



Alfred
代码模版库

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1 比赛配置 and 奇技淫巧

1.1 多组数据代码模板

Listing 1: `template.cpp`

```

1 #include <bits/stdc++.h>
2 using namespace std;
3 using i64 = long long;
4 const i64 N = 1e5 + 10;
5 int t = 1;
6 inline void solve(int Case) {
7     // your code here;
8 }
9 inline void optimizeIO(void) {
10     ios::sync_with_stdio(false);
11     cin.tie(NULL), cout.tie(NULL);
12 }
13 inline void init(void) {}
14 int main(int argc, char const *argv[]) {
15     optimizeIO(), init(), cin >> t;
16     for (int i = 1; i <= t; i++) solve(i);
17     return 0;
18 }

```

1.2 快读快写

Listing 2: `fast-io.cpp`

```

1 #include <bits/stdc++.h>
2
3 namespace fastIO {
4     char c, f, e = 0;
5     namespace usr {
6         template <class _Tp>
7         inline int read(_Tp &x) {
8             x = f = 0, c = getchar();
9             while (!isdigit(c) && !e) f = c == '-', e |= c == EOF, c = getchar();
10            while (isdigit(c) && !e) x = (x << 1) + (x << 3) + (c ^ 48), c = getchar();
11            return (e |= c == EOF) ? 0 : ((f ? x = -x : 0), 1);
12        }
13        template <class _Tp>
14        inline void write(_Tp x) {
15            if (x < 0) putchar('-'), x = -x;
16            if (x > 9) write(x / 10);
17            putchar((x % 10) ^ 48);
18        }
19        template <typename T, typename... V>
20        inline void read(T &t, V &...v) { read(t), read(v...); }
21        template <typename T, typename... V>
22        inline void write(T t, V... v) {
23            write(t), putchar('_'), write(v...);
24        }
25    }
26 }
27 using namespace fastIO::usr;

```

1.3 关闭流与 C 风格输入输出的同步

Listing 3: `io-sync-off.cpp`

```

1 #include <bits/stdc++.h>
2

```

```

3 inline void optimizeIO(void) {
4     ios::sync_with_stdio(false);
5     cin.tie(NULL), cout.tie(NULL);
6 }

```

1.4 .clang-format

Listing 4: .clang-format

```

1 BasedOnStyle: LLVM
2 AlignAfterOpenBracket: BlockIndent
3 # AlignConsecutiveAssignments: Consecutive
4 AlignArrayOfStructures: Right
5 UseTab: Never
6 IndentWidth: 4
7 TabWidth: 4
8 BreakBeforeBraces: Attach
9 AllowShortIfStatementsOnASingleLine: AllIfsAndElse
10 AllowShortLoopsOnASingleLine: true
11 AllowShortBlocksOnASingleLine: true
12 IndentCaseLabels: true
13 ColumnLimit: 0
14 AccessModifierOffset: -4
15 NamespaceIndentation: All
16 FixNamespaceComments: false
17 AllowShortCaseLabelsOnASingleLine: true
18 AlwaysBreakTemplateDeclarations: MultiLine
19 BinPackParameters: true
20 BraceWrapping:
21     AfterCaseLabel: true
22     AfterClass: true
23 AlignConsecutiveMacros: AcrossEmptyLinesAndComments
24 AlignTrailingComments: Always

```

1.5 debug.h

Listing 5: debug.h

```

1 /**
2  * @file      debug.h
3  * @author    Dr.Alfred (abonlinejudge@163.com)
4  * @brief    Local Debug Printer
5  * @version   1.0
6  * @date     2023-12-30
7  *
8  * @copyright Copyright (c) 2019-now <Rhodes Island Inc.>
9  *
10 */
11
12 #include <bits/stdc++.h>
13
14 using std::cerr;
15 using std::pair;
16 using std::string;
17
18 const long long dbg_inf = 9e18 + 19260817;
19
20 void __print(int x) { cerr << x; }
21 void __print(long x) { cerr << x; }
22 void __print(long long x) {
23     if (x != dbg_inf) {
24         cerr << x;
25     } else {
26         cerr << "inf";

```

```

27     }
28 }
29 void __print(unsigned x) { cerr << x; }
30 void __print(unsigned long x) { cerr << x; }
31 void __print(unsigned long long x) { cerr << x; }
32 void __print(float x) { cerr << x; }
33 void __print(double x) { cerr << x; }
34 void __print(long double x) { cerr << x; }
35 void __print(char x) { cerr << '\\' << x << '\\'; }
36 void __print(const char *x) { cerr << "\"" << x << "\""; }
37 void __print(const string &x) { cerr << "\"" << x << "\""; }
38 void __print(bool x) { cerr << (x ? "true" : "false"); }
39 void __print(__int128_t x) {
40     if (x < 0) cerr << '-', x = -x;
41     if (x > 9) __print(x / 10);
42     cerr << char((x % 10) ^ 48);
43 }
44 void dbgendl(void) { cerr << '\n'; }
45
46 template <typename T, typename V>
47 void __print(const pair<T, V> &x) {
48     cerr << '{', __print(x.first), cerr << ",_", __print(x.second), cerr << '}'
49 }
50 template <typename T>
51 void __print(const T &x) {
52     int f = 0;
53     cerr << '{';
54     for (auto i : x) cerr << (f++ ? ",_" : ""), __print(i);
55     cerr << "}";
56 }
57 void _print() { cerr << "]\n"; }
58 template <typename T, typename... V>
59 void _print(T t, V... v) {
60     __print(t);
61     if (sizeof...(v)) cerr << ",_";
62     _print(v...);
63 }
64 #ifdef DEBUG
65 // To customize a struct/class to print, just define the __print function.
66
67 #ifndef NO_DBG_COLOR
68 #define dbg(x...) \
69     cerr << "\e[91m" << __func__ << ":" << __LINE__ << " [" << #x << "]_=_["; \
70     _print(x); \
71     cerr << "\e[39m";
72
73 #define short_dbg(x...) \
74     cerr << "\e[91m["; \
75     _print(x); \
76     cerr << "\e[39m";
77 #else
78 #define dbg(x...) \
79     cerr << __func__ << ":" << __LINE__ << " [" << #x << "]_=_["; \
80     _print(x);
81 #define short_dbg(x...) \
82     cerr << "["; \
83     _print(x);
84 #endif // !NO_DBG_COLOR
85
86 #else
87 #define dbg(x...)
88 #endif

```

1.6 火车头

Listing 6: `optimize-header.h`

```

1 #pragma GCC optimize(3)
2 #pragma GCC target("avx")
3 #pragma GCC optimize("Ofast")
4 #pragma GCC optimize("inline")
5 #pragma GCC optimize("-fgcse")
6 #pragma GCC optimize("-fgcse-lm")
7 #pragma GCC optimize("-fipa-sra")
8 #pragma GCC optimize("-ftree-pre")
9 #pragma GCC optimize("-ftree-vrp")
10 #pragma GCC optimize("-fpeephole2")
11 #pragma GCC optimize("-ffast-math")
12 #pragma GCC optimize("-fsched-spec")
13 #pragma GCC optimize("unroll-loops")
14 #pragma GCC optimize("-falign-jumps")
15 #pragma GCC optimize("-falign-loops")
16 #pragma GCC optimize("-falign-labels")
17 #pragma GCC optimize("-fdevirtualize")
18 #pragma GCC optimize("-fcaller-saves")
19 #pragma GCC optimize("-fcrossjumping")
20 #pragma GCC optimize("-fthread-jumps")
21 #pragma GCC optimize("-funroll-loops")
22 #pragma GCC optimize("-fwhole-program")
23 #pragma GCC optimize("-freorder-blocks")
24 #pragma GCC optimize("-fschedule-insns")
25 #pragma GCC optimize("inline-functions")
26 #pragma GCC optimize("-ftree-tail-merge")
27 #pragma GCC optimize("-fschedule-insns2")
28 #pragma GCC optimize("-fstrict-aliasing")
29 #pragma GCC optimize("-fstrict-overflow")
30 #pragma GCC optimize("-falign-functions")
31 #pragma GCC optimize("-fcse-skip-blocks")
32 #pragma GCC optimize("-fcse-follow-jumps")
33 #pragma GCC optimize("-fsched-interblock")
34 #pragma GCC optimize("-fpartial-inlining")
35 #pragma GCC optimize("no-stack-protector")
36 #pragma GCC optimize("-freorder-functions")
37 #pragma GCC optimize("-findirect-inlining")
38 #pragma GCC optimize("-fhoist-adjacent-loads")
39 #pragma GCC optimize("-frerun-cse-after-loop")
40 #pragma GCC optimize("inline-small-functions")
41 #pragma GCC optimize("-finline-small-functions")
42 #pragma GCC optimize("-ftree-switch-conversion")
43 #pragma GCC optimize("-foptimize-sibling-calls")
44 #pragma GCC optimize("-fexpensive-optimizations")
45 #pragma GCC optimize("-funsafe-loop-optimizations")
46 #pragma GCC optimize("inline-functions-called-once")
47 #pragma GCC optimize("-fdelete-null-pointer-checks")

```

1.7 c-cpp-properties.json

Listing 7: `c-cpp-properties.json`

```

1 {
2   "configurations": [
3     {
4       "name": "macos-gcc-arm64",
5       "includePath": [
6         "${workspaceFolder}/**",

```

```

7         "/usr/local/include/ac-library/"
8     ],
9     "compilerPath": "/usr/local/bin/g++",
10    "cStandard": "c17",
11    "cppStandard": "c++20",
12    "intelliSenseMode": "macos-gcc-arm64",
13    "compilerArgs": [],
14    "configurationProvider": "ms-vscode.makefile-tools"
15  }
16 ],
17 "version": 4
18 }

```

1.8 launch.json

Listing 8: launch.json

```

1 {
2   "version": "0.2.0",
3   "configurations": [
4     {
5       "name": "(lldb)_Launch",
6       "type": "cppdbg",
7       "request": "launch",
8       "program": "${fileDirname}/compiled.out",
9       "args": [],
10      "stopAtEntry": false,
11      "cwd": "dollar{fileDirname}",
12      "environment": [],
13      "externalConsole": true,
14      "internalConsoleOptions": "neverOpen",
15      "MIMode": "lldb",
16      "setupCommands": [
17        {
18          "description": "Enable pretty-printing for lldb",
19          "text": "--enable-pretty-printing",
20          "ignoreFailures": false
21        }
22      ],
23      "preLaunchTask": "Compile"
24    }
25  ],
26 }

```

1.9 settings.json

Listing 9: settings.json

```

1 {
2   "files.defaultLanguage": "cpp",
3   "editor.formatOnType": true,
4   "editor.suggest.snippetsPreventQuickSuggestions": false,
5   "editor.acceptSuggestionOnEnter": "off",
6   "C_Cpp.clang_format_sortIncludes": true,
7   "C_Cpp.errorSquiggles": "disabled",
8   "C_Cpp.default.defines": ["LOCAL", "DEBUG"]
9 }

```

1.10 tasks.json

Listing 10: tasks.json

```

1 // https://code.visualstudio.com/docs/editor/tasks
2 {

```



```

3     "version": "2.0.0",
4     "tasks": [
5         {
6             "label": "Compile", // 任务名称, 与launch.json的preLaunchTask相对应
7             "command": "g++", // 要使用的编译器, C++用g++
8             "args": [
9                 "${file}",
10                "-o", // 指定输出文件名, 不加该参数则默认输出a.exe, Linux下默认a.out
11                "${fileDirname}/compiled.out",
12                "-g", // 生成和调试有关的信息
13                // "-arch aarch64",
14                // "-m64", // 不知为何有时会生成16位程序而无法运行, 此条可强制生成64位的
15                "-Wall", // 开启额外警告
16                "-std=c++20", // c++14
17                "-DLOCAL",
18                "-DDEBUG",
19                "-O3",
20                "-ld_classic", // will be deprecated
21                "-Wno-char-subscripts",
22                "-I",
23                "/usr/local/include/ac-library/"
24                // "-stack=268435456" // 手动扩大栈空间
25            ], // 编译的命令, 其实相当于VSC帮你在终端中输了这些东西
26            "type": "process", // process是把预定义变量和转义解析后直接全部传给command; shell相当于先打开
27                shell再输入命令, 所以args还会经过shell再解析一遍
28            "group": {
29                "kind": "build",
30                "isDefault": true // 不为true时ctrl shift B就要手动选择了
31            },
32            "presentation": {
33                "echo": true,
34                "reveal": "always", // 执行任务时是否跳转到终端面板, 可以为always, silent, never。具体参见
35                    VSC的文档, 即使设为never, 手动点进去还是可以看到
36                "focus": false, // 设为true后可以使执行task时焦点聚集在终端, 但对编译C/C++来说, 设为true没
37                    有意义
38                "panel": "shared" // 不同的文件的编译信息共享一个终端面板
39            },
40            "problemMatcher": "$gcc" // 捕捉编译时终端里的报错信息到问题面板中, 修改代码后需要重新编译才会
41                再次触发
42            // 本来有Lint, 再开problemMatcher就有双重报错, 但MinGW的Lint效果实在太差了; 用Clangd可以注释掉
43        }
44    ]
45 }

```

2 数据结构

2.1 珂朵莉树

支持区间推平, 颜色段统计, 在随机数据下期望复杂度为 $O(n \log n)$ 的暴力数据结构。

Listing 11: chtholly.cpp

```

1 #include <bits/stdc++.h>
2
3 struct ChthollyTree {
4     using i64 = long long;
5     struct Node {
6         mutable i64 l, r, v;
7         inline bool operator<(const Node &x) const { return l < x.l; }
8     };
9     std::set<Node> tr;
10    using iterator = std::set<Node>::iterator;
11    ChthollyTree(void) = default;
12    ChthollyTree(int rng, int val) { init(rng, val); }
13    inline void init(i64 rng, i64 val) noexcept {

```

```

14     tr.insert({1, rng, val}), tr.insert({rng + 1, rng + 1, 0});
15 }
16 inline iterator begin(void) const noexcept { return tr.begin(); }
17 inline iterator end(void) const noexcept { return tr.end(); }
18 inline iterator split(i64 pos) {
19     auto it = tr.lower_bound({pos, 0, 0});
20     if (it != tr.end() && it->l == pos) return it;
21     i64 l = (--it)->l, r = it->r, v = it->v;
22     tr.erase(it), tr.insert({l, pos - 1, v});
23     return tr.insert({pos, r, v}).first;
24 }
25 inline void assign(i64 l, i64 r, i64 v) {
26     auto R = split(r + 1), L = split(l);
27     tr.erase(L, R), tr.insert({l, r, v});
28 }
29 template <class _Functor> // func(iterator)
30 inline void modify(i64 l, i64 r, _Functor func) {
31     auto R = split(r + 1), L = split(l);
32     for (auto it = L; it != R; it++) func(it);
33 }
34 template <class _Functor> // func(i64 &, iterator)
35 inline i64 query(i64 l, i64 r, _Functor func) {
36     i64 ans = 0;
37     auto R = split(r + 1);
38     for (auto it = split(l); it != R; it++) func(ans, it);
39     return ans;
40 }
41 };

```

2.2 树状数组

维护满足结合律且可差分信息的，常数较小的数据结构。

Listing 12: fenwick.cpp

```

1  #include "fenwick.h"
2  #include <bits/stdc++.h>
3
4  template <class T>
5  struct Fenwick {
6      std::vector<T> c;
7      inline int lowbit(int x) { return x & -x; }
8      inline void merge(T &x, T &y) { x = x + y; }
9      inline T subtract(T x, T y) { return x - y; }
10     inline void update(size_t pos, T x) {
11         for (pos++; pos < c.size(); pos += lowbit(pos)) merge(c[pos], x);
12     }
13     inline void clear(void) {
14         for (auto &x : c) x = T();
15     }
16     inline T query(size_t pos) {
17         T ans = T();
18         for (pos++; pos; pos ^= lowbit(pos)) merge(ans, c[pos]);
19         return ans;
20     }
21     inline T query(size_t l, size_t r) {
22         return l == 0 ? query(r) : subtract(query(r), query(l - 1));
23     }
24     inline int kth(const T k) {
25         int ans = 0;
26         for (int i = 1 << std::lg(c.size() - 1); i; i >>= 1) {
27             if (ans + i < (int)c.size() && c[ans + i] <= k) {
28                 k -= c[ans + i], ans += i;

```

```

29         }
30     }
31     return ans;
32 }
33 Fenwick(size_t len) : c(len + 2) {}
34 };

```

2.3 静态可重区间信息（支持 RMQ）

基于 ST 表，支持静态数组可重区间信息的数据结构。

Listing 13: sparse-table.cpp

```

1  #include <bits/stdc++.h>
2
3  template <class T>
4  struct MaxInfo {
5      T val;
6      MaxInfo(void) { val = std::numeric_limits<T>::min(); }
7      template <class InitT>
8      MaxInfo(InitT x) { val = x; }
9      MaxInfo operator+(MaxInfo &x) {
10         return {std::max(val, x.val)};
11     }
12 };
13 template <class T>
14 struct MinInfo {
15     T val;
16     MinInfo(void) { val = std::numeric_limits<T>::max(); }
17     template <class InitT>
18     MinInfo(InitT x) { val = x; }
19     MinInfo operator+(MinInfo &x) {
20         return {std::min(val, x.val)};
21     }
22 };
23 template <class T>
24 struct GcdInfo {
25     T val;
26     GcdInfo(void) { val = T(); }
27     template <class InitT>
28     GcdInfo(InitT x) { val = x; }
29     GcdInfo operator+(GcdInfo &x) {
30 #if __cplusplus >= 201703L
31         return {std::gcd(x.val, val)};
32 #else
33         return {__gcd(x.val, val)};
34 #endif
35     }
36 };
37 template <class T>
38 class SparseTable {
39 private:
40     int n;
41     std::vector<std::vector<T>> ST;
42
43 public:
44     SparseTable(void) {}
45     SparseTable(int N) : n(N), ST(N, std::vector<T>(std::lg(N) + 1)) {}
46     template <class InitT>
47     SparseTable(std::vector<InitT> &init) : SparseTable(init.size()) {
48         for (int i = 0; i < n; i++) ST[i][0] = T(init[i]);
49         for (int i = 1; (1 << i) <= n; i++) {
50             for (int j = 0; j + (1 << i) - 1 < n; j++) {
51                 ST[j][i] = ST[j][i - 1] + ST[j + (1 << i) - 1][i - 1];

```

```

52     }
53 }
54 }
55 inline T query(int l, int r) { // 0 based
56     if (l > r) return T();
57     int w = std::__lg(r - l + 1);
58     return ST[l][w] + ST[r - (1 << w) + 1][w];
59 }
60 inline T disjoint_query(int l, int r) {
61     T ans = T();
62     for (int i = l; i <= r; i += (1 << std::__lg(r - i + 1))) {
63         ans = ans + ST[i][std::__lg(r - i + 1)];
64     }
65     return ans;
66 }
67 };

```

2.4 PBDS 大常数平衡树

GNU PBDS 提供的大常数基于 rb-tree 的平衡树。

Listing 14: **pbds-balance-tree.cpp**

```

1 #include <bits/extc++.h>
2 #include <bits/stdc++.h>
3
4 using namespace std;
5 using namespace __gnu_pbds;
6
7 // TreeTag can also be __gnu_pbds::splay_tree_tag
8 template <class T, class Cmp, class TreeTag = rb_tree_tag>
9 using BalanceTree = tree<T, null_type, Cmp, TreeTag, tree_order_statistics_node_update>;

```

2.5 离散化容器

Listing 15: **discretization.cpp**

```

1 #include <bits/stdc++.h>
2
3 template <class _Tp>
4 struct Mess {
5     std::vector<_Tp> v;
6     bool initialized = false;
7     inline _Tp origin(int idx) { return v[idx - 1]; }
8     inline void insert(_Tp x) { v.push_back(x); }
9     template <typename T, typename... V>
10     inline void insert(T x, V... v) { insert(x), insert(v...); }
11     inline void init(void) {
12         sort(v.begin(), v.end()), initialized = true;
13         v.erase(unique(v.begin(), v.end()), v.end());
14     }
15     inline void clear(void) { v.clear(), initialized = false; }
16     inline int query(_Tp x) {
17         if (!initialized) init();
18         return lower_bound(v.begin(), v.end(), x) - v.begin() + 1;
19     }
20     inline bool exist(_Tp x) { return origin(query(x)) == x; }
21 };

```

2.6 并查集

Listing 16: dsu.cpp

```

1  #include <bits/stdc++.h>
2
3  struct DSU {
4      std::vector<int> fa, siz;
5      DSU(int n) : fa(n + 1), siz(n + 1, 1) {
6          std::iota(fa.begin(), fa.end(), 0);
7      }
8      inline int find(int x) {
9          return fa[x] == x ? x : fa[x] = find(fa[x]);
10     }
11     inline bool same(int x, int y) {
12         return find(x) == find(y);
13     }
14     // true if x and y were not in the same set, false otherwise.
15     inline bool merge(int x, int y) {
16         int fx = find(x), fy = find(y);
17         if (fx == fy) return false;
18         if (siz[fx] < siz[fy]) swap(fx, fy);
19         fa[fy] = fx, siz[fx] += siz[fy], siz[fy] = 0;
20         return true;
21     }
22     // x -> y, a.k.a let x be son of y (disable merge by rank).
23     inline bool directed_merge(int x, int y) {
24         int fx = find(x), fy = find(y);
25         if (fx == fy) return false;
26         fa[fx] = fy, siz[fy] += siz[fx], siz[fx] = 0;
27         return true;
28     }
29 };

```

2.7 可撤销并查集

Listing 17: cancel-dsu.cpp

```

1  #include <bits/stdc++.h>
2
3  struct CancelDSU {
4      std::stack<int> S;
5      std::vector<int> fa, siz;
6      CancelDSU(int n) : fa(n + 1), siz(n + 1, 1) {
7          std::iota(fa.begin(), fa.end(), 0);
8      }
9      inline int find(int x) {
10         return fa[x] == x ? x : find(fa[x]);
11     }
12     inline bool same(int x, int y) {
13         return find(x) == find(y);
14     }
15     inline void merge(int u, int v) {
16         int fu = find(u), fv = find(v);
17         if (fu == fv) return S.push(-1);
18         if (siz[fu] < siz[fv]) swap(fu, fv);
19         siz[fu] += siz[fv], fa[fv] = fu, S.push(fv);
20     }
21     inline void _cancel(void) {
22         if (S.empty()) return;
23         if (S.top() == -1) return S.pop();
24         siz[fa[S.top()]] -= siz[S.top()];
25         fa[S.top()] = S.top(), S.pop();
26     }
27     inline void cancel(int t = 1) {

```

```

28     while (t-->0) _cancel();
29 }
30 };

```

2.8 出现次数统计

$O(n \log n)$ 预处理, $O(\log n)$ 查找的出现次数在线统计

Listing 18: **appear-statistics.cpp**

```

1  #include "discretization.h"
2  #include <bits/stdc++.h>
3
4  template <class T>
5  class AppearStats { // Appear Statistics.
6  private:
7      Mess<T> M;
8      size_t n;
9      std::vector<std::vector<int>>> pos;
10
11 public:
12     AppearStats(void) : n(0) {}
13     AppearStats(std::vector<T> &init) : n(init.size()) { _init(init); }
14     inline void _init(std::vector<T> &init) {
15         for (auto item : init) M.insert(item);
16         n = init.size(), M.init(), pos.resize(M.v.size());
17         for (size_t i = 0; i < n; i++) {
18             pos[M.query(init[i]) - 1].push_back(i);
19         }
20     }
21     // Use [base] as the beginning of index, return -1 if x doesn't exist.
22     inline int first(int l, int r, T x, int base = 0) {
23         l -= base, r -= base;
24         if (!M.exist(x)) return -1;
25         std::vector<int> &P = pos[M.query(x) - 1];
26         auto it = std::lower_bound(P.begin(), P.end(), l);
27         return it == P.end() || *it > r ? -1 : *it + base;
28     }
29     // Use [base] as the beginning of index, return -1 if x doesn't exist.
30     inline int last(int l, int r, T x, int base = 0) {
31         l -= base, r -= base;
32         if (!M.exist(x)) return -1;
33         std::vector<int> &P = pos[M.query(x) - 1];
34         auto it = std::upper_bound(P.begin(), P.end(), r);
35         return it == P.begin() || *std::prev(it) < l ? -1 : *std::prev(it) + base;
36     }
37     inline int count(int l, int r, T x, int base = 0) {
38         l -= base, r -= base;
39         if (!M.exist(x)) return 0;
40         std::vector<int> &P = pos[M.query(x) - 1];
41         auto L = std::lower_bound(P.begin(), P.end(), l);
42         auto R = std::upper_bound(P.begin(), P.end(), r);
43         if (L == P.end() || R == P.begin()) return 0;
44         if (*L > r || *std::prev(R) < l) return 0;
45         return R - L;
46     }
47 };

```

2.9 01-Trie

Listing 19: **binary-trie.cpp**

```

1  // Thanks neal for this template.

