Содержание

1 final/template/template.cpp

```cpp
// team : SPb ITMO University Komanda
#include <bits/stdc++.h>
#ifdef SIR
  #define err(...) fprintf(stderr, __VA_ARGS__)
#else
  #define err(...) 42
#endif

#define db(x) cerr << #x << " = " << x << endl
#define db2(x, y) cerr << "(" << #x << ", " << #y << ") = (" << x << ", " << y << ")\n";
#define db3(x, y, z) cerr << "(" << #x << ", " << #y << ", " << #z << ") = (" << x << ", " << y << ", " << z << ")\n"
#define dbv(a) cerr << #a << " = "; for (auto xxxx: a) cerr << xxxx << " "; cerr << endl

using namespace std;

typedef long long ll;

void solve() {

}

int main() {
#ifdef SIR
  freopen("input.txt", "r", stdin), freopen("output.txt", "w", stdout);
#endif
  ios_base::sync_with_stdio(0);
  cin.tie(0);
  solve();
  return 0;
}
```

2 Practice round

- Посабмитить задачи каждому человеку.
- Распечатать решение.
- IDE для джавы.
- Сравнить скорость локального компьютера и сервера.
- Проверить `int128`.
- Проверить прагмы. Например, на `bitset`.

3 final/stuff/debug.cpp

```cpp
#include <bits/stdc++.h>
#define _GLIBCXX_DEBUG

using namespace std;

template <class T>
struct MyVector : vector<T> {
 MyVector() : vector<T>() { }
 MyVector( int n ) : vector<T>(n) { }
 T &operator [] ( int i )  { return vector<T>::at(i); }
 T operator [] ( int i ) const { return vector<T>::at(i); }
};
```

```
/** Есливвашемкодевместовсех int[] и vector<int> использовать MyVector<int>,
  вывудитевсе range check errorы- */
MyVector<int> b(10), a;

int main() {
  MyVector<int> a(50);
  for (int i = 1; i <= 600; i++) a[i] = i;
  cout << a[500] << "\n";
}
```

4 final/template/fastIO.cpp

```
#include <cstdio>
#include <algorithm>

/** Interface */

inline int readInt();
inline int readUInt();
inline bool isEof();

/** Read */

static const int buf_size = 100000;
static char buf[buf_size];
static int buf_len = 0, pos = 0;

inline bool isEof() {
  if (pos == buf_len) {
    pos = 0, buf_len = fread(buf, 1, buf_size, stdin);
    if (pos == buf_len) return 1;
  }
  return 0;
}

inline int getChar() { return isEof() ? -1 : buf[pos++]; }

inline int readChar() {
  int c = getChar();
  while (c != -1 && c <= 32) c = getChar();
  return c;
}

inline int readUInt() {
  int c = readChar(), x = 0;
  while ('0' <= c && c <= '9') x = x * 10 + c - '0', c = getChar();
  return x;
}

inline int readInt() {
  int s = 1, c = readChar();
  int x = 0;
  if (c == '-') s = -1, c = getChar();
  while ('0' <= c && c <= '9') x = x * 10 + c - '0', c = getChar();
  return s == 1 ? x : -x;
}


// 10M int [0..1e9)
// cin 3.02
// scanf 1.2
// cin sync_with_stdio(false) 0.71
// fastRead getchar 0.53
// fastRead fread 0.15
```

5 final/template/optimizations.cpp

```
inline void fasterLLDivMod(unsigned long long x, unsigned y, unsigned &out_d, unsigned &out_m) {
  unsigned xh = (unsigned)(x >> 32), xl = (unsigned)x, d, m;
#ifdef __GNUC__
  asm(
    "divl %4; \n\t"
    : "=a" (d), "=d" (m)
    : "d" (xh), "a" (xl), "r" (y)
  );
#else
  __asm {
    mov edx, dword ptr[xh];
    mov eax, dword ptr[xl];
    div dword ptr[y];
    mov dword ptr[d], eax;
    mov dword ptr[m], edx;
  };
#endif
  out_d = d; out_m = m;
}

// have no idea what sse flags are really cool; list of some of them
// -- very good with bitsets
#pragma GCC optimize("O3")
#pragma GCC target("sse,sse2,sse3,ssse3,sse4,popcnt,abm,mmx")
```

6 final/template/useful.cpp

```
#include "ext/pb_ds/assoc_container.hpp"
using namespace __gnu_pbds;

template <typename T> using ordered_set = tree<T, null_type, less<T>, rb_tree_tag, tree_order_statistics_node_update>;
template <typename K, typename V> using ordered_map = tree<K, V, less<K>, rb_tree_tag, tree_order_statistics_node_update>;

// HOW TO USE ::
// -- order_of_key(10) returns the number of elements in set/map strictly less than 10
// -- *find_by_order(10) returns 10-th smallest element in set/map (0-based)

bitset<N> a;
for (int i = a._Find_first(); i != a.size(); i = a._Find_next(i)) {
  cout << i << endl;
}
```

7 final/template/Template.java

```
import java.util.*;
import java.io.*;

public class Template {
  FastScanner in;
  PrintWriter out;

  public void solve() throws IOException {
    int n = in.nextInt();
    out.println(n);
  }

  public void run() {
    try {
      in = new FastScanner();
      out = new PrintWriter(System.out);

      solve();

      out.close();
    } catch (IOException e) {
      e.printStackTrace();
    }
  }

  class FastScanner {
    BufferedReader br;
    StringTokenizer st;

    FastScanner() {
      br = new BufferedReader(new InputStreamReader(System.in));
    }

    String next() {
```

```
      while (st == null || !st.hasMoreTokens()) {
        try {
          st = new StringTokenizer(br.readLine());
        } catch (IOException e) {
          e.printStackTrace();
        }
      }
      return st.nextToken();
    }

    int nextInt() {
      return Integer.parseInt(next());
    }
  }

  public static void main(String[] arg) {
    new Template().run();
  }
}
```

8 final/template/bitset.cpp

```

const int SZ = 6;
const int BASE = pw(SZ);
const int MOD = BASE - 1;

struct Bitset {
  typedef unsigned long long T;
  vector<T> data;
  int n;
  void resize(int nn) {
    n = nn;
    data.resize((n + BASE - 1) / BASE);
  }
  void set(int pos, int val) {
    int id = pos >> SZ;
    int rem = pos & MOD;
    data[id] ^= data[id] & pw(rem);
    data[id] |= val * pw(rem);
  }
  int get(int pos) {
    return (data[pos >> SZ] >> (pos & MOD)) & 1;
  }
  // k > 0 -> (*this) << k
  // k < 0 -> (*this) >> (-k)
  Bitset shift (int k) {
    Bitset res;
    res.resize(n);
    int s = k / BASE;
    int rem = k % BASE;
    if (rem < 0) {
      rem += BASE;
      s--;
    }
    int p1 = BASE - rem;
    T mask = (p1 == 64)? -1: pw(p1) - 1;
    for (int i = max(0, -s); i < sz(data) - max(s, 0); i++) {
      res.data[i + s] |= (data[i] & mask) << rem;
    }
    if (rem != 0) {
      for (int i = max(0, -s - 1); i < sz(data) - max(s + 1, 0); i++) {
        res.data[i + s + 1] |= (data[i] >> p1) & (pw(rem) - 1);
      }
    }
    int cc = data.size() * BASE - n;
    res.data.back() <<= cc;
    res.data.back() >>= cc;
    return res;
  }
};
```

9 final/numeric/fft.cpp

```
namespace fft
{
  const int maxBase = 21;
  const int maxN = 1 << maxBase;

  struct num
  {
    dbl x, y;
    num(){}
    num(dbl xx, dbl yy): x(xx), y(yy) {}
    num(dbl alp): x(cos(alp)), y(sin(alp)) {}
  };

  inline num operator + (num a, num b) { return num(a.x + b.x, a.y + b.y); }
  inline num operator - (num a, num b) { return num(a.x - b.x, a.y - b.y); }
  inline num operator * (num a, num b) { return num(a.x * b.x - a.y * b.y, a.x * b.y + a.y * b.x); }
  inline num conj(num a) { return num(a.x, -a.y); }

  const dbl PI = acos(-1);

  num root[maxN];
  int rev[maxN];
  bool rootsPrepared = false;

  void prepRoots()
  {
    if (rootsPrepared) return;
    rootsPrepared = true;
    root[1] = num(1, 0);
    for (int k = 1; k < maxBase; ++k)
    {
      num x(2 * PI / pw(k + 1));
      for (int i = pw(k - 1); i < pw(k); ++i)
      {
        root[2 * i] = root[i];
        root[2 * i + 1] = root[i] * x;
      }
    }
  }

  int base, N;

  int lastRevN = -1;
  void prepRev()
  {
    if (lastRevN == N) return;
    lastRevN = N;
    forn(i, N) rev[i] = (rev[i >> 1] >> 1) + ((i & 1) << (base - 1));
  }

  void fft(num *a, num *f)
  {
    forn(i, N) f[i] = a[rev[i]];
    for (int k = 1; k < N; k <<= 1) for (int i = 0; i < N; i += 2 * k) forn(j, k)
    {
      num z = f[i + j + k] * root[j + k];
      f[i + j + k] = f[i + j] - z;
      f[i + j] = f[i + j] + z;
    }
  }

  num a[maxN], b[maxN], f[maxN], g[maxN];
  ll A[maxN], B[maxN], C[maxN];

  void _multMod(int mod)
  {
    forn(i, N)
    {
      int x = A[i] % mod;
      a[i] = num(x & (pw(15) - 1), x >> 15);
    }
    forn(i, N)
    {
      int x = B[i] % mod;
      b[i] = num(x & (pw(15) - 1), x >> 15);
    }
    fft(a, f);
    fft(b, g);

    forn(i, N)
    {
      int j = (N - i) & (N - 1);
```

```
      num a1 = (f[i] + conj(f[j])) * num(0.5, 0);
      num a2 = (f[i] - conj(f[j])) * num(0, -0.5);
      num b1 = (g[i] + conj(g[j])) * num(0.5 / N, 0);
      num b2 = (g[i] - conj(g[j])) * num(0, -0.5 / N);
      a[j] = a1 * b1 + a2 * b2 * num(0, 1);
      b[j] = a1 * b2 + a2 * b1;
    }

    fft(a, f);
    fft(b, g);

    forn(i, N)
    {
      ll aa = f[i].x + 0.5;
      ll bb = g[i].x + 0.5;
      ll cc = f[i].y + 0.5;
      C[i] = (aa + bb % mod * pw(15) + cc % mod * pw(30)) % mod;
    }
  }

  void prepAB(int n1, int n2)
  {
    base = 1;
    N = 2;
    while (N < n1 + n2) base++, N <<= 1;

    for (int i = n1; i < N; ++i) A[i] = 0;
    for (int i = n2; i < N; ++i) B[i] = 0;

    prepRoots();
    prepRev();
  }

  void mult(int n1, int n2)
  {
    prepAB(n1, n2);
    forn(i, N) a[i] = num(A[i], B[i]);
    fft(a, f);
    forn(i, N)
    {
      int j = (N - i) & (N - 1);
      a[i] = (f[j] * f[j] - conj(f[i] * f[i])) * num(0, -0.25 / N);
    }
    fft(a, f);
    forn(i, N) C[i] = (ll)round(f[i].x);
  }


  void multMod(int n1, int n2, int mod)
  {
    prepAB(n1, n2);
    _multMod(mod);
  }

  int D[maxN];

  void multLL(int n1, int n2)
  {
    prepAB(n1, n2);

    int mod1 = 1.5e9;
    int mod2 = mod1 + 1;

    _multMod(mod1);

    forn(i, N) D[i] = C[i];

    _multMod(mod2);

    forn(i, N)
    {
      C[i] = D[i] + (C[i] - D[i] + (ll)mod2) * (ll)mod1 % mod2 * mod1;
    }
  }
  // HOW TO USE ::
  // -- set correct maxBase
  // -- use mult(n1, n2), multMod(n1, n2, mod) and multLL(n1, n2)
  // -- input : A[], B[]
  // -- output : C[]
}
```

10 final/numeric/fftint.cpp

```

namespace fft {
  const int MOD = 998244353;
  const int maxB = 20;
  const int maxN = 1 << maxB;
  const int initROOT = 646;

  int root[maxN];
  int rev[maxN];
  int N;

  ll inv(ll a, ll m = MOD) {
    if (a == 0) return 0;
    return ((1 - inv(m % a, a) * m) / a + m) % m;
  }

  void _init(int cur_base) {
    N = 1 << cur_base;
    for (int i = 0; i < N; i++) rev[i] = (rev[i >> 1] >> 1) + ((i & 1) << (cur_base - 1));


    int ROOT = initROOT;
    for (int i = cur_base; i < 20; i++) ROOT = 1ll * ROOT * ROOT % MOD;

    int NN = N >> 1;
    int z = 1;
    for (int i = 0; i < NN; i++) {
      root[i + NN] = z;
      z = z * (ll)ROOT % MOD;
    }
    for (int i = NN - 1; i > 0; --i) root[i] = root[2 * i];
  }

  void fft(int *a, int *f) {
    for (int i = 0; i < N; i++) f[i] = a[rev[i]];
    for (int k = 1; k < N; k <<= 1) {
      for (int i = 0; i < N; i += 2 * k) {
        for (int j = 0; j < k; j++) {
          int z = f[i + j + k] * (ll)root[j + k] % MOD;
          f[i + j + k] = (f[i + j] - z + MOD) % MOD;
          f[i + j] = (f[i + j] + z) % MOD;
        }
      }
    }
  }

  int A[maxN], B[maxN], C[maxN];
  int F[maxN], G[maxN];

  void _mult(int eq) {
    fft(A, F);
    if (eq)
      for (int i = 0; i < N; i++)
        G[i] = F[i];
    else fft(B, G);
    int invN = inv(N);
    for (int i = 0; i < N; i++) A[i] = F[i] * (ll)G[i] % MOD * invN % MOD;
    reverse(A + 1, A + N);
    fft(A, C);
  }

  void mult(int n1, int n2, int eq = 0) {
    int n = n1 + n2, cur_base = 0;
    while ((1 << cur_base) < n) cur_base++;
    _init(cur_base + 1);

    for (int i = n1; i < N; ++i) A[i] = 0;
    for (int i = n2; i < N; ++i) B[i] = 0;

    _mult(eq);

    //forn(i, n1 + n2) C[i] = 0;
    //forn(i, n1) forn(j, n2) C[i + j] = (C[i + j] + A[i] * (ll)B[j]) % mod;
  }

  vector<int> mult(vector<int> A, vector<int> B) {
    for (int i = 0; i < A.size(); i++) fft::A[i] = A[i];
    for (int i = 0; i < A.size(); i++) fft::B[i] = B[i];
    mult(A.size(), B.size());
    vector<int> C(A.size() + B.size());
    for (int i = 0; i < A.size() + B.size(); i++) C[i] = fft::C[i];
    return C;
  }
```

```
}
```

