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final/template/vimrc.txt

```

1  map <F9> :wall! <CR> :!g++ -Wall -Wextra -Wshadow -↵
    Wno-unused-result -o %:r % -std=c++14 -DHOME -↵
    D_GLIBCXX_DEBUG -fsanitize=address <CR>
2  map <F7> :wall! <CR> :!g++ -Wall -Wextra -Wshadow -↵
    Wno-unused-result -o %:r % -std=c++14 -DHOME -↵
    O2 <CR>
3  map <F8> :wall! <CR> :!ulimit -s 500000 && ./%:r <CR>↵
    >
4
5  inoremap {<CR> {<CR>}<ESC>O
2  6  map <c-a> ggVG
7
8  set nu
2  9  set rnu
10 syntax on
11
12 map <c-t> :tabnew <CR>
13 map <c-l> :tabn <CR>
4  14 map <c-h> :tabp <CR>
15
16
4  17 set cin
18 set sw=4
19 set so=99
5  20 set bs=2
21 set et
    set sts=4

```

final/template/template.cpp

```

7  1  // team : SPb ITMO University 1
2  #include <bits/stdc++.h>
3
4  #define F first
5  #define S second
6  #define pb push_back
8  7  #define forn(i, n) for(int i = 0 ; (i) < (n) ; ++i)
8  #define eprintf(...) fprintf(stderr, __VA_ARGS__) ,↵
    fflush(stderr)
8  9  #define sz(a) ((int)(a).size())
10 #define all(a) (a).begin(), a.end()
9  11 #define pw(x) (1LL<<(x))
12
13 using namespace std;
9  14
15 typedef long long ll;
16 typedef double dbl;
10 17 typedef vector<int> vi;
18 typedef pair<int, int> pi;
19
10 20 const int INF = 1.01e9;
21 const dbl eps = 1e-9;
10 22
23 /* — main part — */
24
11 25
26
27
11 28
29
30
12 31 int main()
32 {
12 33 #define TASK ""
34 #ifdef home
35     assert(freopen(TASK".in", "r", stdin));
12 36     //assert(freopen(TASK".out", "w", stdout));
37 #endif
38
13 39
40
14 41
42
43 #ifdef home
14 44     eprintf("time = %d ms\n", (int)(clock() * 1000. / ↵
        CLOCKS_PER_SEC));
45 #endif
46     return 0;
15 47 }

```

final/template/fastIO.cpp

```

1 #include <stdio>
2 #include <algorithm>
3
4 /** Interface */
5
6 inline int readInt();
7 inline int readUInt();
8 inline bool isEof();
9
10 /** Read */
11
12 static const int buf_size = 100000;
13 static char buf[buf_size];
14 static int buf_len = 0, pos = 0;
15
16 inline bool isEof() {
17     if (pos == buf_len) {
18         pos = 0, buf_len = fread(buf, 1, buf_size, stdin);
19     }
20     if (pos == buf_len) return 1;
21     return 0;
22 }
23
24 inline int getChar() { return isEof() ? -1 : buf[pos++]; }
25
26 inline int readChar() {
27     int c = getChar();
28     while (c != -1 && c <= 32) c = getChar();
29     return c;
30 }
31
32 inline int readUInt() {
33     int c = readChar(), x = 0;
34     while ('0' <= c && c <= '9') x = x * 10 + c - '0', c = getChar();
35     return x;
36 }
37
38 inline int readInt() {
39     int s = 1, c = readChar();
40     int x = 0;
41     if (c == '-') s = -1, c = getChar();
42     while ('0' <= c && c <= '9') x = x * 10 + c - '0', c = getChar();
43     return s == 1 ? x : -x;
44 }
45
46 // 10M int [0..1e9]
47 // cin 3.02
48 // scanf 1.2
49 // cin_sync_with_stdio(false) 0.71
50 // fastRead getchar 0.53
51 // fastRead fread 0.15
52

```

```

23     return f[i];
24 }
25 };
26
27 hashTable<13, int, int, 0> h;
28
29 #include "ext/pb_ds/assoc_container.hpp"
30 using namespace __gnu_pbds;
31
32 template <typename T> using ordered_set = tree<T, ←
33     null_type, less<T>, rb_tree_tag, ←
34     tree_order_statistics_node_update>;
35
36 template <typename K, typename V> using ordered_map = ←
37     tree<K, V, less<K>, rb_tree_tag, ←
38     tree_order_statistics_node_update>;
39
40 // HOW TO USE ::
41 // -- order_of_key(10) returns the number of ←
42 //    elements in set/map strictly less than 10
43 // -- *find_by_order(10) returns 10-th smallest ←
44 //    element in set/map (0-based)
45

```

final/template/optimizations.cpp

```

1 // from anta code http://codeforces.com/contest/755/←
2 // submission/23864531
3
4 #pragma GCC optimize ("O3")
5 #pragma GCC target ("sse4")
6 inline void fasterLLDivMod(unsigned long long x, ←
7     unsigned y, unsigned &out_d, unsigned &out_m) {
8     unsigned xh = (unsigned)(x >> 32), xl = (unsigned)←
9         x, d, m;
10 #ifdef __GNUC__
11     asm(
12         "divl %4; \n\t"
13         : "=a" (d), "=d" (m)
14         : "d" (xh), "a" (xl), "r" (y)
15     );
16 #else
17     __asm {
18         mov edx, dword ptr[xh];
19         mov eax, dword ptr[xl];
20         div dword ptr[y];
21         mov dword ptr[d], eax;
22         mov dword ptr[m], edx;
23     };
24 #endif
25     out_d = d; out_m = m;
26 }
27
28 // have no idea what sse flags are really cool; list ←
29 // of some of them
30 // -- very good with bitsets
31 #pragma GCC optimize("O3")
32 #pragma GCC target("sse,sse2,sse3,ssse3,sse4,popcnt,←
33     abm,mmx")
34

```

final/template/hashTable.cpp

```

1 template <const int max_size, class HashType, class ←
2     Data, const Data default_value>
3 struct hashTable {
4     HashType hash[max_size];
5     Data f[max_size];
6     int size;
7
8     int position(HashType H) const {
9         int i = H % max_size;
10        while (hash[i] && hash[i] != H)
11            if (++i == max_size)
12                i = 0;
13        return i;
14    }
15
16    Data & operator [] (HashType H) {
17        assert(H != 0);
18        int i = position(H);
19        if (!hash[i]) {
20            hash[i] = H;
21            f[i] = default_value;
22            size++;
23        }
24    }
25

```

final/template/Template.java

```

1 import java.util.*;
2 import java.io.*;
3
4 public class Template {
5     FastScanner in;
6     PrintWriter out;
7
8     public void solve() throws IOException {
9         int n = in.nextInt();
10        out.println(n);
11    }
12
13    public void run() {
14        try {
15            in = new FastScanner();
16            out = new PrintWriter(System.out);
17
18            solve();
19
20            out.close();
21        }
22    }
23

```

```

21     } catch (IOException e) {
22         e.printStackTrace();
23     }
24 }
25
26 class FastScanner {
27     BufferedReader br;
28     StringTokenizer st;
29
30     FastScanner() {
31         br = new BufferedReader(new InputStreamReader(↵
32             System.in));
33     }
34
35     String next() {
36         while (st == null || !st.hasMoreTokens()) {
37             try {
38                 st = new StringTokenizer(br.readLine());
39             } catch (IOException e) {
40                 e.printStackTrace();
41             }
42         }
43         return st.nextToken();
44     }
45
46     int nextInt() {
47         return Integer.parseInt(next());
48     }
49 }
50
51 public static void main(String[] arg) {
52     new Template().run();
53 }

```

final/numeric/fft.cpp

```

1  namespace fft
2  {
3      const int maxBase = 21;
4      const int maxN = 1 << maxBase;
5
6      struct num
7      {
8          dbl x, y;
9          num() {}
10         num(dbl xx, dbl yy): x(xx), y(yy) {}
11         num(dbl alp): x(cos(alp)), y(sin(alp)) {}
12     };
13
14     inline num operator + (num a, num b) { return num(↵
15         a.x + b.x, a.y + b.y); }
16     inline num operator - (num a, num b) { return num(↵
17         a.x - b.x, a.y - b.y); }
18     inline num operator * (num a, num b) { return num(↵
19         a.x * b.x - a.y * b.y, a.x * b.y + a.y * b.x); ↵
20     }
21     inline num conj(num a) { return num(a.x, -a.y); }
22
23     const dbl PI = acos(-1);
24
25     num root[maxN];
26     int rev[maxN];
27     bool rootsPrepared = false;
28
29     void prepRoots()
30     {
31         if (rootsPrepared) return;
32         rootsPrepared = true;
33         root[1] = num(1, 0);
34         for (int k = 1; k < maxBase; ++k)
35         {
36             num x(2 * PI / pw(k + 1));
37             for (int i = pw(k - 1); i < pw(k); ++i)
38             {
39                 root[2 * i] = root[i];
40                 root[2 * i + 1] = root[i] * x;
41             }
42         }
43     }
44
45     int base, N;
46
47     int lastRevN = -1;
48     void prepRev()
49     {
50         if (lastRevN == N) return;
51         lastRevN = N;
52         forn(i, N) rev[i] = (rev[i >> 1] >> 1) + ((i & ↵
53             1) << (base - 1));
54     }
55
56     void fft(num *a, num *f)
57     {
58         forn(i, N) f[i] = a[rev[i]];
59         for (int k = 1; k < N; k <= 1) for (int i = 0; ↵
60             i < N; i += 2 * k) forn(j, k)
61         {
62             num z = f[i + j + k] * root[j + k];
63             f[i + j + k] = f[i + j] - z;
64             f[i + j] = f[i + j] + z;
65         }
66     }
67
68     num a[maxN], b[maxN], f[maxN], g[maxN];
69     ll A[maxN], B[maxN], C[maxN];
70
71     void _multMod(int mod)
72     {
73         forn(i, N)
74         {
75             int x = A[i] % mod;
76             a[i] = num(x & (pw(15) - 1), x >> 15);
77         }
78         forn(i, N)
79         {
80             int x = B[i] % mod;
81             b[i] = num(x & (pw(15) - 1), x >> 15);
82         }
83         fft(a, f);
84         fft(b, g);
85
86         forn(i, N)
87         {
88             int j = (N - i) & (N - 1);
89

