# 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,x,y);
  swap(x,y);
  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;
}
```

# 2 Графы

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

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

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

```
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
    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 {};
```

# 3 xor, and, or-свёртки

## 3.1 and-свёртка

```
vector<int> band(vector<int> a,vector<int> b)
{
  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)) {a[mask-(1<<i)]+=a[
    mask];a[mask-(1<<i)]%=p;}
  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;}
  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))) {c[mask]-=c[mask
    +(1<<i)];c[mask]%=p;}
  return c;
}
```

## 3.2 or-свёртка

```
vector<int> bor(vector<int> a,vector<int> b)
{
  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))) {a[mask+(1<<i)]+=
    a[mask];a[mask+(1<<i)]%=p;}
  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;}
  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)) {c[mask]-=c[mask
    -(1<<i)];c[mask]%=p;}
  return c;
}
```

## 3.3 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;
```

# 4 Структуры данных

## 4.1 Дерево Фенвика

```
int fe[maxn]; /// fenwick tree
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);} //
    / summa na [l,r)
```

## 4.2 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
    >;
```

### 4.3 Дерево отрезков

```cpp
template<typename Data, typename Mod, typename UniteData, typename UniteMod, typename Apply>
struct MassSegmentTree {
  int h, n;
  Data zd;
  Mod zm;
  vector<Data> data;
  vector<Mod> mod;

  UniteData ud; // Data (Data, Data)
  UniteMod um; // Mod (Mod, Mod);
  Apply a; // Data (Data, Mod, 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, 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) {
    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, 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) {}

  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)); }

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

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

  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);
    }
  }

  Data 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);
    }
    Data 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);
    Data cur = zd;
    do {
      l >>= __builtin_ctz(l);
      Data with1;
      with1 = ud(cur, data[l]);
      if (ok(with1, right(l))) {
        cur = with1;
        ++l;
      } else {
        while (l < n) {
          push(l);
          Data with2;
          with2 = ud(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) {
    r += n;
    for (int shift = h; shift > 0; --shift) push((r - 1) >> shift);
    Data cur = zd;
    while (r & (r - 1)) {
      r >>= __builtin_ctz(r);
      Data with1;
      with1 = ud(data[--r], cur);
      if (ok(with1, left(r))) {
        cur = with1;
      } else {
        while (r < n) {
          push(r);
          Data with2;
          with2 = ud(data[2 * r + 1], cur);
          if (ok(with2, right(2 * r))) {
            cur = with2;
            r = 2 * r;
          } else {
            r = 2 * r + 1;
```

```
            }
          }
          return r - n + 1;
        }
      }
      return 0;
    }
};
```

### 4.3.1 Примеры:

- Взятие максимума и прибавление константы

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

- Взятие суммы и прибавление константы

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

- Взятие суммы и присовение

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

# 5 Строковые алгоритмы

## 5.1 Префикс-функция

```
vector<int> prefix_function(string s) {
  vector<int> p(s.size());
  for (int i = 1; i < s.size(); ++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;
}
```

## 5.2 Z-функция

```
vector<int> z_function (string s) { // z[i] - lcp
    of s and s[i:]
 int n = (int) s.length();
 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;
}
```

## 5.3 Алгоритм Манакера

```
vector<int> manacher_odd(const string &s) {
  vector<int> man(s.size(), 0);
  int l = 0, r = 0;
  int n = s.size();
  for (int i = 1; i < n; i++) {
    if (i <= r) {
      man[i] = min(r - i, man[l + r - i]);
    }
    while (i + man[i] + 1 < n && i - man[i] - 1 >=
    0 && s[i + man[i] + 1] == s[i - man[i] - 1]) {
      man[i]++;
    }
    if (i + man[i] > r) {
      l = i - man[i];
      r = i + man[i];
    }
  }
  return man;
}
// abacaba : (0 1 0 3 0 1 0)
// abbaa : (0 0 0 0 0)

vector <int> manacher_even(const string &s) {
  assert(s.size());
  string t;
  for (int i = 0; i + 1 < s.size(); ++i) {
    t += s[i];
    t += '#';
  }
  t += s.back();
  auto odd = manacher_odd(t);
  vector <int> ans;
  for (int i = 1; i < odd.size(); i += 2) {
    ans.push_back((odd[i]+1)/2);
  }
  return ans;
}
// abacaba : (0 0 0 0 0 0)
// abbaa : (0 2 0 1)
```

## 5.4 Суфмассив

Китайский суффмассив