11 final/numeric/berlekamp.cpp

```
vector<int> berlekamp(vector<int> s) {
  int l = 0;
  vector<int> la(1, 1);
  vector<int> b(1, 1);
  for (int r = 1; r <= (int)s.size(); r++) {
    int delta = 0;
    for (int j = 0; j <= l; j++) {
      delta = (delta + 1LL * s[r - 1 - j] * la[j]) % MOD;
    }
    b.insert(b.begin(), 0);
    if (delta != 0) {
      vector<int> t(max(la.size(), b.size()));
      for (int i = 0; i < (int)t.size(); i++) {
        if (i < (int)la.size()) t[i] = (t[i] + la[i]) % MOD;
        if (i < (int)b.size()) t[i] = (t[i] - 1LL * delta * b[i] % MOD + MOD) % MOD;
      }
      if (2 * l <= r - 1) {
        b = la;
        int od = inv(delta);
        for (int &x : b) x = 1LL * x * od % MOD;
        l = r - l;
      }
      la = t;
    }
  }
  assert((int)la.size() == l + 1);
  assert(l * 2 + 30 < (int)s.size());
  reverse(la.begin(), la.end());
  return la;
}

vector<int> mul(vector<int> a, vector<int> b) {
  vector<int> c(a.size() + b.size() - 1);
  for (int i = 0; i < (int)a.size(); i++) {
    for (int j = 0; j < (int)b.size(); j++) {
      c[i + j] = (c[i + j] + 1LL * a[i] * b[j]) % MOD;
    }
  }
  vector<int> res(c.size());
  for (int i = 0; i < (int)res.size(); i++) res[i] = c[i] % MOD;
  return res;
}

vector<int> mod(vector<int> a, vector<int> b) {
  if (a.size() < b.size()) a.resize(b.size() - 1);

  int o = inv(b.back());
  for (int i = (int)a.size() - 1; i >= (int)b.size() - 1; i--) {
    if (a[i] == 0) continue;
    int coef = 1LL * o * (MOD - a[i]) % MOD;
    for (int j = 0; j < (int)b.size(); j++) {
      a[i - (int)b.size() + 1 + j] = (a[i - (int)b.size() + 1 + j] + 1LL * coef * b[j]) % MOD;
    }
  }
  while (a.size() >= b.size()) {
    assert(a.back() == 0);
    a.pop_back();
  }
  return a;
}

vector<int> bin(int n, vector<int> p) {
  vector<int> res(1, 1);
  vector<int> a(2); a[1] = 1;
  while (n) {
    if (n & 1) res = mod(mul(res, a), p);
    a = mod(mul(a, a), p);
    n >>= 1;
  }
  return res;
}

int f(vector<int> t, int m) {
  vector<int> v = berlekamp(t);
  vector<int> o = bin(m - 1, v);
  int res = 0;
  for (int i = 0; i < (int)o.size(); i++) res = (res + 1LL * o[i] * t[i]) % MOD;
  return res;
}
```

12 final/numeric/blackbox.cpp

```
namespace blackbox
{
  int A[N];
  int B[N];
  int C[N];

  int magic(int k, int x)
  {
    B[k] = x;
    C[k] = (C[k] + A[0] * (ll)B[k]) % mod;
    int z = 1;
    if (k == N - 1) return C[k];
    while ((k & (z - 1)) == (z - 1))
    {
      //mult B[k - z + 1 ... k] x A[z .. 2 * z - 1]
      forn(i, z) fft::A[i] = A[z + i];
      forn(i, z) fft::B[i] = B[k - z + 1 + i];
      fft::multMod(z, z, mod);
      forn(i, 2 * z - 1) C[k + 1 + i] = (C[k + 1 + i] + fft::C[i]) % mod;
      z <<= 1;
    }
    return C[k];
  }
  // A -- constant array
  // magic(k, x):: B[k] = x, returns C[k]
  // !! WARNING !! better to set N twice the size needed
}
```

13 final/numeric/crt.cpp

```
int CRT(int a1, int m1, int a2, int m2) {
  return (a1 - a2 % m1 + m1) * (ll)rev(m2, m1) % m1 * m2 + a2;
}
```

14 final/numeric/extendedgcd.cpp

```
int gcd(int a, int b, int &x, int &y) {
  if (a == 0) {
    x = 0, y = 1;
    return b;
  }
  int x1, y1;
  int d = gcd(b % a, a, x1, y1);
  x = y1 - (b / a) * x1;
  y = x1;
  return d;
}
```

15 final/numeric/mulMod.cpp

```
ll mul( ll a, ll b, ll m ) { // works for MOD 8e18
  ll k = (ll)((long double)a * b / m);
  ll r = a * b - m * k;
  if (r < 0) r += m;
  if (r >= m) r -= m;
  return r;
}
```

16 final/numeric/modReverse.cpp

```
int rev(int x, int m) {
  if (x == 1) return 1;
  return (1 - rev(m % x, x) * (ll)m) / x + m;
}
```

17 final/numeric/pollard.cpp

```
namespace pollard
{
  using math::p;

  vector<pair<ll, int>> getFactors(ll N)  {
    vector<ll> primes;

    const int MX = 1e5;
    const ll MX2 = MX * (ll)MX;

    assert(MX <= math::maxP && math::pc > 0);

    function<void(ll)> go = [&go, &primes](ll n) {
      for (ll x : primes) while (n % x == 0) n /= x;
      if (n == 1) return;
      if (n > MX2) {
        auto F = [&](ll x) {
          ll k = ((long double)x * x) / n;
          ll r = (x * x - k * n + 3) % n;
          return r < 0 ? r + n : r;
        };
        ll x = mt19937_64()() % n, y = x;
        const int C = 3 * pow(n, 0.25);

        ll val = 1;
        forn(it, C) {
          x = F(x), y = F(F(y));
          if (x == y) continue;
          ll delta = abs(x - y);
          ll k = ((long double)val * delta) / n;
          val = (val * delta - k * n) % n;
          if (val < 0) val += n;
          if (val == 0)  {
            ll g = __gcd(delta, n);
            go(g), go(n / g);
            return;
          }
          if ((it & 255) == 0) {
            ll g = __gcd(val, n);
            if (g != 1) {
              go(g), go(n / g);
              return;
            }
          }
        }
      }
      primes.pb(n);
    };

    ll n = N;

    for (int i = 0; i < math::pc && p[i] < MX; ++i) if (n % p[i] == 0) {
      primes.pb(p[i]);
      while (n % p[i] == 0) n /= p[i];
    }
    go(n);
    sort(primes.begin(), primes.end());

    vector<pair<ll, int>> res;
    for (ll x : primes) {
      int cnt = 0;
      while (N % x == 0) {
        cnt++;
        N /= x;
      }
      res.push_back({x, cnt});
    }
    return res;
  }
}
```

18 final/numeric/poly.cpp

```
struct poly
{
  vi v;
  poly() {}
  poly(vi vv)
  {
    v = vv;
  }
  int size()
  {
    return (int)v.size();
  }
  poly cut(int maxLen)
  {
    if (maxLen < sz(v)) v.resize(maxLen);
    return *this;
  }
  poly norm()
  {
    while (sz(v) > 1 && v.back() == 0) v.pop_back();
    return *this;
  }
  inline int& operator [] (int i)
  {
    return v[i];
  }
  void out(string name="")
  {
    stringstream ss;
    if (sz(name)) ss << name << "=";
    int fst = 1;
    forn(i, sz(v)) if (v[i])
    {
      int x = v[i];
      int sgn = 1;
      if (x > mod / 2) x = mod-x, sgn = -1;
      if (sgn == -1) ss << "-";
      else if (!fst) ss << "+";
      fst = 0;
      if (!i || x != 1)
      {
        ss << x;
        if (i > 0) ss << "*x";
        if (i > 1) ss << "^" << i;
      }
      else
      {
        ss << "x";
        if (i > 1) ss << "^" << i;
      }
    }
    if (fst) ss <<"0";
    string s;
    ss >> s;
    eprintf("%s\n", s.data());
  }
};

poly operator + (poly A, poly B)
{
  poly C;
  C.v = vi(max(sz(A), sz(B)));
  forn(i, sz(C))
  {
    if (i < sz(A)) C[i] = (C[i] + A[i]) % mod;
    if (i < sz(B)) C[i] = (C[i] + B[i]) % mod;
  }
  return C.norm();
}

poly operator - (poly A, poly B)
{
  poly C;
  C.v = vi(max(sz(A), sz(B)));
  forn(i, sz(C))
  {
    if (i < sz(A)) C[i] = (C[i] + A[i]) % mod;
    if (i < sz(B)) C[i] = (C[i] + mod - B[i]) % mod;
  }
  return C.norm();
}

poly operator * (poly A, poly B)
{
  poly C;
  C.v = vi(sz(A) + sz(B) - 1);

  forn(i, sz(A)) fft::A[i] = A[i];
```

```cpp
  forn(i, sz(B)) fft::B[i] = B[i];
  fft::multMod(sz(A), sz(B), mod);
  forn(i, sz(C)) C[i] = fft::C[i];
  return C.norm();
}

poly inv(poly A, int n) // returns A^-1 mod x^n
{
  assert(sz(A) && A[0] != 0);
  A.cut(n);

  auto cutPoly = [](poly &from, int l, int r)
  {
    poly R;
    R.v.resize(r - l);
    for (int i = l; i < r; ++i)
    {
      if (i < sz(from)) R[i - l] = from[i];
    }
    return R;
  };

  function<int(int, int)> rev = [&rev](int x, int m)->int
  {
    if (x == 1) return 1;
    return (1 - rev(m % x, x) * (ll)m) / x + m;
  };

  poly R({rev(A[0], mod)});
  for (int k = 1; k < n; k <<= 1)
  {
    poly A0 = cutPoly(A, 0, k);
    poly A1 = cutPoly(A, k, 2 * k);
    poly H = A0 * R;
    H = cutPoly(H, k, 2 * k);
    poly R1 = (((A1 * R).cut(k) + H) * (poly({0}) - R)).cut(k);
    R.v.resize(2 * k);
    forn(i, k) R[i + k] = R1[i];
  }
  return R.cut(n).norm();
}

pair<poly, poly> divide(poly A, poly B)
{
  if (sz(A) < sz(B)) return {poly({0}), A};

  auto rev = [](poly f)
  {
    reverse(all(f.v));
    return f;
  };

  poly q = rev((inv(rev(B), sz(A) - sz(B) + 1) * rev(A)).cut(sz(A) - sz(B) + 1));
  poly r = A - B * q;

  return {q, r};
}
```

19 final/numeric/simplex.cpp

```cpp
typedef double T; // long double, Rational, double + mod<P>...
typedef vector<T> vd;
typedef vector<vd> vvd;

const T eps = 1e-8, inf = 1/.0;
#define MP make_pair
#define ltj(X) if(s == -1 || MP(X[j],N[j]) < MP(X[s],N[s])) s=j
#define sz(X) ((X).size())
#define rep(i,l,r) for (int i = (l); i < (r); i++)

struct LPSolver {
  // Description: Solves a general linear maximization problem: maximize $c^T x$ subject to $Ax \le b$, $x \ge 0$.
  // A is a matrix with shape (number of inequalities, number of variables)
  // Returns -inf if there is no solution, inf if there are arbitrarily good solutions, or the maximum value of $c^T x$ otherwise.
  // The input vector is set to an optimal $x$ (or in the unbounded case, an arbitrary solution fulfilling the constraints).

  int m, n;
  vector<int> N, B;
  vvd D;

  LPSolver(const vvd& A, const vd& b, const vd& c) :
      m(sz(b)), n(sz(c)), N(n+1), B(m), D(m+2, vd(n+2)) {
    rep(i,0,m) rep(j,0,n) D[i][j] = A[i][j];
    rep(i,0,m) { B[i] = n+i; D[i][n] = -1; D[i][n+1] = b[i];}
    rep(j,0,n) { N[j] = j; D[m][j] = -c[j]; }
    N[n] = -1; D[m+1][n] = 1;
  }

  void pivot(int r, int s) {
    T *a = D[r].data(), inv = 1 / a[s];
    rep(i,0,m+2) if (i != r && abs(D[i][s]) > eps) {
      T *b = D[i].data(), inv2 = b[s] * inv;
      rep(j,0,n+2) b[j] -= a[j] * inv2;
      b[s] = a[s] * inv2;
    }
    rep(j,0,n+2) if (j != s) D[r][j] *= inv;
    rep(i,0,m+2) if (i != r) D[i][s] *= -inv;
    D[r][s] = inv;
    swap(B[r], N[s]);
  }

  bool simplex(int phase) {
    int x = m + phase - 1;
    for (int it = 0; it < 100; it++) {
      int s = -1;
      rep(j,0,n+1) if (N[j] != -phase) ltj(D[x]);
      if (D[x][s] >= -eps) return true;
      int r = -1;
      rep(i,0,m) {
        if (D[i][s] <= eps) continue;
        if (r == -1 || MP(D[i][n+1] / D[i][s], B[i]) < MP(D[r][n+1] / D[r][s], B[r])) r = i;
      }
      if (r == -1) return false;
      pivot(r, s);
    }
  }

  T solve(vd &x) {
    int r = 0;
    rep(i,1,m) if (D[i][n+1] < D[r][n+1]) r = i;
    if (D[r][n+1] < -eps) {
      pivot(r, n);
      if (!simplex(2) || D[m+1][n+1] < -eps) return -inf;
      rep(i,0,m) if (B[i] == -1) {
        int s = 0;
        rep(j,1,n+1) ltj(D[i]);
        pivot(i, s);
      }
    }
    bool ok = simplex(1); x = vd(n);
    rep(i,0,m) if (B[i] < n) x[B[i]] = D[i][n+1];
    return ok ? D[m][n+1] : inf;
  }
};
```

