
5     for (int i = 1; i < n; i++) {
6         if (i <= r) {
7             man[i] = min(r - i, man[l + r - i]);
8         }
9         while (i + man[i] + 1 < n && i - man[i] - 1 >=
    0 && s[i + man[i] + 1] == s[i - man[i] - 1]) {
10            man[i]++;
11        }
12        if (i + man[i] > r) {
13            l = i - man[i];
14            r = i + man[i];
15        }
16    }
17    return man;
18 }
19 // abacaba : (0 1 0 3 0 1 0)
20 // abbaa : (0 0 0 0 0)
21
22 vector <int> manacher_even(const string &s) {
23    assert(s.size());
24    string t;
25    for (int i = 0; i + 1 < s.size(); ++i) {
26        t += s[i];
27        t += '#';
28    }
29    t += s.back();
30    auto odd = manacher_odd(t);
31    vector <int> ans;
32    for (int i = 1; i < odd.size(); i += 2) {
33        ans.push_back((odd[i]+1)/2);
34    }
35    return ans;
36 }
37 // abacaba : (0 0 0 0 0 0)
38 // abbaa : (0 2 0 1)
```

5.4 Суфмассив

Переработанный китайский суффмассив

```
1 const int inf = 1e9;
2 struct rmq {
3   int n;
4   vector<int> a;
5   void build(const vector<int> &x) {
```

```
 6      assert(x.size() == n);
 7      for (int i = 0; i < n; ++i) a[n + i] = x[i];
 8      for (int i = n - 1; i > 0; --i) a[i] = min(a[2
        * i], a[2 * i + 1]);
 9    }
10    rmq(int n) : n(n), a(2 * n, inf) {}
11    void put(int i, int x) {
12      a[i + n] = min(a[i + n], x);
13      for (i = (i + n) / 2; i > 0; i /= 2) {
14        a[i] = min(a[i * 2], a[i * 2 + 1]);
15      }
16    }
17    int getMin(int l, int r) { //[l;r)
18      assert(l < r);
19      int res = inf;
20      for (l += n, r += n; l < r; l /= 2, r /= 2) {
21        if (l & 1) res = min(res, a[l++]);
22        if (r & 1) res = min(res, a[--r]);
23      }
24      return res;
25    }
26 };
27 template <typename T>
28 struct suar {
29     vector <int> sa, lcp, rank; rmq t;
30     suar (T s, int lim=256) : t((int)s.size() - 1)
       { // s must be nonempty, 0 < s[i] < lim!
31         int n = (int)s.size() + 1, k = 0, a, b; s.
       app(0);
32         vector <int> x(s.begin(), s.end()), y(n),
       ws(max(n, lim));rank.resize(n);
33         sa = lcp = y, iota(sa.begin(), sa.end(), 0)
       ;
34         for (int j = 0, p = 0; p < n; j = max(1ll,
       j * 2), lim = p) {
35             p = j, iota(y.begin(), y.end(), n - j);
36             for (int i = 0; i < n; i++) if (sa[i]
       >= j) y[p++] = sa[i] - j;
37             fill(ws.begin(), ws.end(), 0);
38             for (int i = 0; i < n; i++) ws[x[i]]++;
39             for (int i = 1; i < lim; i++) ws[i] +=
       ws[i - 1];
40             for (int i = n; i--; ) sa[--ws[x[y[i
       ]]]] = y[i];
41             swap(x, y), p = 1, x[sa[0]] = 0;
42             for (int i = 1; i < n; i++) a = sa[i -
       1], b = sa[i], x[b] = (y[a] == y[b] && y[a + j]
        == y[b + j]) ? p - 1 : p++;
43         }
44         for (int i = 1; i < n; i++) rank[sa[i]] = i
       ;
45         for (int i = 0, j; i < n - 1; lcp[rank[i
       ++]]=k)
46             for (k && k--, j = sa[rank[i] - 1];
47                 s[i + k] == s[j + k]; k++);
48         sa.erase(sa.begin()); lcp.erase(lcp.begin()
       ); lcp.erase(lcp.begin());
49         t.build(lcp);
50         for (auto &e : rank) {
51             e--;
52         }
53     }
54     int getLcp(int i, int j) {
55         i = rank[i]; j = rank[j];
56         if (j < i) {
57             swap(i, j);
58         }
59         if (i == j) {
60             return inf;
61         }
62         else {
63             return t.getMin(i, j);
64         }
65     }
66 };
```

5.5   Алгоритм Ахо — Корасик