```

```

83     num a1 = (f[i] + conj(f[j])) * num(0.5, 0);
84     num a2 = (f[i] - conj(f[j])) * num(0, -0.5);
85     num b1 = (g[i] + conj(g[j])) * num(0.5 / N, 0) ←
;
86     num b2 = (g[i] - conj(g[j])) * num(0, -0.5 / N ←
);
87     a[j] = a1 * b1 + a2 * b2 * num(0, 1);
88     b[j] = a1 * b2 + a2 * b1;
89 }
90
91 fft(a, f);
92 fft(b, g);
93
94 forn(i, N)
95 {
96     ll aa = f[i].x + 0.5;
97     ll bb = g[i].x + 0.5;
98     ll cc = f[i].y + 0.5;
99     C[i] = (aa + bb % mod * pw(15) + cc % mod * pw ←
(30)) % mod;
100 }
101
102
103 void prepAB(int n1, int n2)
104 {
105     base = 1;
106     N = 2;
107     while (N < n1 + n2) base++, N <= 1;
108
109     for (int i = n1; i < N; ++i) A[i] = 0;
110     for (int i = n2; i < N; ++i) B[i] = 0;
111
112     prepRoots();
113     prepRev();
114 }
115
116 void mult(int n1, int n2)
117 {
118     prepAB(n1, n2);
119     forn(i, N) a[i] = num(A[i], B[i]);
120     fft(a, f);
121     forn(i, N)
122     {
123         int j = (N - i) & (N - 1);
124         a[i] = (f[j] * f[j] - conj(f[i] * f[i])) * num ←
(0, -0.25 / N);
125     }
126     fft(a, f);
127     forn(i, N) C[i] = (ll)round(f[i].x);
128 }
129
130
131 void multMod(int n1, int n2, int mod)
132 {
133     prepAB(n1, n2);
134     _multMod(mod);
135 }
136
137 int D[maxN];
138
139 void multLL(int n1, int n2)
140 {
141     prepAB(n1, n2);
142
143     int mod1 = 1.5e9;
144     int mod2 = mod1 + 1;
145
146     _multMod(mod1);
147
148     forn(i, N) D[i] = C[i];
149
150     _multMod(mod2);
151
152     forn(i, N)
153     {
154         C[i] = D[i] + (C[i] - D[i] + (ll)mod2) * (ll) ←
mod1 % mod2 * mod1;
155     }
156 }
157 // HOW TO USE ::
158 // — set correct maxBase
159 // — use mult(n1, n2), multMod(n1, n2, mod) and ←
multLL(n1, n2)
160 // — input : A[], B[]
161 // — output : C[]
162 }

```

final/numeric/fftint.cpp

```

1 namespace fft
2 {
3     const int mod = 998244353;
4     const int base = 20;
5     const int N = 1 << base;
6     const int ROOT = 646;
7
8     int root[N];
9     int rev[N];
10
11 void init()
12 {
13     forn(i, N) rev[i] = (rev[i >> 1] >> 1) + ((i & ←
1) << (base - 1));
14     int NN = N >> 1;
15     int z = 1;
16     forn(i, NN)
17     {
18         root[i + NN] = z;
19         z = z * (ll)ROOT % mod;
20     }
21     for (int i = NN - 1; i > 0; --i) root[i] = root ←
[2 * i];
22 }
23
24 void fft(int *a, int *f)
25 {
26     forn(i, N) f[i] = a[rev[i]];
27     for (int k = 1; k < N; k <= 1) for (int i = 0; ←
i < N; i += 2 * k) forn(j, k)
28     {
29         int z = f[i + j + k] * (ll)root[j + k] % mod;
30         f[i + j + k] = (f[i + j] - z + mod) % mod;
31         f[i + j] = (f[i + j] + z) % mod;
32     }
33 }
34
35 int A[N], B[N], C[N];
36 int F[N], G[N];
37
38 void _mult(int eq)
39 {
40     fft(A, F);
41     if (eq) forn(i, N) G[i] = F[i];
42     else fft(B, G);
43     int invN = inv(N);
44     forn(i, N) A[i] = F[i] * (ll)G[i] % mod * invN % ←
mod;
45     reverse(A + 1, A + N);
46     fft(A, C);
47 }
48
49 void mult(int n1, int n2, int eq = 0)
50 {
51     for (int i = n1; i < N; ++i) A[i] = 0;
52     for (int i = n2; i < N; ++i) B[i] = 0;
53
54     _mult(eq);
55
56     //forn(i, n1 + n2) C[i] = 0;
57     //forn(i, n1) forn(j, n2) C[i + j] = (C[i + j] + ←
A[i] * (ll)B[j]) % mod;
58 }
59 }

```

final/numeric/blackbox.cpp

```

1 namespace blackbox
2 {
3     int A[N];
4     int B[N];
5     int C[N];
6
7     int magic(int k, int x)
8     {
9         B[k] = x;
10        C[k] = (C[k] + A[0] * (ll)B[k]) % mod;
11        int z = 1;
12        if (k == N - 1) return C[k];
13        while ((k & (z - 1)) == (z - 1))
14        {
15            //mult B[k - z + 1 ... k] x A[z .. 2 * z - 1]
16            forn(i, z) fft::A[i] = A[z + i];
17            forn(i, z) fft::B[i] = B[k - z + 1 + i];
18            fft::multMod(z, z, mod);
19            forn(i, 2 * z - 1) C[k + 1 + i] = (C[k + 1 + i] ←
+ fft::C[i]) % mod;

```

```

20     z <=<= 1;
21 }
22 return C[k];
23 }
24 // A — constant array
25 // magic(k, x):: B[k] = x, returns C[k]
26 // !! WARNING !! better to set N twice the size ←
27 // needed

```

final/numeric/crt.cpp

```

1 int rev(int x, int m)
2 {
3     if (x == 1) return 1;
4     return (1 - rev(m % x, x) * (ll)m) / x + m;
5 }
6
7 int CRT(int a1, int m1, int a2, int m2)
8 {
9     return (a1 - a2 % m1 + m1) * (ll)rev(m2, m1) % m1 ←
10     * m2 + a2;

```

```

56 ll n = N;
57
58
59 for (int i = 0; i < math::pc && p[i] < MX; ++i) ←
60 if (n % p[i] == 0)
61 {
62     primes.pb(p[i]);
63     while (n % p[i] == 0) n /= p[i];
64 }
65
66 go(n);
67
68 sort(primes.begin(), primes.end());
69
70 vector<pair<ll, int>> res;
71 for (ll x : primes)
72 {
73     int cnt = 0;
74     while (N % x == 0)
75     {
76         cnt++;
77         N /= x;
78     }
79     res.push_back({x, cnt});
80 }
81 return res;
82 }

```

final/numeric/pollard.cpp

```

1 namespace pollard
2 {
3     using math::p;
4
5     vector<pair<ll, int>> getFactors(ll N)
6     {
7         vector<ll> primes;
8
9         const int MX = 1e5;
10        const ll MX2 = MX * (ll)MX;
11
12        assert(MX <= math::maxP && math::pc > 0);
13
14        function<void(ll)> go = [&go, &primes](ll n)
15        {
16            for (ll x : primes) while (n % x == 0) n /= x;
17            if (n == 1) return;
18            if (n > MX2)
19            {
20                auto F = [&](ll x) {
21                    ll k = ((long double)x * x) / n;
22                    ll r = (x * x - k * n + 3) % n;
23                    return r < 0 ? r + n : r;
24                };
25                ll x = mt19937_64()() % n, y = x;
26                const int C = 3 * pow(n, 0.25);
27
28                ll val = 1;
29                forn(it, C)
30                {
31                    x = F(x), y = F(F(y));
32                    if (x == y) continue;
33                    ll delta = abs(x - y);
34                    ll k = ((long double)val * delta) / n;
35                    val = (val * delta - k * n) % n;
36                    if (val < 0) val += n;
37                    if (val == 0)
38                    {
39                        ll g = __gcd(delta, n);
40                        go(g), go(n / g);
41                        return;
42                    }
43                    if ((it & 255) == 0)
44                    {
45                        ll g = __gcd(val, n);
46                        if (g != 1)
47                        {
48                            go(g), go(n / g);
49                            return;
50                        }
51                    }
52                }
53            }
54            primes.pb(n);
55        };