20 final/numeric/sumLine.cpp

```cpp
// sum(i=0..n-1) (a+b*i) div m
ll solve(ll n, ll a, ll b, ll m) {
  if (b == 0) return n * (a / m);
  if (a >= m) return n * (a / m) + solve(n, a % m, b, m);
  if (b >= m) return n * (n - 1) / 2 * (b / m) + solve(n, a, b % m, m);
  return solve((a + b * n) / m, (a + b * n) % m, m, b);
}
```

21 final/numeric/integrate.cpp

```
function<dbl(dbl, dbl, function<dbl(dbl)>)> f = [&](
    dbl L, dbl R, function<dbl(dbl)> g) {
  const int ITERS = 1000000;
  dbl ans = 0;
  dbl step = (R - L) * 1.0 / ITERS;
  for (int it = 0; it < ITERS; it++) {
    double xl = L + step * it;
    double xr = L + step * (it + 1);
    dbl x1 = (xl + xr) / 2;
    dbl x0 = x1 - (x1 - xl) * sqrt(3.0 / 5);
    dbl x2 = x1 + (x1 - xl) * sqrt(3.0 / 5);
    ans += (5 * g(x0) + 8 * g(x1) + 5 * g(x2)) / 18
    * step;
  }
  return ans;
};
```

22 final/geom/commonTangents.cpp

```


vector<Line> commonTangents(pt A, dbl rA, pt B, dbl
    rB) {
  vector<Line> res;
  pt C = B - A;
  dbl z = C.len2();
  for (int i = -1; i <= 1; i += 2) {
    for (int j = -1; j <= 1; j += 2) {
      dbl r = rB * j - rA * i;
      dbl d = z - r * r;
      if (ls(d, 0)) continue;
      d = sqrt(max(0.01, d));
      pt magic = pt(r, d) / z;
      pt v(magic % C, magic * C);
      dbl CC = (rA * i - v % A) / v.len2();
      pt O = v * -CC;
      res.pb(Line(O, O + v.rotate()));
    }
  }
  return res;
}

// HOW TO USE ::
// --    *D*-----------------*F*
// --    *...* -         - *...*
// --   *.....* -       - *.....*
// --  *.......* -     - *.......*
// --  *...A...*  --   *...B...*
// --  *.......* -     - *.......*
// --   *.....* -       - *.....*
// --    *...* -         - *...*
// --    *C*-----------------*E*
// -- res = {CE, CF, DE, DF}
```

23 final/geom/halfplaneIntersection.cpp

```
int getPart(pt v) {
  return ls(v.y, 0) || (eq(0, v.y) && ls(v.x, 0));
}

int cmpV(pt a, pt b) {
  int partA = getPart(a);
  int partB = getPart(b);
  if (partA < partB) return 1;
  if (partA > partB) return -1;
  if (eq(0, a * b)) return 0;
  if (0 < a * b) return -1;
  return 1;
}

double planeInt(vector<Line> l) {
  sort(all(l), [](Line a, Line b) {
      int r = cmpV(a.v, b.v);
      if (r != 0) return r < 0;
      return a.0 % a.v.rotate() > b.0 % a.v.rotate()
      ;
    });

  l.resize(unique(all(l), [](Line A, Line B) {
    return cmpV(A.v, B.v) == 0; }) - l.begin());
  for (int i = 0; i < sz(l); i++)
    l[i].id = i;

  // if an infinite answer is possible
  int flagUp = 0;
  int flagDown = 0;
  for (int i = 0; i < sz(l); i++) {
    int part = getPart(l[i].v);
    if (part == 1) flagUp = 1;
    if (part == 0) flagDown = 1;
  }
  if (!flagUp || !flagDown) return -1;

  for (int i = 0; i < sz(l); i++) {
    pt v = l[i].v;
    pt u = l[(i + 1) % sz(l)].v;
    if (eq(0, v * u) && ls(v % u, 0)) {
      pt dir = l[i].v.rotate();
      if (le(l[(i + 1) % sz(l)].0 % dir, l[i].0 %
    dir)) return 0;
      return -1;
    }
    if (ls(v * u, 0))
      return -1;
  }
  // main part
  vector<Line> st;
  for (int tt = 0; tt < 2; tt++) {
    for (auto L: l) {
      for (; sz(st) >= 2 && le(st[sz(st) - 2].v * (
    st.back() * L - st[sz(st) - 2].0), 0); st.
    pop_back());
      st.pb(L);
      if (sz(st) >= 2 && le(st[sz(st) - 2].v * st.
    back().v, 0)) return 0; // useless line
    }
  }
  vector<int> use(sz(l), -1);
  int left = -1, right = -1;
  for (int i = 0; i < sz(st); i++) {
    if (use[st[i].id] == -1) {
      use[st[i].id] = i;
    }
    else {
      left = use[st[i].id];
      right = i;
      break;
    }
  }
  vector<Line> tmp;
  for (int i = left; i < right; i++)
    tmp.pb(st[i]);
  vector<pt> res;
  for (int i = 0; i < (int)tmp.size(); i++)
    res.pb(tmp[i] * tmp[(i + 1) % tmp.size()]);
  double area = 0;
  for (int i = 0; i < (int)res.size(); i++)
    area += res[i] * res[(i + 1) % res.size()];
  return area / 2;
}
```

24 final/geom/minDisc.cpp

```

pair<pt, dbl> minDisc(vector<pt> p) {
  int n = p.size();
  pt O = pt(0, 0);
  dbl R = 0;
  random_shuffle(all(p));
  for (int i = 0; i < n; i++) {
    if (ls(R, (O - p[i]).len())) {
      O = p[i];
      R = 0;
      for (int j = 0; j < i; j++) {
        if (ls(R, (O - p[j]).len())) {
          O = (p[i] + p[j]) / 2;
          R = (p[i] - p[j]).len() / 2;
          for (int k = 0; k < j; k++) {
            if (ls(R, (O - p[k]).len())) {
              Line l1((p[i] + p[j]) / 2, (p[i] + p[j
    ]) / 2 + (p[i] - p[j]).rotate());
              Line l2((p[k] + p[j]) / 2, (p[k] + p[j
    ]) / 2 + (p[k] - p[j]).rotate());
              O = l1 * l2;
              R = (p[i] - O).len();
            }
          }
        }
      }
```

```
      }
    }
  }
  return {0, R};
}
```

25 final/geom/convexHull3D-N2.cpp

```

struct Plane {
  pt O, v;
  vector<int> id;
};

vector<Plane> convexHull3(vector<pt> p) {
  vector<Plane> res;
  int n = p.size();
  for (int i = 0; i < n; i++)
    p[i].id = i;
  for (int i = 0; i < 4; i++) {
    vector<pt> tmp;
    for (int j = 0; j < 4; j++)
      if (i != j)
        tmp.pb(p[j]);
    res.pb({tmp[0], (tmp[1] - tmp[0]) * (tmp[2] - tmp[0]), {tmp[0].id, tmp[1].id, tmp[2].id}});
    if ((p[i] - res.back().O) % res.back().v > 0) {
      res.back().v = res.back().v * -1;
      swap(res.back().id[0], res.back().id[1]);
    }
  }
  vector<vector<int>> use(n, vector<int>(n, 0));
  int tmr = 0;
  for (int i = 4; i < n; i++) {
    int cur = 0;
    tmr++;
    vector<pair<int,int>> curEdge;
    for (int j = 0; j < sz(res); j++) {
      if ((p[i] - res[j].O) % res[j].v > 0) {
        for (int t = 0; t < 3; t++) {
          int v = res[j].id[t];
          int u = res[j].id[(t + 1) % 3];
          use[v][u] = tmr;
          curEdge.pb({v, u});
        }
      }
      else {
        res[cur++] = res[j];
      }
    }
    res.resize(cur);
    for (auto x: curEdge) {
      if (use[x.S][x.F] == tmr) continue;
      res.pb({p[i], (p[x.F] - p[i]) * (p[x.S] - p[i]), {x.F, x.S, i}});
    }
  }
  return res;
}

// plane in 3d
//(A, v) * (B, u) -> (O, n)

pt n = v * u;
pt m = v * n;
double t = (B - A) % u / (u % m);
pt O = A - m * t;
```

26 final/geom/convexDynamic.cpp

```
struct convex {
  map<ll, ll> M;
  bool get(int x, int y) {
    if (M.size() == 0)
      return false;
    if (M.count(x))
      return M[x] >= y;
    if (x < M.begin()->first || x > M.rbegin()->first)
      return false;

    auto it1 = M.lower_bound(x), it2 = it1;
    it1--;

    return pt(pt(*it1), pt(x, y)) % pt(pt(*it1), pt(*it2)) >= 0;
  }
  void add(int x, int y) {
    if (get(x, y)) return;

    pt P(x, y);
    M[x] = y;

    auto it = M.lower_bound(x), it1 = it;
    it1--;
    auto it2 = it1;
    it2--;

    if (it != M.begin() && it1 != M.begin()) {
      while (it1 != M.begin() && (pt(pt(*it2), pt(*it1)) % pt(pt(*it1), P)) >= 0) {
        M.erase(it1);
        it1 = it2;
        it2--;
      }
    }
    it1 = it, it1++;
    if (it1 == M.end()) return;
    it2 = it1, it2++;

    if (it1 != M.end() && it2 != M.end()) {
      while (it2 != M.end() && (pt(P, pt(*it1)) % pt(pt(*it1), pt(*it2))) >= 0) {
        M.erase(it1);
        it1 = it2;
        it2++;
      }
    }
  }
} H, J;

int solve() {
  int q;
  cin >> q;
  while (q--) {
    int t, x, y;
    cin >> t >> x >> y;
    if (t == 1) {
      H.add(x, y);
      J.add(x, -y);
    }
    else {
      if (H.get(x, y) && J.get(x, -y))
        puts("YES");
      else
        puts("NO");
    }
  }
  return 0;
}
```

27 final/geom/polygonArcCut.cpp

```

struct Meta {
  int type; // 0 - seg, 1 - circle
  pt O;
  dbl R;
};

const Meta SEG = {0, pt(0, 0), 0};

vector<pair<pt, Meta>> cut(vector<pair<pt, Meta>> p, Line l) {
  vector<pair<pt,Meta>> res;
  int n = p.size();
  for (int i = 0; i < n; i++) {
    pt A = p[i].F;
    pt B = p[(i + 1) % n].F;
    if (le(0, l.v * (A - l.O))) {
      if (eq(0, l.v * (A - l.O)) && p[i].S.type == 1 && ls(0, l.v % (p[i].S.O - A)))
        res.pb({A, SEG});
      else
        res.pb(p[i]);
    }
```

```
    if (p[i].S.type == 0) {
      if (sign(l.v * (A - l.O)) * sign(l.v * (B - l.O)) == -1) {
        pt FF = Line(A, B) * l;
        res.pb(make_pair(FF, SEG));
      }
    }
    else {
      pt E, F;
      if (intCL(p[i].S.O, p[i].S.R, l, E, F)) {
        if (onArc(p[i].S.O, A, E, B))
          res.pb({E, SEG});
        if (onArc(p[i].S.O, A, F, B))
          res.pb({F, p[i].S});
      }
    }
  }
  return res;
}
```

28 final/geom/polygonTangent.cpp

```
pt tangent(vector<pt>& p, pt O, int cof) {
  int step = 1;
  for (; step < (int)p.size(); step *= 2);
  int pos = 0;
  int n = p.size();
  for (; step > 0; step /= 2) {
    int best = pos;
    for (int dx = -1; dx <= 1; dx += 2) {
      int id = ((pos + step * dx) % n + n) % n;
      if ((p[id] - O) * (p[best] - O) * cof > 0)
        best = id;
    }
    pos = best;
  }
  return p[pos];
}
```

29 final/geom/checkPlaneInt.cpp

```
bool eq(dbl A, dbl B) { return abs(A - B) < 1e-9; }

bool ls(dbl A, dbl B) { return A < B && !eq(A, B); }

bool le(dbl A, dbl B) { return A < B || eq(A, B); }
struct pt {
  double x, y;
  pt(double x, double y) : x(x), y(y) {}
  pt() : pt(0, 0) {}
  double operator%(pt b) const { return x * b.x + y * b.y; }
  // Orintation of cross product and rotation DO matter in some algorithms
  double operator*(pt b) const { return x * b.y - y * b.x; }
  pt rotate() { return {y, -x}; }
  pt operator-(pt b) const { return {x - b.x, y - b.y}; }
  pt operator*(double t) const { return {x * t, y * t}; }
  pt operator+(pt b) const { return {x + b.x, y + b.y}; }
};

// Also this is half-plane struct
struct Line {
  pt O, v;

  // Ax + By + C <= 0
  Line(double A, double B, double C) {
    double l = sqrt(A * A + B * B);
    A /= l, B /= l, C /= l;
    O = pt(-A * C, -B * C);
    v = pt(-B, A);
  }
  //intersection with l
  pt operator*(Line l) {
    pt u = l.v.rotate();
    dbl t = (l.O - O) % u / (v % u);
    return O + v * t;
  }
  // Half-plane with point O on the border, everything to the LEFT of direction vector v is inside
  Line(pt O, pt v) : O(O), v(v) {}
};

const double EPS = 1e-14;
double INF = 1e50;

// vector<Line> lines{
//     Line(pt(0, 0), pt(0, -1)),
//     Line(pt(0, 0), pt(-1, 0)),
//     Line(pt(1, 1), pt(0, 1)),
// };
// checkPoint(lines, p) == true
// Intersection of lines is rectangle of set o
// Time complexity is O(n)
bool checkPoint(vector<Line> &l, pt &ret) {
  random_shuffle(l.begin(), l.end());
  pt A = l[0].O;
  for (int i = 1; i < l.size(); i++) {
    if (l[i].v * (A - l[i].O) < -EPS) {
      double mn = -INF;
      double mx = INF;
      for (int j = 0; j < i; j++) {
        if (abs(l[j].v * l[i].v) < EPS) {
          if (l[j].v % l[i].v < 0 && (l[j].O - l[i].O) % l[i].v.rotate() < EPS) {
            return false;
          }
        } else {
          pt u = l[j].v.rotate();
          double proj = (l[j].O - l[i].O) % u / (l[i].v % u);
          if (l[i].v * l[j].v > 0) {
            mx = min(mx, proj);
          } else {
            mn = max(mn, proj);
          }
        }
      }
      if (mn <= mx) {
        A = l[i].O + l[i].v * mn;
      } else {
        return false;
      }
    }
  }
  ret = A;
  return true;
}
```