```

```

2  #include <bits/stdc++.h>
3
4  const int BITS = 30;
5  const int INF = 1e9 + 7;
6  struct BinaryTrie { // 01-Trie
7      static const int ALPHABET = 2;
8      struct Node {
9          const int parent;
10         int words_here = 0; // How many words EXACTLY here.
11         int starting_with = 0; // How many words have the PREFIX of this node.
12         int min_index = INF; // The minimum index of words which have PREFIX of this node.
13         int max_index = -INF; // The maximum index of words which have PREFIX of this node.
14         std::array<int, ALPHABET> child;
15         Node(int p = -1) : parent(p) { child.fill(-1); }
16     };
17     static const int ROOT = 0;
18     std::vector<Node> tr = {Node()};
19     BinaryTrie(int total_length = -1) { // Sum of |s|, leave -1 if don't know.
20         if (total_length >= 0) tr.reserve(total_length + 1);
21     }
22     // Returns the Node reference of word.
23     // NOTICE: this function creates a new Node if word isn't in the trie.
24     Node &operator[](uint64_t word) {
25         return tr[build(word, 0)];
26     }
27     // Get or create c-th (c = 0, 1) child of node
28     // Returns BinaryTrie node.
29     int get_or_create_child(int node, int c) {
30         if (tr[node].child[c] == -1) {
31             tr[node].child[c] = (int)tr.size();
32             tr.push_back(Node(node));
33         }
34         return tr[node].child[c];
35     }
36     // Build rootpath of word, insert delta (个) words
37     // Returns BinaryTrie node.
38     int build(uint64_t word, int delta) {
39         int node = ROOT;
40         for (int i = BITS - 1; i >= 0; i--) {
41             tr[node].starting_with += delta;
42             node = get_or_create_child(node, word >> i & 1);
43         }
44         tr[node].starting_with += delta;
45         return node;
46     }
47     // Insert a word with the index of index, INF if index is unknown.
48     // Returns BinaryTrie node.
49     int insert(uint64_t word, int index = INF) {
50         int node = build(word, 1);
51         tr[node].words_here += 1;
52         for (int x = node; x != -1; x = tr[x].parent) {
53             if (index != INF) {
54                 tr[x].min_index = std::min(tr[x].min_index, index);
55                 tr[x].max_index = std::max(tr[x].max_index, index);
56             }
57         }
58         return node;
59     }
60     // Find such an x inserted in the trie that word ^ x is minimized.
61     // Returns such x (x is certain).
62     uint64_t query_min(uint64_t word) {
63         int node = ROOT;
64         uint64_t val = 0;
65         for (int i = BITS - 1; i >= 0; i--) {

```

```

66         int go_bit = word >> i & 1;
67         if (tr[node].child[go_bit] == -1) {
68             go_bit ^= 1;
69         }
70         val |= 1ull << go_bit;
71         node = tr[node].child[go_bit];
72     }
73     return val;
74 }
75 // Find such an x inserted in the trie that word ^ x is maximized.
76 // Returns such x (x is certain).
77 uint64_t query_max(uint64_t word) {
78     int node = ROOT;
79     uint64_t val = 0;
80     for (int i = BITS - 1; i >= 0; i--) {
81         int go_bit = (word >> i & 1) ^ 1;
82         if (tr[node].child[go_bit] == -1) {
83             go_bit ^= 1;
84         }
85         val |= 1ull << go_bit;
86         node = tr[node].child[go_bit];
87     }
88     return val;
89 }
90 // CF1983F: Find such an x inserted in the trie that word ^ x < upper_bound
91 // Returns a pair {min_index, max_index} of x.
92 std::pair<int, int> query_ub(uint64_t word, uint64_t upper_bound) {
93     int mn = INF, mx = -INF, node = ROOT;
94     for (int i = BITS - 1; i >= 0; i--) {
95         int word_bit = word >> i & 1; // digit i of word
96         int ub_bit = upper_bound >> i & 1; // digit i of ub
97         if (ub_bit == 1 && tr[node].child[word_bit] != -1) {
98             // if digit i of ub is 1, then we can choose either
99             // the subtree of word_bit or word_bit ^ 1.
100             mn = std::min(mn, tr[tr[node].child[word_bit]].min_index);
101             mx = std::max(mx, tr[tr[node].child[word_bit]].max_index);
102         }
103         // else if digit i of ub is 0, then we can only choose
104         // the subtree of word_bit. (otherwise, we will violate the range)
105         node = tr[node].child[word_bit ^ ub_bit];
106         if (node == -1) break;
107     }
108     return {mn, mx};
109 }
110 };

```

2.10 滑动窗口

Listing 20: sliding-window.cpp

```

1  #include <bits/stdc++.h>
2
3  template <class T> // default max.
4  std::vector<T> sliding_window(std::vector<T> A, size_t k) {
5      std::vector<T> res;
6      std::deque<size_t> Q;
7      for (size_t i = 0; i < A.size(); i++) {
8          if (!Q.empty() && Q[0] + k == i) {
9              Q.pop_front();
10         }
11         while (!Q.empty() && A[Q.back()] <= A[i]) {
12             Q.pop_back();
13         }

```



```

14     Q.push_back(i);
15     if (i >= k - 1) { // warning: assert k >= 1
16         res.push_back(A[Q[0]]);
17     }
18 }
19 return res;
20 }
21 template <class T>
22 std::vector<std::vector<T>> grid_sliding_window(
23     std::vector<std::vector<T>> &A, size_t x, size_t y
24 ) {
25     const size_t n = A.size(), m = A[0].size();
26     std::vector<std::vector<T>> cols(m - y + 1);
27     std::vector<std::vector<T>> ans(n - x + 1, std::vector<T>(m - y + 1));
28     for (size_t i = 0; i < n; i++) {
29         std::vector<T> res = sliding_window(A[i], y);
30         for (size_t j = 0; j <= m - y; j++) {
31             cols[j].push_back(res[j]);
32         }
33     }
34     for (size_t j = 0; j <= m - y; j++) {
35         std::vector<T> res = sliding_window(cols[j], x);
36         for (size_t i = 0; i <= n - x; i++) {
37             ans[i][j] = res[i];
38         }
39     }
40     return ans;
41 }

```

2.11 (二维) 前缀和

Listing 21: prefix-sum.cpp

```

1  #include <bits/stdc++.h>
2
3  template <class T>
4  class Sum {
5  private:
6      size_t n;
7      std::vector<T> sum;
8
9  public:
10     Sum(void) : n(0) {}
11     template <class InitT>
12     Sum(std::vector<InitT> &init) { _init(init); }
13     template <class InitT>
14     inline void _init(std::vector<InitT> &init) {
15         if (init.empty()) return;
16         sum.resize(n = init.size()), sum[0] = init[0];
17         for (size_t i = 1; i < n; i++) {
18             sum[i] = sum[i - 1] + init[i];
19         }
20     }
21     inline T query(int l, int r) {
22         if (l > r) return T();
23         return l == 0 ? sum[r] : sum[r] - sum[l - 1];
24     }
25 };
26 template <class T>
27 class GridSum {
28 private:
29     size_t n, m;
30     std::vector<std::vector<T>> sum;
31

```

```

32 public:
33     GridSum(void) : n(0), m(0) {}
34     template <class InitT>
35     GridSum(std::vector<std::vector<InitT>> &init) { _init(init); }
36     template <class InitT>
37     inline void _init(std::vector<std::vector<InitT>> &init) {
38         if (init.empty()) return;
39         n = init.size(), m = init[0].size();
40         sum.assign(n, std::vector<T>(m)), sum[0][0] = init[0][0];
41         for (size_t i = 1; i < n; i++) {
42             sum[i][0] = sum[i - 1][0] + init[i][0];
43         }
44         for (size_t i = 1; i < m; i++) {
45             sum[0][i] = sum[0][i - 1] + init[0][i];
46         }
47         for (size_t i = 1; i < n; i++) {
48             for (size_t j = 1; j < m; j++) {
49                 sum[i][j] = sum[i - 1][j] + sum[i][j - 1] - sum[i - 1][j - 1] + init[i][j];
50             }
51         }
52     }
53     inline T query(int x1, int y1, int x2, int y2) {
54         T s1 = x1 == 0 ? 0 : sum[x1 - 1][y2];
55         T s2 = y1 == 0 ? 0 : sum[x2][y1 - 1];
56         T s3 = x1 == 0 || y1 == 0 ? 0 : sum[x1 - 1][y1 - 1];
57         return sum[x2][y2] - s1 - s2 + s3;
58     }
59 };

```

3 数学（数论）算法

3.1 带模整数类

Listing 22: mod-int.cpp

```

1  #include <bits/stdc++.h>
2
3  template <int mod>
4  inline int down(int x) { return x >= mod ? x - mod : x; }
5  template <int mod>
6  struct ModInt {
7      int x;
8      ModInt(void) = default;
9      ModInt(int x) : x(x) {}
10     friend std::istream &operator>>(std::istream &in, ModInt &a) { return in >> a.x; }
11     friend std::ostream &operator<<(std::ostream &out, ModInt a) { return out << a.x; }
12     friend ModInt operator+(ModInt a, ModInt b) { return down<mod>(a.x + b.x); }
13     friend ModInt operator-(ModInt a, ModInt b) { return down<mod>(a.x - b.x + mod); }
14     friend ModInt operator*(ModInt a, ModInt b) { return (long long)a.x * b.x % mod; }
15     friend ModInt operator/(ModInt a, ModInt b) { return a * ~b; }
16     friend ModInt operator^(ModInt a, long long b) {
17         ModInt ans = 1;
18         for (; b >= 1, a *= a)
19             if (b & 1) ans *= a;
20         return ans;
21     }
22     friend ModInt operator~(ModInt a) { return a ^ (mod - 2); }
23     friend ModInt operator~(ModInt a) { return down<mod>(mod - a.x); }
24     friend ModInt &operator+=(ModInt &a, ModInt b) { return a = a + b; }
25     friend ModInt &operator-=(ModInt &a, ModInt b) { return a = a - b; }
26     friend ModInt &operator*=(ModInt &a, ModInt b) { return a = a * b; }
27     friend ModInt &operator/=(ModInt &a, ModInt b) { return a = a / b; }

```

```

28 friend ModInt &operator^=(ModInt &a, long long b) { return a = a ^ b; }
29 friend ModInt &operator++(ModInt &a) { return a += 1; }
30 friend ModInt operator++(ModInt &a, int) {
31     ModInt x = a;
32     a += 1;
33     return x;
34 }
35 friend ModInt &operator--(ModInt &a) { return a -= 1; }
36 friend ModInt operator--(ModInt &a, int) {
37     ModInt x = a;
38     a -= 1;
39     return x;
40 }
41 friend bool operator==(ModInt a, ModInt b) { return a.x == b.x; }
42 friend bool operator!=(ModInt a, ModInt b) { return !(a == b); }
43 };
44 inline void __print(mint x) { std::cerr << x; }

```

3.2 计算几何

Listing 23: **computation-geometry.cpp**

```

1  #include <bits/stdc++.h>
2
3  // Caution: This computation geometry template is pure shit
4  //           because of the terrible math level of the author.
5  //           It will be rewritten some time.
6  template <class T>
7  struct Point {
8      T x, y;
9      Point(void) = default;
10     Point(T X, T Y) : x(X), y(Y) {}
11     inline bool operator==(const Point B) {
12         return x == B.x && y == B.y;
13     }
14     friend std::ostream &operator<<(std::ostream &out, Point P) {
15         return out << "(" << P.x << ",_" << P.y << ")";
16     }
17     friend std::istream &operator>>(std::istream &in, Point &P) {
18         return in >> P.x >> P.y;
19     }
20 };
21 template <class T>
22 struct Line {
23     T A, B, C; // Ax + By + C = 0
24     Line(void) = default;
25     Line(T a, T b, T c) : A(a), B(b), C(c) {} // Ax + By + C = 0
26     Line(T k, T b) : A(k), B(-1), C(b) {} // y = kx + b
27 };
28 template <class T>
29 inline int sign(T x) {
30     return x == 0 ? 0 : (x < 0 ? -1 : 1);
31 }
32 template <class T>
33 inline bool parallel(Line<T> P, Line<T> Q) {
34     return P.A * Q.B == P.B * Q.A;
35 }
36 template <class T>
37 inline Point<T> intersect(Line<T> P, Line<T> Q) {
38     assert(!parallel(P, Q));
39     return Point<T>{
40         (P.C * Q.B - Q.C * P.B) / (Q.A * P.B - P.A * Q.B),
41         (P.C * Q.A - Q.C * P.A) / (P.A * Q.B - Q.A * P.B)

```

```

42     };
43 }
44 template <class T>
45 inline Line<T> get_line(Point<T> P, Point<T> Q) {
46     assert(!(P == Q));
47     if (P.x == Q.x) {
48         return Line<T>(-1, 0, P.x);
49     } else if (P.y == Q.y) {
50         return Line<T>(0, -1, P.y);
51     } else {
52         return Line<T>(
53             Q.y - P.y, P.x - Q.x, P.y * Q.x - P.x * Q.y
54         );
55     }
56 }
57 template <class T>
58 inline bool point_on_line(Point<T> P, Line<T> L) {
59     return L.A * P.x + L.B * P.y + L.C == 0;
60 }
61 template <class T>
62 inline T dis_square(Point<T> P, Point<T> Q) {
63     return (P.x - Q.x) * (P.x - Q.x) + (P.y - Q.y) * (P.y - Q.y);
64 }

```

3.3 组合数学

Listing 24: **comb.cpp**

```

1  #include <bits/stdc++.h>
2
3  template <class mint>
4  struct Comb {
5      int n;
6      std::vector<mint> _fac, _invfac, _inv;
7      Comb(void) : n{0}, _fac{1}, _invfac{1}, _inv{0} {}
8      Comb(int n) : Comb() { init(n); }
9      inline void init(int m) {
10         _fac.resize(m + 1), _inv.resize(m + 1), _invfac.resize(m + 1);
11         for (int i = n + 1; i <= m; i++) {
12             _fac[i] = _fac[i - 1] * i;
13         }
14         _invfac[m] = ~_fac[m];
15         for (int i = m; i > n; i--) {
16             _invfac[i - 1] = _invfac[i] * i;
17             _inv[i] = _invfac[i] * _fac[i - 1];
18         }
19         n = m;
20     }
21     inline mint fac(int m) {
22         if (m > n) init(m);
23         return _fac[m];
24     }
25     inline mint invfac(int m) {
26         if (m > n) init(m);
27         return _invfac[m];
28     }
29     inline mint inv(int m) {
30         if (m > n) init(m);
31         return _inv[m];
32     }
33     inline mint binom(int n, int m) {
34         if (n < m || m < 0) return 0;
35         return fac(n) * invfac(m) * invfac(n - m);

```

```

36     }
37 };
38 Comb<mint> comb;

```

3.4 拉格朗日插值

Listing 25: lagrange.cpp

```

1  #include "comb.h"
2  #include "mod-int.h"
3  #include <bits/stdc++.h>
4
5  inline mint lagrange(std::vector<mint> &x, std::vector<mint> &y, mint k) {
6      mint ans = 0, cur;
7      const int n = x.size();
8      for (int i = 0; i < n; i++) {
9          cur = y[i];
10         for (int j = 0; j < n; j++) {
11             if (j == i) continue;
12             cur *= (k - x[j]) / (x[i] - x[j]);
13         }
14         ans += cur;
15     }
16     return ans;
17 }
18 // y[0] is placeholder.
19 // If for all integer x_i in [1, n], we have f(x_i) = y_i (mod p), find f(k) mod p.
20 inline mint cont_lagrange(std::vector<mint> &y, mint k) {
21     mint ans = 0;
22     const int n = y.size() - 1;
23     std::vector<mint> pre(n + 1, 1), suf(n + 2, 1);
24     for (int i = 1; i <= n; i++) pre[i] = pre[i - 1] * (k - i);
25     for (int i = n; i >= 1; i--) suf[i] = suf[i + 1] * (k - i);
26     for (int i = 1; i <= n; i++) {
27         mint A = pre[i - 1] * suf[i + 1];
28         mint B = comb.fac(i - 1) * comb.fac(n - i);
29         ans += ((n - i) & 1 ? -1 : 1) * y[i] * A / B;
30     }
31     return ans;
32 }
33 // find 1^k + 2^k + ... + n^k. in O(k) of time complexity.
34 inline mint sum_of_kth_powers(mint n, int k) {
35     mint sum = 0;
36     std::vector<mint> Y{0};
37     for (int i = 1; i <= k + 2; i++) {
38         Y.push_back(sum += (mint)i ^ k);
39     }
40     return cont_lagrange(Y, n);
41 }

```

4 字符串算法

4.1 字符串哈希

Listing 26: hashed-string.cpp

```

1  #include <bits/stdc++.h>
2
3  template <int mod, int seed>
4  struct SingleHash {
5      int n;
6      std::vector<int> pow, h;

```

```

7   SingleHash(void) = default;
8   SingleHash(std::string &s) { init(s); }
9   inline void init(std::string &s) {
10       n = s.size(), h.assign(n + 2, 0), pow.assign(n + 2, 1);
11       for (int i = 1; i <= n; i++) {
12           pow[i] = 1ll * pow[i - 1] * seed % mod;
13           h[i] = (1ll * h[i - 1] * seed + s[i - 1]) % mod;
14       }
15   }
16   inline int get_hash(int l, int r) {
17       return (h[r + 1] - 1ll * h[l] * pow[r - l + 1] % mod + mod) % mod;
18   }
19   inline bool check_same(int l1, int r1, int l2, int r2) {
20       return get_hash(l1, r1) == get_hash(l2, r2);
21   }
22 };
23 struct HashedString {
24     SingleHash<998244353, 477> H1;
25     SingleHash<1000000007, 233> H2;
26     HashedString(void) = default;
27     HashedString(std::string s) : H1(s), H2(s) {}
28     inline void init(std::string s) {
29         H1.init(s), H2.init(s);
30     }
31     std::pair<int, int> get_hash(int l, int r) { // not recommended.
32         return {H1.get_hash(l, r), H2.get_hash(l, r)};
33     }
34     // caution: index begins with zero.
35     // If index beginning with one is wanted, use s = ' ' + s
36     inline bool check_same(int l1, int r1, int l2, int r2) {
37         return H1.check_same(l1, r1, l2, r2) && H2.check_same(l1, r1, l2, r2);
38     }
39     inline bool check_period(int l, int r, int p) {
40         return check_same(l, r - p, l + p, r);
41     }
42 };

```

5 jiangly 代码库 (备用, 侵权请提出 issue)

5.1 01 - int128 库函数自定义

Listing 27: others/01-i128-Func.cpp

```

1  /** int128 输出流自定义
2   * 2023-03-20: https://codeforces.com/contest/1806/submission/198413531
3   **/
4  using i128 = __int128;
5
6  std::ostream &operator<<(std::ostream &os, i128 n) {
7      std::string s;
8      while (n) {
9          s += '0' + n % 10;
10         n /= 10;
11     }
12     std::reverse(s.begin(), s.end());
13     return os << s;
14 }
15
16 std::istream &operator>>(std::istream &is, i128 &n) {
17     std::string s;
18     is >> s;
19     for (auto &c : s) {
20         n = n * 10 + c - '0';

```

```

21     }
22     return is;
23 }
24
25 i128 toi128(const std::string &s) {
26     i128 n = 0;
27     for (auto c : s) {
28         n = n * 10 + (c - '0');
29     }
30     return n;
31 }
32
33 i128 sqrti128(i128 n) {
34     i128 lo = 0, hi = 1E16;
35     while (lo < hi) {
36         i128 x = (lo + hi + 1) / 2;
37         if (x * x <= n) {
38             lo = x;
39         } else {
40             hi = x - 1;
41         }
42     }
43     return lo;
44 }

```

5.2 02 - 常用库函数重载

Listing 28: **others/02-Math-Func.cpp**

```

1  using i64 = long long;
2  using i128 = __int128;
3
4  /** 上取整下取整
5   * 2023-10-15: https://codeforces.com/contest/293/submission/228297248
6   **/
7  i64 ceilDiv(i64 n, i64 m) {
8      if (n >= 0) {
9          return (n + m - 1) / m;
10     } else {
11         return n / m;
12     }
13 }
14
15 i64 floorDiv(i64 n, i64 m) {
16     if (n >= 0) {
17         return n / m;
18     } else {
19         return (n - m + 1) / m;
20     }
21 }
22
23 /** 最大值赋值
24 * 2023-09-30: https://codeforces.com/contest/1874/submission/226069129
25 **/
26 template<class T>
27 void chmax(T &a, T b) {
28     if (a < b) {
29         a = b;
30     }
31 }
32
33 /** 最大公约数
34 * -: -
35 **/

```

```

36 i128 gcd(i128 a, i128 b) {
37     return b ? gcd(b, a % b) : a;
38 }
39
40 /** 精确开平方
41 * 2024-03-02: https://qoj.ac/submission/343317
42 **/
43 i64 sqrt(i64 n) {
44     i64 s = std::sqrt(n);
45     while (s * s > n) {
46         s--;
47     }
48     while ((s + 1) * (s + 1) <= n) {
49         s++;
50     }
51     return s;
52 }
53
54 /** 精确开平方
55 * 2023-09-19: https://qoj.ac/submission/183430
56 **/
57 i64 get(i64 n) {
58     i64 u = std::sqrt(2.0L * n);
59     while (u * (u + 1) / 2 < n) {
60         u++;
61     }
62     while (u * (u - 1) / 2 + 1 > n) {
63         u--;
64     }
65     return u;
66 }