```

final/numeric/poly.cpp

```

1 struct poly
2 {
3     vi v;
4     poly() {}
5     poly(vi vv)
6     {
7         v = vv;
8     }
9     int size()
10    {
11        return (int)v.size();
12    }
13    poly cut(int maxLen)
14    {
15        if (maxLen < sz(v)) v.resize(maxLen);
16        return *this;
17    }
18    poly norm()
19    {
20        while (sz(v) > 1 && v.back() == 0) v.pop_back();
21        return *this;
22    }
23    inline int& operator [] (int i)
24    {
25        return v[i];
26    }
27    void out(string name="")
28    {
29        stringstream ss;
30        if (sz(name)) ss << name << " = ";
31        int fst = 1;
32        forn(i, sz(v)) if (v[i])
33        {
34            int x = v[i];
35            int sgn = 1;
36            if (x > mod / 2) x = mod - x, sgn = -1;
37            if (sgn == -1) ss << "-";
38            else if (!fst) ss << "+";
39            fst = 0;
40            if (!i || x != 1)
41            {
42                ss << x;
43                if (i > 0) ss << "*x";
44                if (i > 1) ss << "^" << i;
45            }
46            else
47            {
48                ss << "x";
49                if (i > 1) ss << "^" << i;
50            }
51        }
52        if (fst) ss << "0";
53        string s;
54        ss >> s;
55        eprintf("%s\n", s.data());
56    }

```

```

57 };
58
59 poly operator + (poly A, poly B)
60 {
61     poly C;
62     C.v = vi(max(sz(A), sz(B)));
63     forn(i, sz(C))
64     {
65         if (i < sz(A)) C[i] = (C[i] + A[i]) % mod;
66         if (i < sz(B)) C[i] = (C[i] + B[i]) % mod;
67     }
68     return C.norm();
69 }
70
71 poly operator - (poly A, poly B)
72 {
73     poly C;
74     C.v = vi(max(sz(A), sz(B)));
75     forn(i, sz(C))
76     {
77         if (i < sz(A)) C[i] = (C[i] + A[i]) % mod;
78         if (i < sz(B)) C[i] = (C[i] + mod - B[i]) % mod;
79     }
80     return C.norm();
81 }
82
83 poly operator * (poly A, poly B)
84 {
85     poly C;
86     C.v = vi(sz(A) + sz(B) - 1);
87
88     forn(i, sz(A)) fft::A[i] = A[i];
89     forn(i, sz(B)) fft::B[i] = B[i];
90     fft::multMod(sz(A), sz(B), mod);
91     forn(i, sz(C)) C[i] = fft::C[i];
92     return C.norm();
93 }
94
95 poly inv(poly A, int n) // returns A^{-1} mod x^n
96 {
97     assert(sz(A) && A[0] != 0);
98     A.cut(n);
99
100     auto cutPoly = [](poly &from, int l, int r)
101     {
102         poly R;
103         R.v.resize(r - l);
104         for (int i = l; i < r; ++i)
105         {
106             if (i < sz(from)) R[i - l] = from[i];
107         }
108         return R;
109     };
110
111     function<int(int, int)> rev = [&rev](int x, int m) ←
112     → int
113     {
114         if (x == 1) return 1;
115         return (1 - rev(m % x, x) * (ll)m) / x + m;
116     };
117
118     poly R({rev(A[0], mod)});
119     for (int k = 1; k < n; k <= 1)
120     {
121         poly A0 = cutPoly(A, 0, k);
122         poly A1 = cutPoly(A, k, 2 * k);
123         poly H = A0 * R;
124         H = cutPoly(H, k, 2 * k);
125         poly R1 = (((A1 * R).cut(k) + H) * (poly({0}) - ←
126         R)).cut(k);
127         R.v.resize(2 * k);
128         forn(i, k) R[i + k] = R1[i];
129     }
130     return R.cut(n).norm();
131 }
132
133 pair<poly, poly> divide(poly A, poly B)
134 {
135     if (sz(A) < sz(B)) return {poly({0}), A};
136
137     auto rev = [](poly f)
138     {
139         reverse(all(f.v));
140         return f;
141     };
142
143     poly q = rev((inv(rev(B), sz(A) - sz(B) + 1) * rev ←
144     (A)).cut(sz(A) - sz(B) + 1));
145     poly r = A - B * q;
146
147     return {q, r};
148 }

```

final/numeric/simplex.cpp

```

1
2 namespace simplex {
3     const int MAX_N = -1; // number of variables
4     const int MAX_M = -1; // number of inequalities
5     dbl a[MAX_M][MAX_N];
6     dbl b[MAX_M];
7     dbl c[MAX_N];
8     dbl v;
9     ll n, m;
10    int left[MAX_M];
11    int up[MAX_N];
12    int pos[MAX_N];
13    dbl res[MAX_N];
14
15    void init(int nn, int mm) {
16        n = nn;
17        m = mm;
18        v = 0;
19        for (int i = 0; i < m; i++)
20            for (int j = 0; j < n; j++)
21                a[i][j] = 0;
22        for (int i = 0; i < m; i++)
23            b[i] = 0;
24        for (int i = 0; i < n; i++)
25            c[i] = 0;
26    }
27
28    void pivot(int x, int y) {
29        swap(left[x], up[y]);
30        dbl k = a[x][y];
31        a[x][y] = 1;
32        b[x] /= k;
33        int cur = 0;
34        for (int i = 0; i < n; i++) {
35            a[x][i] = a[x][i] / k;
36            if (!eq(a[x][i], 0))
37                pos[cur++] = i;
38        }
39
40        for (int i = 0; i < m; i++) {
41            if (i == x || eq(a[i][y], 0)) continue;
42            dbl cof = a[i][y];
43            b[i] -= cof * b[x];
44            a[i][y] = 0;
45            for (int j = 0; j < cur; j++)
46                a[i][pos[j]] -= cof * a[x][pos[j]];
47        }
48        dbl cof = c[y];
49        v += cof * b[x];
50        c[y] = 0;
51        for (int i = 0; i < cur; i++) {
52            c[pos[i]] -= cof * a[x][pos[i]];
53        }
54    }
55
56    void solve() {
57        for (int i = 0; i < n; i++)
58            up[i] = i;
59        for (int i = 0; i < m; i++)
60            left[i] = i + n;
61
62        while (1) {
63            int x = -1;
64            for (int i = 0; i < m; i++)
65                if (ls(b[i], 0) && (x == -1 || b[i] < b[x])) ←
66            {
67                x = i;
68            }
69            if (x == -1) break;
70            int y = -1;
71            for (int j = 0; j < n; j++)
72                if (ls(a[x][j], 0)) {
73                    y = j;
74                    break;
75                }
76            if (y == -1) {
77                assert(false); // no solution
78            }
79            pivot(x, y);
80        }
81        while (1) {
82            int y = -1;
83            for (int i = 0; i < n; i++)
84                if (ls(0, c[i]) && (y == -1 || (c[i] > c[y]) ←
85            )) {
86                y = i;
87            }
88            if (y == -1) break;
89        }
90    }
91 }

```

```

87
88     int x = -1;
89     for (int i = 0; i < m; i++) {
90         if (ls(0, a[i][y])) {
91             if (x == -1 || (b[i] / a[i][y] < b[x] / a[←
x][y])) {
92                 x = i;
93             }
94         }
95     }
96     if (y == -1) {
97         assert(false); // infinite solution
98     }
99     pivot(x, y);
100 }
101
102 memset(res, 0, sizeof(res));
103
104 for (int i = 0; i < m; i++) {
105     if (left[i] < n) {
106         res[left[i]] = b[i];
107     }
108 }
109
110 // HOW TO USE ::
111 // — call init(n, m)
112 // — call solve()
113 // — variables in "up" equals to zero
114 // — variables in "left" equals to b
115 // — max: c * x
116 // — b[i] >= a[i] * x
117 // — answer in "v"
118 // — sertificate in "res"
119 };

```

final/geom/commonTangents.cpp

```

1
2
3 vector<Line> commonTangents(pt A, dbl rA, pt B, dbl ←
rB) {
4     vector<Line> res;
5     pt C = B - A;
6     dbl z = C.len2();
7     for (int i = -1; i <= 1; i += 2) {
8         for (int j = -1; j <= 1; j += 2) {
9             dbl r = rB * j - rA * i;
10            dbl d = z - r * r;
11            if (ls(d, 0)) continue;
12            d = sqrt(max(0.01, d));
13            pt magic = pt(r, d) / z;
14            pt v(magic % C, magic * C);
15            dbl CC = (rA * i - v % A) / v.len2();
16            pt O = v * -CC;
17            res.pb(Line(0, 0 + v.rotate()));
18        }
19    }
20    return res;
21 }
22
23 // HOW TO USE ::
24 // — *D*—————*F*
25 // — *...* — — *...*
26 // — *.....* — — *.....*
27 // — *.....* — — *.....*
28 // — *...A...* — — *...B...*
29 // — *.....* — — *.....*
30 // — *.....* — — *.....*
31 // — *...* — — *...*
32 // — *C*—————*E*
33 // — res = {CE, CF, DE, DF}