```
struct SuffixArray {
  vector <int> sa, lcp;
  SuffixArray (string &s, int lim=256) {
    int n = (int)s.size() + 1, k = 0, a, b;
    vector <int> x(s.begin(), s.end() + 1), y(n),
    ws(max(n, lim)), rank(n);
    sa = lcp = y, iota(sa.begin(), sa.end(), 0);
    for (int j = 0, p = 0; p < n; j = max(1ll, j *
    2), lim = p) {
      p = j, iota(y.begin(), y.end(), n - j);
      for (int i = 0; i < n; i++) if (sa[i] >= j) y
    [p++] = sa[i] - j;
      fill(ws.begin(), ws.end(), 0);
      for (int i = 0; i < n; i++) ws[x[i]]++;
      for (int i = 1; i < lim; i++) ws[i] += ws[i -
     1];
      for (int i = n; i--; ) sa[--ws[x[y[i]]]] = y[
    i];
      swap(x, y), p = 1, x[sa[0]] = 0;
      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++;
    }
    for (int i = 1; i < n; i++) rank[sa[i]] = i;
    for (int i = 0, j; i < n - 1; lcp[rank[i++]]=k)
      for (k && k--, j = sa[rank[i] - 1];
          s[i + k] == s[j + k]; k++);
  }
};
struct Rmq {
  const int INF = 1e9;
  int n;
  vector<int> rmq;
  Rmq() {}
  void build(const vector<int> &x) {
    assert(x.size() == n);
    for (int i = 0; i < n; ++i) rmq[n + i] = x[i];
    for (int i = n - 1; i > 0; --i) rmq[i] = min(
    rmq[2 * i], rmq[2 * i + 1]);
  }
  Rmq(int n) : n(n), rmq(2 * n, INF) {}

  void put(int i, int x) {
    rmq[i + n] = min(rmq[i + n], x);
    for (i = (i + n) / 2; i > 0; i /= 2) {
      rmq[i] = min(rmq[i * 2], rmq[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, rmq[l++]);
      if (r & 1) res = min(res, rmq[--r]);
    }
    return res;
  }
};

struct Lc {
  vector<int> pos;
  Rmq rmq;
  Lc(string s) : rmq(s.size()) {
    SuffixArray sa(s);
    auto ss = sa.sa;
    ss.erase(ss.begin());

    auto lcp = sa.lcp;
    lcp.erase(lcp.begin());
    lcp.erase(lcp.begin());

    pos.resize(s.size());
    assert(s.size() == ss.size());
    for (int i = 0; i < ss.size(); ++i) {
      pos[ss[i]] = i;
    }
    int n = s.size();
    assert(lcp.size() == n - 1);
    rmq.build(lcp);
  }
  int getLcp(int i, int j) {
    i = pos[i]; j = pos[j];
    if (j < i) {
      swap(i, j);
    }
    if (i == j) {
      return 1e18;
    }
    else {
      return rmq.getMin(i, j);
    }
  }
};
```

# 6 Потоки

## 6.1 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;
```

## 6.2 Mincost k-flow

### 6.2.1 Строим граф

```
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);
};
```

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

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

#### 6.2.2 Запускаем Форда — Беллмана

```
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);
```

#### 6.2.3 Ищем кратчайший путь Дейкстрой с потенциалами

```
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;
  for (int i = 1; i < n; ++i) {
    int cur = find(cnt.begin(), cnt.end(), false) - cnt.begin();
    for (int j = 0; j < n; ++j) {
      if (!cnt[j] && dist[j] < dist[cur]) cur = j;
    }
    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) {
        dist[edge.next] = dist[cur] + weight;
        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;
}
```

#### 6.2.4 Восстанавливаем ответ

```
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';
}
```

# 7 FFT & co

## 7.1 NTT & 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*1LL*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] = (static_cast<long long>(g[l]) * g[l]) % M;
    }
    assert((static_cast<long long>(g[1]) * 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] = (static_cast<long long>(g[l]) * g[i]) % M;
      }
    }
  }
  void fft(vector<int> &x) const {
    const int n = x.size();
    assert(!(n & (n - 1)) && n <= 1 << K);
    for (int h = __builtin_ctz(n); h--; ) {
      const int l = 1 << h;
      for (int i = 0; i < n >> 1 >> h; ++i) {
        for (int j = i << 1 << h; j < ((i << 1) + 1) << h; ++j) {
          const int t = (static_cast<long long>(g[i]) * x[j | l]) % M;
          if ((x[j | l] = x[j] - t) < 0) x[j | l] += M;
          if ((x[j] += t) >= M) x[j] -= M;
```

```cpp
        }
      }
    }
    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(const vector<int> &a, const vector<int> &b) const {
    if(a.empty() || b.empty()) return {};
    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;
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);
}
vector<int> inv(vector<int> v,int n)
{
    v=form(v,n);assert(v[0]!=0);if(v.size()==1) {return {inv(v[0])};} vector<int> v1=trmi(v);
    vector<int> a=v1*v;a=form(a,2*n);
    vector<int> b((n+1)/2);for(int i=0;i<b.size();++i) b[i]=a[2*i];
    vector<int> ans1=inv(b,b.size());vector<int> ans2(n);for(int i=0;i<n;++i) {if(i%2==0) ans2[i]=ans1[i/2]; else ans2[i]=0;}
    return form(v1*ans2,n);
}
vector<int> operator/(vector<int> a,vector<int> b)
{
    while(!a.empty() && a.back()==0) a.pop_back(); while(!b.empty() && b.back()==0) b.pop_back();
    int n=a.size();int m=b.size();if(n<m) return {};
    reverse(a.begin(),a.end());reverse(b.begin(),b.end());vector<int> ans=a*inv(b,n-m+1);while(ans.size()>n-m+1) ans.pop_back();
    reverse(ans.begin(),ans.end());while(!ans.empty() && ans.back()==0) ans.pop_back();return ans;
}
vector<int> operator%(vector<int> a,vector <int> b)
{
    vector<int> ans=a-b*(a/b);while(!ans.empty() && ans.back()==0) ans.pop_back(); return ans;
}
```