```

5.3 03 - 字符调整

Listing 29: **others/03-Char.cpp**

```

1 /** 大小写转换、获取字母序
2 * 2024-03-16: https://qoj.ac/submission/355156
3 **/
4 void rev(std::string &s) {
5     int l = s.size();
6     for (int i = 1; i < l; i += 2) {
7         if (std::isupper(s[i])) {
8             s[i] = std::tolower(s[i]);
9         } else {
10             s[i] = std::toupper(s[i]);
11         }
12     }
13 }
14
15 int get(char c) {
16     int x;
17     if (std::islower(c)) {
18         x = c - 'a';
19     } else {
20         x = 26 + c - 'A';
21     }
22     return x;
23 }

```

5.4 04A - 二分算法 (整数域)

Listing 30: others/04A-Binary-Search.cpp

```

1  /** 二分算法 (整数域): 前驱
2  *   2023-09-18: https://qoj.ac/submission/182628
3  **/
4  int lo = 1, hi = 1E9;
5  while (lo < hi) {
6      int m = (lo + hi + 1) / 2;
7      if (check(m)) {
8          lo = m;
9      } else {
10         hi = m - 1;
11     }
12 }
13 std::cout << lo << "\n";
14
15 /** 二分算法 (整数域): 后继
16 *   2023-09-18: https://qoj.ac/submission/182752
17 **/
18 int lo = 1, hi = n;
19 while (lo < hi) {
20     int m = (lo + hi) / 2;
21     if (check(m)) {
22         hi = m;
23     } else {
24         lo = m + 1;
25     }
26 }
27 std::cout << lo << "\n";

```

5.5 04B - 二分算法 (实数域)

Listing 31: others/04B-Binary-Search.cpp

```

1  /** 二分算法 (实数域)
2  *   2023-10-21: https://qoj.ac/submission/222042
3  **/
4  auto check = [&](double t) {
5      // write
6  };
7
8  double lo = 0;
9  double hi = 1E12;
10 while (hi - lo > std::max(1.0, lo) * eps) {
11     double x = (lo + hi) / 2;
12     if (check(x)) {
13         hi = x;
14     } else {
15         lo = x;
16     }
17 }
18
19 std::cout << lo << "\n";
20
21 /** 二分算法 (实数域)
22 *   2023-09-15: https://qoj.ac/submission/179994
23 **/
24 using i64 = long long;
25 using real = long double;
26
27 constexpr real eps = 1E-7;
28
29 auto get = [&](const auto &f) {
30     real lo = -1E4, hi = 1E4;
31     while (hi - lo > 3 * eps) {

```

```

32     real x1 = (lo + hi - eps) / 2;
33     real x2 = (lo + hi + eps) / 2;
34     if (f(x1) > f(x2)) {
35         lo = x1;
36     } else {
37         hi = x2;
38     }
39 }
40 return f((lo + hi) / 2);
41 };
42
43 std::cout << get([&](real px) {
44     return get([&](real py) {
45         // write
46     });
47 }) << "\n";

```

5.6 01 - 强连通分量缩点 (SCC)

Listing 32: graph/01-SCC.cpp

```

1  /** 强连通分量缩点 (SCC)
2   *   2023-06-18: https://codeforces.com/contest/1835/submission/210147209
3   **/
4  struct SCC {
5      int n;
6      std::vector<std::vector<int>> adj;
7      std::vector<int> stk;
8      std::vector<int> dfn, low, bel;
9      int cur, cnt;
10
11      SCC() {}
12      SCC(int n) {
13          init(n);
14      }
15
16      void init(int n) {
17          this->n = n;
18          adj.assign(n, {});
19          dfn.assign(n, -1);
20          low.resize(n);
21          bel.assign(n, -1);
22          stk.clear();
23          cur = cnt = 0;
24      }
25
26      void addEdge(int u, int v) {
27          adj[u].push_back(v);
28      }
29
30      void dfs(int x) {
31          dfn[x] = low[x] = cur++;
32          stk.push_back(x);
33
34          for (auto y : adj[x]) {
35              if (dfn[y] == -1) {
36                  dfs(y);
37                  low[x] = std::min(low[x], low[y]);
38              } else if (bel[y] == -1) {
39                  low[x] = std::min(low[x], dfn[y]);
40              }
41          }
42

```

```

43     if (dfn[x] == low[x]) {
44         int y;
45         do {
46             y = stk.back();
47             bel[y] = cnt;
48             stk.pop_back();
49         } while (y != x);
50         cnt++;
51     }
52 }
53
54 std::vector<int> work() {
55     for (int i = 0; i < n; i++) {
56         if (dfn[i] == -1) {
57             dfs(i);
58         }
59     }
60     return bel;
61 }
62 };

```

5.7 02 - 割边与割边缩点 (EBCC)

Listing 33: graph/02-EBCC.cpp

```

1  /** 割边与割边缩点 (EBCC)
2   *   2023-05-11: https://codeforces.com/contest/118/submission/205426518
3   **/
4  std::set<std::pair<int, int>> E;
5
6  struct EBCC {
7      int n;
8      std::vector<std::vector<int>> adj;
9      std::vector<int> stk;
10     std::vector<int> dfn, low, bel;
11     int cur, cnt;
12
13     EBCC() {}
14     EBCC(int n) {
15         init(n);
16     }
17
18     void init(int n) {
19         this->n = n;
20         adj.assign(n, {});
21         dfn.assign(n, -1);
22         low.resize(n);
23         bel.assign(n, -1);
24         stk.clear();
25         cur = cnt = 0;
26     }
27
28     void addEdge(int u, int v) {
29         adj[u].push_back(v);
30         adj[v].push_back(u);
31     }
32
33     void dfs(int x, int p) {
34         dfn[x] = low[x] = cur++;
35         stk.push_back(x);
36
37         for (auto y : adj[x]) {
38             if (y == p) {

```

```

39         continue;
40     }
41     if (dfn[y] == -1) {
42         E.emplace(x, y);
43         dfs(y, x);
44         low[x] = std::min(low[x], low[y]);
45     } else if (bel[y] == -1 && dfn[y] < dfn[x]) {
46         E.emplace(x, y);
47         low[x] = std::min(low[x], dfn[y]);
48     }
49 }
50
51 if (dfn[x] == low[x]) {
52     int y;
53     do {
54         y = stk.back();
55         bel[y] = cnt;
56         stk.pop_back();
57     } while (y != x);
58     cnt++;
59 }
60 }
61
62 std::vector<int> work() {
63     dfs(0, -1);
64     return bel;
65 }
66
67 struct Graph {
68     int n;
69     std::vector<std::pair<int, int>> edges;
70     std::vector<int> siz;
71     std::vector<int> cnte;
72 };
73 Graph compress() {
74     Graph g;
75     g.n = cnt;
76     g.siz.resize(cnt);
77     g.cnte.resize(cnt);
78     for (int i = 0; i < n; i++) {
79         g.siz[bel[i]]++;
80         for (auto j : adj[i]) {
81             if (bel[i] < bel[j]) {
82                 g.edges.emplace_back(bel[i], bel[j]);
83             } else if (i < j) {
84                 g.cnte[bel[i]]++;
85             }
86         }
87     }
88     return g;
89 }
90 };

```

5.8 03 - 二分图最大权匹配 (MaxAssignment 基于 KM)

Listing 34: graph/03-Max-Assignment.cpp

```

1  /** 二分图最大权匹配 (MaxAssignment 基于KM)
2   *   2022-04-10: https://atcoder.jp/contests/abc247/submissions/30867023
3   *   2023-09-21: https://qoj.ac/submission/184824
4   **/
5  constexpr int inf = 1E7;
6  template<class T>
7  struct MaxAssignment {

```

```

8 public:
9     T solve(int nx, int ny, std::vector<std::vector<T>> a) {
10         assert(0 <= nx && nx <= ny);
11         assert(int(a.size()) == nx);
12         for (int i = 0; i < nx; ++i) {
13             assert(int(a[i].size()) == ny);
14             for (auto x : a[i])
15                 assert(x >= 0);
16         }
17
18         auto update = [&](int x) {
19             for (int y = 0; y < ny; ++y) {
20                 if (lx[x] + ly[y] - a[x][y] < slack[y]) {
21                     slack[y] = lx[x] + ly[y] - a[x][y];
22                     slackx[y] = x;
23                 }
24             }
25         };
26
27         costs.resize(nx + 1);
28         costs[0] = 0;
29         lx.assign(nx, std::numeric_limits<T>::max());
30         ly.assign(ny, 0);
31         xy.assign(nx, -1);
32         yx.assign(ny, -1);
33         slackx.resize(ny);
34         for (int cur = 0; cur < nx; ++cur) {
35             std::queue<int> que;
36             visx.assign(nx, false);
37             visy.assign(ny, false);
38             slack.assign(ny, std::numeric_limits<T>::max());
39             p.assign(nx, -1);
40
41             for (int x = 0; x < nx; ++x) {
42                 if (xy[x] == -1) {
43                     que.push(x);
44                     visx[x] = true;
45                     update(x);
46                 }
47             }
48
49             int ex, ey;
50             bool found = false;
51             while (!found) {
52                 while (!que.empty() && !found) {
53                     auto x = que.front();
54                     que.pop();
55                     for (int y = 0; y < ny; ++y) {
56                         if (a[x][y] == lx[x] + ly[y] && !visy[y]) {
57                             if (yx[y] == -1) {
58                                 ex = x;
59                                 ey = y;
60                                 found = true;
61                                 break;
62                             }
63                             que.push(yx[y]);
64                             p[yx[y]] = x;
65                             visy[y] = visx[yx[y]] = true;
66                             update(yx[y]);
67                         }
68                     }
69                 }
70                 if (found)

```

```

71         break;
72
73         T delta = std::numeric_limits<T>::max();
74         for (int y = 0; y < ny; ++y)
75             if (!visy[y])
76                 delta = std::min(delta, slack[y]);
77         for (int x = 0; x < nx; ++x)
78             if (visx[x])
79                 lx[x] -= delta;
80         for (int y = 0; y < ny; ++y) {
81             if (visy[y]) {
82                 ly[y] += delta;
83             } else {
84                 slack[y] -= delta;
85             }
86         }
87         for (int y = 0; y < ny; ++y) {
88             if (!visy[y] && slack[y] == 0) {
89                 if (yx[y] == -1) {
90                     ex = slackx[y];
91                     ey = y;
92                     found = true;
93                     break;
94                 }
95                 que.push(yx[y]);
96                 p[yx[y]] = slackx[y];
97                 visy[y] = visx[yx[y]] = true;
98                 update(yx[y]);
99             }
100         }
101     }
102
103     costs[cur + 1] = costs[cur];
104     for (int x = ex, y = ey, ty; x != -1; x = p[x], y = ty) {
105         costs[cur + 1] += a[x][y];
106         if (xy[x] != -1)
107             costs[cur + 1] -= a[x][xy[x]];
108         ty = xy[x];
109         xy[x] = y;
110         yx[y] = x;
111     }
112 }
113 return costs[nx];
114 }
115 std::vector<int> assignment() {
116     return xy;
117 }
118 std::pair<std::vector<T>, std::vector<T>> labels() {
119     return std::make_pair(lx, ly);
120 }
121 std::vector<T> weights() {
122     return costs;
123 }
124 private:
125     std::vector<T> lx, ly, slack, costs;
126     std::vector<int> xy, yx, p, slackx;
127     std::vector<bool> visx, visy;
128 };

```

5.9 04 - 一般图最大匹配 (Graph 带花树算法)【久远】

Listing 35: graph/04-Graph-Match.cpp

1 /** 一般图最大匹配 (Graph 带花树算法)【久远】

```

2  *    2021-12-24: https://codeforces.com/contest/1615/submission/140509278
3  **/
4  struct Graph {
5      int n;
6      std::vector<std::vector<int>> e;
7      Graph(int n) : n(n), e(n) {}
8      void addEdge(int u, int v) {
9          e[u].push_back(v);
10         e[v].push_back(u);
11     }
12     std::vector<int> findMatching() {
13         std::vector<int> match(n, -1), vis(n), link(n), f(n), dep(n);
14
15         // disjoint set union
16         auto find = [&](int u) {
17             while (f[u] != u)
18                 u = f[u] = f[f[u]];
19             return u;
20         };
21
22         auto lca = [&](int u, int v) {
23             u = find(u);
24             v = find(v);
25             while (u != v) {
26                 if (dep[u] < dep[v])
27                     std::swap(u, v);
28                 u = find(link[match[u]]);
29             }
30             return u;
31         };
32
33         std::queue<int> que;
34         auto blossom = [&](int u, int v, int p) {
35             while (find(u) != p) {
36                 link[u] = v;
37                 v = match[u];
38                 if (vis[v] == 0) {
39                     vis[v] = 1;
40                     que.push(v);
41                 }
42                 f[u] = f[v] = p;
43                 u = link[v];
44             }
45         };
46
47         // find an augmenting path starting from u and augment (if exist)
48         auto augment = [&](int u) {
49
50             while (!que.empty())
51                 que.pop();
52
53             std::iota(f.begin(), f.end(), 0);
54
55             // vis = 0 corresponds to inner vertices, vis = 1 corresponds to outer vertices
56             std::fill(vis.begin(), vis.end(), -1);
57
58             que.push(u);
59             vis[u] = 1;
60             dep[u] = 0;
61
62             while (!que.empty()) {
63                 int u = que.front();
64                 que.pop();

```

```

65         for (auto v : e[u]) {
66             if (vis[v] == -1) {
67
68                 vis[v] = 0;
69                 link[v] = u;
70                 dep[v] = dep[u] + 1;
71
72                 // found an augmenting path
73                 if (match[v] == -1) {
74                     for (int x = v, y = u, temp; y != -1; x = temp, y = x == -1 ? -1 : link[x]) {
75                         temp = match[y];
76                         match[x] = y;
77                         match[y] = x;
78                     }
79                     return;
80                 }
81
82                 vis[match[v]] = 1;
83                 dep[match[v]] = dep[u] + 2;
84                 que.push(match[v]);
85
86             } else if (vis[v] == 1 && find(v) != find(u)) {
87                 // found a blossom
88                 int p = lca(u, v);
89                 blossom(u, v, p);
90                 blossom(v, u, p);
91             }
92         }
93     }
94 };
95
96 // find a maximal matching greedily (decrease constant)
97 auto greedy = [&]() {
98
99     for (int u = 0; u < n; ++u) {
100         if (match[u] != -1)
101             continue;
102         for (auto v : e[u]) {
103             if (match[v] == -1) {
104                 match[u] = v;
105                 match[v] = u;
106                 break;
107             }
108         }
109     }
110 };
111
112 greedy();
113
114 for (int u = 0; u < n; ++u)
115     if (match[u] == -1)
116         augment(u);
117
118 return match;
119 }
120 };

```

5.10 05 - TwoSat (2-Sat)

Listing 36: graph/05-Two-Sat.cpp

```

1  /** TwoSat (2-Sat)
2  *    2023-09-29: https://atcoder.jp/contests/arc161/submissions/46031530

```



```

3  **/
4  struct TwoSat {
5      int n;
6      std::vector<std::vector<int>> e;
7      std::vector<bool> ans;
8      TwoSat(int n) : n(n), e(2 * n), ans(n) {}
9      void addClause(int u, bool f, int v, bool g) {
10         e[2 * u + !f].push_back(2 * v + g);
11         e[2 * v + !g].push_back(2 * u + f);
12     }
13     bool satisfiable() {
14         std::vector<int> id(2 * n, -1), dfn(2 * n, -1), low(2 * n, -1);
15         std::vector<int> stk;
16         int now = 0, cnt = 0;
17         std::function<void(int)> tarjan = [&](int u) {
18             stk.push_back(u);
19             dfn[u] = low[u] = now++;
20             for (auto v : e[u]) {
21                 if (dfn[v] == -1) {
22                     tarjan(v);
23                     low[u] = std::min(low[u], low[v]);
24                 } else if (id[v] == -1) {
25                     low[u] = std::min(low[u], dfn[v]);
26                 }
27             }
28             if (dfn[u] == low[u]) {
29                 int v;
30                 do {
31                     v = stk.back();
32                     stk.pop_back();
33                     id[v] = cnt;
34                 } while (v != u);
35                 ++cnt;
36             }
37         };
38         for (int i = 0; i < 2 * n; ++i) if (dfn[i] == -1) tarjan(i);
39         for (int i = 0; i < n; ++i) {
40             if (id[2 * i] == id[2 * i + 1]) return false;
41             ans[i] = id[2 * i] > id[2 * i + 1];
42         }
43         return true;
44     }
45     std::vector<bool> answer() { return ans; }
46 };

```

5.11 06A - 最大流 (Flow 旧版其一, 整数应用)

Listing 37: graph/06A-Max-Flow.cpp

```

1  /** 最大流 (Flow 旧版其一, 整数应用)
2   *   2022-09-03: https://codeforces.com/contest/1717/submission/170688062
3   **/
4  template<class T>
5  struct Flow {
6      const int n;
7      struct Edge {
8          int to;
9          T cap;
10         Edge(int to, T cap) : to(to), cap(cap) {}
11     };
12     std::vector<Edge> e;
13     std::vector<std::vector<int>> g;
14     std::vector<int> cur, h;

```

```

15     Flow(int n) : n(n), g(n) {}
16
17     bool bfs(int s, int t) {
18         h.assign(n, -1);
19         std::queue<int> que;
20         h[s] = 0;
21         que.push(s);
22         while (!que.empty()) {
23             const int u = que.front();
24             que.pop();
25             for (int i : g[u]) {
26                 auto [v, c] = e[i];
27                 if (c > 0 && h[v] == -1) {
28                     h[v] = h[u] + 1;
29                     if (v == t) {
30                         return true;
31                     }
32                     que.push(v);
33                 }
34             }
35         }
36         return false;
37     }
38
39     T dfs(int u, int t, T f) {
40         if (u == t) {
41             return f;
42         }
43         auto r = f;
44         for (int &i = cur[u]; i < int(g[u].size()); ++i) {
45             const int j = g[u][i];
46             auto [v, c] = e[j];
47             if (c > 0 && h[v] == h[u] + 1) {
48                 auto a = dfs(v, t, std::min(r, c));
49                 e[j].cap -= a;
50                 e[j ^ 1].cap += a;
51                 r -= a;
52                 if (r == 0) {
53                     return f;
54                 }
55             }
56         }
57         return f - r;
58     }
59     void addEdge(int u, int v, T c) {
60         g[u].push_back(e.size());
61         e.emplace_back(v, c);
62         g[v].push_back(e.size());
63         e.emplace_back(u, 0);
64     }
65     T maxFlow(int s, int t) {
66         T ans = 0;
67         while (bfs(s, t)) {
68             cur.assign(n, 0);
69             ans += dfs(s, t, std::numeric_limits<T>::max());
70         }
71         return ans;
72     }
73 };

```

5.12 06B - 最大流 (Flow 旧版其二, 浮点数应用)

Listing 38: graph/06B-Max-Flow.cpp

```

1  /** 最大流 (Flow 旧版其二, 浮点数应用)
2  *   2022-04-09: https://cf.dianhsu.com/gym/104288/submission/201412765
3  **/
4  template<class T>
5  struct Flow {
6      const int n;
7      struct Edge {
8          int to;
9          T cap;
10         Edge(int to, T cap) : to(to), cap(cap) {}
11     };
12     std::vector<Edge> e;
13     std::vector<std::vector<int>>> g;
14     std::vector<int> cur, h;
15     Flow(int n) : n(n), g(n) {}
16
17     bool bfs(int s, int t) {
18         h.assign(n, -1);
19         std::queue<int> que;
20         h[s] = 0;
21         que.push(s);
22         while (!que.empty()) {
23             const int u = que.front();
24             que.pop();
25             for (int i : g[u]) {
26                 auto [v, c] = e[i];
27                 if (c > 0 && h[v] == -1) {
28                     h[v] = h[u] + 1;
29                     if (v == t) {
30                         return true;
31                     }
32                     que.push(v);
33                 }
34             }
35         }
36         return false;
37     }
38
39     T dfs(int u, int t, T f) {
40         if (u == t) {
41             return f;
42         }
43         auto r = f;
44         double res = 0;
45         for (int &i = cur[u]; i < int(g[u].size()); ++i) {
46             const int j = g[u][i];
47             auto [v, c] = e[j];
48             if (c > 0 && h[v] == h[u] + 1) {
49                 auto a = dfs(v, t, std::min(r, c));
50                 res += a;
51                 e[j].cap -= a;
52                 e[j ^ 1].cap += a;
53                 r -= a;
54                 if (r == 0) {
55                     return f;
56                 }
57             }
58         }
59         return res;
60     }
61
62     void addEdge(int u, int v, T c) {
63         g[u].push_back(e.size());
64         e.emplace_back(v, c);

```

```

64     g[v].push_back(e.size());
65     e.emplace_back(u, 0);
66 }
67 T maxFlow(int s, int t) {
68     T ans = 0;
69     while (bfs(s, t)) {
70         cur.assign(n, 0);
71         ans += dfs(s, t, 1E100);
72     }
73     return ans;
74 }
75 };

```

5.13 06C - 最大流 (MaxFlow 新版)

Listing 39: graph/06C-Max-Flow.cpp

```

1  /** 最大流 (MaxFlow 新版)
2  *   2023-07-21: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=62915815
3  **/
4  constexpr int inf = 1E9;
5  template<class T>
6  struct MaxFlow {
7      struct _Edge {
8          int to;
9          T cap;
10         _Edge(int to, T cap) : to(to), cap(cap) {}
11     };
12
13     int n;
14     std::vector<_Edge> e;
15     std::vector<std::vector<int>> g;
16     std::vector<int> cur, h;
17
18     MaxFlow() {}
19     MaxFlow(int n) {
20         init(n);
21     }
22
23     void init(int n) {
24         this->n = n;
25         e.clear();
26         g.assign(n, {});
27         cur.resize(n);
28         h.resize(n);
29     }
30
31     bool bfs(int s, int t) {
32         h.assign(n, -1);
33         std::queue<int> que;
34         h[s] = 0;
35         que.push(s);
36         while (!que.empty()) {
37             const int u = que.front();
38             que.pop();
39             for (int i : g[u]) {
40                 auto [v, c] = e[i];
41                 if (c > 0 && h[v] == -1) {
42                     h[v] = h[u] + 1;
43                     if (v == t) {
44                         return true;
45                     }
46                     que.push(v);