```
 1 struct node{
```

```
 2    int next[alpha] = {}, link[alpha] = {};
 3    int suf = 0;
 4    ll visited = 0, ans = 0;
 5    vector<int> term;
 6    node() {}
 7 };
 8
 9 vector<node> mem;
10
11 int get_next(int nd, char c) {
12    if (!mem[nd].next[c - a]) { mem[nd].next[c - a] =
        mem.size(); mem.emplace_back(); }
13    return mem[nd].next[c - a];
14 }
15
16 void find(string s, vector<string> t) {
17    mem.reserve(1e6 + 100);mem.clear();
18    mem.emplace_back();mem.emplace_back();
19    // 0th element is nullptr, 1st is the root
20    int q = t.size();
21    for (int j = 0; j < q; ++j) {
22      int cur = 1;
23      for (char c : ts[j]) cur = get_next(cur, c);
24      mem[cur].term.push_back(j);
25    }
26    vector<int> bfs_order;
27    queue<int> bfs;
28    {
29        node &root = mem[1];
30        root.suf = 1;
31        for (char c = a; c < a + alpha; ++c) {
32            root.link[c - a] = (root.next[c - a] ?
       root.next[c - a] : 1);
33        }
34        bfs.push(1);
35    }
36    while (!bfs.empty()) {
37      int cur_idx = bfs.front();
38      bfs.pop();
39      node &cur = mem[cur_idx];
40      bfs_order.push_back(cur_idx);
41      for (char c = a; c < a + alpha; ++c) {
42        int nxt_idx = cur.next[c - a];
43        if (!nxt_idx) continue;
44        node &nxt = mem[nxt_idx];
45        nxt.suf = (cur_idx == 1 ? 1 : mem[cur.suf].
       link[c - a]);
46        for (char c = a; c < a + alpha; ++c) {
47          nxt.link[c - a] = (nxt.next[c - a] ? nxt.
       next[c - a] : mem[nxt.suf].link[c - a]);
48        }
49        bfs.push(nxt_idx);
50      }
51    }
52    // do something
53 }
```

5.6   Дерево палиндромов

```
 1 struct palindromic{
 2    int n;
 3    vector<int> p, suf{0, 0}, len{-1, 0};
 4    vector<array<int, alpha>> to{{}, {}};
 5    int sz = 2;
 6
 7    palindromic(const string &s) : n(s.size()), p(n +
        1, 1) {
 8      suf.reserve(n);
 9      len.reserve(n);
10      for (int i = 0; i < n; ++i) {
11        auto check = [&](int l) { return i > l && s[i
       ] == s[i - l - 1]; };
12        int par = p[i];
13        while (!check(len[par])) par = suf[par];
14        if (to[par][s[i] - a]) {
15          p[i + 1] = to[par][s[i] - a];
16          continue;
17        }
18        p[i + 1] = sz++;
19        to[par][s[i] - a] = p[i + 1];
20        to.emplace_back();
```

```
21        len.emplace_back(len[par] + 2);
22        do {
23          par = suf[par];
24        } while (!check(len[par]));
25        int link = to[par][s[i] - a];
26        if (link == p[i + 1]) link = 1;
27        suf.emplace_back(link);
28      }
29    }
30 };
```

6   Потоки

6.1   Алгоритм Диница

```
1  #define pb push_back
2  struct Dinic{
3  struct edge{
4    int to, flow, cap;
5  };
6
7  const static int N = 555; //count of vertices
8
9  vector<edge> e;
10 vector<int> g[N + 7];
11 int dp[N + 7];
12 int ptr[N + 7];
13
14 void clear(){
15   for (int i = 0; i < N + 7; i++) g[i].clear();
16   e.clear();
17 }
18
19 void addEdge(int a, int b, int cap){
20   g[a].pb(e.size());
21   e.pb({b, 0, cap});
22   g[b].pb(e.size());
23   e.pb({a, 0, 0});
24 }
25
26 int minFlow, start, finish;
27
28 bool bfs(){
29   for (int i = 0; i < N; i++) dp[i] = -1;
30   dp[start] = 0;
31   vector<int> st;
32   int uk = 0;
33   st.pb(start);
34   while(uk < st.size()){
35     int v = st[uk++];
36     for (int to : g[v]){
37       auto ed = e[to];
38       if (ed.cap - ed.flow >= minFlow && dp[ed.to]
   == -1){
39         dp[ed.to] = dp[v] + 1;
40         st.pb(ed.to);
41       }
42     }
43   }
44   return dp[finish] != -1;
45 }
46
47 int dfs(int v, int flow){
48   if (v == finish) return flow;
49   for (; ptr[v] < g[v].size(); ptr[v]++){
50     int to = g[v][ptr[v]];
51     edge ed = e[to];
52     if (ed.cap - ed.flow >= minFlow && dp[ed.to] ==
    dp[v] + 1){
53       int add = dfs(ed.to, min(flow, ed.cap - ed.
   flow));
54       if (add){
55         e[to].flow += add;
56         e[to ^ 1].flow -= add;
57         return add;
58       }
59     }
60   }
61   return 0;
62 }
```