```

final/geom/halfplaneIntersection.cpp

```

1 int getPart(pt v) {
2     return less(0, v.y) || (equal(0, v.y) && less(v.x, ←
0));
3 }
4
5 int cmpV(pt a, pt b) {
6     int partA = getPart(a);
7     int partB = getPart(b);
8     if (partA < partB) return -1;
9     if (partA > partB) return 1;
10    if (equal(0, a * b)) return 0;
11    if (0 < a * b) return -1;
12    return 1;
13 }
14
15 double planeInt(vector<Line> l) {
16     int n = l.size();
17     sort(all(l), [](Line a, Line b) {
18         int r = cmpV(a.v, b.v);
19         if (r != 0) return r < 0;
20         return a.O % a.v.rotate() < b.O % a.v.rotate() ←
;
21     });
22
23     int cur = 0;
24     for (int i = 0; i < n; ) {
25         int j = i;
26         for (; i < n && cmpV(l[j].v, l[i].v) == 0 && ←
cmpV(l[i].v, l[j].v) == 0; i++);
27         l[cur++] = l[i - 1];
28     }
29     n = cur;
30
31     for (int i = 0; i < n; i++)
32         l[i].id = i;
33
34     int flagUp = 0;
35     int flagDown = 0;
36     for (int i = 0; i < n; i++) {
37         int part = getPart(l[i].v);
38         if (part == 1) flagUp = 1;
39         if (part == 0) flagDown = 1;
40     }
41     if (!flagUp || !flagDown) return -1;
42 }

```

```

43 for (int i = 0; i < n; i++) {
44     pt v = l[i].v;
45     pt u = l[(i + 1) % n].v;
46     if (equal(0, v * u) && less(v % u, 0)) {
47         pt dir = l[i].v.rotate();
48         if (lessE(l[(i + 1) % n].0 % dir, l[i].0 % dir ←
49     )) return 0;
50     return -1;
51 }
52 if (less(v * u, 0))
53     return -1;
54 }
55
56 cur = 0;
57 vector<Line> st(n * 2);
58 for (int tt = 0; tt < 2; tt++) {
59     for (int i = 0; i < n; i++) {
60         for (; cur >= 2; cur--) {
61             pt G = st[cur - 1] * l[i];
62             if (!lessE(st[cur - 2].v * (G - st[cur - 2]. ←
63         0), 0))
64                 break;
65             st[cur++] = l[i];
66             if (cur >= 2 && lessE(st[cur - 2].v * st[cur ←
67         1].v, 0)) return 0;
68         }
69     }
70     vector<int> use(n, -1);
71     int left = -1, right = -1;
72     for (int i = 0; i < cur; i++) {
73         if (use[st[i].id] == -1) {
74             use[st[i].id] = i;
75         }
76     }
77     else {
78         left = use[st[i].id];
79         right = i;
80         break;
81     }
82 }
83 vector<Line> tmp;
84 for (int i = left; i < right; i++)
85     tmp.pb(st[i]);
86 vector<pt> res;
87 for (int i = 0; i < (int)tmp.size(); i++)
88     res.pb(tmp[i] * tmp[(i + 1) % tmp.size()]);
89 double area = 0;
90 for (int i = 0; i < (int)res.size(); i++)
91     area += res[i] * res[(i + 1) % res.size()];
92 return area / 2;

```

final/geom/minDisc.cpp

```

1 pair<pt, dbl> minDisc(vector<pt> p) {
2     int n = p.size();
3     pt 0 = pt(0, 0);
4     dbl R = 0;
5     random_shuffle(all(p));
6     for (int i = 0; i < n; i++) {
7         if (ls(R, (0 - p[i]).len())) {
8             0 = p[i];
9             R = 0;
10            for (int j = 0; j < i; j++) {
11                if (ls(R, (0 - p[j]).len())) {
12                    0 = (p[i] + p[j]) / 2;
13                    R = (p[i] - p[j]).len() / 2;
14                    for (int k = 0; k < j; k++) {
15                        if (ls(R, (0 - p[k]).len())) {
16                            Line l1((p[i] + p[j]) / 2, (p[i] + p[j] ←
17                )) / 2 + (p[i] - p[j]).rotate();
18                            Line l2((p[k] + p[j]) / 2, (p[k] + p[j] ←
19                )) / 2 + (p[k] - p[j]).rotate();
20                            0 = l1 * l2;
21                            R = (p[i] - 0).len();
22                        }
23                    }
24                }
25            }
26        }
27    }
28    return {0, R};

```

final/geom/convexHull3D-N2.cpp

```

1 struct Plane {
2     pt 0, v;
3     vector<int> id;
4 };
5
6 vector<Plane> convexHull3(vector<pt> p) {
7     vector<Plane> res;
8     int n = p.size();
9     for (int i = 0; i < n; i++)
10         p[i].id = i;
11     for (int i = 0; i < 4; i++) {
12         vector<pt> tmp;
13         for (int j = 0; j < 4; j++)
14             if (i != j)
15                 tmp.pb(p[j]);
16         res.pb({tmp[0], (tmp[1] - tmp[0]) * (tmp[2] - ←
17         tmp[0]), {tmp[0].id, tmp[1].id, tmp[2].id}});
18         if ((p[i] - res.back().0) % res.back().v > 0) {
19             res.back().v = res.back().v * -1;
20             swap(res.back().id[0], res.back().id[1]);
21         }
22     }
23     vector<vector<int>> use(n, vector<int>(n, 0));
24     int tnr = 0;
25     for (int i = 4; i < n; i++) {
26         int cur = 0;
27         tnr++;
28         vector<pair<int, int>> curEdge;
29         for (int j = 0; j < sz(res); j++) {
30             if ((p[i] - res[j].0) % res[j].v > 0) {
31                 for (int t = 0; t < 3; t++) {
32                     int v = res[j].id[t];
33                     int u = res[j].id[(t + 1) % 3];
34                     use[v][u] = tnr;
35                     curEdge.pb({v, u});
36                 }
37             }
38             else {
39                 res[cur++] = res[j];
40             }
41         }
42         res.resize(cur);
43         for (auto x: curEdge) {
44             if (use[x.S][x.F] == tnr) continue;
45             res.pb({p[i], (p[x.F] - p[i]) * (p[x.S] - p[i] ←
46             )}, {x.F, x.S, i});
47         }
48     }
49     return res;
50 }
51 // plane in 3d
52 // (A, v) * (B, u) -> (O, n)
53
54 pt n = v * u;
55 pt m = v * n;
56 double t = (B - A) % u / (u % m);
57 pt 0 = A - m * t;

```

final/geom/polygonArcCut.cpp

```

1 struct Meta {
2     int type; // 0 - seg, 1 - circle
3     pt 0;
4     dbl R;
5 };
6
7 const Meta SEG = {0, pt(0, 0), 0};
8
9 vector<pair<pt, Meta>> cut(vector<pair<pt, Meta>> p, ←
10     Line l) {
11     vector<pair<pt, Meta>> res;
12     int n = p.size();
13     for (int i = 0; i < n; i++) {
14         pt A = p[i].F;
15         pt B = p[(i + 1) % n].F;
16         if (le(0, l.v * (A - l.0))) {
17             if (eq(0, l.v * (A - l.0)) && p[i].S.type == 1 ←
18             && ls(0, l.v % (p[i].S.0 - A)))
19                 res.pb({A, SEG});

```



```

19     else
20         res.pb(p[i]);
21     }
22     if (p[i].S.type == 0) {
23         if (sign(l.v * (A - l.0)) * sign(l.v * (B - l.0)) == -1) {
24             pt FF = Line(A, B) * l;
25             res.pb(make_pair(FF, SEG));
26         }
27     }
28     else {
29         pt E, F;
30         if (intCL(p[i].S.O, p[i].S.R, l, E, F)) {
31             if (onArc(p[i].S.O, A, E, B))
32                 res.pb({E, SEG});
33             if (onArc(p[i].S.O, A, F, B))
34                 res.pb({F, p[i].S});
35         }
36     }
37     return res;
38 }

```

final/strings/eertree.cpp

```

1 namespace eertree {
2     const int INF = 1e9;
3     const int N = 5e6 + 10;
4     char _s[N];
5     char *s = _s + 1;
6     int to[N][2];
7     int suf[N], len[N];
8     int sz, last;
9
10     const int odd = 1, even = 2, blank = 3;
11
12     void go(int &u, int pos) {
13         while (u != blank && s[pos - len[u] - 1] != s[pos]) {
14             u = suf[u];
15         }
16     }
17
18     int add(int pos) {
19         go(last, pos);
20         int u = suf[last];
21         go(u, pos);
22         int c = s[pos] - 'a';
23         int res = 0;
24         if (!to[last][c]) {
25             res = 1;
26             to[last][c] = sz;
27             len[sz] = len[last] + 2;
28             suf[sz] = to[u][c];
29             sz++;
30         }
31         last = to[last][c];
32         return res;
33     }
34
35     void init() {
36         to[blank][0] = to[blank][1] = even;
37         len[blank] = suf[blank] = INF;
38         len[even] = 0, suf[even] = odd;
39         len[odd] = -1, suf[odd] = blank;
40         last = even;
41         sz = 4;
42     }
43 }