```

```

47         }
48     }
49 }
50 return false;
51 }
52
53 T dfs(int u, int t, T f) {
54     if (u == t) {
55         return f;
56     }
57     auto r = f;
58     for (int &i = cur[u]; i < int(g[u].size()); ++i) {
59         const int j = g[u][i];
60         auto [v, c] = e[j];
61         if (c > 0 && h[v] == h[u] + 1) {
62             auto a = dfs(v, t, std::min(r, c));
63             e[j].cap -= a;
64             e[j ^ 1].cap += a;
65             r -= a;
66             if (r == 0) {
67                 return f;
68             }
69         }
70     }
71     return f - r;
72 }
73
74 void addEdge(int u, int v, T c) {
75     g[u].push_back(e.size());
76     e.emplace_back(v, c);
77     g[v].push_back(e.size());
78     e.emplace_back(u, 0);
79 }
80
81 T flow(int s, int t) {
82     T ans = 0;
83     while (bfs(s, t)) {
84         cur.assign(n, 0);
85         ans += dfs(s, t, std::numeric_limits<T>::max());
86     }
87     return ans;
88 }
89
90 std::vector<bool> minCut() {
91     std::vector<bool> c(n);
92     for (int i = 0; i < n; i++) {
93         c[i] = (h[i] != -1);
94     }
95     return c;
96 }
97
98 struct Edge {
99     int from;
100     int to;
101     T cap;
102     T flow;
103 };
104
105 std::vector<Edge> edges() {
106     std::vector<Edge> a;
107     for (int i = 0; i < e.size(); i += 2) {
108         Edge x;
109         x.from = e[i + 1].to;
110         x.to = e[i].to;
111         x.cap = e[i].cap + e[i + 1].cap;
112         x.flow = e[i + 1].cap;
113         a.push_back(x);
114     }
115     return a;
116 }

```

```

111     }
112     return a;
113 }
114 };

```

5.14 07A - 费用流 (MCFGraph 旧版)

Listing 40: graph/07A-Min-Cost-Flow.cpp

```

1  /** 费用流 (MCFGraph 旧版)
2  *   2022-12-12: https://codeforces.com/contest/1766/submission/184974697
3  *
4  *   下方为最小费用**最大流**模板, 如需求解最小费用**可行流**, 需要去除建边限制
5  **/
6  struct MCFGraph {
7      struct Edge {
8          int v, c, f;
9          Edge(int v, int c, int f) : v(v), c(c), f(f) {}
10     };
11     const int n;
12     std::vector<Edge> e;
13     std::vector<std::vector<int>> g;
14     std::vector<i64> h, dis;
15     std::vector<int> pre;
16     bool dijkstra(int s, int t) {
17         dis.assign(n, std::numeric_limits<i64>::max());
18         pre.assign(n, -1);
19         std::priority_queue<std::pair<i64, int>, std::vector<std::pair<i64, int>>, std::greater<std::pair<
20             i64, int>>> que;
21         dis[s] = 0;
22         que.emplace(0, s);
23         while (!que.empty()) {
24             i64 d = que.top().first;
25             int u = que.top().second;
26             que.pop();
27             if (dis[u] < d) continue;
28             for (int i : g[u]) {
29                 int v = e[i].v;
30                 int c = e[i].c;
31                 int f = e[i].f;
32                 if (c > 0 && dis[v] > d + h[u] - h[v] + f) {
33                     dis[v] = d + h[u] - h[v] + f;
34                     pre[v] = i;
35                     que.emplace(dis[v], v);
36                 }
37             }
38         }
39         return dis[t] != std::numeric_limits<i64>::max();
40     }
41     MCFGraph(int n) : n(n), g(n) {}
42     void addEdge(int u, int v, int c, int f) {
43         // if (f < 0) {
44             g[u].push_back(e.size());
45             e.emplace_back(v, 0, f);
46             g[v].push_back(e.size());
47             e.emplace_back(u, c, -f);
48         // } else {
49             // g[u].push_back(e.size());
50             // e.emplace_back(v, c, f);
51             // g[v].push_back(e.size());
52             // e.emplace_back(u, 0, -f);
53         // }
54     }

```

```

54     std::pair<int, i64> flow(int s, int t) {
55         int flow = 0;
56         i64 cost = 0;
57         h.assign(n, 0);
58         while (dijkstra(s, t)) {
59             for (int i = 0; i < n; ++i) h[i] += dis[i];
60             int aug = std::numeric_limits<int>::max();
61             for (int i = t; i != s; i = e[pre[i] ^ 1].v) aug = std::min(aug, e[pre[i]].c);
62             for (int i = t; i != s; i = e[pre[i] ^ 1].v) {
63                 e[pre[i]].c -= aug;
64                 e[pre[i] ^ 1].c += aug;
65             }
66             flow += aug;
67             cost += i64(aug) * h[t];
68         }
69         return std::make_pair(flow, cost);
70     }
71 };

```

5.15 07B - 费用流 (MinCostFlow 新版)

Listing 41: graph/07B-Min-Cost-Flow.cpp

```

1  /** MinCostFlow 新版
2   *   2023-11-09: https://qoj.ac/submission/244680
3   **/
4  template<class T>
5  struct MinCostFlow {
6      struct _Edge {
7          int to;
8          T cap;
9          T cost;
10         _Edge(int to_, T cap_, T cost_) : to(to_), cap(cap_), cost(cost_) {}
11     };
12     int n;
13     std::vector<_Edge> e;
14     std::vector<std::vector<int>>> g;
15     std::vector<T> h, dis;
16     std::vector<int> pre;
17     bool dijkstra(int s, int t) {
18         dis.assign(n, std::numeric_limits<T>::max());
19         pre.assign(n, -1);
20         std::priority_queue<std::pair<T, int>, std::vector<std::pair<T, int>>, std::greater<std::pair<T,
21             int>>> que;
22         dis[s] = 0;
23         que.emplace(0, s);
24         while (!que.empty()) {
25             T d = que.top().first;
26             int u = que.top().second;
27             que.pop();
28             if (dis[u] != d) {
29                 continue;
30             }
31             for (int i : g[u]) {
32                 int v = e[i].to;
33                 T cap = e[i].cap;
34                 T cost = e[i].cost;
35                 if (cap > 0 && dis[v] > d + h[u] - h[v] + cost) {
36                     dis[v] = d + h[u] - h[v] + cost;
37                     pre[v] = i;
38                     que.emplace(dis[v], v);
39                 }
40             }
41         }
42     }

```

```

41     return dis[t] != std::numeric_limits<T>::max();
42 }
43 MinCostFlow() {}
44 MinCostFlow(int n_) {
45     init(n_);
46 }
47 void init(int n_) {
48     n = n_;
49     e.clear();
50     g.assign(n, {});
51 }
52 void addEdge(int u, int v, T cap, T cost) {
53     g[u].push_back(e.size());
54     e.emplace_back(v, cap, cost);
55     g[v].push_back(e.size());
56     e.emplace_back(u, 0, -cost);
57 }
58 std::pair<T, T> flow(int s, int t) {
59     T flow = 0;
60     T cost = 0;
61     h.assign(n, 0);
62     while (dijkstra(s, t)) {
63         for (int i = 0; i < n; ++i) {
64             h[i] += dis[i];
65         }
66         T aug = std::numeric_limits<int>::max();
67         for (int i = t; i != s; i = e[pre[i] ^ 1].to) {
68             aug = std::min(aug, e[pre[i]].cap);
69         }
70         for (int i = t; i != s; i = e[pre[i] ^ 1].to) {
71             e[pre[i]].cap -= aug;
72             e[pre[i] ^ 1].cap += aug;
73         }
74         flow += aug;
75         cost += aug * h[t];
76     }
77     return std::make_pair(flow, cost);
78 }
79 struct Edge {
80     int from;
81     int to;
82     T cap;
83     T cost;
84     T flow;
85 };
86 std::vector<Edge> edges() {
87     std::vector<Edge> a;
88     for (int i = 0; i < e.size(); i += 2) {
89         Edge x;
90         x.from = e[i + 1].to;
91         x.to = e[i].to;
92         x.cap = e[i].cap + e[i + 1].cap;
93         x.cost = e[i].cost;
94         x.flow = e[i + 1].cap;
95         a.push_back(x);
96     }
97     return a;
98 }
99 };

```

5.16 08 - 树链剖分 (HLD)

Listing 42: graph/08-HLD.cpp

```

1  /** 树链剖分 (HLD)
2  *   2023-08-31: https://codeforces.com/contest/1863/submission/221214363
3  **/
4  struct HLD {
5      int n;
6      std::vector<int> siz, top, dep, parent, in, out, seq;
7      std::vector<std::vector<int>> adj;
8      int cur;
9
10     HLD() {}
11     HLD(int n) {
12         init(n);
13     }
14     void init(int n) {
15         this->n = n;
16         siz.resize(n);
17         top.resize(n);
18         dep.resize(n);
19         parent.resize(n);
20         in.resize(n);
21         out.resize(n);
22         seq.resize(n);
23         cur = 0;
24         adj.assign(n, {});
25     }
26     void addEdge(int u, int v) {
27         adj[u].push_back(v);
28         adj[v].push_back(u);
29     }
30     void work(int root = 0) {
31         top[root] = root;
32         dep[root] = 0;
33         parent[root] = -1;
34         dfs1(root);
35         dfs2(root);
36     }
37     void dfs1(int u) {
38         if (parent[u] != -1) {
39             adj[u].erase(std::find(adj[u].begin(), adj[u].end(), parent[u]));
40         }
41
42         siz[u] = 1;
43         for (auto &v : adj[u]) {
44             parent[v] = u;
45             dep[v] = dep[u] + 1;
46             dfs1(v);
47             siz[u] += siz[v];
48             if (siz[v] > siz[adj[u][0]]) {
49                 std::swap(v, adj[u][0]);
50             }
51         }
52     }
53     void dfs2(int u) {
54         in[u] = cur++;
55         seq[in[u]] = u;
56         for (auto v : adj[u]) {
57             top[v] = v == adj[u][0] ? top[u] : v;
58             dfs2(v);
59         }
60         out[u] = cur;
61     }
62     int lca(int u, int v) {

```

```

63     while (top[u] != top[v]) {
64         if (dep[top[u]] > dep[top[v]]) {
65             u = parent[top[u]];
66         } else {
67             v = parent[top[v]];
68         }
69     }
70     return dep[u] < dep[v] ? u : v;
71 }
72
73 int dist(int u, int v) {
74     return dep[u] + dep[v] - 2 * dep[lca(u, v)];
75 }
76
77 int jump(int u, int k) {
78     if (dep[u] < k) {
79         return -1;
80     }
81
82     int d = dep[u] - k;
83
84     while (dep[top[u]] > d) {
85         u = parent[top[u]];
86     }
87
88     return seq[in[u] - dep[u] + d];
89 }
90
91 bool isAncestor(int u, int v) {
92     return in[u] <= in[v] && in[v] < out[u];
93 }
94
95 int rootedParent(int u, int v) {
96     std::swap(u, v);
97     if (u == v) {
98         return u;
99     }
100     if (!isAncestor(u, v)) {
101         return parent[u];
102     }
103     auto it = std::upper_bound(adj[u].begin(), adj[u].end(), v, [&](int x, int y) {
104         return in[x] < in[y];
105     }) - 1;
106     return *it;
107 }
108
109 int rootedSize(int u, int v) {
110     if (u == v) {
111         return n;
112     }
113     if (!isAncestor(v, u)) {
114         return siz[v];
115     }
116     return n - siz[rootedParent(u, v)];
117 }
118
119 int rootedLca(int a, int b, int c) {
120     return lca(a, b) ^ lca(b, c) ^ lca(c, a);
121 }
122 };

```

5.17 01 - 快速幂

Listing 43: **math/01-Power.cpp**

```

1  /** 快速幂 — 普通版
2   *   2023-10-09: https://atcoder.jp/contests/tenka1-2017/submissions/46411797
3   **/
4  int power(int a, i64 b, int p) {
5      int res = 1;
6      for (; b; b /= 2, a = 1LL * a * a % p) {
7          if (b % 2) {
8              res = 1LL * res * a % p;
9          }
10     }
11     return res;
12 }
13
14 /** 快速幂 — 手写乘法
15 *   2023-09-27: https://qoj.ac/submission/189343
16 **/
17 using i64 = long long;
18
19 i64 mul(i64 a, i64 b, i64 p) {
20     i64 c = a * b - i64(1.0L * a * b / p) * p;
21     c %= p;
22     if (c < 0) {
23         c += p;
24     }
25     return c;
26 }
27
28 i64 power(i64 a, i64 b, i64 p) {
29     i64 res = 1;
30     for (; b; b /= 2, a = mul(a, a, p)) {
31         if (b % 2) {
32             res = mul(res, a, p);
33         }
34     }
35     return res;
36 }

```

5.18 02 - 基姆拉尔森公式

Listing 44: **math/02-Kim-Larsen.cpp**

```

1  /** 基姆拉尔森公式
2   *   2023-09-05: https://qoj.ac/submission/164735
3   **/
4  const int d[] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
5
6  bool isLeap(int y) {
7      return y % 400 == 0 || (y % 4 == 0 && y % 100 != 0);
8  }
9
10 int daysInMonth(int y, int m) {
11     return d[m - 1] + (isLeap(y) && m == 2);
12 }
13
14 int getDay(int y, int m, int d) {
15     int ans = 0;
16     for (int i = 1970; i < y; i++) {
17         ans += 365 + isLeap(i);
18     }
19     for (int i = 1; i < m; i++) {
20         ans += daysInMonth(y, i);
21     }
22     ans += d;

```

```

23     return (ans + 2) % 7 + 1;
24 }

```

5.19 03 - 欧拉筛

Listing 45: **math/03-Euler-Sieve.cpp**

```

1  /** 欧拉筛
2   *   2023-11-14: https://qoj.ac/submission/251234
3   **/
4  std::vector<int> minp, primes;
5
6  void sieve(int n) {
7      minp.assign(n + 1, 0);
8      primes.clear();
9
10     for (int i = 2; i <= n; i++) {
11         if (minp[i] == 0) {
12             minp[i] = i;
13             primes.push_back(i);
14         }
15
16         for (auto p : primes) {
17             if (i * p > n) {
18                 break;
19             }
20             minp[i * p] = p;
21             if (p == minp[i]) {
22                 break;
23             }
24         }
25     }
26 }
27
28 bool isprime(int n) {
29     return minp[n] == n;
30 }

```

5.20 04 - 莫比乌斯函数筛 (莫比乌斯反演)

Listing 46: **math/04-Mu-Sieve.cpp**

```

1  /** 莫比乌斯函数筛 (莫比乌斯函数/反演)
2   *   2023-03-04: https://atcoder.jp/contests/tupc2022/submissions/39391116
3   **/
4  std::unordered_map<int, Z> fMu;
5
6  constexpr int N = 1E7;
7  std::vector<int> minp, primes;
8  std::vector<Z> mu;
9
10 void sieve(int n) {
11     minp.assign(n + 1, 0);
12     mu.resize(n);
13     primes.clear();
14
15     mu[1] = 1;
16     for (int i = 2; i <= n; i++) {
17         if (minp[i] == 0) {
18             mu[i] = -1;
19             minp[i] = i;
20             primes.push_back(i);
21         }

```

```

22
23     for (auto p : primes) {
24         if (i * p > n) {
25             break;
26         }
27         minp[i * p] = p;
28         if (p == minp[i]) {
29             break;
30         }
31         mu[i * p] = -mu[i];
32     }
33 }
34
35 for (int i = 1; i <= n; i++) {
36     mu[i] += mu[i - 1];
37 }
38 }
39
40 Z sumMu(int n) {
41     if (n <= N) {
42         return mu[n];
43     }
44     if (fMu.count(n)) {
45         return fMu[n];
46     }
47     if (n == 0) {
48         return 0;
49     }
50     Z ans = 1;
51     for (int l = 2, r; l <= n; l = r + 1) {
52         r = n / (n / l);
53         ans -= (r - l + 1) * sumMu(n / l);
54     }
55     return ans;
56 }

```

5.21 05 - 扩展欧几里得 (exgcd)

Listing 47: math/05-Exgcd.cpp

```

1  /** 扩展欧几里得 (exgcd)
2   *   2023-10-09: https://atcoder.jp/contests/tenka1-2017/submissions/46411797
3   **/
4  int exgcd(int a, int b, int &x, int &y) {
5      if (!b) {
6          x = 1, y = 0;
7          return a;
8      }
9      int g = exgcd(b, a % b, y, x);
10     y -= a / b * x;
11     return g;
12 }
13
14 /** 扩展欧几里得 (exgcd)
15 *   2023-09-05: https://qoj.ac/submission/165983
16 **/
17 std::array<i64, 3> exgcd(i64 a, i64 b) {
18     if (!b) {
19         return {a, 1, 0};
20     }
21     auto [g, x, y] = exgcd(b, a % b);
22     return {g, y, x - a / b * y};
23 }

```

5.22 06A - 欧拉函数 (求解单个数的欧拉函数)

Listing 48: math/06A-Phi.cpp

```

1  /** 欧拉函数 (求解单个数的欧拉函数)
2   *   2023-10-09: https://atcoder.jp/contests/tenka1-2017/submissions/46411797
3   **/
4  int phi(int n) {
5      int res = n;
6      for (int i = 2; i * i <= n; i++) {
7          if (n % i == 0) {
8              while (n % i == 0) {
9                  n /= i;
10             }
11             res = res / i * (i - 1);
12         }
13     }
14     if (n > 1) {
15         res = res / n * (n - 1);
16     }
17     return res;
18 }

```

5.23 06B - 欧拉函数 (求解全部数的欧拉函数)

Listing 49: math/06B-Phi-Sieve.cpp

```

1  /** 欧拉函数 (求解全部数的欧拉函数)
2   *   2023-09-24: https://qoj.ac/submission/187055
3   **/
4  constexpr int N = 1E7;
5  constexpr int P = 1000003;
6
7  bool isprime[N + 1];
8  int phi[N + 1];
9  std::vector<int> primes;
10
11 void sieve(void) {
12     std::fill(isprime + 2, isprime + N + 1, true);
13     phi[1] = 1;
14     for (int i = 2; i <= N; i++) {
15         if (isprime[i]) {
16             primes.push_back(i);
17             phi[i] = i - 1;
18         }
19         for (auto p : primes) {
20             if (i * p > N) {
21                 break;
22             }
23             isprime[i * p] = false;
24             if (i % p == 0) {
25                 phi[i * p] = phi[i] * p;
26                 break;
27             }
28             phi[i * p] = phi[i] * (p - 1);
29         }
30     }
31 }

```

5.24 07A - 组合数 (小范围预处理, 逆元 + 杨辉三角)

Listing 50: math/07A-Comb.cpp

```

1  /** 组合数 (小范围预处理, 逆元+杨辉三角)

```

```

2  * 2024-03-14: https://qoj.ac/submission/353877
3  * 2023-10-06: https://qoj.ac/submission/203196
4  **/
5  constexpr int P = 1000000007;
6  constexpr int L = 10000;
7
8  int fac[L + 1], invfac[L + 1];
9  int sumbinom[L + 1][7];
10
11 int binom(int n, int m) {
12     if (n < m || m < 0) {
13         return 0;
14     }
15     return 1LL * fac[n] * invfac[m] % P * invfac[n - m] % P;
16 }
17
18 int power(int a, int b) {
19     int res = 1;
20     for (; b; b /= 2, a = 1LL * a * a % P) {
21         if (b % 2) {
22             res = 1LL * res * a % P;
23         }
24     }
25     return res;
26 }
27
28 int main() {
29     fac[0] = 1;
30     for (int i = 1; i <= L; i++) {
31         fac[i] = 1LL * fac[i - 1] * i % P;
32     }
33     invfac[L] = power(fac[L], P - 2);
34     for (int i = L; i; i--) {
35         invfac[i - 1] = 1LL * invfac[i] * i % P;
36     }
37
38     sumbinom[0][0] = 1;
39     for (int i = 1; i <= L; i++) {
40         for (int j = 0; j < 7; j++) {
41             sumbinom[i][j] = (sumbinom[i - 1][j] + sumbinom[i - 1][(j + 6) % 7]) % P;
42         }
43     }
44 }

```

5.25 07B - 组合数 (Comb, with. ModIntBase)

Listing 51: math/07B-Comb.cpp

```

1  /** 组合数 (Comb, with. MInt & MLong)
2  * 2023-08-26: https://codeforces.com/contest/1864/submission/220584872
3  **/
4  struct Comb {
5      int n;
6      std::vector<Z> _fac;
7      std::vector<Z> _invfac;
8      std::vector<Z> _inv;
9
10     Comb() : n{0}, _fac{1}, _invfac{1}, _inv{0} {}
11     Comb(int n) : Comb() {
12         init(n);
13     }
14
15     void init(int m) {
16         m = std::min(m, Z::getMod() - 1);

```

```

17     if (m <= n) return;
18     _fac.resize(m + 1);
19     _invfac.resize(m + 1);
20     _inv.resize(m + 1);
21
22     for (int i = n + 1; i <= m; i++) {
23         _fac[i] = _fac[i - 1] * i;
24     }
25     _invfac[m] = _fac[m].inv();
26     for (int i = m; i > n; i--) {
27         _invfac[i - 1] = _invfac[i] * i;
28         _inv[i] = _invfac[i] * _fac[i - 1];
29     }
30     n = m;
31 }
32
33 Z fac(int m) {
34     if (m > n) init(2 * m);
35     return _fac[m];
36 }
37 Z invfac(int m) {
38     if (m > n) init(2 * m);
39     return _invfac[m];
40 }
41 Z inv(int m) {
42     if (m > n) init(2 * m);
43     return _inv[m];
44 }
45 Z binom(int n, int m) {
46     if (n < m || m < 0) return 0;
47     return fac(n) * invfac(m) * invfac(n - m);
48 }
49 } comb;

```

5.26 08 - 素数测试与因式分解 (Miller-Rabin and Pollard-Rho)

Listing 52: **math/08-Prime.cpp**

```

1  i64 mul(i64 a, i64 b, i64 m) {
2      return static_cast<__int128>(a) * b % m;
3  }
4  i64 power(i64 a, i64 b, i64 m) {
5      i64 res = 1 % m;
6      for (; b >>= 1; a = mul(a, a, m))
7          if (b & 1)
8              res = mul(res, a, m);
9      return res;
10 }
11 bool isprime(i64 n) {
12     if (n < 2)
13         return false;
14     static constexpr int A[] = {2, 3, 5, 7, 11, 13, 17, 19, 23};
15     int s = __builtin_ctzll(n - 1);
16     i64 d = (n - 1) >> s;
17     for (auto a : A) {
18         if (a == n)
19             return true;
20         i64 x = power(a, d, n);
21         if (x == 1 || x == n - 1)
22             continue;
23         bool ok = false;
24         for (int i = 0; i < s - 1; ++i) {
25             x = mul(x, x, n);