```
63
64 int dinic(int start, int finish){
65   Dinic::start = start;
66   Dinic::finish = finish;
67   int flow = 0;
68   for (minFlow = (1 << 30); minFlow; minFlow >>= 1)
     {
69     while(bfs()){
70       for (int i = 0; i < N; i++) ptr[i] = 0;
71       while(int now = dfs(start, (int)2e9 + 7))
       flow += now;
72     }
73   }
74   return flow;
75 }
76 } dinic;
```

6.2   Mincost k-flow

6.2.1   Строим граф

```
1  struct edge {
2    int next, capacity, cost, flow = 0;
3
4    edge() = default;
5
6    edge(int next, int capacity, int cost) : next(
     next), capacity(capacity), cost(cost) {}
7
8    int rem() const { return capacity - flow; }
9
10   int operator+=(int f) { return flow += f; }
11
12   int operator-=(int f) { return flow -= f; }
13 };
14 auto addEdge = [&](auto from, auto next, auto
     capacity, int cost) {
15   g[from].push_back(e.size());
16   e.emplace_back(next, capacity, cost);
17   g[next].push_back(e.size());
18   e.emplace_back(from, 0, -cost);
19 };
```

Если граф ориентированный, то addEdge вызываем один раз. Если неориентированный, то два, вот так:

```
1  addEdge(u, v, capacity, cost);
2  addEdge(v, u, capacity, cost);
```

6.2.2   Запускаем Форда — Беллмана

```
1  vector<ll> phi(n, 0);
2  auto fordBellman = [&](int s, int t) {
3    phi.assign(n, 0);
4    for (int iter = 0; iter < n; ++iter) {
5      bool changed = false;
6      for (int u = 0; u < n; ++u) {
7        for (auto index : g[u]) {
8          auto edge = e[index];
9          if (edge.rem() > 0 && phi[edge.next] > phi[
     u] + edge.cost) {
10           phi[edge.next] = phi[u] + edge.cost;
11           changed = true;
12         }
13       }
14     }
15     if (!changed) break;
16   }
17 };
18 fordBellman(s, t);
```

6.2.3   Ищем кратчайший путь Дейкстрой с потенциалами

```
1  vector<ll> dist;
2  vector<int> from;
3  vector<bool> cnt;
4  auto dijkstra = [&](int s, int t) {
5    dist.assign(n, 1e18);
6    from.assign(n, -1);
```

7

```
 7    cnt.assign(n, false);
 8    dist[s] = 0;
 9    set <pair <int, int> > se;
10    se.insert({0, s});
11    while ((int)(se.size())) {
12      int cur = se.begin()->y;
13      se.erase(se.begin());
14      cnt[cur] = true;
15      for (int index : g[cur]) {
16        auto &edge = e[index];
17        if (edge.rem() == 0) continue;
18        ll weight = edge.cost + phi[cur] - phi[edge.
    next];
19        if (dist[edge.next] > dist[cur] + weight) {
20          se.erase({dist[edge.next], edge.next});
21          dist[edge.next] = dist[cur] + weight;
22          se.insert({dist[edge.next], edge.next});
23          from[edge.next] = cur;
24        }
25      }
26    }
27    if (dist[t] == (ll) 1e18) return -1LL;
28    ll cost = 0;
29    for (int p = t; p != s; p = from[p]) {
30      for (auto index : g[from[p]]) {
31        auto &edge = e[index];
32        ll weight = edge.cost + phi[from[p]] - phi[
    edge.next];
33        if (edge.rem() > 0 && edge.next == p && dist[
    edge.next] == dist[from[p]] + weight) {
34          edge += 1;
35          e[index ^ 1] -= 1;
36          cost += edge.cost;
37          break;
38        }
39      }
40    }
41    for (int i = 0; i < n; ++i) {
42      phi[i] += dist[i];
43    }
44    return cost;
45  };
46  ll cost = 0;
47  for (int flow = 0; flow < k; ++flow) {
48    ll a = dijkstra(s, t);
49    if (a == -1) {
50      cout << "-1\n";
51      return;
52    }
53    cost += a;
54  }
```

6.2.4 Восстанавливаем ответ