30 final/geom/furthestPoints.cpp

```
ll furthestPoints(vector<pt> p) {
  int n = p.size();
  int cur = 1;
  ll answer = 0;
  for (int i = 0; i < n; i++) {
    for (; (p[(i + 1) % n] - p[i]) * (p[(cur + 1) % n] - p[cur]) > 0; cur = (cur + 1) % n);
    answer = max(answer, (p[i] - p[cur]).len2());
  }
  return answer;
}
```

31 final/geom/chtDynamic.cpp

```

const ll is_query = -(1LL << 62);

struct Line {
  ll m, b;
  mutable function<const Line *()> succ;

  bool operator<(const Line &rhs) const {
    if (rhs.b != is_query) return m < rhs.m;
    const Line *s = succ();
    if (!s) return 0;
    ll x = rhs.m;
```

```cpp
    return b - s->b < (s->m - m) * x;
  }
};

struct HullDynamic : public multiset<Line> {
  bool bad(iterator y) {
    auto z = next(y);
    if (y == begin()) {
      if (z == end()) return 0;
      return y->m == z->m && y->b <= z->b;
    }
    auto x = prev(y);
    if (z == end()) return y->m == x->m && y->b <= x->b;
    return (x->b - y->b) * (z->m - y->m) >= (y->b - z->b) * (y->m - x->m);
  }

  void insert_line(ll m, ll b) {
    auto y = insert({m, b});
    y->succ = [=] { return next(y) == end() ? 0 : &*next(y); };
    if (bad(y)) {
      erase(y);
      return;
    }
    while (next(y) != end() && bad(next(y))) erase(next(y));
    while (y != begin() && bad(prev(y))) erase(prev(y));
  }

  ll eval(ll x) {
    auto l = *lower_bound((Line) {x, is_query});
    return l.m * x + l.b;
  }
};
```

32 final/strings/eertree.cpp

```cpp
namespace eertree {
  const int INF = 1e9;
  const int N = 5e6 + 10;
  char _s[N];
  char *s = _s + 1;
  int to[N][2];
  int suf[N], len[N];
  int sz, last;

  const int odd = 1, even = 2, blank = 3;

  void go(int &u, int pos) {
    while (u != blank && s[pos - len[u] - 1] != s[pos]) {
      u = suf[u];
    }
  }

  int add(int pos) {
    go(last, pos);
    int u = suf[last];
    go(u, pos);
    int c = s[pos] - 'a';
    int res = 0;
    if (!to[last][c]) {
      res = 1;
      to[last][c] = sz;
      len[sz] = len[last] + 2;
      suf[sz] = to[u][c];
      sz++;
    }
    last = to[last][c];
    return res;
  }

  void init() {
    to[blank][0] = to[blank][1] = even;
    len[blank] = suf[blank] = INF;
    len[even] = 0, suf[even] = odd;
    len[odd] = -1, suf[odd] = blank;
    last = even;
    sz = 4;
  }
}
```

33 final/strings/manacher.cpp

```cpp
vector<int> Pal1(string s) {
  int n = (int)s.size();
  vector<int> d1(n);
  int l = 0, r = -1;
  for (int i = 0, k; i < n; i++) {
    if (i > r) k = 1;
    else k = min(d1[l + r - i], r - i);
    while (0 <= i - k && i + k < n && s[i - k] == s[i + k]) k++;
    d1[i] = k;
    if (i + k - 1 > r) r = i + k - 1, l = i - k + 1;
  }
  return d1;
}

vector<int> Pal2(string s) {
  int n = (int)s.size();
  vector<int> d2(n);
  int l = 0, r = -1;
  for (int i = 0, k; i < n; i++) {
    if (i > r) k = 0;
    else k = min(d2[l + r - i + 1], r - i + 1);
    while (i + k < n && i - k - 1 >= 0 && s[i + k] == s[i - k - 1]) k++;
    d2[i] = k;
    if (i + k - 1 > r) l = i - k, r = i + k - 1;
  }
  return d2;
}
```

34 final/strings/sufAutomaton.cpp

```cpp
namespace SA {
  const int MAXN = 1 << 18;
  const int SIGMA = 26;

  int sz, last;
  int nxt[MAXN][SIGMA];
  int link[MAXN], len[MAXN], pos[MAXN];

  void init() {
    memset(nxt, -1, sizeof(nxt));
    memset(link, -1, sizeof(link));
    memset(len, 0, sizeof(len));
    last = 0;
    sz = 1;
  }

  void add(int c) {
    int cur = sz++;
    len[cur] = len[last] + 1;
    pos[cur] = len[cur];
    int p = last;
    last = cur;
    for (; p != -1 && nxt[p][c] == -1; p = link[p]) nxt[p][c] = cur;
    if (p == -1) {
      link[cur] = 0;
      return;
    }
    int q = nxt[p][c];
    if (len[p] + 1 == len[q]) {
      link[cur] = q;
      return;
    }
    int clone = sz++;
    memcpy(nxt[clone], nxt[q], sizeof(nxt[q]));
    len[clone] = len[p] + 1;
    pos[clone] = pos[q];
    link[clone] = link[q];
    link[q] = link[cur] = clone;
    for (; p != -1 && nxt[p][c] == q; p = link[p]) nxt[p][c] = clone;
  }

  int n;
  string s;
  int l[MAXN], r[MAXN];
  int e[MAXN][SIGMA];

  void getSufTree(string _s) {
    memset(e, -1, sizeof(e));
    s = _s;
    n = s.length();
    reverse(s.begin(), s.end());
    init();
    for (int i = 0; i < n; i++) add(s[i] - 'a');
    reverse(s.begin(), s.end());
    for (int i = 1; i < sz; i++) {
      int j = link[i];
      l[i] = n - pos[i] + len[j];
      r[i] = n - pos[i] + len[i];
      e[j][s[l[i]] - 'a'] = i;
    }
  }
}
```

35 final/strings/sufArray.cpp

```cpp
int n;
char s[N];
int p[N], pn[N], c[N], cn[N], cnt[N];
int o[N];
int lcp[N];

void build() {
  for (int i = 0; i < 256; i++) cnt[i] = 0;
  for (int i = 0; i < n; i++) cnt[(int)s[i]]++;
  for (int i = 1; i < 256; i++) cnt[i] += cnt[i - 1];
  for (int i = n - 1; i >= 0; i--) p[--cnt[(int)s[i]]] = i;
  int cl = 1;
  c[p[0]] = 0;
  for (int i = 1; i < n; i++) {
    cl += s[p[i]] != s[p[i - 1]];
    c[p[i]] = cl - 1;
  }

  for (int len = 1; len < n; len <<= 1) {
    for (int i = 0; i < cl; i++) cnt[i] = 0;
    for (int i = 0; i < n; i++) cnt[c[i]]++;
    for (int i = 1; i < cl; i++) cnt[i] += cnt[i - 1];
    for (int i = 0; i < n; i++) pn[i] = (p[i] - len + n) % n;
    for (int i = n - 1; i >= 0; i--) p[--cnt[c[pn[i]]]] = pn[i];
    cl = 1;
    cn[p[0]] = 0;
    for (int i = 1; i < n; i++) {
      cl += c[p[i]] != c[p[i - 1]] || c[(p[i] + len) % n] != c[(p[i - 1] + len) % n];
      cn[p[i]] = cl - 1;
    }
    for (int i = 0; i < n; i++) c[i] = cn[i];
  }

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

  int z = 0;
  for (int i = 0; i < n; i++) {
    int j = o[i];
    if (j == n - 1) {
      z = 0;
    } else {
      while (s[i + z] == s[p[j + 1] + z]) z++;
    }
    lcp[j] = z;
    z -= !!z;
  }
}
```

36 final/strings/sufArrayLinear.cpp

```cpp
const int dd = (int)2e6 + 3;

ll cnt2[dd];
int AN;
int A[3 * dd + 100];
int cnt[dd + 1]; // Should be >= 256
int SA[dd + 1];

/* Used by suffix_array. */
void radix_pass(int* A, int AN, int* R, int RN, int* D) {
 memset(cnt, 0, sizeof(int) * (AN + 1));
 int* C = cnt + 1;
 for(int i = 0; i < RN; i++) ++C[A[R[i]]];
 for(int i = -1, v = 0; i <= AN && v < RN; v += C[i++]) swap(v, C[i]);
 for(int i = 0; i < RN; i++) D[C[A[R[i]]]++] = R[i];
}

/* DC3 in O(N) using 20N bytes of memory. Stores the suffix array of the string
 * [A,A+AN) into SA where SA[i] (0<=i<=AN) gives the starting position of the
 * i-th least suffix of A (including the empty suffix).
 */
void suffix_array(int* A, int AN) {
 // Base case... length 1 string.
 if(!AN) {
  SA[0] = 0;
 } else if(AN == 1) {
  SA[0] = 1; SA[1] = 0;
  return;
 }

 // Sort all strings of length 3 starting at non-multiples of 3 into R.
 int RN = 0;
 int* SUBA = A + AN + 2;
 int* R = SUBA + AN + 2;
 for(int i = 1; i < AN; i += 3) SUBA[RN++] = i;
 for(int i = 2; i < AN; i += 3) SUBA[RN++] = i;
 A[AN + 1] = A[AN] = -1;
 radix_pass(A + 2, AN - 2, SUBA, RN, R);
 radix_pass(A + 1, AN - 1, R, RN, SUBA);
 radix_pass(A + 0, AN - 0, SUBA, RN, R);
```

```

  // Compute the relabel array if we need to recursively solve for the
  // non-multiples.
  int resfix, resmul, v;
  if(AN % 3 == 1) {
   resfix = 1; resmul = RN >> 1;
  } else {
   resfix = 2; resmul = RN + 1 >> 1;
  }
  for(int i = v = 0; i < RN; i++) {
   v += i && (A[R[i - 1] + 0] != A[R[i] + 0] ||
         A[R[i - 1] + 1] != A[R[i] + 1] ||
         A[R[i - 1] + 2] != A[R[i] + 2]);
   SUBA[R[i] / 3 + (R[i] % 3 == resfix) * resmul] = v;
  }

  // Recursively solve if needed to compute relative ranks in the final suffix
  // array of all non-multiples.
  if(v + 1 != RN) {
   suffix_array(SUBA, RN);
   SA[0] = AN;
   for(int i = 1; i <= RN; i++) {
    SA[i] = SA[i] < resmul ? 3 * SA[i] + (resfix==1?2:1) :
         3 * (SA[i] - resmul) + resfix;
   }
  } else {
   SA[0] = AN;
   memcpy(SA + 1, R, sizeof(int) * RN);
  }

  // Compute the relative ordering of the multiples.
  int NMN = RN;
  for(int i = RN = 0; i <= NMN; i++) {
   if(SA[i] % 3 == 1) {
    SUBA[RN++] = SA[i] - 1;
   }
  }
  radix_pass(A, AN, SUBA, RN, R);

  // Compute the reverse SA for what we know so far.
  for(int i = 0; i <= NMN; i++) {
   SUBA[SA[i]] = i;
  }

  // Merge the orderings.
  int ii = RN - 1;
  int jj = NMN;
  int pos;
  for(pos = AN; ii >= 0; pos--) {
   int i = R[ii];
   int j = SA[jj];
   int v = A[i] - A[j];
   if(!v) {
    if(j % 3 == 1) {
     v = SUBA[i + 1] - SUBA[j + 1];
    } else {
     v = A[i + 1] - A[j + 1];
     if(!v) v = SUBA[i + 2] - SUBA[j + 2];
    }
   }
   SA[pos] = v < 0 ? SA[jj--] : R[ii--];
  }
}

char s[dd + 1];

/* Copies the string in s into A and reduces the characters as needed. */
void prep_string() {
  int v = AN = 0;
  memset(cnt, 0, 256 * sizeof(int));
  for(char* ss = s; *ss; ++ss, ++AN) cnt[*ss]++;
  for(int i = 0; i < AN; i++) cnt[s[i]]++;
  for(int i = 0; i < 256; i++) cnt[i] = cnt[i] ? v++ : -1;
  for(int i = 0; i < AN; i++) A[i] = cnt[s[i]];
}

/* Computes the reverse SA index. REVSA[i] gives the index of the suffix
 * starting a i in the SA array. In other words, REVSA[i] gives the number of
 * suffixes before the suffix starting at i. This can be useful in itself but
 * is also used for compute_lcp().
 */
int REVSA[dd + 1];
void compute_reverse_sa() {
  for(int i = 0; i <= AN; i++) {
   REVSA[SA[i]] = i;
  }
}

/* Computes the longest common prefix between adjacent suffixes. LCP[i] gives
 * the longest common suffix between the suffix starting at i and the next
 * smallest suffix. Runs in O(N) time.
 */
int LCP[dd + 1];
void compute_lcp() {
  int len = 0;
  for(int i = 0; i < AN; i++, len = max(0, len - 1)) {
   int s = REVSA[i];
   int j = SA[s - 1];
   for(; i + len < AN && j + len < AN && A[i + len] == A[j + len]; len++);
   LCP[s] = len;
  }
}
```