```

```

10     memset(nxt, -1, sizeof(nxt));
11     memset(link, -1, sizeof(link));
12     memset(len, 0, sizeof(len));
13     last = 0;
14     sz = 1;
15 }
16
17 void add(int c) {
18     int cur = sz++;
19     len[cur] = len[last] + 1;
20     pos[cur] = len[cur];
21     int p = last;
22     last = cur;
23     for (; p != -1 && nxt[p][c] == -1; p = link[p]) ←
24         nxt[p][c] = cur;
25     if (p == -1) {
26         link[cur] = 0;
27         return;
28     }
29     int q = nxt[p][c];
30     if (len[p] + 1 == len[q]) {
31         link[cur] = q;
32         return;
33     }
34     int clone = sz++;
35     memcpy(nxt[clone], nxt[q], sizeof(nxt[q]));
36     len[clone] = len[p] + 1;
37     pos[clone] = pos[q];
38     link[clone] = link[q];
39     link[q] = link[cur] = clone;
40     for (; p != -1 && nxt[p][c] == q; p = link[p]) ←
41         nxt[p][c] = clone;
42 }
43
44 int n;
45 string s;
46 int l[MAXN], r[MAXN];
47 int e[MAXN][SIGMA];
48
49 void getSufTree(string _s) {
50     memset(e, -1, sizeof(e));
51     s = _s;
52     n = s.length();
53     reverse(s.begin(), s.end());
54     init();
55     for (int i = 0; i < n; i++) add(s[i] - 'a');
56     reverse(s.begin(), s.end());
57     for (int i = 1; i < sz; i++) {
58         int j = link[i];
59         l[i] = n - pos[i] + len[j];
60         r[i] = n - pos[i] + len[i];
61         e[j][s[l[i]] - 'a'] = i;
62     }
63 }
64
65 namespace duval {
66     string s;
67     int n = (int) s.length();
68     int i = 0;
69     while (i < n) {
70         int j = i + 1, k = i;
71         while (j < n && s[k] <= s[j]) {
72             if (s[k] < s[j])
73                 k = i;
74             else
75                 ++k;
76             ++j;
77         }
78         while (i <= k) {
79             cout << s.substr(i, j - k) << ' ';
80             i += j - k;
81         }
82     }
83 }

```

final/strings/sufAutomaton.cpp

```

1 namespace SA {
2     const int MAXN = 1 << 18;
3     const int SIGMA = 26;
4
5     int sz, last;
6     int nxt[MAXN][SIGMA];
7     int link[MAXN], len[MAXN], pos[MAXN];
8
9     void init() {

```

final/graphs/centroid.cpp

```

1 // original author: burunduk1, rewritten by me (←
  enot110)
2 // !!! warning !!! this code is not tested well
3 const int N = 1e5, K = 17;
4
5 int pivot, level[N], parent[N];
6 vector<int> v[N];
7
8 int get_pivot( int x, int xx, int n ) {
9     int size = 1;
10    for ( int y : v[x] )
11    {
12        if ( y != xx && level[y] == -1 ) size += get_pivot(
13            (y, x, n));
14    }
15    if (pivot == -1 && (size * 2 >= n || xx == -1)) ←
16        pivot = x;
17    return size;
18 }
19
20 void build( int x, int xx, int dep, int size ) {
21     assert(dep < K);
22     pivot = -1;
23     get_pivot(x, -1, size);
24     x = pivot;
25     level[x] = dep, parent[x] = xx;
26     for ( int y : v[x] ) if ( level[y] == -1 )
27     {
28         build(y, x, dep + 1, size / 2);
29     }
30 }

```

final/graphs/dinica.cpp

```

1 namespace flow
2 {
3     const int maxn = 1e5 + 10;
4     const int maxe = 2 * maxn;
5
6     int head[maxn], next[maxe], to[maxe], f[maxe], ec ←
7     = 1;
8     int ST, EN, N = maxn;
9
10    inline void setN( int n )
11    {
12        ST = n;
13        EN = n + 1;
14        N = n + 2;
15    }
16
17    inline void _add( int x, int y, int ff )
18    {
19        ++ec;
20        to[ec] = y;
21        next[ec] = head[x];
22        head[x] = ec;
23        f[ec] = ff;
24    }
25
26    inline int add( int x, int y, int ff )
27    {
28        _add(x, y, ff);
29        _add(y, x, 0);
30        return ec - 1;
31    }
32
33    void clear()
34    {
35        for( i, N ) head[i] = 0;
36        ec = 1;
37    }
38
39    int d[maxn];
40    int q[maxn], st = 0, en = 0;
41
42    int bfs()
43    {
44        for( i, N ) d[i] = 1e9;
45        st = 0, en = 0;
46        d[ST] = 0;
47        q[en++] = ST;
48        while ( st < en )

```

```

48    {
49        int x = q[st++];
50        if ( x == EN ) return 1;
51        for ( int e = head[x]; e; e = next[e] )
52        {
53            int y = to[e];
54            if ( d[y] == 1e9 && f[e] )
55            {
56                d[y] = d[x] + 1;
57                q[en++] = y;
58            }
59        }
60    }
61    return 0;
62 }
63
64 int pushed;
65 int fst[maxn];
66
67 int dfs( int x, int flow = 1e9 )
68 {
69     if ( x == EN )
70     {
71         pushed = flow;
72         return 1;
73     }
74     for ( ; fst[x]; fst[x] = next[fst[x]] )
75     {
76         int e = fst[x];
77         int y = to[e];
78         if ( d[y] == d[x] + 1 && f[e] && dfs(y, min(f[e] ←
79             ], flow)) )
80         {
81             f[e] -= pushed;
82             f[e ^ 1] += pushed;
83             return 1;
84         }
85     }
86     return 0;
87 }
88
89 ll calcFlow()
90 {
91     ll res = 0;
92     while ( bfs() )
93     {
94         for( i, N ) fst[i] = head[i];
95         while ( dfs(ST) )
96         {
97             res += pushed;
98         }
99     }
100    return res;
101 }
102
103 // HOW TO USE ::
104 // — set maxn and maxe (special for izban)
105 // — add adges using add(x, y, f), call setN(n)
106 // — run calcFlow
107 }

```

final/graphs/dominatorTree.cpp

```

1 namespace domtree {
2     const int MAXN = 300100;
3     int n;
4     vector<int> e[MAXN];
5     vector<int> g[MAXN];
6     int par[MAXN];
7     int in[MAXN], rin[MAXN], tnr;
8     int dom[MAXN], sdom[MAXN], cmn[MAXN];
9     int p[MAXN];
10    int adom[MAXN];
11    vector<int> vct[MAXN];
12
13    void init( int _n ) {
14        n = _n;
15        for ( int i = 0; i < n; i++ ) {
16            e[i].clear();
17        }
18    }
19
20    void addEdge( int from, int to ) {
21        e[from].push_back(to);
22    }
23 }

```

```

24 void dfs(int v) {
25     in[v] = tmr++;
26     rin[in[v]] = v;
27     for (int to : e[v]) {
28         if (in[to] == -1) {
29             dfs(to);
30             par[in[to]] = in[v];
31         }
32         g[in[to]].push_back(in[v]);
33     }
34 }
35
36 int get(int u, int x = 0) {
37     if (u == p[u]) return x ? -1 : u;
38     int v = get(p[u], x + 1);
39     if (v < 0) return u;
40     if (sdom[cmn[p[u]]] < sdom[cmn[u]]) cmn[u] = cmn[←
41         [p[u]];
42     p[u] = v;
43     return x ? v : cmn[u];
44 }
45
46 void uni(int u, int v) {
47     p[v] = u;
48 }
49
50 void calc() {
51     for (int i = 0; i < n; i++) {
52         in[i] = -1;
53         adom[i] = -1;
54         dom[i] = sdom[i] = p[i] = cmn[i] = i;
55         vct[i].clear();
56         g[i].clear();
57     }
58     tmr = 0;
59     dfs(0);
60     for (int i = tmr - 1; i >= 0; i--) {
61         for (int to : g[i]) sdom[i] = min(sdom[i], ←
62             sdom[get(to)]);
63         if (i > 0) vct[sdom[i]].push_back(i);
64         for (int w : vct[i]) {
65             int v = get(w);
66             if (sdom[v] == sdom[w]) dom[w] = sdom[w];
67             else dom[w] = v;
68         }
69         if (i > 0) uni(par[i], i);
70     }
71     for (int i = 1; i < tmr; i++) {
72         if (dom[i] != sdom[i]) dom[i] = dom[dom[i]];
73         adom[rin[i]] = rin[dom[i]];
74     }
75 }