```



```

26         if (x == n - 1) {
27             ok = true;
28             break;
29         }
30     }
31     if (!ok)
32         return false;
33 }
34 return true;
35 }
36 std::vector<i64> factorize(i64 n) {
37     std::vector<i64> p;
38     std::function<void(i64)> f = [&](i64 n) {
39         if (n <= 10000) {
40             for (int i = 2; i * i <= n; ++i)
41                 for (; n % i == 0; n /= i)
42                     p.push_back(i);
43             if (n > 1)
44                 p.push_back(n);
45             return;
46         }
47         if (isprime(n)) {
48             p.push_back(n);
49             return;
50         }
51         auto g = [&](i64 x) {
52             return (mul(x, x, n) + 1) % n;
53         };
54         i64 x0 = 2;
55         while (true) {
56             i64 x = x0;
57             i64 y = x0;
58             i64 d = 1;
59             i64 power = 1, lam = 0;
60             i64 v = 1;
61             while (d == 1) {
62                 y = g(y);
63                 ++lam;
64                 v = mul(v, std::abs(x - y), n);
65                 if (lam % 127 == 0) {
66                     d = std::gcd(v, n);
67                     v = 1;
68                 }
69                 if (power == lam) {
70                     x = y;
71                     power *= 2;
72                     lam = 0;
73                     d = std::gcd(v, n);
74                     v = 1;
75                 }
76             }
77             if (d != n) {
78                 f(d);
79                 f(n / d);
80                 return;
81             }
82             ++x0;
83         }
84     };
85     f(n);
86     std::sort(p.begin(), p.end());
87     return p;
88 }

```

5.27 09A - 平面几何 (Point)

Listing 53: math/09A-Flat-Geometry.cpp

```

1  /** 平面几何 (Point)
2   *   2023-09-22: https://qoj.ac/submission/185408
3   **/
4  template<class T>
5  struct Point {
6      T x;
7      T y;
8      Point(const T &x_ = 0, const T &y_ = 0) : x(x_), y(y_) {}
9
10     template<class U>
11     operator Point<U>() {
12         return Point<U>(U(x), U(y));
13     }
14     Point &operator+=(const Point &p) & {
15         x += p.x;
16         y += p.y;
17         return *this;
18     }
19     Point &operator-=(const Point &p) & {
20         x -= p.x;
21         y -= p.y;
22         return *this;
23     }
24     Point &operator*=(const T &v) & {
25         x *= v;
26         y *= v;
27         return *this;
28     }
29     Point &operator/=(const T &v) & {
30         x /= v;
31         y /= v;
32         return *this;
33     }
34     Point operator-() const {
35         return Point(-x, -y);
36     }
37     friend Point operator+(Point a, const Point &b) {
38         return a += b;
39     }
40     friend Point operator-(Point a, const Point &b) {
41         return a -= b;
42     }
43     friend Point operator*(Point a, const T &b) {
44         return a *= b;
45     }
46     friend Point operator/(Point a, const T &b) {
47         return a /= b;
48     }
49     friend Point operator*(const T &a, Point b) {
50         return b *= a;
51     }
52     friend bool operator==(const Point &a, const Point &b) {
53         return a.x == b.x && a.y == b.y;
54     }
55     friend std::istream &operator>>(std::istream &is, Point &p) {
56         return is >> p.x >> p.y;
57     }
58     friend std::ostream &operator<<(std::ostream &os, const Point &p) {
59         return os << "(" << p.x << ",_" << p.y << ")";
60     }
61 };

```

```

62
63 template<class T>
64 struct Line {
65     Point<T> a;
66     Point<T> b;
67     Line(const Point<T> &a_ = Point<T>(), const Point<T> &b_ = Point<T>()) : a(a_), b(b_) {}
68 };
69
70 template<class T>
71 T dot(const Point<T> &a, const Point<T> &b) {
72     return a.x * b.x + a.y * b.y;
73 }
74
75 template<class T>
76 T cross(const Point<T> &a, const Point<T> &b) {
77     return a.x * b.y - a.y * b.x;
78 }
79
80 template<class T>
81 T square(const Point<T> &p) {
82     return dot(p, p);
83 }
84
85 template<class T>
86 double length(const Point<T> &p) {
87     return std::sqrt(square(p));
88 }
89
90 template<class T>
91 double length(const Line<T> &l) {
92     return length(l.a - l.b);
93 }
94
95 template<class T>
96 Point<T> normalize(const Point<T> &p) {
97     return p / length(p);
98 }
99
100 template<class T>
101 bool parallel(const Line<T> &l1, const Line<T> &l2) {
102     return cross(l1.b - l1.a, l2.b - l2.a) == 0;
103 }
104
105 template<class T>
106 double distance(const Point<T> &a, const Point<T> &b) {
107     return length(a - b);
108 }
109
110 template<class T>
111 double distancePL(const Point<T> &p, const Line<T> &l) {
112     return std::abs(cross(l.a - l.b, l.a - p)) / length(l);
113 }
114
115 template<class T>
116 double distancePS(const Point<T> &p, const Line<T> &l) {
117     if (dot(p - l.a, l.b - l.a) < 0) {
118         return distance(p, l.a);
119     }
120     if (dot(p - l.b, l.a - l.b) < 0) {
121         return distance(p, l.b);
122     }
123     return distancePL(p, l);
124 }
125

```

```

126 template<class T>
127 Point<T> rotate(const Point<T> &a) {
128     return Point(-a.y, a.x);
129 }
130
131 template<class T>
132 int sgn(const Point<T> &a) {
133     return a.y > 0 || (a.y == 0 && a.x > 0) ? 1 : -1;
134 }
135
136 template<class T>
137 bool pointOnLineLeft(const Point<T> &p, const Line<T> &l) {
138     return cross(l.b - l.a, p - l.a) > 0;
139 }
140
141 template<class T>
142 Point<T> lineIntersection(const Line<T> &l1, const Line<T> &l2) {
143     return l1.a + (l1.b - l1.a) * (cross(l2.b - l2.a, l1.a - l2.a) / cross(l2.b - l2.a, l1.a - l1.b));
144 }
145
146 template<class T>
147 bool pointOnSegment(const Point<T> &p, const Line<T> &l) {
148     return cross(p - l.a, l.b - l.a) == 0 && std::min(l.a.x, l.b.x) <= p.x && p.x <= std::max(l.a.x, l.b.x)
149         && std::min(l.a.y, l.b.y) <= p.y && p.y <= std::max(l.a.y, l.b.y);
150 }
151
152 template<class T>
153 bool pointInPolygon(const Point<T> &a, const std::vector<Point<T>> &p) {
154     int n = p.size();
155     for (int i = 0; i < n; i++) {
156         if (pointOnSegment(a, Line(p[i], p[(i + 1) % n]))) {
157             return true;
158         }
159     }
160
161     int t = 0;
162     for (int i = 0; i < n; i++) {
163         auto u = p[i];
164         auto v = p[(i + 1) % n];
165         if (u.x < a.x && v.x >= a.x && pointOnLineLeft(a, Line(v, u))) {
166             t ^= 1;
167         }
168         if (u.x >= a.x && v.x < a.x && pointOnLineLeft(a, Line(u, v))) {
169             t ^= 1;
170         }
171     }
172
173     return t == 1;
174 }
175
176 // 0 : not intersect
177 // 1 : strictly intersect
178 // 2 : overlap
179 // 3 : intersect at endpoint
180 template<class T>
181 std::tuple<int, Point<T>, Point<T>> segmentIntersection(const Line<T> &l1, const Line<T> &l2) {
182     if (std::max(l1.a.x, l1.b.x) < std::min(l2.a.x, l2.b.x)) {
183         return {0, Point<T>(), Point<T>()};
184     }
185     if (std::min(l1.a.x, l1.b.x) > std::max(l2.a.x, l2.b.x)) {
186         return {0, Point<T>(), Point<T>()};
187     }
188     if (std::max(l1.a.y, l1.b.y) < std::min(l2.a.y, l2.b.y)) {

```

```

189     return {0, Point<T>(), Point<T>()};
190 }
191 if (std::min(l1.a.y, l1.b.y) > std::max(l2.a.y, l2.b.y)) {
192     return {0, Point<T>(), Point<T>()};
193 }
194 if (cross(l1.b - l1.a, l2.b - l2.a) == 0) {
195     if (cross(l1.b - l1.a, l2.a - l1.a) != 0) {
196         return {0, Point<T>(), Point<T>()};
197     } else {
198         auto maxx1 = std::max(l1.a.x, l1.b.x);
199         auto minx1 = std::min(l1.a.x, l1.b.x);
200         auto maxy1 = std::max(l1.a.y, l1.b.y);
201         auto miny1 = std::min(l1.a.y, l1.b.y);
202         auto maxx2 = std::max(l2.a.x, l2.b.x);
203         auto minx2 = std::min(l2.a.x, l2.b.x);
204         auto maxy2 = std::max(l2.a.y, l2.b.y);
205         auto miny2 = std::min(l2.a.y, l2.b.y);
206         Point<T> p1(std::max(minx1, minx2), std::max(miny1, miny2));
207         Point<T> p2(std::min(maxx1, maxx2), std::min(maxy1, maxy2));
208         if (!pointOnSegment(p1, l1)) {
209             std::swap(p1.y, p2.y);
210         }
211         if (p1 == p2) {
212             return {3, p1, p2};
213         } else {
214             return {2, p1, p2};
215         }
216     }
217 }
218 auto cp1 = cross(l2.a - l1.a, l2.b - l1.a);
219 auto cp2 = cross(l2.a - l1.b, l2.b - l1.b);
220 auto cp3 = cross(l1.a - l2.a, l1.b - l2.a);
221 auto cp4 = cross(l1.a - l2.b, l1.b - l2.b);
222
223 if ((cp1 > 0 && cp2 > 0) || (cp1 < 0 && cp2 < 0) || (cp3 > 0 && cp4 > 0) || (cp3 < 0 && cp4 < 0)) {
224     return {0, Point<T>(), Point<T>()};
225 }
226
227 Point p = lineIntersection(l1, l2);
228 if (cp1 != 0 && cp2 != 0 && cp3 != 0 && cp4 != 0) {
229     return {1, p, p};
230 } else {
231     return {3, p, p};
232 }
233 }
234
235 template<class T>
236 double distanceSS(const Line<T> &l1, const Line<T> &l2) {
237     if (std::get<0>(segmentIntersection(l1, l2)) != 0) {
238         return 0.0;
239     }
240     return std::min({distancePS(l1.a, l2), distancePS(l1.b, l2), distancePS(l2.a, l1), distancePS(l2.b, l1)});
241 }
242
243 template<class T>
244 bool segmentInPolygon(const Line<T> &l, const std::vector<Point<T>> &p) {
245     int n = p.size();
246     if (!pointInPolygon(l.a, p)) {
247         return false;
248     }
249     if (!pointInPolygon(l.b, p)) {
250         return false;

```

```

251     }
252     for (int i = 0; i < n; i++) {
253         auto u = p[i];
254         auto v = p[(i + 1) % n];
255         auto w = p[(i + 2) % n];
256         auto [t, p1, p2] = segmentIntersection(l, Line(u, v));
257
258         if (t == 1) {
259             return false;
260         }
261         if (t == 0) {
262             continue;
263         }
264         if (t == 2) {
265             if (pointOnSegment(v, l) && v != l.a && v != l.b) {
266                 if (cross(v - u, w - v) > 0) {
267                     return false;
268                 }
269             }
270         } else {
271             if (p1 != u && p1 != v) {
272                 if (pointOnLineLeft(l.a, Line(v, u))
273                     || pointOnLineLeft(l.b, Line(v, u))) {
274                     return false;
275                 }
276             } else if (p1 == v) {
277                 if (l.a == v) {
278                     if (pointOnLineLeft(u, l)) {
279                         if (pointOnLineLeft(w, l)
280                             && pointOnLineLeft(w, Line(u, v))) {
281                             return false;
282                         }
283                     } else {
284                         if (pointOnLineLeft(w, l)
285                             || pointOnLineLeft(w, Line(u, v))) {
286                             return false;
287                         }
288                     }
289                 } else if (l.b == v) {
290                     if (pointOnLineLeft(u, Line(l.b, l.a))) {
291                         if (pointOnLineLeft(w, Line(l.b, l.a))
292                             && pointOnLineLeft(w, Line(u, v))) {
293                             return false;
294                         }
295                     } else {
296                         if (pointOnLineLeft(w, Line(l.b, l.a))
297                             || pointOnLineLeft(w, Line(u, v))) {
298                             return false;
299                         }
300                     }
301                 } else {
302                     if (pointOnLineLeft(u, l)) {
303                         if (pointOnLineLeft(w, Line(l.b, l.a))
304                             || pointOnLineLeft(w, Line(u, v))) {
305                             return false;
306                         }
307                     } else {
308                         if (pointOnLineLeft(w, l)
309                             || pointOnLineLeft(w, Line(u, v))) {
310                             return false;
311                         }
312                     }
313                 }

```

```

314     }
315 }
316 }
317 return true;
318 }
319
320 template<class T>
321 std::vector<Point<T>> hp(std::vector<Line<T>> lines) {
322     std::sort(lines.begin(), lines.end(), [&](auto l1, auto l2) {
323         auto d1 = l1.b - l1.a;
324         auto d2 = l2.b - l2.a;
325
326         if (sgn(d1) != sgn(d2)) {
327             return sgn(d1) == 1;
328         }
329
330         return cross(d1, d2) > 0;
331     });
332
333     std::deque<Line<T>> ls;
334     std::deque<Point<T>> ps;
335     for (auto l : lines) {
336         if (ls.empty()) {
337             ls.push_back(l);
338             continue;
339         }
340
341         while (!ps.empty() && !pointOnLineLeft(ps.back(), l)) {
342             ps.pop_back();
343             ls.pop_back();
344         }
345
346         while (!ps.empty() && !pointOnLineLeft(ps[0], l)) {
347             ps.pop_front();
348             ls.pop_front();
349         }
350
351         if (cross(l.b - l.a, ls.back().b - ls.back().a) == 0) {
352             if (dot(l.b - l.a, ls.back().b - ls.back().a) > 0) {
353
354                 if (!pointOnLineLeft(ls.back().a, l)) {
355                     assert(ls.size() == 1);
356                     ls[0] = l;
357                 }
358                 continue;
359             }
360             return {};
361         }
362
363         ps.push_back(lineIntersection(ls.back(), l));
364         ls.push_back(l);
365     }
366
367     while (!ps.empty() && !pointOnLineLeft(ps.back(), ls[0])) {
368         ps.pop_back();
369         ls.pop_back();
370     }
371     if (ls.size() <= 2) {
372         return {};
373     }
374     ps.push_back(lineIntersection(ls[0], ls.back()));
375
376     return std::vector(ps.begin(), ps.end());
377 }

```

```

378
379 using real = long double;
380 using P = Point<real>;
381
382 constexpr real eps = 0;

```

5.28 09B - 平面几何 (with. std::complex)

Listing 54: **math/09B-Flat-Geometry.cpp**

```

1  /** 平面几何 (with. std::complex)
2   *   2023-09-04: https://qoj.ac/submission/164445
3   **/
4  using Point = std::complex<long double>;
5
6  #define x real
7  #define y imag
8
9  long double dot(const Point &a, const Point &b) {
10     return (std::conj(a) * b).x();
11 }
12
13 long double cross(const Point &a, const Point &b) {
14     return (std::conj(a) * b).y();
15 }
16
17 long double length(const Point &a) {
18     return std::sqrt(dot(a, a));
19 }
20
21 long double dist(const Point &a, const Point &b) {
22     return length(a - b);
23 }
24
25 long double get(const Point &a, const Point &b, const Point &c, const Point &d) {
26     auto e = a + (b - a) * cross(c - a, d - a) / cross(b - a, d - c);
27     return dist(d, e);
28 }

```

5.29 10 - 立体几何 (Point)

Listing 55: **math/10-Solid-Geometry.cpp**

```

1  /** 立体几何
2   *   2023-09-25 (i64): https://qoj.ac/submission/188519
3   *   2023-09-28 (double): https://qoj.ac/submission/190463
4   **/
5  using i64 = long long;
6  using real = double;
7
8  struct Point {
9     real x = 0;
10    real y = 0;
11    real z = 0;
12 };
13
14 Point operator+(const Point &a, const Point &b) {
15     return {a.x + b.x, a.y + b.y, a.z + b.z};
16 }
17
18 Point operator-(const Point &a, const Point &b) {
19     return {a.x - b.x, a.y - b.y, a.z - b.z};
20 }

```



```

21
22 Point operator*(const Point &a, real b) {
23     return {a.x * b, a.y * b, a.z * b};
24 }
25
26 Point operator/(const Point &a, real b) {
27     return {a.x / b, a.y / b, a.z / b};
28 }
29
30 real length(const Point &a) {
31     return std::hypot(a.x, a.y, a.z);
32 }
33
34 Point normalize(const Point &a) {
35     real l = length(a);
36     return {a.x / l, a.y / l, a.z / l};
37 }
38
39 real getAng(real a, real b, real c) {
40     return std::acos((a * a + b * b - c * c) / 2 / a / b);
41 }
42
43 std::ostream &operator<<(std::ostream &os, const Point &a) {
44     return os << "(" << a.x << ",_" << a.y << ",_" << a.z << ")";
45 }
46
47 real dot(const Point &a, const Point &b) {
48     return a.x * b.x + a.y * b.y + a.z * b.z;
49 }
50
51 Point cross(const Point &a, const Point &b) {
52     return {
53         a.y * b.z - a.z * b.y,
54         a.z * b.x - a.x * b.z,
55         a.x * b.y - a.y * b.x
56     };
57 }

```

5.30 11A - 静态凸包 (with. Point, 旧版)

Listing 56: **math/11A-Convex-Hull.cpp**

```

1 /** 静态凸包 (with. Point, 旧版)
2  * 2023-04-09: https://cf.dianhsu.com/gym/104288/submission/201412835
3  **/
4 struct Point {
5     i64 x;
6     i64 y;
7     Point(i64 x = 0, i64 y = 0) : x(x), y(y) {}
8 };
9
10 bool operator==(const Point &a, const Point &b) {
11     return a.x == b.x && a.y == b.y;
12 }
13
14 Point operator+(const Point &a, const Point &b) {
15     return Point(a.x + b.x, a.y + b.y);
16 }
17
18 Point operator-(const Point &a, const Point &b) {
19     return Point(a.x - b.x, a.y - b.y);
20 }
21
22 i64 dot(const Point &a, const Point &b) {

```

```

23     return a.x * b.x + a.y * b.y;
24 }
25
26 i64 cross(const Point &a, const Point &b) {
27     return a.x * b.y - a.y * b.x;
28 }
29
30 void norm(std::vector<Point> &h) {
31     int i = 0;
32     for (int j = 0; j < int(h.size()); j++) {
33         if (h[j].y < h[i].y || (h[j].y == h[i].y && h[j].x < h[i].x)) {
34             i = j;
35         }
36     }
37     std::rotate(h.begin(), h.begin() + i, h.end());
38 }
39
40 int sgn(const Point &a) {
41     return a.y > 0 || (a.y == 0 && a.x > 0) ? 0 : 1;
42 }
43
44 std::vector<Point> getHull(std::vector<Point> p) {
45     std::vector<Point> h, l;
46     std::sort(p.begin(), p.end(), [&](auto a, auto b) {
47         if (a.x != b.x) {
48             return a.x < b.x;
49         } else {
50             return a.y < b.y;
51         }
52     });
53     p.erase(std::unique(p.begin(), p.end()), p.end());
54     if (p.size() <= 1) {
55         return p;
56     }
57
58     for (auto a : p) {
59         while (h.size() > 1 && cross(a - h.back(), a - h[h.size() - 2]) <= 0) {
60             h.pop_back();
61         }
62         while (l.size() > 1 && cross(a - l.back(), a - l[l.size() - 2]) >= 0) {
63             l.pop_back();
64         }
65         l.push_back(a);
66         h.push_back(a);
67     }
68
69     l.pop_back();
70     std::reverse(h.begin(), h.end());
71     h.pop_back();
72     l.insert(l.end(), h.begin(), h.end());
73     return l;
74 }

```

5.31 11B - 静态凸包 (with. Point, 新版)

Listing 57: math/11B-Convex-Hull.cpp

```

1  /** 静态凸包 (with. Point, 新版)
2   *   2024-04-06: https://qoj.ac/submission/379920
3   **/
4  struct Point {
5      i64 x;
6      i64 y;

```

```

7   Point() : x{0}, y{0} {}
8   Point(i64 x_, i64 y_) : x{x_}, y{y_} {}
9 };
10
11 i64 dot(Point a, Point b) {
12     return a.x * b.x + a.y * b.y;
13 }
14
15 i64 cross(Point a, Point b) {
16     return a.x * b.y - a.y * b.x;
17 }
18
19 Point operator+(Point a, Point b) {
20     return Point(a.x + b.x, a.y + b.y);
21 }
22
23 Point operator-(Point a, Point b) {
24     return Point(a.x - b.x, a.y - b.y);
25 }
26
27 auto getHull(std::vector<Point> p) {
28     std::sort(p.begin(), p.end(),
29         [&](auto a, auto b) {
30             return a.x < b.x || (a.x == b.x && a.y < b.y);
31         });
32
33     std::vector<Point> hi, lo;
34     for (auto p : p) {
35         while (hi.size() > 1 && cross(hi.back() - hi[hi.size() - 2], p - hi.back()) >= 0) {
36             hi.pop_back();
37         }
38         while (!hi.empty() && hi.back().x == p.x) {
39             hi.pop_back();
40         }
41         hi.push_back(p);
42         while (lo.size() > 1 && cross(lo.back() - lo[lo.size() - 2], p - lo.back()) <= 0) {
43             lo.pop_back();
44         }
45         if (lo.empty() || lo.back().x < p.x) {
46             lo.push_back(p);
47         }
48     }
49     return std::make_pair(hi, lo);
50 }
51
52 const double inf = INFINITY;

```

5.32 11C - 静态凸包 (with. std::complex)

Listing 58: math/11C-Convex-Hull.cpp

```

1  /** 静态凸包 (with. std::complex)
2  *   2022-02-04: https://loj.ac/s/1370861
3  **/
4  using Point = std::complex<i64>;
5
6  #define x real
7  #define y imag
8
9  auto dot(const Point &a, const Point &b) {
10     return (std::conj(a) * b).x();
11 }
12

```

```

13 auto cross(const Point &a, const Point &b) {
14     return (std::conj(a) * b).y();
15 }
16
17 auto rot(const Point &p) {
18     return Point(-p.y(), p.x());
19 }
20
21 auto complexHull(std::vector<Point> a) {
22     std::sort(a.begin(), a.end(), [&](auto a, auto b) {
23         if (a.x() != b.x()) {
24             return a.x() < b.x();
25         } else {
26             return a.y() < b.y();
27         }
28     });
29
30     std::vector<Point> l, h;
31
32     for (auto p : a) {
33         while (l.size() > 1 && cross(l.back() - l[l.size() - 2], p - l.back()) <= 0) {
34             l.pop_back();
35         }
36
37         while (h.size() > 1 && cross(h.back() - h[h.size() - 2], p - h.back()) >= 0) {
38             h.pop_back();
39         }
40
41         l.push_back(p);
42         h.push_back(p);
43     }
44
45     std::reverse(h.begin(), h.end());
46
47     h.insert(h.end(), l.begin() + 1, l.end() - 1);
48
49     return h;
50 }
51
52 int sgn(Point p) {
53     if (p.y() > 0 || (p.y() == 0 && p.x() < 0)) {
54         return 0;
55     } else {
56         return 1;
57     }
58 }

```

5.33 12A - 多项式 (Poly, with. Z)