```
 1 auto findPath = [&](int s, int t) {
 2   vector<int> ans;
 3   int cur = s;
 4   while (cur != t) {
 5     for (auto index : g[cur]) {
 6       auto &edge = e[index];
 7       if (edge.flow <= 0) continue;
 8       edge -= 1;
 9       e[index ^ 1] += 1;
10       ans.push_back(index / 4);
11 // index / 4 because each edge has 4 copies
12       cur = edge.next;
13       break;
14     }
15   }
16   return ans;
17 };
18 for (int flow = 0; flow < k; ++flow) {
19   auto p = findPath(s, t);
20   cout << p.size() << ' ';
21   for (int x : p) cout << x + 1 << ' ';
22   cout << '\n';
23 }
```

7 FFT & co

7.1 NTT & co

```
 1 #define int long long
 2 using namespace std;
 3 typedef long long ll;
 4 const int p=998244353;
 5 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
     *1LL*u)%p;} else {int u=po(a,b-1);return (a*1LL
     *u)%p;}}
 6 int inv(int x) {return po(x,p-2);}
 7 template<int M, int K, int G> struct Fft {
 8   // 1, 1/4, 1/8, 3/8, 1/16, 5/16, 3/16, 7/16, ...
 9   int g[1 << (K - 1)];
10   Fft() : g() { //if tl constexpr...
11     static_assert(K >= 2, "Fft: K >= 2 must hold");
12     g[0] = 1;
13     g[1 << (K - 2)] = G;
14     for (int l = 1 << (K - 2); l >= 2; l >>= 1) {
15       g[l >> 1] = (g[l] * 1LL* g[l]) % M;
16     }
17     assert((g[1]*1LL * g[1]) % M == M - 1);
18     for (int l = 2; l <= 1 << (K - 2); l <<= 1) {
19       for (int i = 1; i < l; ++i) {
20         g[l + i] = (g[l] * 1LL * g[i]) % M;
21       }
22     }
23   }
24   void fft(vector<int> &x) const {
25     const int n = x.size();
26     assert(n <= 1 << K);
27     for (int h = __builtin_ctz(n); h--; ) {
28       const int l = (1 << h);
29       for (int i = 0; i < n >> (h+1); ++i) {
30         for (int j = i << (h+1); j < (((i << 1) +
    1) << h); ++j) {
31           const int t = (g[i] * 1LL* x[j | l]) % M;
32           x[j | l] = x[j] - t;
33           if (x[j|l] < 0) x[j | l] += M;
34           x[j]+=t;
35           if (x[j] >= M) x[j] -= M;
36         }
37       }
38     }
39     for (int i = 0, j = 0; i < n; ++i) {
40       if (i < j) std::swap(x[i], x[j]);
41       for (int l = n; (l >>= 1) && !((j ^= l) & l);
    ) {}
42     }
43   }
44   vector<int> convolution(const vector<int> &a,
    const vector<int> &b) const {
45     if(a.empty() || b.empty()) return {};
46     const int na = a.size(), nb = b.size();
47     int n, invN = 1;
48     for (n = 1; n < na + nb - 1; n <<= 1) invN = ((
    invN & 1) ? (invN + M) : invN) >> 1;
49     vector<int> x(n, 0), y(n, 0);
50     std::copy(a.begin(), a.end(), x.begin());
51     std::copy(b.begin(), b.end(), y.begin());
52     fft(x);
53     fft(y);
54     for (int i = 0; i < n; ++i) x[i] = (((
    static_cast<long long>(x[i]) * y[i]) % M) *
    invN) % M;
55     std::reverse(x.begin() + 1, x.end());
56     fft(x);
57     x.resize(na + nb - 1);
58     return x;
59   }
60 };
61 Fft<998244353,23,31> muls;
62 vector<int> form(vector<int> v,int n)
63 {
64   while(v.size()<n) v.push_back(0);
65   while(v.size()>n) v.pop_back();
66   return v;
67 }
```