```

final/graphs/fenwick-min.cpp

```

1 const int inf = 1.01e9;
2 const int maxn = 1e5;
3
4 namespace fenwick
5 {
6     const int N = maxn + 1;
7
8     int a[N], l[N], r[N];
9
10 void modify(int q, int v) {
11     q++;
12     a[q] = min(a[q], v);
13     int x = q;
14     while (x < N) {
15         l[x] = min(l[x], v);
16         x = (x | (x - 1)) + 1;
17     }
18     x = q;
19     while (x > 0) {
20         r[x] = min(r[x], v);
21         x &= x - 1;
22     }
23 }
24
25 int find_min(int ll, int rr) {
26     ll++;
27     rr++;
28     int res = inf;
29     int x = ll;
30     while ((x | (x - 1)) + 1 <= rr) {
31         res = min(res, r[x]);

```

```

32     x = (x | (x - 1)) + 1;
33 }
34 res = min(res, a[x]);
35 x = rr;
36 while ((x & (x - 1)) >= ll) {
37     res = min(res, l[x]);
38     x &= x - 1;
39 }
40 return res;
41 }
42
43 // indexes 0 .. maxn-1
44 // (!) to init fill (a, l, r) with INF
45 // (!) modify supports only decreasing of the ←
46     value
47 // find_min [l, r] (both inclusive)

```

final/graphs/generalMatching.cpp

```

1 //COPYPASTED FROM E-MAXX
2 namespace GeneralMatching {
3     const int MAXN = 256;
4     int n;
5     vector<int> g[MAXN];
6     int match[MAXN], p[MAXN], base[MAXN], q[MAXN];
7     bool used[MAXN], blossom[MAXN];
8
9     int lca (int a, int b) {
10         bool used[MAXN] = { 0 };
11         for (;;) {
12             a = base[a];
13             used[a] = true;
14             if (match[a] == -1) break;
15             a = p[match[a]];
16         }
17         for (;;) {
18             b = base[b];
19             if (used[b]) return b;
20             b = p[match[b]];
21         }
22     }
23
24 void mark_path (int v, int b, int children) {
25     while (base[v] != b) {
26         blossom[base[v]] = blossom[base[match[v]]] = ←
27             true;
28         p[v] = children;
29         children = match[v];
30         v = p[match[v]];
31     }
32 }
33
34 int find_path (int root) {
35     memset (used, 0, sizeof used);
36     memset (p, -1, sizeof p);
37     for (int i=0; i<n; ++i)
38         base[i] = i;
39
40     used[root] = true;
41     int qh=0, qt=0;
42     q[qt++] = root;
43     while (qh < qt) {
44         int v = q[qh++];
45         for (size_t i=0; i<g[v].size(); ++i) {
46             int to = g[v][i];
47             if (base[v] == base[to] || match[v] == to) ←
48                 continue;
49             if (to == root || (match[to] != -1 && p[←
50                 match[to]] != -1)) {
51                 int curbase = lca (v, to);
52                 memset (blossom, 0, sizeof blossom);
53                 mark_path (v, curbase, to);
54                 mark_path (to, curbase, v);
55                 for (int i=0; i<n; ++i)
56                     if (blossom[base[i]]) {
57                         base[i] = curbase;
58                         if (!used[i]) {
59                             used[i] = true;
60                             q[qt++] = i;
61                         }
62                     }
63             }
64             else if (p[to] == -1) {
65                 p[to] = v;
66                 if (match[to] == -1)
67                     return to;

```

```

65         to = match[to];
66         used[to] = true;
67         q[qt++] = to;
68     }
69 }
70 }
71 return -1;
72 }
73
74 vector<pair<int, int>> solve(int _n, vector<pair<int, int>> edges) {
75     n = _n;
76     for (int i = 0; i < n; i++) g[i].clear();
77     for (auto o : edges) {
78         g[o.first].push_back(o.second);
79         g[o.second].push_back(o.first);
80     }
81     memset (match, -1, sizeof match);
82     for (int i=0; i<n; ++i) {
83         if (match[i] == -1) {
84             int v = find_path (i);
85             while (v != -1) {
86                 int pv = p[v], ppv = match[pv];
87                 match[v] = pv, match[pv] = v;
88                 v = ppv;
89             }
90         }
91     }
92     vector<pair<int, int>> ans;
93     for (int i = 0; i < n; i++) {
94         if (match[i] > i) {
95             ans.push_back(make_pair(i, match[i]));
96         }
97     }
98     return ans;
99 }
100 }

```

final/graphs/heavyLight.cpp

```

1 namespace hld {
2     const int N = 1 << 17;
3     int par[N], heavy[N], h[N];
4     int root[N], pos[N];
5     int n;
6     vector<vector<int>> e;
7     segtree tree;
8
9     int dfs(int v) {
10         int sz = 1, mx = 0;
11         for (int to : e[v]) {
12             if (to == par[v]) continue;
13             par[to] = v;
14             h[to] = h[v] + 1;
15             int cur = dfs(to);
16             if (cur > mx) heavy[v] = to, mx = cur;
17             sz += cur;
18         }
19         return sz;
20     }
21
22     template <typename T>
23     void path(int u, int v, T op) {
24         for (; root[u] != root[v]; v = par[root[v]]) {
25             if (h[root[u]] > h[root[v]]) swap(u, v);
26             op(pos[root[v]], pos[v] + 1);
27         }
28         if (h[u] > h[v]) swap(u, v);
29         op(pos[u], pos[v] + 1);
30     }
31
32     void init(vector<vector<int>> _e) {
33         e = _e;
34         n = e.size();
35         tree = segtree(n);
36         memset(heavy, -1, sizeof(heavy[0]) * n);
37         par[0] = -1;
38         h[0] = 0;
39         dfs(0);
40         for (int i = 0, cpos = 0; i < n; i++) {
41             if (par[i] == -1 || heavy[par[i]] != i) {
42                 for (int j = i; j != -1; j = heavy[j]) {
43                     root[j] = i;
44                     pos[j] = cpos++;
45                 }
46             }
47         }
48     }
49 }

```

```

48     }
49
50     void add(int v, int x) {
51         tree.add(pos[v], x);
52     }
53
54     int get(int u, int v) {
55         int res = 0;
56         path(u, v, [&](int l, int r) {
57             res = max(res, tree.get(l, r));
58         });
59         return res;
60     }
61 }

```

final/graphs/hungary.cpp

```

1 namespace hungary
2 {
3     const int N = 210;
4
5     int a[N][N];
6     int ans[N];
7
8     int calc(int n, int m)
9     {
10         ++n, ++m;
11         vi u(n), v(m), p(m), prev(m);
12         for (int i = 1; i < n; ++i)
13         {
14             p[0] = i;
15             int x = 0;
16             vi mn(m, inf);
17             vi was(m, 0);
18             while (p[x])
19             {
20                 was[x] = 1;
21                 int ii = p[x], dd = inf, y = 0;
22                 for (int j = 1; j < m; ++j) if (!was[j])
23                 {
24                     int cur = a[ii][j] - u[ii] - v[j];
25                     if (cur < mn[j]) mn[j] = cur, prev[j] = x;
26                     if (mn[j] < dd) dd = mn[j], y = j;
27                 }
28                 forn(j, m)
29                 {
30                     if (was[j]) u[p[j]] += dd, v[j] -= dd;
31                     else mn[j] -= dd;
32                 }
33                 x = y;
34             }
35             while (x)
36             {
37                 int y = prev[x];
38                 p[x] = p[y];
39                 x = y;
40             }
41         }
42         for (int j = 1; j < m; ++j)
43         {
44             ans[p[j]] = j;
45         }
46         return -v[0];
47     }
48
49     // HOW TO USE ::
50     // — set values to a[1..n][1..m] (n <= m)
51     // — run calc(n, m) to find MINIMUM
52     // — to restore permutation use ans[]
53     // — everything works on negative numbers
54     // !! i don't understand this code, it's ←
55     // copped from e-maxx (and rewritten by enot110←)
56 }

```

final/graphs/max-flow-min-cost.cpp

```

1 namespace flow
2 {
3     const int maxn = 2e5 + 10;
4     const int maxe = 2 * maxn;
5 }

```

```

5
6 int head[maxn], next[maxe], to[maxe], flow[maxe], ←
  cost[maxe], ec = 1;
7 int ST, EN, N = maxn;
8
9 inline void setN(int n)
10 {
11     ST = n;
12     EN = n + 1;
13     N = n + 2;
14 }
15
16 inline void _add(int x, int y, int f, int c)
17 {
18     ++ec;
19     to[ec] = y;
20     next[ec] = head[x];
21     head[x] = ec;
22     flow[ec] = f;
23     cost[ec] = c;
24 }
25
26 inline int add(int x, int y, int f, int c)
27 {
28     _add(x, y, f, c);
29     _add(y, x, 0, -c);
30     return ec - 1;
31 }
32
33 void clear()
34 {
35     forn(i, N) head[i] = 0;
36     ec = 1;
37 }
38
39 ll d[maxn], p[maxn];
40 int last[maxn];
41 int used[maxn];
42
43 pair<ll, ll> _calc(int flag)
44 {
45     const ll INF = 1e12;
46     forn(i, N) p[i] = INF;
47     p[ST] = 0;
48     forn(_, N) forn(x, N) for (int e = head[x]; e; e ←
49         = next[e]) if (flow[e] > 0)
50     {
51         int y = to[e];
52         if (p[y] > p[x] + cost[e])
53         {
54             p[y] = p[x] + cost[e];
55         }
56     }
57     ll resFlow = 0, resCost = 0;
58     while (1)
59     {
60         forn(i, N) d[i] = INF, used[i] = 0;
61         d[ST] = 0;
62         forn(_, N)
63         {
64             int x = -1;
65             forn(i, N) if (!used[i] && (x == -1 || d[x] ←
66                 > d[i])) x = i;
67             used[x] = 1;
68             if (d[x] == INF) break;
69             for (int e = head[x]; e; e = next[e]) if (←
70                 flow[e] > 0)
71             {
72                 int y = to[e];
73                 ll len = cost[e] + p[x] - p[y];
74                 if (d[y] > d[x] + len)
75                 {
76                     d[y] = d[x] + len;
77                     last[y] = e;
78                 }
79             }
80             if (d[EN] == INF) break;
81
82             ll realCost = d[EN] + p[EN] - p[ST];
83             if (flag && realCost > 0) break;
84
85             int pushed = inf;
86             int x = EN;
87             while (x != ST)
88             {
89                 int e = last[x];
90                 pushed = min(pushed, flow[e]);
91                 x = to[e ^ 1];
92             }
93