37 final/strings/duval.cpp

```
void duval(string s) {
  int n = (int) s.length();
  int i=0;
  while (i < n) {
    int j=i+1, k=i;
    while (j < n && s[k] <= s[j]) {
      if (s[k] < s[j])
        k = i;
      else
        ++k;
      ++j;
    }
    while (i <= k) {
      cout << s.substr (i, j-k) << ' ';
      i += j - k;
    }
  }
}
```

38 final/graphs/centroid.cpp

```cpp
// original author: burunduk1, rewritten by me (enot110)
// !!! warning !!! this code is not tested well
const int N = 1e5, K = 17;

int pivot, level[N], parent[N];
vector<int> v[N];

int get_pivot( int x, int xx, int n ) {
  int size = 1;
  for (int y : v[x])
  {
    if (y != xx && level[y] == -1) size += get_pivot(y, x, n);
  }
  if (pivot == -1 && (size * 2 >= n || xx == -1)) pivot = x;
  return size;
}

void build( int x, int xx, int dep, int size ) {
  assert(dep < K);
  pivot = -1;
  get_pivot(x, -1, size);
  x = pivot;
  level[x] = dep, parent[x] = xx;
  for (int y : v[x]) if (level[y] == -1)
  {
    build(y, x, dep + 1, size / 2);
  }
}
```

39 final/graphs/dominatorTree.cpp

```cpp
namespace domtree {
  const int K = 18;
  const int N = 1 << K;

  int n, root;
  vector<int> e[N], g[N];
  int sdom[N], dom[N];
  int p[N][K], h[N], pr[N];
  int in[N], out[N], tmr, rev[N];

  void init(int _n, int _root) {
    n = _n;
    root = _root;
    tmr = 0;
    for (int i = 0; i < n; i++) {
      e[i].clear();
      g[i].clear();
      in[i] = -1;
    }
  }

  void addEdge(int u, int v) {
    e[u].push_back(v);
    g[v].push_back(u);
  }

  void dfs(int v) {
    in[v] = tmr++;
    for (int to : e[v]) {
      if (in[to] != -1) continue;
      pr[to] = v;
      dfs(to);
    }
    out[v] = tmr - 1;
  }

  int lca(int u, int v) {
    if (h[u] < h[v]) swap(u, v);
    for (int i = 0; i < K; i++) if ((h[u] - h[v]) & (1 << i)) u = p[u][i];
    if (u == v) return u;
    for (int i = K - 1; i >= 0; i--) {
      if (p[u][i] != p[v][i]) {
        u = p[u][i];
        v = p[v][i];
      }
    }
    return p[u][0];
  }

  void solve(int _n, int _root, vector<pair<int, int> > _edges) {
    init(_n, _root);
    for (auto ed : _edges) addEdge(ed.first, ed.second);

    dfs(root);
    for (int i = 0; i < n; i++) if (in[i] != -1) rev[in[i]] = i;
    segtree tr(tmr); // a[i]:=min(a[i],x) and return a[i]
    for (int i = tmr - 1; i >= 0; i--) {
      int v = rev[i];
      int cur = i;
      for (int to : g[v]) {
        if (in[to] == -1) continue;
        if (in[to] < in[v]) cur = min(cur, in[to]);
        else cur = min(cur, tr.get(in[to]));
      }
      sdom[v] = rev[cur];
      tr.upd(in[v], out[v], in[sdom[v]]);
    }
    for (int i = 0; i < tmr; i++) {
      int v = rev[i];
      if (i == 0) {
        dom[v] = v;
        h[v] = 0;
      } else {
        dom[v] = lca(sdom[v], pr[v]);
        h[v] = h[dom[v]] + 1;
      }
      p[v][0] = dom[v];
      for (int j = 1; j < K; j++) p[v][j] = p[p[v][j - 1]][j - 1];
    }
    for (int i = 0; i < n; i++) if (in[i] == -1) dom[i] = -1;
  }
}
```

40 final/graphs/generalMatching.cpp

```cpp
//COPYPASTED FROM E-MAXX
namespace GeneralMatching {
  const int MAXN = 256;
  int n;
  vector<int> g[MAXN];
  int match[MAXN], p[MAXN], base[MAXN], q[MAXN];
  bool used[MAXN], blossom[MAXN];

  int lca (int a, int b) {
    bool used[MAXN] = { 0 };
    for (;;) {
      a = base[a];
      used[a] = true;
      if (match[a] == -1) break;
      a = p[match[a]];
    }
    for (;;) {
      b = base[b];
      if (used[b]) return b;
      b = p[match[b]];
    }
  }

  void mark_path (int v, int b, int children) {
    while (base[v] != b) {
      blossom[base[v]] = blossom[base[match[v]]] = true;
      p[v] = children;
      children = match[v];
      v = p[match[v]];
    }
  }

  int find_path (int root) {
    memset (used, 0, sizeof used);
    memset (p, -1, sizeof p);
    for (int i=0; i<n; ++i)
      base[i] = i;

    used[root] = true;
    int qh=0, qt=0;
    q[qt++] = root;
    while (qh < qt) {
```

```
      int v = q[qh++];
      for (size_t i=0; i<g[v].size(); ++i) {
        int to = g[v][i];
        if (base[v] == base[to] || match[v] == to) continue;
        if (to == root || (match[to] != -1 && p[match[to]] != -1)) {
          int curbase = lca (v, to);
          memset (blossom, 0, sizeof blossom);
          mark_path (v, curbase, to);
          mark_path (to, curbase, v);
          for (int i=0; i<n; ++i)
            if (blossom[base[i]]) {
              base[i] = curbase;
              if (!used[i]) {
                used[i] = true;
                q[qt++] = i;
              }
            }
        }
        else if (p[to] == -1) {
          p[to] = v;
          if (match[to] == -1)
            return to;
          to = match[to];
          used[to] = true;
          q[qt++] = to;
        }
      }
    }
    return -1;
  }

  vector<pair<int, int> > solve(int _n, vector<pair<int, int> > edges) {
    n = _n;
    for (int i = 0; i < n; i++) g[i].clear();
    for (auto o : edges) {
      g[o.first].push_back(o.second);
      g[o.second].push_back(o.first);
    }
    memset (match, -1, sizeof match);
    for (int i=0; i<n; ++i) {
      if (match[i] == -1) {
        int v = find_path (i);
        while (v != -1) {
          int pv = p[v], ppv = match[pv];
          match[v] = pv, match[pv] = v;
          v = ppv;
        }
      }
    }
    vector<pair<int, int> > ans;
    for (int i = 0; i < n; i++) {
      if (match[i] > i) {
        ans.push_back(make_pair(i, match[i]));
      }
    }
    return ans;
  }
}
```

41 final/graphs/heavyLight.cpp

```
namespace hld {
  const int N = 1 << 17;
  int par[N], heavy[N], h[N];
  int root[N], pos[N];
  int n;
  vector<vector<int> > e;
  segtree tree;

  int dfs(int v) {
    int sz = 1, mx = 0;
    for (int to : e[v]) {
      if (to == par[v]) continue;
      par[to] = v;
      h[to] = h[v] + 1;
      int cur = dfs(to);
      if (cur > mx) heavy[v] = to, mx = cur;
      sz += cur;
    }
    return sz;
  }

  template <typename T>
  void path(int u, int v, T op) {
    for (; root[u] != root[v]; v = par[root[v]]) {
      if (h[root[u]] > h[root[v]]) swap(u, v);
      op(pos[root[v]], pos[v] + 1);
    }
    if (h[u] > h[v]) swap(u, v);
    op(pos[u], pos[v] + 1);
  }

  void init(vector<vector<int> > _e) {
    e = _e;
    n = e.size();
    tree = segtree(n);
    memset(heavy, -1, sizeof(heavy[0]) * n);
    par[0] = -1;
    h[0] = 0;
    dfs(0);
    for (int i = 0, cpos = 0; i < n; i++) {
      if (par[i] == -1 || heavy[par[i]] != i) {
        for (int j = i; j != -1; j = heavy[j]) {
          root[j] = i;
          pos[j] = cpos++;
        }
      }
    }
  }

  void add(int v, int x) {
    tree.add(pos[v], x);
  }

  int get(int u, int v) {
    int res = 0;
    path(u, v, [&](int l, int r) {
      res = max(res, tree.get(l, r));
    });
    return res;
  }
}
```

42 final/graphs/hungary.cpp

```
namespace hungary
{
  const int N = 210;

  int a[N][N];
  int ans[N];

  int calc(int n, int m)
  {
    ++n, ++m;
    vi u(n), v(m), p(m), prev(m);
    for (int i = 1; i < n; ++i)
    {
      p[0] = i;
      int x = 0;
      vi mn(m, inf);
      vi was(m, 0);
      while (p[x])
      {
        was[x] = 1;
        int ii = p[x], dd = inf, y = 0;
        for (int j = 1; j < m; ++j) if (!was[j])
        {
          int cur = a[ii][j] - u[ii] - v[j];
          if (cur < mn[j]) mn[j] = cur, prev[j] = x;
          if (mn[j] < dd) dd = mn[j], y = j;
        }
        forn(j, m)
        {
          if (was[j]) u[p[j]] += dd, v[j] -= dd;
          else mn[j] -= dd;
        }
        x = y;
      }
      while (x)
      {
        int y = prev[x];
        p[x] = p[y];
        x = y;
      }
    }
    for (int j = 1; j < m; ++j)
    {
      ans[p[j]] = j;
    }
    return -v[0];
```

```
  }
  // HOW TO USE ::
  // -- set values to a[1..n][1..m] (n <= m)
  // -- run calc(n, m) to find MINIMUM
  // -- to restore permutation use ans[]
  // -- everything works on negative numbers
  //
  // !! i don't understand this code, it's copypasted from e-maxx (and rewrited by enot110)
}
```

43 final/graphs/minCost.cpp

```
ll findflow(int s, int t) {
  ll cost = 0;
  ll flow = 0;

  forn(i, N) G[i] = inf;

  queue<int> q;

  q.push(s);
  used[s] = true;
  G[s] = 0;

  while (q.size()) {
    int v = q.front();
    used[v] = false;
    q.pop();

    forn(i, E[v].size()) {
      auto &e = E[v][i];
      if (e.f < e.c && G[e.to] > G[v] + e.w) {
        G[e.to] = G[v] + e.w;
        if (!used[e.to]) {
          q.push(e.to);
          used[e.to] = true;
        }
      }
    }
  }

  while (1) {
    forn(i, N)
      d[i] = inf, p[i] = { -1, -1 }, used[i] = 0;

    d[s] = 0;
    while (1) {
      int v = -1;
      forn(i, N) {
        if (!used[i] && d[i] != inf && (v == -1 || d[i] < d[v]))
          v = i;
      }
      if (v == -1)
        break;
      used[v] = 1;

      forn(i, E[v].size()) {

        auto &e = E[v][i];
        if (e.f < e.c && d[e.to] > d[v] + e.w + G[v] - G[e.to]) {
          p[e.to] = mp(v, i);
          d[e.to] = d[v] + e.w + G[v] - G[e.to];
        }
      }

    }
    if (p[t].first == -1) {
      break;
    }
    int add = inf;
    for (int i = t; p[i].first != -1; i = p[i].first) {
      add = min(add, E[p[i].first][p[i].second].c - E[p[i].first][p[i].second].f);
    }
    for (int i = t; p[i].first != -1; i = p[i].first) {
      auto &e = E[p[i].first][p[i].second];
      cost += 1ll * add * e.w;
      e.f += add;
      E[e.to][e.back].f -= add;
    }
    flow += add;
```

```
    if (add == 0)
      break;
    forn(i, N)
      G[i] += d[i];
  }
  return cost;
}
```

44 final/graphs/minCostNegCycle.cpp

```
struct Edge {
  int from, to, cap, flow;
  double cost;

};

struct Graph {
  int n;
  vector<Edge> edges;
  vector<vector<int> > e;

  Graph(int _n) {
    n = _n;
    e.resize(n);
  }

  void addEdge(int from, int to, int cap, double cost) {
    e[from].push_back(edges.size());
    edges.push_back({ from, to, cap, 0, cost });
    e[to].push_back(edges.size());
    edges.push_back({ to, from, 0, 0, -cost });
  }

  void maxflow() {
    while (1) {
      queue<int> q;
      vector<int> d(n, INF);
      vector<int> pr(n, -1);
      q.push(0);
      d[0] = 0;
      while (!q.empty()) {
        int v = q.front();
        q.pop();
        for (int i = 0; i < (int)e[v].size(); i++) {
          Edge cur = edges[e[v][i]];
          if (d[cur.to] > d[v] + 1 && cur.flow < cur.cap) {
            d[cur.to] = d[v] + 1;
            pr[cur.to] = e[v][i];
            q.push(cur.to);
          }
        }
      }
      if (d[n - 1] == INF) break;
      int v = n - 1;
      while (v) {
        edges[pr[v]].flow++;
        edges[pr[v] ^ 1].flow--;
        v = edges[pr[v]].from;
      }
    }
  }

  bool findcycle() {
    int iters = n;
    vector<int> changed;
    for (int i = 0; i < n; i++) changed.push_back(i);

    vector<vector<double> > d(iters + 1, vector<double>(n, INF));
    vector<vector<int> > p(iters + 1, vector<int>(n, -1));
    d[0].assign(n, 0);
    for (int it = 0; it < iters; it++) {
      d[it + 1] = d[it];
      vector<int> nchanged(n, 0);
      for (int v : changed) {
        for (int id : e[v]) {
          Edge cur = edges[id];
          if (d[it + 1][cur.to] > d[it][v] + cur.cost && cur.flow < cur.cap) {
            d[it + 1][cur.to] = d[it][v] + cur.cost;
            p[it + 1][cur.to] = id;
            nchanged[cur.to] = 1;
          }
```

```
        }
      }
      changed.clear();
      for (int i = 0; i < n; i++) if (nchanged[i]) changed.push_back(i);
    }
    if (changed.empty()) return 0;

    int bestU = 0, bestK = 1;
    double bestAns = INF;
    for (int u = 0; u < n; u++) {
      double curMax = -INF;
      for (int k = 0; k < iters; k++) {
        double curVal = (d[iters][u] - d[k][u]) / (iters - k);
        curMax = max(curMax, curVal);
      }
      if (bestAns > curMax) {
        bestAns = curMax;
        bestU = u;
      }
    }

    int v = bestU;
    int it = iters;
    vector<int> was(n, -1);
    while (was[v] == -1) {
      was[v] = it;
      v = edges[p[it][v]].from;
      it--;
    }
    int vv = v;
    it = was[v];
    double sum = 0;
    do {
      edges[p[it][v]].flow++;
      sum += edges[p[it][v]].cost;
      edges[p[it][v] ^ 1].flow--;
      v = edges[p[it][v]].from;
      it--;
    } while (v != vv);
    return 1;
  }
};
```