Listing 59: **math/12A-Poly.cpp**

```

1  /** 多项式相关 (Poly, with. Z)
2   *   2023-02-06: https://atcoder.jp/contests/arc155/submissions/38664055
3   **/
4  std::vector<int> rev;
5  std::vector<Z> roots{0, 1};
6  void dft(std::vector<Z> &a) {
7      int n = a.size();
8
9      if (int(rev.size()) != n) {
10         int k = __builtin_ctz(n) - 1;
11         rev.resize(n);
12         for (int i = 0; i < n; i++) {

```

```

13         rev[i] = rev[i >> 1] >> 1 | (i & 1) << k;
14     }
15 }
16
17 for (int i = 0; i < n; i++) {
18     if (rev[i] < i) {
19         std::swap(a[i], a[rev[i]]);
20     }
21 }
22 if (int(roots.size()) < n) {
23     int k = __builtin_ctz(roots.size());
24     roots.resize(n);
25     while ((1 << k) < n) {
26         Z e = power(Z(3), (P - 1) >> (k + 1));
27         for (int i = 1 << (k - 1); i < (1 << k); i++) {
28             roots[2 * i] = roots[i];
29             roots[2 * i + 1] = roots[i] * e;
30         }
31         k++;
32     }
33 }
34 for (int k = 1; k < n; k *= 2) {
35     for (int i = 0; i < n; i += 2 * k) {
36         for (int j = 0; j < k; j++) {
37             Z u = a[i + j];
38             Z v = a[i + j + k] * roots[k + j];
39             a[i + j] = u + v;
40             a[i + j + k] = u - v;
41         }
42     }
43 }
44 }
45 void idft(std::vector<Z> &a) {
46     int n = a.size();
47     std::reverse(a.begin() + 1, a.end());
48     dft(a);
49     Z inv = (1 - P) / n;
50     for (int i = 0; i < n; i++) {
51         a[i] *= inv;
52     }
53 }
54 struct Poly {
55     std::vector<Z> a;
56     Poly() {}
57     explicit Poly(int size, std::function<Z(int)> f = [](int) { return 0; }) : a(size) {
58         for (int i = 0; i < size; i++) {
59             a[i] = f(i);
60         }
61     }
62     Poly(const std::vector<Z> &a) : a(a) {}
63     Poly(const std::initializer_list<Z> &a) : a(a) {}
64     int size() const {
65         return a.size();
66     }
67     void resize(int n) {
68         a.resize(n);
69     }
70     Z operator[](int idx) const {
71         if (idx < size()) {
72             return a[idx];
73         } else {
74             return 0;
75         }
76     }

```

```

76     }
77     Z &operator[](int idx) {
78         return a[idx];
79     }
80     Poly mulxk(int k) const {
81         auto b = a;
82         b.insert(b.begin(), k, 0);
83         return Poly(b);
84     }
85     Poly modxk(int k) const {
86         k = std::min(k, size());
87         return Poly(std::vector<Z>(a.begin(), a.begin() + k));
88     }
89     Poly divxk(int k) const {
90         if (size() <= k) {
91             return Poly();
92         }
93         return Poly(std::vector<Z>(a.begin() + k, a.end()));
94     }
95     friend Poly operator+(const Poly &a, const Poly &b) {
96         std::vector<Z> res(std::max(a.size(), b.size()));
97         for (int i = 0; i < int(res.size()); i++) {
98             res[i] = a[i] + b[i];
99         }
100        return Poly(res);
101    }
102    friend Poly operator-(const Poly &a, const Poly &b) {
103        std::vector<Z> res(std::max(a.size(), b.size()));
104        for (int i = 0; i < int(res.size()); i++) {
105            res[i] = a[i] - b[i];
106        }
107        return Poly(res);
108    }
109    friend Poly operator~(const Poly &a) {
110        std::vector<Z> res(a.size());
111        for (int i = 0; i < int(res.size()); i++) {
112            res[i] = -a[i];
113        }
114        return Poly(res);
115    }
116    friend Poly operator*(Poly a, Poly b) {
117        if (a.size() == 0 || b.size() == 0) {
118            return Poly();
119        }
120        if (a.size() < b.size()) {
121            std::swap(a, b);
122        }
123        if (b.size() < 128) {
124            Poly c(a.size() + b.size() - 1);
125            for (int i = 0; i < a.size(); i++) {
126                for (int j = 0; j < b.size(); j++) {
127                    c[i + j] += a[i] * b[j];
128                }
129            }
130            return c;
131        }
132        int sz = 1, tot = a.size() + b.size() - 1;
133        while (sz < tot) {
134            sz *= 2;
135        }
136        a.a.resize(sz);
137        b.a.resize(sz);
138        dft(a.a);

```

```

139     dft(b.a);
140     for (int i = 0; i < sz; ++i) {
141         a.a[i] = a[i] * b[i];
142     }
143     idft(a.a);
144     a.resize(tot);
145     return a;
146 }
147 friend Poly operator*(Z a, Poly b) {
148     for (int i = 0; i < int(b.size()); i++) {
149         b[i] *= a;
150     }
151     return b;
152 }
153 friend Poly operator*(Poly a, Z b) {
154     for (int i = 0; i < int(a.size()); i++) {
155         a[i] *= b;
156     }
157     return a;
158 }
159 Poly &operator+=(Poly b) {
160     return (*this) = (*this) + b;
161 }
162 Poly &operator-=(Poly b) {
163     return (*this) = (*this) - b;
164 }
165 Poly &operator*=(Poly b) {
166     return (*this) = (*this) * b;
167 }
168 Poly &operator*=(Z b) {
169     return (*this) = (*this) * b;
170 }
171 Poly deriv() const {
172     if (a.empty()) {
173         return Poly();
174     }
175     std::vector<Z> res(size() - 1);
176     for (int i = 0; i < size() - 1; ++i) {
177         res[i] = (i + 1) * a[i + 1];
178     }
179     return Poly(res);
180 }
181 Poly integr() const {
182     std::vector<Z> res(size() + 1);
183     for (int i = 0; i < size(); ++i) {
184         res[i + 1] = a[i] / (i + 1);
185     }
186     return Poly(res);
187 }
188 Poly inv(int m) const {
189     Poly x{a[0].inv()};
190     int k = 1;
191     while (k < m) {
192         k *= 2;
193         x = (x * (Poly{2} - modxk(k) * x)).modxk(k);
194     }
195     return x.modxk(m);
196 }
197 Poly log(int m) const {
198     return (deriv() * inv(m)).integr().modxk(m);
199 }
200 Poly exp(int m) const {
201     Poly x{1};

```

```

202     int k = 1;
203     while (k < m) {
204         k *= 2;
205         x = (x * (Poly{1} - x.log(k) + modxk(k))).modxk(k);
206     }
207     return x.modxk(m);
208 }
209 Poly pow(int k, int m) const {
210     int i = 0;
211     while (i < size() && a[i].val() == 0) {
212         i++;
213     }
214     if (i == size() || 1LL * i * k >= m) {
215         return Poly(std::vector<Z>(m));
216     }
217     Z v = a[i];
218     auto f = divxk(i) * v.inv();
219     return (f.log(m - i * k) * k).exp(m - i * k).mulxk(i * k) * power(v, k);
220 }
221 Poly sqrt(int m) const {
222     Poly x{1};
223     int k = 1;
224     while (k < m) {
225         k *= 2;
226         x = (x + (modxk(k) * x.inv(k)).modxk(k)) * ((P + 1) / 2);
227     }
228     return x.modxk(m);
229 }
230 Poly mulT(Poly b) const {
231     if (b.size() == 0) {
232         return Poly();
233     }
234     int n = b.size();
235     std::reverse(b.a.begin(), b.a.end());
236     return ((*this) * b).divxk(n - 1);
237 }
238 std::vector<Z> eval(std::vector<Z> x) const {
239     if (size() == 0) {
240         return std::vector<Z>(x.size(), 0);
241     }
242     const int n = std::max(int(x.size()), size());
243     std::vector<Poly> q(4 * n);
244     std::vector<Z> ans(x.size());
245     x.resize(n);
246     std::function<void(int, int, int)> build = [&](int p, int l, int r) {
247         if (r - l == 1) {
248             q[p] = Poly{1, -x[l]};
249         } else {
250             int m = (l + r) / 2;
251             build(2 * p, l, m);
252             build(2 * p + 1, m, r);
253             q[p] = q[2 * p] * q[2 * p + 1];
254         }
255     };
256     build(1, 0, n);
257     std::function<void(int, int, int, const Poly &)> work = [&](int p, int l, int r, const Poly &num) {
258         if (r - l == 1) {
259             if (l < int(ans.size())) {
260                 ans[l] = num[0];
261             }
262         } else {
263             int m = (l + r) / 2;
264             work(2 * p, l, m, num.mulT(q[2 * p + 1]).modxk(m - l));

```



```

265         work(2 * p + 1, m, r, num.mulT(q[2 * p]).modxk(r - m));
266     }
267 };
268 work(1, 0, n, mulT(q[1].inv(n)));
269 return ans;
270 }
271 };

```

5.34 12B - 多项式 (Poly, with. MInt)

Listing 60: math/12B-Poly.cpp

```

1  /** 多项式相关 (Poly, with. MInt & MLong)
2   *   2023-09-20: https://atcoder.jp/contests/arc163/submissions/45737810
3   **/
4  std::vector<int> rev;
5  template<int P>
6  std::vector<MInt<P>> roots{0, 1};
7
8  template<int P>
9  constexpr MInt<P> findPrimitiveRoot() {
10     MInt<P> i = 2;
11     int k = __builtin_ctz(P - 1);
12     while (true) {
13         if (power(i, (P - 1) / 2) != 1) {
14             break;
15         }
16         i += 1;
17     }
18     return power(i, (P - 1) >> k);
19 }
20
21 template<int P>
22 constexpr MInt<P> primitiveRoot = findPrimitiveRoot<P>();
23
24 template<>
25 constexpr MInt<998244353> primitiveRoot<998244353> {31};
26
27 template<int P>
28 constexpr void dft(std::vector<MInt<P>> &a) {
29     int n = a.size();
30
31     if (int(rev.size()) != n) {
32         int k = __builtin_ctz(n) - 1;
33         rev.resize(n);
34         for (int i = 0; i < n; i++) {
35             rev[i] = rev[i >> 1] >> 1 | (i & 1) << k;
36         }
37     }
38
39     for (int i = 0; i < n; i++) {
40         if (rev[i] < i) {
41             std::swap(a[i], a[rev[i]]);
42         }
43     }
44     if (roots<P>.size() < n) {
45         int k = __builtin_ctz(roots<P>.size());
46         roots<P>.resize(n);
47         while ((1 << k) < n) {
48             auto e = power(primitiveRoot<P>, 1 << (__builtin_ctz(P - 1) - k - 1));
49             for (int i = 1 << (k - 1); i < (1 << k); i++) {
50                 roots<P>[2 * i] = roots<P>[i];
51                 roots<P>[2 * i + 1] = roots<P>[i] * e;

```

```

52         }
53         k++;
54     }
55 }
56 for (int k = 1; k < n; k *= 2) {
57     for (int i = 0; i < n; i += 2 * k) {
58         for (int j = 0; j < k; j++) {
59             MInt<P> u = a[i + j];
60             MInt<P> v = a[i + j + k] * roots<P>[k + j];
61             a[i + j] = u + v;
62             a[i + j + k] = u - v;
63         }
64     }
65 }
66 }
67
68 template<int P>
69 constexpr void idft(std::vector<MInt<P>> &a) {
70     int n = a.size();
71     std::reverse(a.begin() + 1, a.end());
72     dft(a);
73     MInt<P> inv = (1 - P) / n;
74     for (int i = 0; i < n; i++) {
75         a[i] *= inv;
76     }
77 }
78
79 template<int P = 998244353>
80 struct Poly : public std::vector<MInt<P>> {
81     using Value = MInt<P>;
82
83     Poly() : std::vector<Value>() {}
84     explicit constexpr Poly(int n) : std::vector<Value>(n) {}
85
86     explicit constexpr Poly(const std::vector<Value> &a) : std::vector<Value>(a) {}
87     constexpr Poly(const std::initializer_list<Value> &a) : std::vector<Value>(a) {}
88
89     template<class InputIt, class = std::_RequireInputIter<InputIt>>
90     explicit constexpr Poly(InputIt first, InputIt last) : std::vector<Value>(first, last) {}
91
92     template<class F>
93     explicit constexpr Poly(int n, F f) : std::vector<Value>(n) {
94         for (int i = 0; i < n; i++) {
95             (*this)[i] = f(i);
96         }
97     }
98
99     constexpr Poly shift(int k) const {
100         if (k >= 0) {
101             auto b = *this;
102             b.insert(b.begin(), k, 0);
103             return b;
104         } else if (this->size() <= -k) {
105             return Poly();
106         } else {
107             return Poly(this->begin() + (-k), this->end());
108         }
109     }
110     constexpr Poly trunc(int k) const {
111         Poly f = *this;
112         f.resize(k);
113         return f;
114     }
115     constexpr friend Poly operator+(const Poly &a, const Poly &b) {

```

```

116     Poly res(std::max(a.size(), b.size()));
117     for (int i = 0; i < a.size(); i++) {
118         res[i] += a[i];
119     }
120     for (int i = 0; i < b.size(); i++) {
121         res[i] += b[i];
122     }
123     return res;
124 }
125 constexpr friend Poly operator+(const Poly &a, const Poly &b) {
126     Poly res(std::max(a.size(), b.size()));
127     for (int i = 0; i < a.size(); i++) {
128         res[i] += a[i];
129     }
130     for (int i = 0; i < b.size(); i++) {
131         res[i] += b[i];
132     }
133     return res;
134 }
135 constexpr friend Poly operator-(const Poly &a) {
136     std::vector<Value> res(a.size());
137     for (int i = 0; i < int(res.size()); i++) {
138         res[i] = -a[i];
139     }
140     return Poly(res);
141 }
142 constexpr friend Poly operator*(Poly a, Poly b) {
143     if (a.size() == 0 || b.size() == 0) {
144         return Poly();
145     }
146     if (a.size() < b.size()) {
147         std::swap(a, b);
148     }
149     int n = 1, tot = a.size() + b.size() - 1;
150     while (n < tot) {
151         n *= 2;
152     }
153     if (((P - 1) & (n - 1)) != 0 || b.size() < 128) {
154         Poly c(a.size() + b.size() - 1);
155         for (int i = 0; i < a.size(); i++) {
156             for (int j = 0; j < b.size(); j++) {
157                 c[i + j] += a[i] * b[j];
158             }
159         }
160         return c;
161     }
162     a.resize(n);
163     b.resize(n);
164     dft(a);
165     dft(b);
166     for (int i = 0; i < n; ++i) {
167         a[i] *= b[i];
168     }
169     idft(a);
170     a.resize(tot);
171     return a;
172 }
173 constexpr friend Poly operator*(Value a, Poly b) {
174     for (int i = 0; i < int(b.size()); i++) {
175         b[i] *= a;
176     }
177     return b;
178 }

```

```

179     constexpr friend Poly operator*(Poly a, Value b) {
180         for (int i = 0; i < int(a.size()); i++) {
181             a[i] *= b;
182         }
183         return a;
184     }
185     constexpr friend Poly operator/(Poly a, Value b) {
186         for (int i = 0; i < int(a.size()); i++) {
187             a[i] /= b;
188         }
189         return a;
190     }
191     constexpr Poly &operator+=(Poly b) {
192         return (*this) = (*this) + b;
193     }
194     constexpr Poly &operator-=(Poly b) {
195         return (*this) = (*this) - b;
196     }
197     constexpr Poly &operator*=(Poly b) {
198         return (*this) = (*this) * b;
199     }
200     constexpr Poly &operator*=(Value b) {
201         return (*this) = (*this) * b;
202     }
203     constexpr Poly &operator/=(Value b) {
204         return (*this) = (*this) / b;
205     }
206     constexpr Poly deriv() const {
207         if (this->empty()) {
208             return Poly();
209         }
210         Poly res(this->size() - 1);
211         for (int i = 0; i < this->size() - 1; ++i) {
212             res[i] = (i + 1) * (*this)[i + 1];
213         }
214         return res;
215     }
216     constexpr Poly integr() const {
217         Poly res(this->size() + 1);
218         for (int i = 0; i < this->size(); ++i) {
219             res[i + 1] = (*this)[i] / (i + 1);
220         }
221         return res;
222     }
223     constexpr Poly inv(int m) const {
224         Poly x{(*this)[0].inv()};
225         int k = 1;
226         while (k < m) {
227             k *= 2;
228             x = (x * (Poly{2} - trunc(k) * x)).trunc(k);
229         }
230         return x.trunc(m);
231     }
232     constexpr Poly log(int m) const {
233         return (deriv() * inv(m)).integr().trunc(m);
234     }
235     constexpr Poly exp(int m) const {
236         Poly x{1};
237         int k = 1;
238         while (k < m) {
239             k *= 2;
240             x = (x * (Poly{1} - x.log(k) + trunc(k))).trunc(k);
241         }

```

```

242     return x.trunc(m);
243 }
244 constexpr Poly pow(int k, int m) const {
245     int i = 0;
246     while (i < this->size() && (*this)[i] == 0) {
247         i++;
248     }
249     if (i == this->size() || 1LL * i * k >= m) {
250         return Poly(m);
251     }
252     Value v = (*this)[i];
253     auto f = shift(-i) * v.inv();
254     return (f.log(m - i * k) * k).exp(m - i * k).shift(i * k) * power(v, k);
255 }
256 constexpr Poly sqrt(int m) const {
257     Poly x{1};
258     int k = 1;
259     while (k < m) {
260         k *= 2;
261         x = (x + (trunc(k) * x.inv(k)).trunc(k)) * CInv<2, P>;
262     }
263     return x.trunc(m);
264 }
265 constexpr Poly mult(Poly b) const {
266     if (b.size() == 0) {
267         return Poly();
268     }
269     int n = b.size();
270     std::reverse(b.begin(), b.end());
271     return ((*this) * b).shift(-(n - 1));
272 }
273 constexpr std::vector<Value> eval(std::vector<Value> x) const {
274     if (this->size() == 0) {
275         return std::vector<Value>(x.size(), 0);
276     }
277     const int n = std::max(x.size(), this->size());
278     std::vector<Poly> q(4 * n);
279     std::vector<Value> ans(x.size());
280     x.resize(n);
281     std::function<void(int, int, int)> build = [&](int p, int l, int r) {
282         if (r - l == 1) {
283             q[p] = Poly{1, -x[l]};
284         } else {
285             int m = (l + r) / 2;
286             build(2 * p, l, m);
287             build(2 * p + 1, m, r);
288             q[p] = q[2 * p] * q[2 * p + 1];
289         }
290     };
291     build(1, 0, n);
292     std::function<void(int, int, int, const Poly &)> work = [&](int p, int l, int r, const Poly &num) {
293         if (r - l == 1) {
294             if (l < int(ans.size())) {
295                 ans[l] = num[0];
296             }
297         } else {
298             int m = (l + r) / 2;
299             work(2 * p, l, m, num.mult(q[2 * p + 1]).resize(m - l));
300             work(2 * p + 1, m, r, num.mult(q[2 * p]).resize(r - m));
301         }
302     };
303     work(1, 0, n, mult(q[1].inv(n)));
304     return ans;

```

```

305     }
306 };
307
308 template<int P = 998244353>
309 Poly<P> berlekampMassey(const Poly<P> &s) {
310     Poly<P> c;
311     Poly<P> oldC;
312     int f = -1;
313     for (int i = 0; i < s.size(); i++) {
314         auto delta = s[i];
315         for (int j = 1; j <= c.size(); j++) {
316             delta -= c[j - 1] * s[i - j];
317         }
318         if (delta == 0) {
319             continue;
320         }
321         if (f == -1) {
322             c.resize(i + 1);
323             f = i;
324         } else {
325             auto d = oldC;
326             d *= -1;
327             d.insert(d.begin(), 1);
328             MInt<P> df1 = 0;
329             for (int j = 1; j <= d.size(); j++) {
330                 df1 += d[j - 1] * s[f + 1 - j];
331             }
332             assert(df1 != 0);
333             auto coef = delta / df1;
334             d *= coef;
335             Poly<P> zeros(i - f - 1);
336             zeros.insert(zeros.end(), d.begin(), d.end());
337             d = zeros;
338             auto temp = c;
339             c += d;
340             if (i - temp.size() > f - oldC.size()) {
341                 oldC = temp;
342                 f = i;
343             }
344         }
345     }
346     c *= -1;
347     c.insert(c.begin(), 1);
348     return c;
349 }
350
351 template<int P = 998244353>
352 MInt<P> linearRecurrence(Poly<P> p, Poly<P> q, i64 n) {
353     int m = q.size() - 1;
354     while (n > 0) {
355         auto newq = q;
356         for (int i = 1; i <= m; i += 2) {
357             newq[i] *= -1;
358         }
359         auto newp = p * newq;
360         newq = q * newq;
361         for (int i = 0; i < m; i++) {
362             p[i] = newp[i * 2 + n % 2];
363         }
364         for (int i = 0; i <= m; i++) {
365             q[i] = newq[i * 2];
366         }
367     }
368     n /= 2;

```

```

369     }
370     return p[0] / q[0];
371 }
372
373 struct Comb {
374     int n;
375     std::vector<Z> _fac;
376     std::vector<Z> _invfac;
377     std::vector<Z> _inv;
378
379     Comb() : n{0}, _fac{1}, _invfac{1}, _inv{0} {}
380     Comb(int n) : Comb() {
381         init(n);
382     }
383
384     void init(int m) {
385         m = std::min(m, Z::getMod() - 1);
386         if (m <= n) return;
387         _fac.resize(m + 1);
388         _invfac.resize(m + 1);
389         _inv.resize(m + 1);
390
391         for (int i = n + 1; i <= m; i++) {
392             _fac[i] = _fac[i - 1] * i;
393         }
394         _invfac[m] = _fac[m].inv();
395         for (int i = m; i > n; i--) {
396             _invfac[i - 1] = _invfac[i] * i;
397             _inv[i] = _invfac[i] * _fac[i - 1];
398         }
399         n = m;
400     }
401
402     Z fac(int m) {
403         if (m > n) init(2 * m);
404         return _fac[m];
405     }
406     Z invfac(int m) {
407         if (m > n) init(2 * m);
408         return _invfac[m];
409     }
410     Z inv(int m) {
411         if (m > n) init(2 * m);
412         return _inv[m];
413     }
414     Z binom(int n, int m) {
415         if (n < m || m < 0) return 0;
416         return fac(n) * invfac(m) * invfac(n - m);
417     }
418 } comb;
419
420 Poly<P> get(int n, int m) {
421     if (m == 0) {
422         return Poly(n + 1);
423     }
424     if (m % 2 == 1) {
425         auto f = get(n, m - 1);
426         Z p = 1;
427         for (int i = 0; i <= n; i++) {
428             f[n - i] += comb.binom(n, i) * p;
429             p *= m;
430         }
431         return f;
432     }