```cpp
68  vector<int> operator *(vector<int> v1,vector<int>
        v2)
69  {
70    return muls.convolution(v1,v2);
71  }
72  vector<int> operator +(vector<int> v1,vector<int>
        v2)
73  {
74    while(v2.size()<v1.size()) v2.push_back(0); while
        (v1.size()<v2.size()) v1.push_back(0);
75    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;}
76    return v1;
77  }
78  vector<int> operator -(vector<int> v1,vector<int>
        v2)
79  {
80    int sz=max(v1.size(),v2.size());while(v1.size()<
        sz) v1.push_back(0); while(v2.size()<sz) v2.
        push_back(0);
81    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;
82  }
83  vector<int> trmi(vector<int> v)
84  {
85    for(int i=1;i<v.size();i+=2) {if(v[i]>0) v[i]=p-v
        [i]; else v[i]=(-v[i]);}
86    return v;
87  }
88  vector<int> deriv(vector<int> v)
89  {
90    if(v.empty()) return{};
91    vector<int> ans(v.size()-1);
92    for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)
        %p;
93    return ans;
94  }
95  vector<int> integ(vector<int> v)
96  {
97    vector<int> ans(v.size()+1);ans[0]=0;
98    for(int i=1;i<v.size();++i) ans[i-1]=(v[i]*1LL*i)
        %p;
99    return ans;
100 }
101 vector<int> mul(vector<vector<int> > v)
102 {
103   if(v.size()==1) return v[0];
104   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]);
105   return muls.convolution(mul(v1),mul(v2));
106 }
107 vector<int> inv1(vector<int> v,int n)
108 {
109   assert(v[0]!=0);
110   int sz=1;v=form(v,n);vector<int> a={inv(v[0])};
111   while(sz<n)
112   {
113     vector<int> vsz;for(int i=0;i<min(n,2*sz);++i)
          vsz.push_back(v[i]);
114     vector<int> b=((vector<int>) {1})-muls.
          convolution(a,vsz);
115     for(int i=0;i<sz;++i) assert(b[i]==0);
116     b.erase(b.begin(),b.begin()+sz);
117     vector<int> c=muls.convolution(b,a);
118     for(int i=0;i<sz;++i) a.push_back(c[i]);
119     sz*=2;
120   }
121   return form(a,n);
122 }
```

7.2   старое доброе FFT

```cpp
1  using cd = complex<double>;
2  const double PI = acos(-1);
3
4  void fft(vector<cd> & a, bool invert) {
5    int n = a.size();
6
7    for (int i = 1, j = 0; i < n; i++) {
8      int bit = n >> 1;
9      for (; j & bit; bit >>= 1)
10       j ^= bit;
11     j ^= bit;
12
13     if (i < j)
14       swap(a[i], a[j]);
15   }
16
17   for (int len = 2; len <= n; len <<= 1) {
18     double ang = 2 * PI / len * (invert ? -1 : 1);
19     cd wlen(cos(ang), sin(ang));
20     for (int i = 0; i < n; i += len) {
21       cd w(1);
22       for (int j = 0; j < len / 2; j++) {
23         cd u = a[i+j], v = a[i+j+len/2] * w;
24         a[i+j] = u + v;
25         a[i+j+len/2] = u - v;
26         w *= wlen;
27       }
28     }
29   }
30
31   if (invert) {
32     for (cd & x : a)
33       x /= n;
34   }
35 }
36 vector<int> multiply(vector<int> const& a, vector<
       int> const& b) {
37   vector<cd> fa(a.begin(), a.end()), fb(b.begin(),
       b.end());
38   int n = 1;
39   while (n < a.size() + b.size())
40     n <<= 1;
41   fa.resize(n);
42   fb.resize(n);
43
44   fft(fa, false);
45   fft(fb, false);
46   for (int i = 0; i < n; i++)
47     fa[i] *= fb[i];
48   fft(fa, true);
49
50   vector<int> result(n);
51   for (int i = 0; i < n; i++)
52     result[i] = round(fa[i].real());
53   while (!result.empty() && !result.back()) result.
       pop_back();
54   return result;
55 }
```

8   Геома

8.1   Касательные