45 final/graphs/retro.cpp

```
namespace retro
{
  const int N = 4e5 + 10;

  vi v[N];
  vi vrev[N];

  void add(int x, int y)
  {
    v[x].pb(y);
    vrev[y].pb(x);
  }

  const int UD = 0;
  const int WIN = 1;
  const int LOSE = 2;

  int res[N];
  int moves[N];
  int deg[N];
  int q[N], st, en;

  void calc(int n)
  {
    forn(i, n) deg[i] = sz(v[i]);
    st = en = 0;
    forn(i, n) if (!deg[i])
    {
      q[en++] = i;
      res[i] = LOSE;
    }
    while (st < en)
    {
      int x = q[st++];
      for (int y : vrev[x])
      {
        if (res[y] == UD && (res[x] == LOSE || (--deg[y] == 0 && res[x] == WIN)))
        {
          res[y] = 3 - res[x];
          moves[y] = moves[x] + 1;
          q[en++] = y;
        }
      }
    }
  }
}
```

46 final/graphs/mincut.cpp

```
const int MAXN = 500;
int n, g[MAXN][MAXN];
int best_cost = 1000000000;
vector<int> best_cut;

void mincut() {
  vector<int> v[MAXN];
  for (int i=0; i<n; ++i)
    v[i].assign (1, i);
  int w[MAXN];
  bool exist[MAXN], in_a[MAXN];
  memset (exist, true, sizeof exist);
  for (int ph=0; ph<n-1; ++ph) {
    memset (in_a, false, sizeof in_a);
    memset (w, 0, sizeof w);
    for (int it=0, prev; it<n-ph; ++it) {
      int sel = -1;
      for (int i=0; i<n; ++i)
        if (exist[i] && !in_a[i] && (sel == -1 || w[i] > w[sel]))
          sel = i;
      if (it == n-ph-1) {
        if (w[sel] < best_cost)
          best_cost = w[sel], best_cut = v[sel];
        v[prev].insert (v[prev].end(), v[sel].begin(), v[sel].end());
        for (int i=0; i<n; ++i)
          g[prev][i] = g[i][prev] += g[sel][i];
        exist[sel] = false;
      }
      else {
        in_a[sel] = true;
        for (int i=0; i<n; ++i)
          w[i] += g[sel][i];
        prev = sel;
      }
    }
  }
}
```

47 final/graphs/twoChineseFast.cpp

```
namespace twoc {
  struct Heap {
    static Heap* null;
    ll x, xadd;
    int ver, h;
    /* ANS */ int ei;
    Heap *l, *r;
    Heap(ll xx, int vv) : x(xx), xadd(0), ver(vv), h(1), l(null), r(null) {}
    Heap(const char*) : x(0), xadd(0), ver(0), h(0), l(this), r(this) {}
    void add(ll a) { x += a; xadd += a; }
    void push() {
      if (l != null) l->add(xadd);
      if (r != null) r->add(xadd);
      xadd = 0;
    }
  };
  Heap *Heap::null = new Heap("wqeqw");
  Heap* merge(Heap *l, Heap *r) {
    if (l == Heap::null) return r;
    if (r == Heap::null) return l;
    l->push(); r->push();
    if (l->x > r->x)
      swap(l, r);
    l->r = merge(l->r, r);
    if (l->l->h < l->r->h)
      swap(l->l, l->r);
    l->h = l->r->h + 1;
```

```cpp
    return l;
  }
  Heap *pop(Heap *h) {
    h->push();
    return merge(h->l, h->r);
  }
  const int N = 666666;
  struct DSU {
    int p[N];
    void init(int nn) { iota(p, p + nn, 0); }
    int get(int x) { return p[x] == x ? x : p[x] = get(p[x]); }
    void merge(int x, int y) { p[get(y)] = get(x); }
  } dsu;
  Heap *eb[N];
  int n;
  /* ANS */ struct Edge {
  /* ANS */   int x, y;
  /* ANS */   ll c;
  /* ANS */ };
  /* ANS */ vector<Edge> edges;
  /* ANS */ int answer[N];
  void init(int nn) {
    n = nn;
    dsu.init(n);
    fill(eb, eb + n, Heap::null);
    edges.clear();
  }
  void addEdge(int x, int y, ll c) {
    Heap *h = new Heap(c, x);
    /* ANS */ h->ei = sz(edges);
    /* ANS */ edges.push_back({x, y, c});
    eb[y] = merge(eb[y], h);
  }
  ll solve(int root = 0) {
    ll ans = 0;
    static int done[N], pv[N];
    memset(done, 0, sizeof(int) * n);
    done[root] = 1;
    int tt = 1;
    /* ANS */ int cnum = 0;
    /* ANS */ static vector<ipair> eout[N];
    /* ANS */ for (int i = 0; i < n; ++i) eout[i].clear();
    for (int i = 0; i < n; ++i) {
      int v = dsu.get(i);
      if (done[v])
        continue;
      ++tt;
      while (true) {
        done[v] = tt;
        int nv = -1;
        while (eb[v] != Heap::null) {
          nv = dsu.get(eb[v]->ver);
          if (nv == v) {
            eb[v] = pop(eb[v]);
            continue;
          }
          break;
        }
        if (nv == -1)
          return LINF;
        ans += eb[v]->x;
        eb[v]->add(-eb[v]->x);
        /* ANS */ int ei = eb[v]->ei;
        /* ANS */ eout[edges[ei].x].push_back({++cnum, ei});
        if (!done[nv]) {
          pv[v] = nv;
          v = nv;
          continue;
        }
        if (done[nv] != tt)
          break;
        int v1 = nv;
        while (v1 != v) {
          eb[v] = merge(eb[v], eb[v1]);
          dsu.merge(v, v1);
          v1 = dsu.get(pv[v1]);
        }
      }
    }
    /* ANS */ memset(answer, -1, sizeof(int) * n);
    /* ANS */ answer[root] = 0;
    /* ANS */ set<ipair> es(all(eout[root]));
    /* ANS */ while (!es.empty()) {
    /* ANS */   auto it = es.begin();
    /* ANS */   int ei = it->second;
    /* ANS */   es.erase(it);
    /* ANS */   int nv = edges[ei].y;
    /* ANS */   if (answer[nv] != -1)
    /* ANS */     continue;
    /* ANS */   answer[nv] = ei;
    /* ANS */   es.insert(all(eout[nv]));
    /* ANS */ }
    /* ANS */ answer[root] = -1;
    return ans;
  }
  /* Usage: twoc::init(vertex_count);
   *   twoc::addEdge(v1, v2, cost);
   *   twoc::solve(root); - returns cost or LINF
   * twoc::answer contains index of ingoing edge for each vertex
   */
}
```

48 final/graphs/linkcut.cpp

```cpp
#include <iostream>
#include <cstdio>
#include <cassert>

using namespace std;

// BEGIN ALGO

const int MAXN = 110000;

typedef struct _node{
 _node *l, *r, *p, *pp;
 int size; bool rev;
 _node();
 explicit _node(nullptr_t){
  l = r = p = pp = this;
  size = rev = 0;
 }
 void push(){
  if (rev){
   l->rev ^= 1; r->rev ^= 1;
   rev = 0; swap(l,r);
  }
 }
 void update();
}* node;
node None = new _node(nullptr);
node v2n[MAXN];
_node::_node(){
 l = r = p = pp = None;
 size = 1; rev = false;
}
void _node::update(){
 size = (this != None) + l->size + r->size;
 l->p = r->p = this;
}
void rotate(node v){
 assert(v != None && v->p != None);
 assert(!v->rev); assert(!v->p->rev);
 node u = v->p;
 if (v == u->l)
  u->l = v->r, v->r = u;
 else
  u->r = v->l, v->l = u;
 swap(u->p,v->p); swap(v->pp,u->pp);
 if (v->p != None){
  assert(v->p->l == u || v->p->r == u);
  if (v->p->r == u) v->p->r = v;
  else v->p->l = v;
 }
 u->update(); v->update();
}
void bigRotate(node v){
 assert(v->p != None);
 v->p->p->push();
 v->p->push();
 v->push();
 if (v->p->p != None){
  if ((v->p->l == v) ^ (v->p->p->r == v->p))
   rotate(v->p);
  else
   rotate(v);
 }
 rotate(v);
}
inline void Splay(node v){
 while (v->p != None) bigRotate(v);
}
inline void splitAfter(node v){
 v->push();
 Splay(v);
 v->r->p = None;
```

```
 v->r->pp = v;
 v->r = None;
 v->update();
}
void expose(int x){
 node v = v2n[x];
 splitAfter(v);
 while (v->pp != None){
  assert(v->p == None);
  splitAfter(v->pp);
  assert(v->pp->r == None);
  assert(v->pp->p == None);
  assert(!v->pp->rev);
  v->pp->r = v;
  v->pp->update();
  v = v->pp;
  v->r->pp = None;
 }
 assert(v->p == None);
 Splay(v2n[x]);
}
inline void makeRoot(int x){
 expose(x);
 assert(v2n[x]->p == None);
 assert(v2n[x]->pp == None);
 assert(v2n[x]->r == None);
 v2n[x]->rev ^= 1;
}
inline void link(int x,int y){
 makeRoot(x); v2n[x]->pp = v2n[y];
}
inline void cut(int x,int y){
 expose(x);
 Splay(v2n[y]);
 if (v2n[y]->pp != v2n[x]){
  swap(x,y);
  expose(x);
  Splay(v2n[y]);
  assert(v2n[y]->pp == v2n[x]);
 }
 v2n[y]->pp = None;
}
inline int get(int x,int y){
 if (x == y) return 0;
 makeRoot(x);
 expose(y); expose(x);
 Splay(v2n[y]);
 if (v2n[y]->pp != v2n[x]) return -1;
 return v2n[y]->size;
}
// END ALGO

_node mem[MAXN];


int main(){
 freopen("linkcut.in","r",stdin);
 freopen("linkcut.out","w",stdout);

 int n,m;
 scanf("%d %d",&n,&m);

 for (int i = 0; i < n; i++)
  v2n[i] = &mem[i];

 for (int i = 0; i < m; i++){
  int a,b;
  if (scanf(" link %d %d",&a,&b) == 2)
   link(a-1,b-1);
  else if (scanf(" cut %d %d",&a,&b) == 2)
   cut(a-1,b-1);
  else if (scanf(" get %d %d",&a,&b) == 2)
   printf("%d\n",get(a-1,b-1));
  else
   assert(false);
 }
 return 0;
}
```

49 final/graphs/chordaltree.cpp

```
void chordaltree(vector<vector<int>> e) {
  int n = e.size();

  vector<int> mark(n);
  set<pair<int, int> > st;
  for (int i = 0; i < n; i++) st.insert({-mark[i], i});

  vector<int> vct(n);
  vector<pair<int, int> > ted;
  vector<vector<int> > who(n);
  vector<vector<int> > verts(1);
  vector<int> cliq(n, -1);
  cliq.push_back(0);
  vector<int> last(n + 1, n);
  int prev = n + 1;
  for (int i = n - 1; i >= 0; i--) {
    int x = st.begin()->second;
    st.erase(st.begin());
    if (mark[x] <= prev) {
      vector<int> cur = who[x];
      cur.push_back(x);
      verts.push_back(cur);
      ted.push_back({cliq[last[x]], (int)verts.size() - 1});
    } else {
      verts.back().push_back(x);
    }
    for (int y : e[x]) {
      if (cliq[y] != -1) continue;
      who[y].push_back(x);
      st.erase({-mark[y], y});
      mark[y]++;
      st.insert({-mark[y], y});
      last[y] = x;
    }
    prev = mark[x];
    vct[i] = x;
    cliq[x] = (int)verts.size() - 1;
  }

  int k = verts.size();
  vector<int> pr(k);
  vector<vector<int> > g(k);
  for (auto o : ted) {
    pr[o.second] = o.first;
    g[o.first].push_back(o.second);
  }
}
```

50 final/graphs/minimization.cpp

```
namespace mimimi /* ^_^ */ {
  const int N = 100555;
  const int S = 3;
  int e[N][S];
  int label[N];
  vector<int> eb[N][S];
  int ans[N];
  void solve(int n) {
    for (int i = 0; i < n; ++i)
      for (int j = 0; j < S; ++j)
        eb[i][j].clear();
    for (int i = 0; i < n; ++i)
      for (int j = 0; j < S; ++j)
        eb[e[i][j]][j].push_back(i);
    vector<unordered_set<int>> classes(*max_element(label, label + n) + 1);
    for (int i = 0; i < n; ++i)
      classes[label[i]].insert(i);
    for (int i = 0; i < sz(classes); ++i)
      if (classes[i].empty()) {
        classes[i].swap(classes.back());
        classes.pop_back();
        --i;
      }
    for (int i = 0; i < sz(classes); ++i)
      for (int v : classes[i])
        ans[v] = i;
    for (int i = 0; i < sz(classes); ++i)
      for (int c = 0; c < S; ++c) {
        unordered_map<int, unordered_set<int>> involved;
        for (int v : classes[i])
          for (int nv : eb[v][c])
            involved[ans[nv]].insert(nv);
        for (auto &pp : involved) {
          int cl = pp.X;
          auto &cls = classes[cl];
          if (sz(pp.Y) == sz(cls))
            continue;
          for (int x : pp.Y)
```

```cpp
            cls.erase(x);
          if (sz(cls) < sz(pp.Y))
            cls.swap(pp.Y);
          for (int x : pp.Y)
            ans[x] = sz(classes);
          classes.push_back(move(pp.Y));
        }
      }
  }
  /* Usage: initialize edges: e[vertex][character]
             labels: label[vertex]
       solve(n)
       ans[] - classes
  */
}
```