```

```

433 auto f = get(n, m / 2);
434 auto fm = f;
435 for (int i = 0; i <= n; i++) {
436     fm[i] *= comb.fac(i);
437 }
438 Poly pw(n + 1);
439 pw[0] = 1;
440 for (int i = 1; i <= n; i++) {
441     pw[i] = pw[i - 1] * (m / 2);
442 }
443 for (int i = 0; i <= n; i++) {
444     pw[i] *= comb.invfac(i);
445 }
446 fm = fm.mulT(pw);
447 for (int i = 0; i <= n; i++) {
448     fm[i] *= comb.invfac(i);
449 }
450 return f + fm;
451 }

```

5.35 12C - 多项式乘法

Listing 61: math/12C-Poly.cpp

```

1  /** 多项式乘法
2   *   2024-03-10: https://qoj.ac/submission/350298
3   **/
4  constexpr int P = 998244353;
5
6  int power(int a, int b) {
7      int res = 1;
8      for (; b; b /= 2, a = 1LL * a * a % P) {
9          if (b % 2) {
10             res = 1LL * res * a % P;
11         }
12     }
13     return res;
14 }
15
16 std::vector<int> rev, roots {0, 1};
17
18 void dft(std::vector<int> &a) {
19     int n = a.size();
20     if (int(rev.size()) != n) {
21         int k = __builtin_ctz(n) - 1;
22         rev.resize(n);
23         for (int i = 0; i < n; i++) {
24             rev[i] = rev[i >> 1] >> 1 | (i & 1) << k;
25         }
26     }
27     for (int i = 0; i < n; i++) {
28         if (rev[i] < i) {
29             std::swap(a[i], a[rev[i]]);
30         }
31     }
32     if (roots.size() < n) {
33         int k = __builtin_ctz(roots.size());
34         roots.resize(n);
35         while ((1 << k) < n) {
36             int e = power(31, 1 << (__builtin_ctz(P - 1) - k - 1));
37             for (int i = 1 << (k - 1); i < (1 << k); i++) {
38                 roots[2 * i] = roots[i];
39                 roots[2 * i + 1] = 1LL * roots[i] * e % P;

```



```

40     }
41     k++;
42 }
43 }
44
45 for (int k = 1; k < n; k *= 2) {
46     for (int i = 0; i < n; i += 2 * k) {
47         for (int j = 0; j < k; j++) {
48             int u = a[i + j];
49             int v = 1LL * a[i + j + k] * roots[k + j] % P;
50             a[i + j] = (u + v) % P;
51             a[i + j + k] = (u - v) % P;
52         }
53     }
54 }
55 }
56
57 void idft(std::vector<int> &a) {
58     int n = a.size();
59     std::reverse(a.begin() + 1, a.end());
60     dft(a);
61     int inv = (1 - P) / n;
62     for (int i = 0; i < n; i++) {
63         a[i] = 1LL * a[i] * inv % P;
64     }
65 }
66
67 std::vector<int> mul(std::vector<int> a, std::vector<int> b) {
68     int n = 1, tot = a.size() + b.size() - 1;
69     while (n < tot) {
70         n *= 2;
71     }
72     if (tot < 128) {
73         std::vector<int> c(a.size() + b.size() - 1);
74         for (int i = 0; i < a.size(); i++) {
75             for (int j = 0; j < b.size(); j++) {
76                 c[i + j] = (c[i + j] + 1LL * a[i] * b[j]) % P;
77             }
78         }
79         return c;
80     }
81     a.resize(n);
82     b.resize(n);
83     dft(a);
84     dft(b);
85     for (int i = 0; i < n; i++) {
86         a[i] = 1LL * a[i] * b[i] % P;
87     }
88     idft(a);
89     a.resize(tot);
90     return a;
91 }

```

5.36 13A - 生成函数 (q-int)

Listing 62: math/13A-Q-Int.cpp

```

1  /** 生成函数 (q-int)
2   * 2023-09-04: https://qoj.ac/submission/163986
3   **/
4  using i64 = long long;
5  using i128 = __int128;
6

```

```

7  i64 power(i64 a, i64 b, i64 p) {
8      i64 res = 1;
9      for (; b; b /= 2, a = i128(a) * a % p) {
10         if (b % 2) {
11             res = i128(res) * a % p;
12         }
13     }
14     return res;
15 }
16
17 std::pair<int, int> qint(int q, int n, int p) {
18     q %= p;
19     for (int x = 2; x * x <= n; x++) {
20         if (n % x == 0) {
21             auto [v1, e1] = qint(q, x, p);
22             auto [v2, e2] = qint(power(q, x, p), n / x, p);
23             return {1LL * v1 * v2 % p, e1 + e2};
24         }
25     }
26     if (q == 1) {
27         if (n == p) {
28             return {0, 1};
29         }
30         return {n, 0};
31     }
32     // std::cerr << q << " " << n << " " << p << "\n";
33     i64 v = 1 - power(q, n, 1LL * p * p);
34     if (v < 0) {
35         v += 1LL * p * p;
36     }
37     assert(v != 0);
38     int inv = power(1 - q + p, p - 2, p);
39     if (v % p == 0) {
40         return {(v / p) * inv % p, 1};
41     } else {
42         return {v % p * inv % p, 0};
43     }
44 }

```

5.37 13B - 生成函数 (q-Binomial)

Listing 63: math/13B-Q-Binomial.cpp

```

1  /** 生成函数 (q-Binomial)
2   *   2023-09-04: https://qoj.ac/submission/164128
3   **/
4  int power(int a, int b, int p) {
5      int res = 1;
6      for (; b; b /= 2, a = 1LL * a * a % p) {
7          if (b % 2) {
8              res = 1LL * res * a % p;
9          }
10     }
11     return res;
12 }
13
14 int qint(int n, int q, int p) {
15     return 1LL * (power(q, n, p) - 1) * power(q - 1, p - 2, p) % p;
16 }
17
18 int qBinomial(int n, int k, int q, int p) {
19     if (q == 0) {
20         return 1;

```

```

21     }
22     int r = 0;
23     int x = 1;
24     do {
25         x = 1LL * x * q % p;
26         r++;
27     } while (x != 1);
28
29     if (n / r > k / r + (n - k) / r) {
30         return 0;
31     }
32     int num = 1, den = 1;
33     for (int i = 1; i <= k % r; i++) {
34         num = 1LL * num * qint(n % r - i + 1, q, p) % p;
35         den = 1LL * den * qint(i, q, p) % p;
36     }
37     n /= r, k /= r;
38     while (n > 0 || k > 0) {
39         if (n % p < k % p) {
40             return 0;
41         }
42         for (int i = 1; i <= k % p; i++) {
43             num = 1LL * num * (n % p - i + 1) % p;
44             den = 1LL * den * i % p;
45         }
46         n /= p, k /= p;
47     }
48     int ans = 1LL * num * power(den, p - 2, p) % p;
49     return ans;
50 }

```

5.38 13C - 生成函数 (Binomial 任意模数二项式)

Listing 64: `math/13C-Q-Binomial.cpp`

```

1  /** 生成函数 (Binomial 任意模数二项式)
2   *   2023-08-22: https://codeforces.com/contest/896/submission/219861532
3   **/
4  std::vector<std::pair<int, int>> factorize(int n) {
5      std::vector<std::pair<int, int>> factors;
6      for (int i = 2; static_cast<long long>(i) * i <= n; i++) {
7          if (n % i == 0) {
8              int t = 0;
9              for (; n % i == 0; n /= i)
10                 ++t;
11             factors.emplace_back(i, t);
12         }
13     }
14     if (n > 1)
15         factors.emplace_back(n, 1);
16     return factors;
17 }
18 constexpr int power(int base, i64 exp) {
19     int res = 1;
20     for (; exp > 0; base *= base, exp /= 2) {
21         if (exp % 2 == 1) {
22             res *= base;
23         }
24     }
25     return res;
26 }
27 constexpr int power(int base, i64 exp, int mod) {
28     int res = 1 % mod;
29     for (; exp > 0; base = 1LL * base * base % mod, exp /= 2) {

```

```

30     if (exp % 2 == 1) {
31         res = 1LL * res * base % mod;
32     }
33 }
34 return res;
35 }
36 int inverse(int a, int m) {
37     int g = m, r = a, x = 0, y = 1;
38     while (r != 0) {
39         int q = g / r;
40         g %= r;
41         std::swap(g, r);
42         x -= q * y;
43         std::swap(x, y);
44     }
45     return x < 0 ? x + m : x;
46 }
47 int solveModuloEquations(const std::vector<std::pair<int, int>> &e) {
48     int m = 1;
49     for (std::size_t i = 0; i < e.size(); i++) {
50         m *= e[i].first;
51     }
52     int res = 0;
53     for (std::size_t i = 0; i < e.size(); i++) {
54         int p = e[i].first;
55         res = (res + 1LL * e[i].second * (m / p) * inverse(m / p, p)) % m;
56     }
57     return res;
58 }
59 constexpr int N = 1E5;
60 class Binomial {
61     const int mod;
62 private:
63     const std::vector<std::pair<int, int>> factors;
64     std::vector<int> pk;
65     std::vector<std::vector<int>> prod;
66     static constexpr i64 exponent(i64 n, int p) {
67         i64 res = 0;
68         for (n /= p; n > 0; n /= p) {
69             res += n;
70         }
71         return res;
72     }
73     int product(i64 n, std::size_t i) {
74         int res = 1;
75         int p = factors[i].first;
76         for (; n > 0; n /= p) {
77             res = 1LL * res * power(prod[i].back(), n / pk[i], pk[i]) % pk[i] * prod[i][n % pk[i]] % pk[i];
78         }
79         return res;
80     }
81 public:
82     Binomial(int mod) : mod(mod), factors(factorize(mod)) {
83         pk.resize(factors.size());
84         prod.resize(factors.size());
85         for (std::size_t i = 0; i < factors.size(); i++) {
86             int p = factors[i].first;
87             int k = factors[i].second;
88             pk[i] = power(p, k);
89             prod[i].resize(std::min(N + 1, pk[i]));
90             prod[i][0] = 1;
91             for (int j = 1; j < prod[i].size(); j++) {
92                 if (j % p == 0) {
93                     prod[i][j] = prod[i][j - 1];

```

```

94         } else {
95             prod[i][j] = 1LL * prod[i][j - 1] * j % pk[i];
96         }
97     }
98 }
99 }
100 int operator()(i64 n, i64 m) {
101     if (n < m || m < 0) {
102         return 0;
103     }
104     std::vector<std::pair<int, int>> ans(factors.size());
105     for (int i = 0; i < factors.size(); i++) {
106         int p = factors[i].first;
107         int k = factors[i].second;
108         int e = exponent(n, p) - exponent(m, p) - exponent(n - m, p);
109         if (e >= k) {
110             ans[i] = std::make_pair(pk[i], 0);
111         } else {
112             int pn = product(n, i);
113             int pm = product(m, i);
114             int pd = product(n - m, i);
115             int res = 1LL * pn * inverse(pm, pk[i]) % pk[i] * inverse(pd, pk[i]) % pk[i] * power(p, e)
116                 % pk[i];
117             ans[i] = std::make_pair(pk[i], res);
118         }
119     }
120     return solveModuloEquations(ans);
121 };

```

5.39 14 - 自适应辛普森法 Simpson

Listing 65: math/14-Simpson.cpp

```

1  /** 自适应辛普森法 Simpson
2   * 2023-09-02: https://qoj.ac/submission/161388
3   **/
4  const double Pi = std::acos(-1.0);
5  constexpr double EPS = 1e-9;
6  double v, r, d;
7  double f(double x) {
8      double s = std::sin(x);
9      return 1 / v / (std::sqrt(s * s + 3) - s);
10 }
11 double simpson(double l, double r) {
12     return (f(l) + 4 * f((l + r) / 2) + f(r)) * (r - l) / 6;
13 }
14 double integral(double l, double r, double eps, double st) {
15     double mid = (l + r) / 2;
16     double sl = simpson(l, mid);
17     double sr = simpson(mid, r);
18     if (std::abs(sl + sr - st) <= 15 * eps)
19         return sl + sr + (sl + sr - st) / 15;
20     return integral(l, mid, eps / 2, sl) + integral(mid, r, eps / 2, sr);
21 }
22 double integral(double l, double r) {
23     return integral(l, r, EPS, simpson(l, r));
24 }

```

5.40 15 - 矩阵 (Matrix)

Listing 66: **math/15-Matrix.cpp**

```

1  /** 矩阵 (Matrix)
2   *   2024-03-14: https://qoj.ac/submission/353771
3   **/
4  using i64 = long long;
5  using u64 = unsigned long long;
6
7  using Matrix = std::array<u64, 65>;
8
9  Matrix operator*(const Matrix &a, const Matrix &b) {
10     Matrix c{};
11     for (int i = 0; i <= 64; i++) {
12         for (int j = 0; j <= 64; j++) {
13             if (j == 64 ? i == 64 : (a[i] >> j & 1)) {
14                 c[i] ^= b[j];
15             }
16         }
17     }
18     return c;
19 }
20
21 u64 operator*(u64 a, const Matrix &b) {
22     u64 c = 0;
23     for (int i = 0; i <= 64; i++) {
24         if (i == 64 || (a >> i & 1)) {
25             c ^= b[i];
26         }
27     }
28     return c;
29 }
30
31 Matrix readMatrix() {
32     int m;
33     std::cin >> m;
34
35     Matrix f{};
36     for (int i = 0; i < m; i++) {
37         int s, o;
38         u64 A;
39         std::cin >> s >> o >> A;
40
41         if (o == 0) {
42             for (int j = 0; j < 64; j++) {
43                 if (A >> ((j + s) % 64) & 1) {
44                     f[64] ^= 1ULL << ((j + s) % 64);
45                 } else {
46                     f[j] ^= 1ULL << ((j + s) % 64);
47                 }
48             }
49         } else {
50             for (int j = 0; j < 64; j++) {
51                 if (A >> ((j + s) % 64) & 1) {
52                     f[j] ^= 1ULL << ((j + s) % 64);
53                 }
54             }
55         }
56     }
57
58     u64 B;
59     std::cin >> B;
60     f[64] ^= B;
61
62     return f;
63 }

```

5.41 16 - 高斯消元 (guess) 【久远】

Listing 67: math/16-Gauss-Elimination.cpp

```

1  /** 高斯消元 (guess) 【久远】
2  *   2020-12-02: https://www.codechef.com/viewsolution/39942900
3  **/
4  std::vector<double> gauss(std::vector<std::vector<double>> a, std::vector<double> b) {
5      int n = a.size();
6      for (int i = 0; i < n; ++i) {
7          double x = a[i][i];
8          for (int j = i; j < n; ++j) a[i][j] /= x;
9          b[i] /= x;
10         for (int j = 0; j < n; ++j) {
11             if (i == j) continue;
12             x = a[j][i];
13             for (int k = i; k < n; ++k) a[j][k] -= a[i][k] * x;
14             b[j] -= b[i] * x;
15         }
16     }
17     return b;
18 }

```

5.42 01A - 树状数组 (Fenwick 旧版)

Listing 68: ds/01A-Fenwick.cpp

```

1  /** 树状数组 (Fenwick 旧版)
2  *   2023-08-11: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=63382128
3  **/
4  template <typename T>
5  struct Fenwick {
6      int n;
7      std::vector<T> a;
8
9      Fenwick(int n = 0) {
10         init(n);
11     }
12
13     void init(int n) {
14         this->n = n;
15         a.assign(n, T());
16     }
17
18     void add(int x, T v) {
19         for (int i = x + 1; i <= n; i += i & -i) {
20             a[i - 1] += v;
21         }
22     }
23
24     T sum(int x) {
25         auto ans = T();
26         for (int i = x; i > 0; i -= i & -i) {
27             ans += a[i - 1];
28         }
29         return ans;
30     }
31
32     T rangeSum(int l, int r) {
33         return sum(r) - sum(l);
34     }
35
36     int kth(T k) {
37         int x = 0;

```

```

38     for (int i = 1 << std::__lg(n); i; i /= 2) {
39         if (x + i <= n && k >= a[x + i - 1]) {
40             x += i;
41             k -= a[x - 1];
42         }
43     }
44     return x;
45 }
46 };

```

5.43 01B - 树状数组 (Fenwick 新版)

Listing 69: ds/01B-Fenwick.cpp

```

1  /** 树状数组 (Fenwick 新版)
2  *   2023-12-28: https://codeforces.com/contest/1915/submission/239262801
3  **/
4  template <typename T>
5  struct Fenwick {
6      int n;
7      std::vector<T> a;
8
9      Fenwick(int n_ = 0) {
10         init(n_);
11     }
12
13     void init(int n_) {
14         n = n_;
15         a.assign(n, T{});
16     }
17
18     void add(int x, const T &v) {
19         for (int i = x + 1; i <= n; i += i & -i) {
20             a[i - 1] = a[i - 1] + v;
21         }
22     }
23
24     T sum(int x) {
25         T ans{};
26         for (int i = x; i > 0; i -= i & -i) {
27             ans = ans + a[i - 1];
28         }
29         return ans;
30     }
31
32     T rangeSum(int l, int r) {
33         return sum(r) - sum(l);
34     }
35
36     int select(const T &k) {
37         int x = 0;
38         T cur{};
39         for (int i = 1 << std::__lg(n); i; i /= 2) {
40             if (x + i <= n && cur + a[x + i - 1] <= k) {
41                 x += i;
42                 cur = cur + a[x - 1];
43             }
44         }
45         return x;
46     }
47 };

```

5.44 02 - 并查集 (DSU)

Listing 70: ds/02-DSU.cpp

```

1  /**  并查集 (DSU)
2  *    2023-08-04: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=63239142
3  **/
4  struct DSU {
5      std::vector<int> f, siz;
6
7      DSU() {}
8      DSU(int n) {
9          init(n);
10     }
11
12     void init(int n) {
13         f.resize(n);
14         std::iota(f.begin(), f.end(), 0);
15         siz.assign(n, 1);
16     }
17
18     int find(int x) {
19         while (x != f[x]) {
20             x = f[x] = f[f[x]];
21         }
22         return x;
23     }
24
25     bool same(int x, int y) {
26         return find(x) == find(y);
27     }
28
29     bool merge(int x, int y) {
30         x = find(x);
31         y = find(y);
32         if (x == y) {
33             return false;
34         }
35         siz[x] += siz[y];
36         f[y] = x;
37         return true;
38     }
39
40     int size(int x) {
41         return siz[find(x)];
42     }
43 };

```

5.45 03A - 线段树 (SegmentTree+Info 区间加 + 单点修改)

Listing 71: ds/03A-Segment-Tree.cpp

```

1  /**  线段树 (SegmentTree+Info 区间加+单点修改)
2  *    2023-09-13: https://qoj.ac/submission/178310
3  **/
4  struct SegmentTree {
5      int n;
6      std::vector<int> tag;
7      std::vector<Info> info;
8      SegmentTree(int n_) : n(n_), tag(4 * n), info(4 * n) {}
9
10     void pull(int p) {
11         info[p] = info[2 * p] + info[2 * p + 1];
12     }
13
14     void add(int p, int v) {

```

```

15     tag[p] += v;
16     info[p].max += v;
17 }
18
19 void push(int p) {
20     add(2 * p, tag[p]);
21     add(2 * p + 1, tag[p]);
22     tag[p] = 0;
23 }
24
25 Info query(int p, int l, int r, int x, int y) {
26     if (l >= y || r <= x) {
27         return {};
28     }
29     if (l >= x && r <= y) {
30         return info[p];
31     }
32     int m = (l + r) / 2;
33     push(p);
34     return query(2 * p, l, m, x, y) + query(2 * p + 1, m, r, x, y);
35 }
36
37 Info query(int x, int y) {
38     return query(1, 0, n, x, y);
39 }
40
41 void rangeAdd(int p, int l, int r, int x, int y, int v) {
42     if (l >= y || r <= x) {
43         return;
44     }
45     if (l >= x && r <= y) {
46         return add(p, v);
47     }
48     int m = (l + r) / 2;
49     push(p);
50     rangeAdd(2 * p, l, m, x, y, v);
51     rangeAdd(2 * p + 1, m, r, x, y, v);
52     pull(p);
53 }
54
55 void rangeAdd(int x, int y, int v) {
56     rangeAdd(1, 0, n, x, y, v);
57 }
58
59 void modify(int p, int l, int r, int x, const Info &v) {
60     if (r - l == 1) {
61         info[p] = v;
62         return;
63     }
64     int m = (l + r) / 2;
65     push(p);
66     if (x < m) {
67         modify(2 * p, l, m, x, v);
68     } else {
69         modify(2 * p + 1, m, r, x, v);
70     }
71     pull(p);
72 }
73
74 void modify(int x, const Info &v) {
75     modify(1, 0, n, x, v);
76 }
77 };

```

5.46 03B - 线段树 (SegmentTree 区间乘 + 单点加)

Listing 72: ds/03B-Segment-Tree.cpp

```

1  /** 线段树 (SegmentTree 区间乘+单点加)
2   *   2023-10-18: https://cf.dianhsu.com/gym/104417/submission/223800089
3   **/
4  struct SegmentTree {
5      int n;
6      std::vector<int> tag, sum;
7      SegmentTree(int n_) : n(n_), tag(4 * n, 1), sum(4 * n) {}
8
9      void pull(int p) {
10         sum[p] = (sum[2 * p] + sum[2 * p + 1]) % P;
11     }
12
13     void mul(int p, int v) {
14         tag[p] = 1LL * tag[p] * v % P;
15         sum[p] = 1LL * sum[p] * v % P;
16     }
17
18     void push(int p) {
19         mul(2 * p, tag[p]);
20         mul(2 * p + 1, tag[p]);
21         tag[p] = 1;
22     }
23
24     int query(int p, int l, int r, int x, int y) {
25         if (l >= y || r <= x) {
26             return 0;
27         }
28         if (l >= x && r <= y) {
29             return sum[p];
30         }
31         int m = (l + r) / 2;
32         push(p);
33         return (query(2 * p, l, m, x, y) + query(2 * p + 1, m, r, x, y)) % P;
34     }
35
36     int query(int x, int y) {
37         return query(1, 0, n, x, y);
38     }
39
40     void rangeMul(int p, int l, int r, int x, int y, int v) {
41         if (l >= y || r <= x) {
42             return;
43         }
44         if (l >= x && r <= y) {
45             return mul(p, v);
46         }
47         int m = (l + r) / 2;
48         push(p);
49         rangeMul(2 * p, l, m, x, y, v);
50         rangeMul(2 * p + 1, m, r, x, y, v);
51         pull(p);
52     }
53
54     void rangeMul(int x, int y, int v) {
55         rangeMul(1, 0, n, x, y, v);
56     }
57
58     void add(int p, int l, int r, int x, int v) {
59         if (r - l == 1) {
60             sum[p] = (sum[p] + v) % P;

```

```

61         return;
62     }
63     int m = (l + r) / 2;
64     push(p);
65     if (x < m) {
66         add(2 * p, l, m, x, v);
67     } else {
68         add(2 * p + 1, m, r, x, v);
69     }
70     pull(p);
71 }
72
73 void add(int x, int v) {
74     add(1, 0, n, x, v);
75 }
76 };

```

5.47 03C - 线段树 (SegmentTree+Info 初始赋值 + 单点修改 + 查找前驱后继)