```cpp
1   auto max = [&] (auto cmp) {
2       int k = 0;
3       for (int lg = 18; lg >= 0; --lg) {
4           int i = k + (1 << lg), j = k - (1 << lg
    );
5           i = (i % n + n) % n;
6           j = (j % n + n) % n;
7           array<int, 3> ind{i, j, k};
8           sort(all(ind), cmp);
9           k = ind[2];
10      }
11      return k;
12  };
13  auto uppert = [&](Point p) { //last vertex in
    counterclockwise order about p
14      auto cmp = [&] (int i, int j) {return (a[i]
     - p) < (a[j] - p); };
15      return max(cmp);
16  };
17  auto lowert = [&](Point p) { //first vertex in
    counterclockwise order about p
```

```
18        auto cmp = [&] (int i, int j) {return (a[i]
    - p) > (a[j] - p); };
19        return max(cmp);
20    };
21    auto uppertinf = [&](Point p) { //upper tangent
     line parallel to vector p
22        swap(p.x, p.y);
23        p.x = -p.x;
24        auto cmp = [&] (int i, int j) { return a[i]
    % p < a[j] % p; };
25        return max(cmp);
26    };
27    auto lowertinf = [&](Point p) { //lower tangent
     line parallel to vector p
28        swap(p.x, p.y);
29        p.x = -p.x;
30        auto cmp = [&] (int i, int j) { return a[i]
    % p > a[j] % p; };
31        return max(cmp);
32    };
```

8.2　Примитивы

```
1  struct Point {
2      int x, y;
3      Point(){}
4      Point (int x_, int y_) {
5          x = x_; y = y_;
6      }
7      Point operator + (Point p) {
8          return Point(x+p.x,y+p.y);
9      }
10     Point operator - (Point p) {
11         return Point(x - p.x, y - p.y);
12     }
13     int operator * (Point p) {
14         return x * p.y - y * p.x;
15     }
16     int operator % (Point p) {
17         return x * p.x + y * p.y;
18     }
19     bool operator < (Point v) {
20         return (*this) * v > 0;
21     }
22     bool operator > (Point v) {
23         return v < (*this);
24     };
25     bool operator <= (Point v) {
26         return (*this) * v >= 0;
27     }
28 };
29 bool line(Point a, Point b, Point c) {
30     return (b-a)*(c-b)==0;
31 }
32 bool ord(Point a, Point p, Point b) {
33     return (p - a)%(p - b)<0;
34 }
```

8.3　Точка нестрого внутри выпуклости

```
1      auto inT = [&] (Point a, Point b, Point c,
    Point p) {
2          a = a-p; b = b-p; c = c-p;
3          return abs(a*b)+abs(b*c)+abs(c*a) == abs(a*
    b+b*c+c*a);
4      };
5      auto inP = [&] (Point p) { //a must be in
    counterclockwise order!
6          int l = 1, r = n - 1;
7          while (l < r - 1) {
8              int m = (l + r) / 2;
9              if ((a[m] - a[0]) < (p - a[0])) {
10                 l = m;
11             }
12             else {
13                 r = m;
14             }
15         }
16         return inT(a[l], a[0], a[r], p);
17     };
```

9　Разное

9.1　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
```

9.1.1　Сеточка в vim

https://codeforces.com/blog/entry/122540

```
1  i|<esc>25A   |<esc>
2  o+<esc>25A---+<esc>
3  Vky35Pdd
```

9.2　Что сделать на пробном туре

- Убедиться, что работаают все IDE. Разобраться, как настраивать в них LOCAL.

- В системе ML — это ML или RE?

- Максимальный размер файла

- Можно посмотреть на время работы серверов позапуская Флойда — Варшалла

9.3　Шаблон

```
1  #include<bits/stdc++.h>
2
3  using namespace std;
4
5  #define int long long
6  #define app push_back
7  #define all(x) x.begin(), x.end()
8  #ifdef LOCAL
9  #define debug(...) [](auto...a){ ((cout << a <<
       ' '), ...) << endl; }(#__VA_ARGS__, ":",
       __VA_ARGS__)
10 #else
11 #define debug(...)
12 #endif
13
14 int32_t main() {
15     cin.tie(0);ios_base::sync_with_stdio(0);
16 }
```