51 final/graphs/matroidIntersection.cpp

```cpp
struct Graph {
  vector<vector<int>> G;

  Graph(int n = 0) {
    G.resize(n);
  }

  void add_edge(int v, int u) {
    G[v].push_back(u);
  }

  vector<int> get_path(vector<int> &s, vector<int> &t) {
    int n = G.size();
    vector<int> dist(n, inf), pr(n, -1);
    queue<int> Q;
    for (int i : s) {
      dist[i] = 0;
      Q.push(i);
    }
    while (!Q.empty()) {
      int v = Q.front();
      Q.pop();
      for (int to : G[v]) if (dist[to] > dist[v] + 1) {
        dist[to] = dist[v] + 1;
        pr[to] = v;
        Q.push(to);
      }
    }
    int V = -1;
    for (int i : t) if (V == -1 || dist[i] < dist[V]) {
      V = i;
    }
    if (V == -1 || dist[V] == inf) return {};
    vector<int> path;
    while (V != -1) {
      path.push_back(V);
      V = pr[V];
    }
    return path;
  }
};

void get_ans(vector<int> &used, int m) {
  Graph G(m);
  for (int i = 0; i < m; ++i) if (used[i]) {
    Gauss gauss;
    vector<int> color(130, 0);
    for (int j = 0; j < m; ++j) if (used[j] && j != i) {
        gauss.add(a[j]);
        color[c[j]] = 1;
      }
    for (int j = 0; j < m; ++j) if (!used[j]) {
      if (gauss.check(a[j])) {
        G.add_edge(i, j);
      }
      if (!color[c[j]]) {
        G.add_edge(j, i);
      }
    }
  }

  Gauss gauss;
  vector<int> color(130, 0);
  for (int i = 0; i < m; ++i) if (used[i]) {
    gauss.add(a[i]);
    color[c[i]] = 1;
  }
  vector<int> x1, x2;
  for (int i = 0; i < m; ++i) if (!used[i]) {
    if (gauss.check(a[i])) {
      x1.push_back(i);
    }
    if (!color[c[i]]) {
      x2.push_back(i);
    }
  }
  vector<int> path = G.get_path(x1, x2);
  if (!path.size()) return;
  for (int i : path) used[i] ^= 1;
  get_ans(used, m);
}
```

dbl Simpson() { return (F(-1) + 4 * F(0) + F(1)) / 6; } dbl Runge2() { return (F(-sqrtl(1.0 / 3)) + F(sqrtl(1.0 / 3))) / 2; } dbl Runge3() { return (F(-sqrtl(3.0 / 5)) * 5 + F(0) * 8 + F(sqrtl(3.0 / 5)) * 5) / 18; }

Simpson и Runge2 – точны для полиномов степени <= 3 Runge3 – точен для полиномов степени <= 5

—

Явный Рунге-Кутт четвертого порядка, ошибка O(h^4)

y' = f(x, y) y_(n+1) = y_n + (k1 + 2 * k2 + 2 * k3 + k4) * h / 6

k1 = f(xn, yn) k2 = f(xn + h/2, yn + h/2 * k1) k3 = f(xn + h/2, yn + h/2 * k2) k4 = f(xn + h, yn + h * k3)

Методы Адамса-Башфорта

y_n+3 = y_n+2 + h * (23/12 * f(x_n+2,y_n+2) - 4/3 * f(x_n+1,y_n+1) + 5/12 * f(x_n,y_n)) y_n+4 = y_n+3 + h * (55/24 * f(x_n+3,y_n+3) - 59/24 * f(x_n+2,y_n+2) + 37/24 * f(x_n+1,y_n+1) - 3/8 * f(x_n,y_n)) y_n+5 = y_n+4 + h * (1901/720 * f(x_n+4,y_n+4) - 1387/360 * f(x_n+3,y_n+3) + 109/30 * f(x_n+2,y_n+2) - 637/360 * f(x_n+1,y_n+1) + 251/720 * f(x_n,y_n))

—

Извлечение корня по простому модулю (от Сережи) 3 <= p, 1 <= a < p, найти x^2 = a

1) Если a^((p - 1)/2) != 1, return -1 2) Выбрать случайный 1 <= i < p 3) T(x) = (x + i)^((p - 1)/2) mod (x^2 - a) = bx + c 4) Если b != 0 то вернуть c/b, иначе к шагу 2)

—

Иногда вместо того чтобы считать первообразный у простого числа, можно написать чекер ответа и перебирать случайный первообразный.

Иногда можно представить ответ в виде многочлена и вместо подсчета самих к-тов посчитать значения и проинтерполировать

—

Лемма Бернсайда:

Группа G действует на множество X Тогда число классов эквивалентности = (sum |f(g)| for g in G) / |G| где f(g) = число x (из X) : g(x) == x

—

Число простых быстрее O(n):

dp(n, k) – число чисел от 1 до n в которых все простые >= p[k] dp(n, 1) = n dp(n, j) = dp(n, j + 1) + dp(n / p[j], j), т. е. dp(n, j + 1) = dp(n, j) - dp(n / p[j], j)

Если p[j], p[k] > sqrt(n) то dp(n, j) + j == dp(n, k) + k

Делаешь все оптимайзы сверху, но не считаешь глубже dp(n, k), n < K Потом фенвиком+сортировкой подсчитываешь за (K+Q)log все эти запросы Делаешь во второй раз, но на этот раз берешь прекальканные значения

Если sqrt(n) < p[k] < n то (число простых до n)=dp(n, k) + k - 1

—

sum(k=1..n) k^2 = n(n+1)(2n+1)/6

sum(k=1..n) k^3 = n^2(n+1)^2/4

Чиселки:

Фибоначчи 45: 1134903170 46: 1836311903 47: 2971215073 91: 4660046610375530309 92: 7540113804746346429 93: 12200160415121876738

Числа с кучей делителей 20: d(12)=6 50: d(48)=10 100: d(60)=12 1000: d(840)=32 10^4: d(9240)=64 10^5: d(83160)=128 10^6: d(720720)=240 10^7: d(8648640)=448 10^8: d(91891800)=768 10^9: d(931170240)=1344 10^{11}: d(97772875200)=4032 10^{12}: d(963761198400)=6720 10^{15}: d(866421317361600)=26880 10^{18}: d(897612484786617600)=103680

Bell numbers: 0:1, 1:1, 2:2, 3:5, 4:15, 5:52, 6:203, 7:877, 8:4140, 9:21147, 10:115975, 11:678570, 12:4213597, 13:27644437, 14:190899322, 15:1382958545, 16:10480142147, 17:82864869804, 18:682076806159, 19:5832742205057, 20:51724158235372, 21:474869816156751, 22:4506715738447323, 23:44152005855084346

Catalan numbers: 0:1, 1:1, 2:2, 3:5, 4:14, 5:42, 6:132, 7:429, 8:1430, 9:4862, 10:16796, 11:58786, 12:208012, 13:742900, 14:2674440, 15:9694845, 16:35357670, 17:129644790, 18:477638700, 19:1767263190, 20:6564120420, 21:24466267020, 22:91482563640, 23:343059613650, 24:1289904147324, 25:4861946401452

Partitions numbers: 0:1, 1:1, 2:2, 3:3, 4:5, 5:7, 6:11, 7:15, 8:22, 9:30, 10:42, 20:627, 30:5604, 40:37338, 50:204226, 60:966467, 70:4087968, 80:15796476, 90:56634173, 100:190569292

prod (k=1..+inf) (1-x^k) = sum(q=-inf..+inf) (-1)^q x^((3q^2-q)/2)

Table of Integrals*

Basic Forms

$$\int x^n dx = \frac{1}{n+1}x^{n+1} \quad (1)$$

$$\int \frac{1}{x}dx = \ln|x| \quad (2)$$

$$\int udv = uv - \int vdu \quad (3)$$

$$\int \frac{1}{ax+b}dx = \frac{1}{a}\ln|ax+b| \quad (4)$$

Integrals of Rational Functions

$$\int \frac{1}{(x+a)^2}dx = -\frac{1}{x+a} \quad (5)$$

$$\int (x+a)^n dx = \frac{(x+a)^{n+1}}{n+1}, n \neq -1 \quad (6)$$

$$\int x(x+a)^n dx = \frac{(x+a)^{n+1}((n+1)x-a)}{(n+1)(n+2)} \quad (7)$$

$$\int \frac{1}{1+x^2}dx = \tan^{-1}x \quad (8)$$

$$\int \frac{1}{a^2+x^2}dx = \frac{1}{a}\tan^{-1}\frac{x}{a} \quad (9)$$

$$\int \frac{x}{a^2+x^2}dx = \frac{1}{2}\ln|a^2+x^2| \quad (10)$$

$$\int \frac{x^2}{a^2+x^2}dx = x - a\tan^{-1}\frac{x}{a} \quad (11)$$

$$\int \frac{x^3}{a^2+x^2}dx = \frac{1}{2}x^2 - \frac{1}{2}a^2\ln|a^2+x^2| \quad (12)$$

$$\int \frac{1}{ax^2+bx+c}dx = \frac{2}{\sqrt{4ac-b^2}}\tan^{-1}\frac{2ax+b}{\sqrt{4ac-b^2}} \quad (13)$$

$$\int \frac{1}{(x+a)(x+b)}dx = \frac{1}{b-a}\ln\frac{a+x}{b+x}, \ a \neq b \quad (14)$$

$$\int \frac{x}{(x+a)^2}dx = \frac{a}{a+x} + \ln|a+x| \quad (15)$$

$$\int \frac{x}{ax^2+bx+c}dx = \frac{1}{2a}\ln|ax^2+bx+c| - \frac{b}{a\sqrt{4ac-b^2}}\tan^{-1}\frac{2ax+b}{\sqrt{4ac-b^2}} \quad (16)$$

Integrals with Roots

$$\int \sqrt{x-a}\,dx = \frac{2}{3}(x-a)^{3/2} \quad (17)$$

$$\int \frac{1}{\sqrt{x\pm a}}dx = 2\sqrt{x\pm a} \quad (18)$$

$$\int \frac{1}{\sqrt{a-x}}dx = -2\sqrt{a-x} \quad (19)$$

$$\int x\sqrt{x-a}\,dx = \frac{2}{3}a(x-a)^{3/2} + \frac{2}{5}(x-a)^{5/2} \quad (20)$$

$$\int \sqrt{ax+b}\,dx = \left(\frac{2b}{3a} + \frac{2x}{3}\right)\sqrt{ax+b} \quad (21)$$

$$\int (ax+b)^{3/2}dx = \frac{2}{5a}(ax+b)^{5/2} \quad (22)$$

$$\int \frac{x}{\sqrt{x\pm a}}dx = \frac{2}{3}(x\mp 2a)\sqrt{x\pm a} \quad (23)$$

$$\int \sqrt{\frac{x}{a-x}}dx = -\sqrt{x(a-x)} - a\tan^{-1}\frac{\sqrt{x(a-x)}}{x-a} \quad (24)$$

$$\int \sqrt{\frac{x}{a+x}}dx = \sqrt{x(a+x)} - a\ln\left[\sqrt{x}+\sqrt{x+a}\right] \quad (25)$$

$$\int x\sqrt{ax+b}\,dx = \frac{2}{15a^2}(-2b^2+abx+3a^2x^2)\sqrt{ax+b} \quad (26)$$

$$\int \sqrt{x(ax+b)}\,dx = \frac{1}{4a^{3/2}}\left[(2ax+b)\sqrt{ax(ax+b)} - b^2\ln\left|a\sqrt{x}+\sqrt{a(ax+b)}\right|\right] \quad (27)$$

$$\int \sqrt{x^3(ax+b)}\,dx = \left[\frac{b}{12a} - \frac{b^2}{8a^2x} + \frac{x}{3}\right]\sqrt{x^3(ax+b)} + \frac{b^3}{8a^{5/2}}\ln\left|a\sqrt{x}+\sqrt{a(ax+b)}\right| \quad (28)$$

$$\int \sqrt{x^2\pm a^2}\,dx = \frac{1}{2}x\sqrt{x^2\pm a^2} \pm \frac{1}{2}a^2\ln\left|x+\sqrt{x^2\pm a^2}\right| \quad (29)$$

$$\int \sqrt{a^2-x^2}\,dx = \frac{1}{2}x\sqrt{a^2-x^2} + \frac{1}{2}a^2\tan^{-1}\frac{x}{\sqrt{a^2-x^2}} \quad (30)$$

$$\int x\sqrt{x^2\pm a^2}\,dx = \frac{1}{3}\left(x^2\pm a^2\right)^{3/2} \quad (31)$$

$$\int \frac{1}{\sqrt{x^2\pm a^2}}dx = \ln\left|x+\sqrt{x^2\pm a^2}\right| \quad (32)$$

$$\int \frac{1}{\sqrt{a^2-x^2}}dx = \sin^{-1}\frac{x}{a} \quad (33)$$

$$\int \frac{x}{\sqrt{x^2\pm a^2}}dx = \sqrt{x^2\pm a^2} \quad (34)$$

$$\int \frac{x}{\sqrt{a^2-x^2}}dx = -\sqrt{a^2-x^2} \quad (35)$$

$$\int \frac{x^2}{\sqrt{x^2\pm a^2}}dx = \frac{1}{2}x\sqrt{x^2\pm a^2} \mp \frac{1}{2}a^2\ln\left|x+\sqrt{x^2\pm a^2}\right| \quad (36)$$

$$\int \sqrt{ax^2+bx+c}\,dx = \frac{b+2ax}{4a}\sqrt{ax^2+bx+c} + \frac{4ac-b^2}{8a^{3/2}}\ln\left|2ax+b+2\sqrt{a(ax^2+bx^+c)}\right| \quad (37)$$

$$\int x\sqrt{ax^2+bx+c} = \frac{1}{48a^{5/2}}\Big(2\sqrt{a}\sqrt{ax^2+bx+c} \times \left(-3b^2+2abx+8a(c+ax^2)\right) + 3(b^3-4abc)\ln\left|b+2ax+2\sqrt{a}\sqrt{ax^2+bx+c}\right|\Big) \quad (38)$$