```

```

94     resCost += realCost * pushed;
95     resFlow += pushed;
96
97     x = EN;
98     while (x != ST)
99     {
100         int e = last[x];
101         flow[e] -= pushed;
102         flow[e ^ 1] += pushed;
103         x = to[e ^ 1];
104     }
105
106     forn(i, N) p[i] += d[i];
107 }
108 return mp(resFlow, resCost);
109 }
110
111 pair<ll, ll> maxFlow()
112 {
113     return _calc(0);
114 }
115
116 pair<ll, ll> minCost()
117 {
118     return _calc(1);
119 }
120
121 // HOW TO USE::
122 // — add adges using add(x, y, f, c), call setN(n ←
123 // — run maxFlow/minCost, returns pair(flow, cost ←
124 }

```

final/graphs/retro.cpp

```

1 namespace retro
2 {
3     const int N = 4e5 + 10;
4
5     vi v[N];
6     vi vrev[N];
7
8     void add(int x, int y)
9     {
10         v[x].pb(y);
11         vrev[y].pb(x);
12     }
13
14     const int UD = 0;
15     const int WIN = 1;
16     const int LOSE = 2;
17
18     int res[N];
19     int moves[N];
20     int deg[N];
21     int q[N], st, en;
22
23     void calc(int n)
24     {
25         forn(i, n) deg[i] = sz(v[i]);
26         st = en = 0;
27         forn(i, n) if (!deg[i])
28         {
29             q[en++] = i;
30             res[i] = LOSE;
31         }
32         while (st < en)
33         {
34             int x = q[st++];
35             for (int y : vrev[x])
36             {
37                 if (res[y] == UD && (res[x] == LOSE || (←
38                     deg[y] == 0 && res[x] == WIN)))
39                 {
40                     res[y] = 3 - res[x];
41                     moves[y] = moves[x] + 1;
42                     q[en++] = y;
43                 }
44             }
45         }
46     }

```

final/graphs/smith.cpp

```

1  const int N = 1e5 + 10;
2
3  struct graph
4  {
5      int n;
6
7      vi v[N];
8      vi vrev[N];
9
10     void read()
11     {
12         int m;
13         scanf("%d%d", &n, &m);
14         forn(i, m)
15         {
16             int x, y;
17             scanf("%d%d", &x, &y);
18             --x, --y;
19             v[x].pb(y);
20             vrev[y].pb(x);
21         }
22     }
23
24     int deg[N], cnt[N], used[N], f[N];
25     int q[N], st, en;
26
27     set<int> s[N];
28
29     void calc()
30     {
31         forn(x, n) f[x] = -1, cnt[x] = 0;
32         int val = 0;
33         while (1)
34         {
35             st = en = 0;
36             forn(x, n)
37             {
38                 deg[x] = 0;
39                 used[x] = 0;
40                 for (int y : v[x]) if (f[y] == -1) deg[x]++;
41             }
42             forn(x, n) if (!deg[x] && f[x] == -1 && cnt[x] <= val)
43             {
44                 q[en++] = x;
45                 f[x] = val;
46             }
47             if (!en) break;
48             while (st < en)
49             {
50                 int x = q[st];
51                 st++;
52                 for (int y : vrev[x])
53                 {
54                     if (used[y] == 0 && f[y] == -1)
55                     {
56                         used[y] = 1;
57                         cnt[y]++;
58                         for (int z : vrev[y])
59                         {
60                             deg[z]--;
61                             if (f[z] == -1 && deg[z] == 0 && cnt[z] <= val)
62                             {
63                                 f[z] = val;
64                                 q[en++] = z;
65                             }
66                         }
67                     }
68                 }
69                 val++;
70             }
71         }
72         forn(x, n) eprintf("%d%c", f[x], " \n"[x + 1 == n]);
73         forn(x, n) if (f[x] == -1)
74         {
75             for (int y : v[x]) if (f[y] != -1) s[x].insert(f[y]);
76         }
77     }
78     g1, g2;
79
80     string get(int x, int y)
81     {
82         int f1 = g1.f[x], f2 = g2.f[y];
83         if (f1 == -1 && f2 == -1) return "draw";
84         if (f1 == -1) {

```

```

85         if (g1.s[x].count(f2)) return "first";
86         return "draw";
87     }
88     if (f2 == -1) {
89         if (g2.s[y].count(f1)) return "first";
90         return "draw";
91     }
92     if (f1 ^ f2) return "first";
93     return "second";
94 }

```

final/graphs/twoChinese.cpp

```

1  const int INF = 1e9;
2  struct Edge {
3      int from, to, w, id;
4  };
5  namespace dmst {
6      int n;
7      vector<int> p;
8      vector<Edge> edges;
9
10     int get(int x) {
11         if (x == p[x]) return x;
12         return p[x] = get(p[x]);
13     }
14
15     void uni(int u, int v) {
16         p[get(v)] = get(u);
17     }
18
19     vector<Edge> solve() {
20         vector<int> id(n, -1);
21         vector<int> vert;
22         int cn = 0;
23         for (int i = 0; i < n; i++) if (get(i) == i) {
24             vert.push_back(i);
25             id[i] = cn++;
26         }
27         if (cn == 1) return vector<Edge>();
28
29         vector<vector<int>> e(cn);
30         for (int i = 0; i < (int)edges.size(); i++) {
31             if (get(edges[i].to) != get(edges[i].from)) {
32                 e[id[get(edges[i].to)]].push_back(i);
33             }
34         }
35
36         vector<int> nxtId(cn, -1);
37         for (int i = 0; i < cn; i++) {
38             int mn = INF;
39             for (int id : e[i]) mn = min(mn, edges[id].w);
40             for (int id : e[i]) {
41                 edges[id].w -= mn;
42                 if (edges[id].w == 0) nxtId[i] = id;
43             }
44         }
45
46         vector<char> vis(cn);
47         vis[0] = 1;
48         int cur = 1;
49         while (!vis[cur]) {
50             vis[cur] = 1;
51             cur = id[get(edges[nxtId[cur]].from)];
52         }
53         vector<Edge> ans;
54         if (cur == 0) {
55             for (int i = 0; i < cn; i++) {
56                 if (vis[i] && i != 0) {
57                     ans.push_back(edges[nxtId[i]]);
58                     uni(0, vert[i]);
59                 }
60             }
61             auto nans = solve();
62             for (auto ee : nans) ans.push_back(ee);
63             return ans;
64         }
65         vector<int> cp = p;
66         int o = cur;
67         while (1) {
68             uni(vert[o], vert[cur]);
69             ans.push_back(edges[nxtId[cur]]);
70             int to = id[get(edges[nxtId[cur]].from)];
71             if (to == o) break;
72             cur = to;
73         }
74         vector<Edge> nedges = solve();

```

```

75     p = cp;
76     vector<char> covered(cn);
77     for (auto ee : nedges) covered[id[get(ee.to)]] ←
78         1;
79     for (auto ee : ans) if (!covered[id[get(ee.to)]] ←
80         []) nedges.push_back(ee);
81     return nedges;
82 }
83 // root is 0
84 vector<Edge> getMst(int _n, vector<Edge> _edges) {
85     n = _n;
86     edges = _edges;
87     p.resize(n);
88     for (int i = 0; i < n; i++) p[i] = i;
89     return solve();
90 }
91 }