$$\int \frac{1}{\sqrt{ax^2+bx+c}}dx = \frac{1}{\sqrt{a}}\ln\left|2ax+b+2\sqrt{a(ax^2+bx+c)}\right| \quad (39)$$

$$\int \frac{x}{\sqrt{ax^2+bx+c}}dx = \frac{1}{a}\sqrt{ax^2+bx+c} - \frac{b}{2a^{3/2}}\ln\left|2ax+b+2\sqrt{a(ax^2+bx+c)}\right| \quad (40)$$

$$\int \frac{dx}{(a^2+x^2)^{3/2}} = \frac{x}{a^2\sqrt{a^2+x^2}} \quad (41)$$

Integrals with Logarithms

$$\int \ln ax\,dx = x\ln ax - x \quad (42)$$

$$\int \frac{\ln ax}{x}dx = \frac{1}{2}(\ln ax)^2 \quad (43)$$

$$\int \ln(ax+b)dx = \left(x+\frac{b}{a}\right)\ln(ax+b) - x, a \neq 0 \quad (44)$$

$$\int \ln(x^2+a^2)\,\mathrm{d}x = x\ln(x^2+a^2) + 2a\tan^{-1}\frac{x}{a} - 2x \quad (45)$$

$$\int \ln(x^2-a^2)\,\mathrm{d}x = x\ln(x^2-a^2) + a\ln\frac{x+a}{x-a} - 2x \quad (46)$$

$$\int \ln\left(ax^2+bx+c\right)\mathrm{d}x = \frac{1}{a}\sqrt{4ac-b^2}\tan^{-1}\frac{2ax+b}{\sqrt{4ac-b^2}} - 2x + \left(\frac{b}{2a}+x\right)\ln\left(ax^2+bx+c\right) \quad (47)$$

$$\int x\ln(ax+b)dx = \frac{bx}{2a} - \frac{1}{4}x^2 + \frac{1}{2}\left(x^2-\frac{b^2}{a^2}\right)\ln(ax+b) \quad (48)$$

$$\int x\ln\left(a^2-b^2x^2\right)\mathrm{d}x = -\frac{1}{2}x^2 + \frac{1}{2}\left(x^2-\frac{a^2}{b^2}\right)\ln\left(a^2-b^2x^2\right) \quad (49)$$

Integrals with Exponentials

$$\int e^{ax}dx = \frac{1}{a}e^{ax} \quad (50)$$

$$\int \sqrt{x}e^{ax}dx = \frac{1}{a}\sqrt{x}e^{ax} + \frac{i\sqrt{\pi}}{2a^{3/2}}\mathrm{erf}\left(i\sqrt{ax}\right), \text{ where } \mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt \quad (51)$$

$$\int xe^x dx = (x-1)e^x \quad (52)$$

$$\int xe^{ax}dx = \left(\frac{x}{a}-\frac{1}{a^2}\right)e^{ax} \quad (53)$$

$$\int x^2e^x dx = \left(x^2-2x+2\right)e^x \quad (54)$$

$$\int x^2e^{ax}dx = \left(\frac{x^2}{a}-\frac{2x}{a^2}+\frac{2}{a^3}\right)e^{ax} \quad (55)$$

$$\int x^3e^x dx = \left(x^3-3x^2+6x-6\right)e^x \quad (56)$$

$$\int x^n e^{ax}\,\mathrm{d}x = \frac{x^n e^{ax}}{a} - \frac{n}{a}\int x^{n-1}e^{ax}\,\mathrm{d}x \quad (57)$$

$$\int x^n e^{ax}\,\mathrm{d}x = \frac{(-1)^n}{a^{n+1}}\Gamma[1+n,-ax], \text{ where } \Gamma(a,x) = \int_x^\infty t^{a-1}e^{-t}\,\mathrm{d}t \quad (58)$$

$$\int e^{ax^2}\,\mathrm{d}x = -\frac{i\sqrt{\pi}}{2\sqrt{a}}\mathrm{erf}\left(ix\sqrt{a}\right) \quad (59)$$

$$\int e^{-ax^2}\,\mathrm{d}x = \frac{\sqrt{\pi}}{2\sqrt{a}}\mathrm{erf}\left(x\sqrt{a}\right) \quad (60)$$

$$\int xe^{-ax^2}\,\mathrm{d}x = -\frac{1}{2a}e^{-ax^2} \quad (61)$$

$$\int x^2e^{-ax^2}\,\mathrm{d}x = \frac{1}{4}\sqrt{\frac{\pi}{a^3}}\mathrm{erf}(x\sqrt{a}) - \frac{x}{2a}e^{-ax^2} \quad (62)$$

Integrals with Trigonometric Functions

$$\int \sin ax dx = -\frac{1}{a}\cos ax \tag{63}$$

$$\int \sin^2 ax dx = \frac{x}{2} - \frac{\sin 2ax}{4a} \tag{64}$$

$$\int \sin^n ax dx = -\frac{1}{a}\cos ax \;\, {}_2F_1\left[\frac{1}{2}, \frac{1-n}{2}, \frac{3}{2}, \cos^2 ax\right] \tag{65}$$

$$\int \sin^3 ax dx = -\frac{3\cos ax}{4a} + \frac{\cos 3ax}{12a} \tag{66}$$

$$\int \cos ax dx = \frac{1}{a}\sin ax \tag{67}$$

$$\int \cos^2 ax dx = \frac{x}{2} + \frac{\sin 2ax}{4a} \tag{68}$$

$$\int \cos^p ax dx = -\frac{1}{a(1+p)}\cos^{1+p} ax \times {}_2F_1\left[\frac{1+p}{2}, \frac{1}{2}, \frac{3+p}{2}, \cos^2 ax\right] \tag{69}$$

$$\int \cos^3 ax dx = \frac{3\sin ax}{4a} + \frac{\sin 3ax}{12a} \tag{70}$$

$$\int \cos ax \sin bx dx = \frac{\cos[(a-b)x]}{2(a-b)} - \frac{\cos[(a+b)x]}{2(a+b)}, a \neq b \tag{71}$$

$$\int \sin^2 ax \cos bx dx = -\frac{\sin[(2a-b)x]}{4(2a-b)} + \frac{\sin bx}{2b} - \frac{\sin[(2a+b)x]}{4(2a+b)} \tag{72}$$

$$\int \sin^2 x \cos x dx = \frac{1}{3}\sin^3 x \tag{73}$$

$$\int \cos^2 ax \sin bx dx = \frac{\cos[(2a-b)x]}{4(2a-b)} - \frac{\cos bx}{2b} - \frac{\cos[(2a+b)x]}{4(2a+b)} \tag{74}$$

$$\int \cos^2 ax \sin ax dx = -\frac{1}{3a}\cos^3 ax \tag{75}$$

$$\int \sin^2 ax \cos^2 bx dx = \frac{x}{4} - \frac{\sin 2ax}{8a} - \frac{\sin[2(a-b)x]}{16(a-b)} + \frac{\sin 2bx}{8b} - \frac{\sin[2(a+b)x]}{16(a+b)} \tag{76}$$

$$\int \sin^2 ax \cos^2 ax dx = \frac{x}{8} - \frac{\sin 4ax}{32a} \tag{77}$$

$$\int \tan ax dx = -\frac{1}{a}\ln\cos ax \tag{78}$$

$$\int \tan^2 ax dx = -x + \frac{1}{a}\tan ax \tag{79}$$

$$\int \tan^n ax dx = \frac{\tan^{n+1} ax}{a(1+n)} \times {}_2F_1\left(\frac{n+1}{2}, 1, \frac{n+3}{2}, -\tan^2 ax\right) \tag{80}$$

$$\int \tan^3 ax dx = \frac{1}{a}\ln\cos ax + \frac{1}{2a}\sec^2 ax \tag{81}$$

$$\int \sec x dx = \ln|\sec x + \tan x| = 2\tanh^{-1}\left(\tan\frac{x}{2}\right) \tag{82}$$

$$\int \sec^2 ax dx = \frac{1}{a}\tan ax \tag{83}$$

$$\int \sec^3 x \, \mathrm{dx} = \frac{1}{2}\sec x \tan x + \frac{1}{2}\ln|\sec x + \tan x| \tag{84}$$

$$\int \sec x \tan x dx = \sec x \tag{85}$$

$$\int \sec^2 x \tan x dx = \frac{1}{2}\sec^2 x \tag{86}$$

$$\int \sec^n x \tan x dx = \frac{1}{n}\sec^n x, n \neq 0 \tag{87}$$

$$\int \csc x dx = \ln\left|\tan\frac{x}{2}\right| = \ln|\csc x - \cot x| + C \tag{88}$$

$$\int \csc^2 ax dx = -\frac{1}{a}\cot ax \tag{89}$$

$$\int \csc^3 x dx = -\frac{1}{2}\cot x \csc x + \frac{1}{2}\ln|\csc x - \cot x| \tag{90}$$

$$\int \csc^n x \cot x dx = -\frac{1}{n}\csc^n x, n \neq 0 \tag{91}$$

$$\int \sec x \csc x dx = \ln|\tan x| \tag{92}$$

Products of Trigonometric Functions and Monomials

$$\int x \cos x dx = \cos x + x \sin x \tag{93}$$

$$\int x \cos ax dx = \frac{1}{a^2}\cos ax + \frac{x}{a}\sin ax \tag{94}$$

$$\int x^2 \cos x dx = 2x\cos x + \left(x^2 - 2\right)\sin x \tag{95}$$

$$\int x^2 \cos ax dx = \frac{2x\cos ax}{a^2} + \frac{a^2x^2 - 2}{a^3}\sin ax \tag{96}$$

$$\int x^n cosx dx = -\frac{1}{2}(i)^{n+1}\left[\Gamma(n+1, -ix) + (-1)^n\Gamma(n+1, ix)\right] \tag{97}$$

$$\int x^n cosax dx = \frac{1}{2}(ia)^{1-n}\left[(-1)^n\Gamma(n+1, -iax) - \Gamma(n+1, ixa)\right] \tag{98}$$

$$\int x \sin x dx = -x\cos x + \sin x \tag{99}$$

$$\int x \sin ax dx = -\frac{x\cos ax}{a} + \frac{\sin ax}{a^2} \tag{100}$$

$$\int x^2 \sin x dx = \left(2 - x^2\right)\cos x + 2x\sin x \tag{101}$$

$$\int x^2 \sin ax dx = \frac{2 - a^2x^2}{a^3}\cos ax + \frac{2x\sin ax}{a^2} \tag{102}$$

$$\int x^n \sin x dx = -\frac{1}{2}(i)^n\left[\Gamma(n+1, -ix) - (-1)^n\Gamma(n+1, -ix)\right] \tag{103}$$

Products of Trigonometric Functions and Exponentials

$$\int e^x \sin x dx = \frac{1}{2}e^x(\sin x - \cos x) \tag{104}$$

$$\int e^{bx}\sin ax dx = \frac{1}{a^2+b^2}e^{bx}(b\sin ax - a\cos ax) \tag{105}$$

$$\int e^x \cos x dx = \frac{1}{2}e^x(\sin x + \cos x) \tag{106}$$

$$\int e^{bx}\cos ax dx = \frac{1}{a^2+b^2}e^{bx}(a\sin ax + b\cos ax) \tag{107}$$

$$\int xe^x \sin x dx = \frac{1}{2}e^x(\cos x - x\cos x + x\sin x) \tag{108}$$

$$\int xe^x \cos x dx = \frac{1}{2}e^x(x\cos x - \sin x + x\sin x) \tag{109}$$

Integrals of Hyperbolic Functions

$$\int \cosh ax dx = \frac{1}{a}\sinh ax \tag{110}$$

$$\int e^{ax}\cosh bx dx = \begin{cases} \dfrac{e^{ax}}{a^2-b^2}[a\cosh bx - b\sinh bx] & a \neq b \\ \dfrac{e^{2ax}}{4a} + \dfrac{x}{2} & a = b \end{cases} \tag{111}$$

$$\int \sinh ax dx = \frac{1}{a}\cosh ax \tag{112}$$

$$\int e^{ax}\sinh bx dx = \begin{cases} \dfrac{e^{ax}}{a^2-b^2}[-b\cosh bx + a\sinh bx] & a \neq b \\ \dfrac{e^{2ax}}{4a} - \dfrac{x}{2} & a = b \end{cases} \tag{113}$$

$$\int e^{ax}\tanh bx dx = \begin{cases} \dfrac{e^{(a+2b)x}}{(a+2b)}{}_2F_1\left[1+\dfrac{a}{2b}, 1, 2+\dfrac{a}{2b}, -e^{2bx}\right] \\ \quad -\dfrac{1}{a}e^{ax}{}_2F_1\left[\dfrac{a}{2b}, 1, 1E, -e^{2bx}\right] & a \neq b \\ \dfrac{e^{ax} - 2\tan^{-1}[e^{ax}]}{a} & a = b \end{cases} \tag{114}$$

$$\int \tanh ax \, dx = \frac{1}{a}\ln\cosh ax \tag{115}$$

$$\int \cos ax \cosh bx dx = \frac{1}{a^2+b^2}\left[a\sin ax\cosh bx + b\cos ax\sinh bx\right] \tag{116}$$

$$\int \cos ax \sinh bx dx = \frac{1}{a^2+b^2}\left[b\cos ax\cosh bx + a\sin ax\sinh bx\right] \tag{117}$$

$$\int \sin ax \cosh bx dx = \frac{1}{a^2+b^2}\left[-a\cos ax\cosh bx + b\sin ax\sinh bx\right] \tag{118}$$

$$\int \sin ax \sinh bx dx = \frac{1}{a^2+b^2}\left[b\cosh bx\sin ax - a\cos ax\sinh bx\right] \tag{119}$$

$$\int \sinh ax \cosh ax dx = \frac{1}{4a}\left[-2ax + \sinh 2ax\right] \tag{120}$$

$$\int \sinh ax \cosh bx dx = \frac{1}{b^2-a^2}\left[b\cosh bx\sinh ax - a\cosh ax\sinh bx\right] \tag{121}$$