```

final/graphs/linkcut.cpp

```

1  #include <iostream>
2  #include <cstdio>
3  #include <cassert>
4
5  using namespace std;
6
7  // BEGIN ALGO
8
9  const int MAXN = 110000;
10
11  typedef struct _node{
12     _node *l, *r, *p, *pp;
13     int size; bool rev;
14     _node();
15     explicit _node(nullptr_t){
16         l = r = p = pp = this;
17         size = rev = 0;
18     }
19     void push(){
20         if (rev){
21             l->rev ^= 1; r->rev ^= 1;
22             rev = 0; swap(l,r);
23         }
24     }
25     void update();
26 }* node;
27 node None = new _node(nullptr);
28 node v2n[MAXN];
29 _node::_node(){
30     l = r = p = pp = None;
31     size = 1; rev = false;
32 }
33 void _node::update(){
34     size = (this != None) + l->size + r->size;
35     l->p = r->p = this;
36 }
37 void rotate(node v){
38     assert(v != None && v->p != None);
39     assert(!v->rev); assert(!v->p->rev);
40     node u = v->p;
41     if (v == u->l)
42         u->l = v->r, v->r = u;
43     else
44         u->r = v->l, v->l = u;
45     swap(u->p, v->p); swap(v->pp, u->pp);
46     if (v->p != None){
47         assert(v->p->l == u || v->p->r == u);
48         if (v->p->r == u) v->p->r = v;
49         else v->p->l = v;
50     }
51     u->update(); v->update();
52 }
53 void bigRotate(node v){
54     assert(v->p != None);
55     v->p->p->push();
56     v->p->push();
57     v->push();
58     if (v->p->p != None){
59         if ((v->p->l == v) ^ (v->p->p->r == v->p))
60             rotate(v->p);
61         else
62             rotate(v);
63     }
64     rotate(v);
65 }

```

```

66 inline void Splay(node v){
67     while (v->p != None) bigRotate(v);
68 }
69 inline void splitAfter(node v){
70     v->push();
71     Splay(v);
72     v->r->p = None;
73     v->r->pp = v;
74     v->r = None;
75     v->update();
76 }
77 void expose(int x){
78     node v = v2n[x];
79     splitAfter(v);
80     while (v->pp != None){
81         assert(v->p == None);
82         splitAfter(v->pp);
83         assert(v->pp->r == None);
84         assert(v->pp->p == None);
85         assert(!v->pp->rev);
86         v->pp->r = v;
87         v->pp->update();
88         v = v->pp;
89         v->r->pp = None;
90     }
91     assert(v->p == None);
92     Splay(v2n[x]);
93 }
94 inline void makeRoot(int x){
95     expose(x);
96     assert(v2n[x]->p == None);
97     assert(v2n[x]->pp == None);
98     assert(v2n[x]->r == None);
99     v2n[x]->rev ^= 1;
100 }
101 inline void link(int x, int y){
102     makeRoot(x); v2n[x]->pp = v2n[y];
103 }
104 inline void cut(int x, int y){
105     expose(x);
106     Splay(v2n[y]);
107     if (v2n[y]->pp != v2n[x]){
108         swap(x,y);
109         expose(x);
110         Splay(v2n[y]);
111         assert(v2n[y]->pp == v2n[x]);
112     }
113     v2n[y]->pp = None;
114 }
115 inline int get(int x, int y){
116     if (x == y) return 0;
117     makeRoot(x);
118     expose(y); expose(x);
119     Splay(v2n[y]);
120     if (v2n[y]->pp != v2n[x]) return -1;
121     return v2n[y]->size;
122 }
123 // END ALGO
124
125 _node mem[MAXN];
126
127
128 int main(){
129     freopen("linkcut.in", "r", stdin);
130     freopen("linkcut.out", "w", stdout);
131
132     int n, m;
133     scanf("%d %d", &n, &m);
134
135     for (int i = 0; i < n; i++)
136         v2n[i] = &mem[i];
137
138     for (int i = 0; i < m; i++){
139         int a, b;
140         if (scanf(" link %d %d", &a, &b) == 2)
141             link(a-1, b-1);
142         else if (scanf(" cut %d %d", &a, &b) == 2)
143             cut(a-1, b-1);
144         else if (scanf(" get %d %d", &a, &b) == 2)
145             printf("%d\n", get(a-1, b-1));
146         else
147             assert(false);
148     }
149     return 0;
150 }

```

```
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) $3 \leq p$, $1 \leq a < p$, найти $x^2 = a$

```
1) Если  $a^{((p-1)/2)} \neq 1$ , return -1 2) Выбрать слу-
чайный  $1 \leq i < p$  3)  $T(x) = (x+i)^{((p-1)/2)} \bmod (x^2
-a) = bx + c$  4) Если  $b \neq 0$  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.

Не заходит FFT по TL-ю – чекнуть что стоит double, а не long double

mt19937 генерит случайный unsigned int, если хочется больше есть mt19937_64

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

Перед сабмитом чекнуть что все выводится в printf, а не eprintf!!!

—
Лемма Бернсайда:

Группа G действует на множество X Тогда число классов эквивалентности $= (\sum |f(g)| \text{ for } g \text{ in } G) / |G|$ 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
 $\geq p[k]$   $dp(n, 1) = n$   $dp(n, j) = dp(n, j+1) + dp(n / p[j], j)$ , т. е.  $dp(n, j+1) = dp(n, j) - dp(n / p[j], j)$ 
```

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

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

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

—
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

Table of Integrals*

Basic Forms

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

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

$$\int u dv = uv - \int v du \quad (3)$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Integrals with Logarithms

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

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

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

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

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

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

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

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

Integrals with Exponentials

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

$$\int \sqrt{x} e^{ax} dx = \frac{1}{a} \sqrt{x} e^{ax} + \frac{i\sqrt{\pi}}{2a^{3/2}} \operatorname{erf}(i\sqrt{ax}),$$

where $\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$ (51)

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

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

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

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

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

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

$$\int x^n e^{ax} dx = \frac{(-1)^n}{a^{n+1}} \Gamma[1+n, -ax],$$

where $\Gamma(a, x) = \int_x^\infty t^{a-1} e^{-t} dt$ (58)

$$\int e^{ax^2} dx = -\frac{i\sqrt{\pi}}{2\sqrt{a}} \operatorname{erf}(i\sqrt{a}x) \quad (59)$$

$$\int e^{-ax^2} dx = \frac{\sqrt{\pi}}{2\sqrt{a}} \operatorname{erf}(x\sqrt{a}) \quad (60)$$

$$\int x e^{-ax^2} dx = -\frac{1}{2a} e^{-ax^2} \quad (61)$$

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

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Integrals with Trigonometric Functions

$$\int \sin ax dx = -\frac{1}{a} \cos ax \quad (63)$$

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

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

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

$$\int \cos ax dx = \frac{1}{a} \sin ax \quad (67)$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\int \sec^3 x dx = \frac{1}{2} \sec x \tan x + \frac{1}{2} \ln |\sec x + \tan x| \quad (84)$$

$$\int \sec x \tan x dx = \sec x \quad (85)$$

$$\int \sec^2 x \tan x dx = \frac{1}{2} \sec^2 x \quad (86)$$

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

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

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

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

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

$$\int \sec x \csc x dx = \ln |\tan x| \quad (92)$$

Products of Trigonometric Functions and Monomials

$$\int x \cos x dx = \cos x + x \sin x \quad (93)$$

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

$$\int x^2 \cos x dx = 2x \cos x + (x^2 - 2) \sin x \quad (95)$$

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

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

$$\int x^n \cos ax dx = \frac{1}{2} (ia)^{1-n} [(-1)^n \Gamma(n+1, -iax) - \Gamma(n+1, iax)] \quad (98)$$

$$\int x \sin x dx = -x \cos x + \sin x \quad (99)$$

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

$$\int x^2 \sin x dx = (2 - x^2) \cos x + 2x \sin x \quad (101)$$

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

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

Products of Trigonometric Functions and Exponentials

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

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

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

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

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

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

Integrals of Hyperbolic Functions

$$\int \cosh ax dx = \frac{1}{a} \sinh ax \quad (110)$$

$$\int e^{ax} \cosh bxdx = \begin{cases} \frac{e^{ax}}{a^2 - b^2} [a \cosh bx - b \sinh bx] & a \neq b \\ \frac{e^{2ax}}{4a} + \frac{x}{2} & a = b \end{cases} \quad (111)$$

$$\int \sinh ax dx = \frac{1}{a} \cosh ax \quad (112)$$

$$\int e^{ax} \sinh bxdx = \begin{cases} \frac{e^{ax}}{a^2 - b^2} [-b \cosh bx + a \sinh bx] & a \neq b \\ \frac{e^{2ax}}{4a} - \frac{x}{2} & a = b \end{cases} \quad (113)$$

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

$$\int \tanh ax dx = \frac{1}{a} \ln \cosh ax \quad (115)$$

$$\int \cos ax \cosh bxdx = \frac{1}{a^2 + b^2} [a \sin ax \cosh bx + b \cos ax \sinh bx] \quad (116)$$

$$\int \cos ax \sinh bxdx = \frac{1}{a^2 + b^2} [b \cos ax \cosh bx + a \sin ax \sinh bx] \quad (117)$$

$$\int \sin ax \cosh bxdx = \frac{1}{a^2 + b^2} [-a \cos ax \cosh bx + b \sin ax \sinh bx] \quad (118)$$

$$\int \sin ax \sinh bxdx = \frac{1}{a^2 + b^2} [b \cosh bx \sin ax - a \cos ax \sinh bx] \quad (119)$$

$$\int \sinh ax \cosh ax dx = \frac{1}{4a} [-2ax + \sinh 2ax] \quad (120)$$

$$\int \sinh ax \cosh bxdx = \frac{1}{b^2 - a^2} [b \cosh bx \sinh ax - a \cosh ax \sinh bx] \quad (121)$$