Listing 73: ds/03C-Segment-Tree.cpp

```

1  /** 线段树 (SegmentTree+Info 初始赋值+单点修改+查找前驱后继)
2  *   2023-07-17: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=62804432
3  *   2024-06-25: https://codeforces.com/contest/1982/submission/267353839
4  **/
5  template<class Info>
6  struct SegmentTree {
7      int n;
8      std::vector<Info> info;
9      SegmentTree() : n(0) {}
10     SegmentTree(int n_, Info v_ = Info()) {
11         init(n_, v_);
12     }
13     template<class T>
14     SegmentTree(std::vector<T> init_) {
15         init(init_);
16     }
17     void init(int n_, Info v_ = Info()) {
18         init(std::vector(n_, v_));
19     }
20     template<class T>
21     void init(std::vector<T> init_) {
22         n = init_.size();
23         info.assign(4 << std::lg(n), Info());
24         std::function<void(int, int, int)> build = [&](int p, int l, int r) {
25             if (r - l == 1) {
26                 info[p] = init_[l];
27                 return;
28             }
29             int m = (l + r) / 2;
30             build(2 * p, l, m);
31             build(2 * p + 1, m, r);
32             pull(p);
33         };
34         build(1, 0, n);
35     }
36     void pull(int p) {
37         info[p] = info[2 * p] + info[2 * p + 1];
38     }
39     void modify(int p, int l, int r, int x, const Info &v) {
40         if (r - l == 1) {
41             info[p] = v;
42             return;

```

```

43     }
44     int m = (l + r) / 2;
45     if (x < m) {
46         modify(2 * p, l, m, x, v);
47     } else {
48         modify(2 * p + 1, m, r, x, v);
49     }
50     pull(p);
51 }
52 void modify(int p, const Info &v) {
53     modify(1, 0, n, p, v);
54 }
55 Info rangeQuery(int p, int l, int r, int x, int y) {
56     if (l >= y || r <= x) {
57         return Info();
58     }
59     if (l >= x && r <= y) {
60         return info[p];
61     }
62     int m = (l + r) / 2;
63     return rangeQuery(2 * p, l, m, x, y) + rangeQuery(2 * p + 1, m, r, x, y);
64 }
65 Info rangeQuery(int l, int r) {
66     return rangeQuery(1, 0, n, l, r);
67 }
68 template<class F>
69 int findFirst(int p, int l, int r, int x, int y, F &&pred) {
70     if (l >= y || r <= x) {
71         return -1;
72     }
73     if (l >= x && r <= y && !pred(info[p])) {
74         return -1;
75     }
76     if (r - l == 1) {
77         return l;
78     }
79     int m = (l + r) / 2;
80     int res = findFirst(2 * p, l, m, x, y, pred);
81     if (res == -1) {
82         res = findFirst(2 * p + 1, m, r, x, y, pred);
83     }
84     return res;
85 }
86 template<class F>
87 int findFirst(int l, int r, F &&pred) {
88     return findFirst(1, 0, n, l, r, pred);
89 }
90 template<class F>
91 int findLast(int p, int l, int r, int x, int y, F &&pred) {
92     if (l >= y || r <= x) {
93         return -1;
94     }
95     if (l >= x && r <= y && !pred(info[p])) {
96         return -1;
97     }
98     if (r - l == 1) {
99         return l;
100    }
101    int m = (l + r) / 2;
102    int res = findLast(2 * p + 1, m, r, x, y, pred);
103    if (res == -1) {
104        res = findLast(2 * p, l, m, x, y, pred);
105    }

```

```

106     return res;
107 }
108 template<class F>
109 int findLast(int l, int r, F &&pred) {
110     return findLast(1, 0, n, l, r, pred);
111 }
112 };

```

5.48 03D - 线段树 (SegmentTree+Info+Merge 初始赋值 + 单点修改 + 区间合并)

Listing 74: ds/03D-Segment-Tree.cpp

```

1  /**  线段树 (SegmentTree+Info+Merge 初始赋值+单点修改+区间合并)
2  *   *  2022-04-23: https://codeforces.com/contest/1672/submission/154766851
3  */
4  template<class Info,
5           class Merge = std::plus<Info>>
6  struct SegmentTree {
7      const int n;
8      const Merge merge;
9      std::vector<Info> info;
10     SegmentTree(int n) : n(n), merge(Merge()), info(4 << std::__lg(n)) {}
11     SegmentTree(std::vector<Info> init) : SegmentTree(init.size()) {
12         std::function<void(int, int, int)> build = [&](int p, int l, int r) {
13             if (r - l == 1) {
14                 info[p] = init[l];
15                 return;
16             }
17             int m = (l + r) / 2;
18             build(2 * p, l, m);
19             build(2 * p + 1, m, r);
20             pull(p);
21         };
22         build(1, 0, n);
23     }
24     void pull(int p) {
25         info[p] = merge(info[2 * p], info[2 * p + 1]);
26     }
27     void modify(int p, int l, int r, int x, const Info &v) {
28         if (r - l == 1) {
29             info[p] = v;
30             return;
31         }
32         int m = (l + r) / 2;
33         if (x < m) {
34             modify(2 * p, l, m, x, v);
35         } else {
36             modify(2 * p + 1, m, r, x, v);
37         }
38         pull(p);
39     }
40     void modify(int p, const Info &v) {
41         modify(1, 0, n, p, v);
42     }
43     Info rangeQuery(int p, int l, int r, int x, int y) {
44         if (l >= y || r <= x) {
45             return Info();
46         }
47         if (l >= x && r <= y) {
48             return info[p];
49         }
50         int m = (l + r) / 2;
51         return merge(rangeQuery(2 * p, l, m, x, y), rangeQuery(2 * p + 1, m, r, x, y));

```

```

52     }
53     Info rangeQuery(int l, int r) {
54         return rangeQuery(1, 0, n, l, r);
55     }
56 };

```

5.49 04 - 懒标记线段树 (LazySegmentTree)

Listing 75: ds/04-Lazy-Segt.cpp

```

1  /** 懒标记线段树 (LazySegmentTree)
2   *   2023-03-03: https://atcoder.jp/contests/joi2023yo2/submissions/39363123
3   *   2023-03-12: https://codeforces.com/contest/1804/submission/197106837
4   *   2023-07-17: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=62804432
5   *   2023-11-12: https://qoj.ac/submission/249505
6  **/
7  template<class Info, class Tag>
8  struct LazySegmentTree {
9      int n;
10     std::vector<Info> info;
11     std::vector<Tag> tag;
12     LazySegmentTree() : n(0) {}
13     LazySegmentTree(int n_, Info v_ = Info()) {
14         init(n_, v_);
15     }
16     template<class T>
17     LazySegmentTree(std::vector<T> init_) {
18         init(init_);
19     }
20     void init(int n_, Info v_ = Info()) {
21         init(std::vector(n_, v_));
22     }
23     template<class T>
24     void init(std::vector<T> init_) {
25         n = init_.size();
26         info.assign(4 << std::__lg(n), Info());
27         tag.assign(4 << std::__lg(n), Tag());
28         std::function<void(int, int, int)> build = [&](int p, int l, int r) {
29             if (r - l == 1) {
30                 info[p] = init_[l];
31                 return;
32             }
33             int m = (l + r) / 2;
34             build(2 * p, l, m);
35             build(2 * p + 1, m, r);
36             pull(p);
37         };
38         build(1, 0, n);
39     }
40     void pull(int p) {
41         info[p] = info[2 * p] + info[2 * p + 1];
42     }
43     void apply(int p, const Tag &v) {
44         info[p].apply(v);
45         tag[p].apply(v);
46     }
47     void push(int p) {
48         apply(2 * p, tag[p]);
49         apply(2 * p + 1, tag[p]);
50         tag[p] = Tag();
51     }
52     void modify(int p, int l, int r, int x, const Info &v) {
53         if (r - l == 1) {

```

```

54         info[p] = v;
55         return;
56     }
57     int m = (l + r) / 2;
58     push(p);
59     if (x < m) {
60         modify(2 * p, l, m, x, v);
61     } else {
62         modify(2 * p + 1, m, r, x, v);
63     }
64     pull(p);
65 }
66 void modify(int p, const Info &v) {
67     modify(1, 0, n, p, v);
68 }
69 Info rangeQuery(int p, int l, int r, int x, int y) {
70     if (l >= y || r <= x) {
71         return Info();
72     }
73     if (l >= x && r <= y) {
74         return info[p];
75     }
76     int m = (l + r) / 2;
77     push(p);
78     return rangeQuery(2 * p, l, m, x, y) + rangeQuery(2 * p + 1, m, r, x, y);
79 }
80 Info rangeQuery(int l, int r) {
81     return rangeQuery(1, 0, n, l, r);
82 }
83 void rangeApply(int p, int l, int r, int x, int y, const Tag &v) {
84     if (l >= y || r <= x) {
85         return;
86     }
87     if (l >= x && r <= y) {
88         apply(p, v);
89         return;
90     }
91     int m = (l + r) / 2;
92     push(p);
93     rangeApply(2 * p, l, m, x, y, v);
94     rangeApply(2 * p + 1, m, r, x, y, v);
95     pull(p);
96 }
97 void rangeApply(int l, int r, const Tag &v) {
98     return rangeApply(1, 0, n, l, r, v);
99 }
100 void half(int p, int l, int r) {
101     if (info[p].act == 0) {
102         return;
103     }
104     if ((info[p].min + 1) / 2 == (info[p].max + 1) / 2) {
105         apply(p, {-(info[p].min + 1) / 2});
106         return;
107     }
108     int m = (l + r) / 2;
109     push(p);
110     half(2 * p, l, m);
111     half(2 * p + 1, m, r);
112     pull(p);
113 }
114 void half() {
115     half(1, 0, n);

```



```

116     }
117
118     template<class F>
119     int findFirst(int p, int l, int r, int x, int y, F pred) {
120         if (l >= y || r <= x || !pred(info[p])) {
121             return -1;
122         }
123         if (r - l == 1) {
124             return l;
125         }
126         int m = (l + r) / 2;
127         push(p);
128         int res = findFirst(2 * p, l, m, x, y, pred);
129         if (res == -1) {
130             res = findFirst(2 * p + 1, m, r, x, y, pred);
131         }
132         return res;
133     }
134     template<class F>
135     int findFirst(int l, int r, F pred) {
136         return findFirst(1, 0, n, l, r, pred);
137     }
138     template<class F>
139     int findLast(int p, int l, int r, int x, int y, F pred) {
140         if (l >= y || r <= x || !pred(info[p])) {
141             return -1;
142         }
143         if (r - l == 1) {
144             return l;
145         }
146         int m = (l + r) / 2;
147         push(p);
148         int res = findLast(2 * p + 1, m, r, x, y, pred);
149         if (res == -1) {
150             res = findLast(2 * p, l, m, x, y, pred);
151         }
152         return res;
153     }
154     template<class F>
155     int findLast(int l, int r, F pred) {
156         return findLast(1, 0, n, l, r, pred);
157     }
158
159     void maintainL(int p, int l, int r, int pre) {
160         if (info[p].difl > 0 && info[p].maxlowl < pre) {
161             return;
162         }
163         if (r - l == 1) {
164             info[p].max = info[p].maxlowl;
165             info[p].maxl = info[p].maxr = l;
166             info[p].maxlowl = info[p].maxlowr = -inf;
167             return;
168         }
169         int m = (l + r) / 2;
170         push(p);
171         maintainL(2 * p, l, m, pre);
172         pre = std::max(pre, info[2 * p].max);
173         maintainL(2 * p + 1, m, r, pre);
174         pull(p);
175     }
176     void maintainL() {
177         maintainL(1, 0, n, -1);
178     }

```

```

179 void maintainR(int p, int l, int r, int suf) {
180     if (info[p].difr > 0 && info[p].maxlowr < suf) {
181         return;
182     }
183     if (r - l == 1) {
184         info[p].max = info[p].maxlowl;
185         info[p].maxl = info[p].maxr = l;
186         info[p].maxlowl = info[p].maxlowr = -inf;
187         return;
188     }
189     int m = (l + r) / 2;
190     push(p);
191     maintainR(2 * p + 1, m, r, suf);
192     suf = std::max(suf, info[2 * p + 1].max);
193     maintainR(2 * p, l, m, suf);
194     pull(p);
195 }
196 void maintainR() {
197     maintainR(1, 0, n, -1);
198 }
199 };
200
201 struct Tag {
202     int x = 0;
203     void apply(const Tag &t) & {
204         x = std::max(x, t.x);
205     }
206 };
207
208 struct Info {
209     int x = 0;
210     void apply(const Tag &t) & {
211         x = std::max(x, t.x);
212     }
213 };
214
215 Info operator+(const Info &a, const Info &b) {
216     return {std::max(a.x, b.x)};
217 }

```

5.50 05A - 取模类 (Z 旧版)

Listing 76: ds/05A-ModInt-Old.cpp

```

1  constexpr int P = 998244353;
2  using i64 = long long;
3  // assume -P <= x < 2P
4  int norm(int x) {
5      if (x < 0) {
6          x += P;
7      }
8      if (x >= P) {
9          x -= P;
10     }
11     return x;
12 }
13 template<class T>
14 T power(T a, i64 b) {
15     T res = 1;
16     for (; b; b /= 2, a *= a) {
17         if (b % 2) {
18             res *= a;
19         }
20     }

```

```

21     return res;
22 }
23 struct Z {
24     int x;
25     Z(int x = 0) : x(norm(x)) {}
26     Z(i64 x) : x(norm(x % P)) {}
27     int val() const {
28         return x;
29     }
30     Z operator-() const {
31         return Z(norm(P - x));
32     }
33     Z inv() const {
34         assert(x != 0);
35         return power(*this, P - 2);
36     }
37     Z operator*=(const Z &rhs) {
38         x = i64(x) * rhs.x % P;
39         return *this;
40     }
41     Z operator+=(const Z &rhs) {
42         x = norm(x + rhs.x);
43         return *this;
44     }
45     Z operator-=(const Z &rhs) {
46         x = norm(x - rhs.x);
47         return *this;
48     }
49     Z operator/=(const Z &rhs) {
50         return *this *= rhs.inv();
51     }
52     friend Z operator*(const Z &lhs, const Z &rhs) {
53         Z res = lhs;
54         res *= rhs;
55         return res;
56     }
57     friend Z operator+(const Z &lhs, const Z &rhs) {
58         Z res = lhs;
59         res += rhs;
60         return res;
61     }
62     friend Z operator-(const Z &lhs, const Z &rhs) {
63         Z res = lhs;
64         res -= rhs;
65         return res;
66     }
67     friend Z operator/(const Z &lhs, const Z &rhs) {
68         Z res = lhs;
69         res /= rhs;
70         return res;
71     }
72     friend std::istream &operator>>(std::istream &is, Z &a) {
73         i64 v;
74         is >> v;
75         a = Z(v);
76         return is;
77     }
78     friend std::ostream &operator<<(std::ostream &os, const Z &a) {
79         return os << a.val();
80     }
81 };

```

5.51 05B - 取模类 (MLong and MInt 新版)

Listing 77: ds/05B-ModInt-New.cpp

```

1  template <class T>
2  constexpr T power(T a, i64 b) {
3      T res = 1;
4      for (; b; b /= 2, a *= a) {
5          if (b % 2) {
6              res *= a;
7          }
8      }
9      return res;
10 }
11
12 constexpr i64 mul(i64 a, i64 b, i64 p) {
13     i64 res = a * b - i64(1.L * a * b / p) * p;
14     res %= p;
15     if (res < 0) {
16         res += p;
17     }
18     return res;
19 }
20 template <i64 P>
21 struct MLong {
22     i64 x;
23     constexpr MLong() : x{} {}
24     constexpr MLong(i64 x) : x{norm(x % getMod())} {}
25
26     static i64 Mod;
27     constexpr static i64 getMod() {
28         if (P > 0) {
29             return P;
30         } else {
31             return Mod;
32         }
33     }
34     constexpr static void setMod(i64 Mod_) {
35         Mod = Mod_;
36     }
37     constexpr i64 norm(i64 x) const {
38         if (x < 0) {
39             x += getMod();
40         }
41         if (x >= getMod()) {
42             x -= getMod();
43         }
44         return x;
45     }
46     constexpr i64 val() const {
47         return x;
48     }
49     explicit constexpr operator i64() const {
50         return x;
51     }
52     constexpr MLong operator-() const {
53         MLong res;
54         res.x = norm(getMod() - x);
55         return res;
56     }
57     constexpr MLong inv() const {
58         assert(x != 0);
59         return power(*this, getMod() - 2);
60     }

```

```

61     constexpr MLong &operator*=(MLong rhs) & {
62         x = mul(x, rhs.x, getMod());
63         return *this;
64     }
65     constexpr MLong &operator+=(MLong rhs) & {
66         x = norm(x + rhs.x);
67         return *this;
68     }
69     constexpr MLong &operator-=(MLong rhs) & {
70         x = norm(x - rhs.x);
71         return *this;
72     }
73     constexpr MLong &operator/=(MLong rhs) & {
74         return *this *= rhs.inv();
75     }
76     friend constexpr MLong operator*(MLong lhs, MLong rhs) {
77         MLong res = lhs;
78         res *= rhs;
79         return res;
80     }
81     friend constexpr MLong operator+(MLong lhs, MLong rhs) {
82         MLong res = lhs;
83         res += rhs;
84         return res;
85     }
86     friend constexpr MLong operator-(MLong lhs, MLong rhs) {
87         MLong res = lhs;
88         res -= rhs;
89         return res;
90     }
91     friend constexpr MLong operator/(MLong lhs, MLong rhs) {
92         MLong res = lhs;
93         res /= rhs;
94         return res;
95     }
96     friend constexpr std::istream &operator>>(std::istream &is, MLong &a) {
97         i64 v;
98         is >> v;
99         a = MLong(v);
100        return is;
101    }
102    friend constexpr std::ostream &operator<<(std::ostream &os, const MLong &a) {
103        return os << a.val();
104    }
105    friend constexpr bool operator==(MLong lhs, MLong rhs) {
106        return lhs.val() == rhs.val();
107    }
108    friend constexpr bool operator!=(MLong lhs, MLong rhs) {
109        return lhs.val() != rhs.val();
110    }
111 };
112
113 template <>
114 i64 MLong<0LL>::Mod = i64(1E18) + 9;
115
116 template <int P>
117 struct MInt {
118     int x;
119     constexpr MInt() : x{} {}
120     constexpr MInt(i64 x) : x{norm(x % getMod())} {}
121
122     static int Mod;
123     constexpr static int getMod() {
124         if (P > 0) {

```

```

125         return P;
126     } else {
127         return Mod;
128     }
129 }
130 constexpr static void setMod(int Mod_) {
131     Mod = Mod_;
132 }
133 constexpr int norm(int x) const {
134     if (x < 0) {
135         x += getMod();
136     }
137     if (x >= getMod()) {
138         x -= getMod();
139     }
140     return x;
141 }
142 constexpr int val() const {
143     return x;
144 }
145 explicit constexpr operator int() const {
146     return x;
147 }
148 constexpr MInt operator-() const {
149     MInt res;
150     res.x = norm(getMod() - x);
151     return res;
152 }
153 constexpr MInt inv() const {
154     assert(x != 0);
155     return power(*this, getMod() - 2);
156 }
157 constexpr MInt &operator*=(MInt rhs) & {
158     x = 1LL * x * rhs.x % getMod();
159     return *this;
160 }
161 constexpr MInt &operator+=(MInt rhs) & {
162     x = norm(x + rhs.x);
163     return *this;
164 }
165 constexpr MInt &operator-=(MInt rhs) & {
166     x = norm(x - rhs.x);
167     return *this;
168 }
169 constexpr MInt &operator/=(MInt rhs) & {
170     return *this *= rhs.inv();
171 }
172 friend constexpr MInt operator*(MInt lhs, MInt rhs) {
173     MInt res = lhs;
174     res *= rhs;
175     return res;
176 }
177 friend constexpr MInt operator+(MInt lhs, MInt rhs) {
178     MInt res = lhs;
179     res += rhs;
180     return res;
181 }
182 friend constexpr MInt operator-(MInt lhs, MInt rhs) {
183     MInt res = lhs;
184     res -= rhs;
185     return res;
186 }
187 friend constexpr MInt operator/(MInt lhs, MInt rhs) {
188     MInt res = lhs;

```

```

189     res /= rhs;
190     return res;
191 }
192 friend constexpr std::istream &operator>>(std::istream &is, MInt &a) {
193     i64 v;
194     is >> v;
195     a = MInt(v);
196     return is;
197 }
198 friend constexpr std::ostream &operator<<(std::ostream &os, const MInt &a) {
199     return os << a.val();
200 }
201 friend constexpr bool operator==(MInt lhs, MInt rhs) {
202     return lhs.val() == rhs.val();
203 }
204 friend constexpr bool operator!=(MInt lhs, MInt rhs) {
205     return lhs.val() != rhs.val();
206 }
207 };
208
209 template <>
210 int MInt<0>::Mod = 998244353;
211
212 template <int V, int P>
213 constexpr MInt<P> CInv = MInt<P>(V).inv();
214
215 constexpr int P = 1000000007;
216 using Z = MInt<P>;

```

5.52 05C - 动态取模类 (ModIntBase)

Listing 78: ds/05C-Dynamic-ModInt.cpp

```

1  /** 动态取模类 (ModIntBase)
2   *   2024-08-14: https://ac.nowcoder.com/acm/contest/view-submission?submissionId=70980889&returnHomeType=1&uid=329687984
3   **/
4  // TODO: Dynamic ModInt
5
6  template <typename T>
7  constexpr T power(T a, u64 b) {
8      T res{1};
9      for (; b != 0; b /= 2, a *= a) {
10         if (b % 2 == 1) {
11             res *= a;
12         }
13     }
14     return res;
15 }
16
17 template <u32 P>
18 constexpr u32 mulMod(u32 a, u32 b) {
19     return 1ULL * a * b % P;
20 }
21
22 template <u64 P>
23 constexpr u64 mulMod(u64 a, u64 b) {
24     u64 res = a * b - u64(1.L * a * b / P - 0.5L) * P;
25     res %= P;
26     return res;
27 }
28
29 template <typename U, U P>
30 requires std::unsigned_integral<U>

```

```

31 struct ModIntBase {
32 public:
33     constexpr ModIntBase() : x{0} {}
34
35     template <typename T>
36         requires std::integral<T>
37     constexpr ModIntBase(T x_) : x{norm(x_ % T{P})} {}
38
39     constexpr static U norm(U x) {
40         if ((x >> (8 * sizeof(U) - 1) & 1) == 1) {
41             x += P;
42         }
43         if (x >= P) {
44             x -= P;
45         }
46         return x;
47     }
48
49     constexpr U val() const {
50         return x;
51     }
52
53     constexpr ModIntBase operator-() const {
54         ModIntBase res;
55         res.x = norm(P - x);
56         return res;
57     }
58
59     constexpr ModIntBase inv() const {
60         return power(*this, P - 2);
61     }
62
63     constexpr ModIntBase &operator*=(const ModIntBase &rhs) & {
64         x = mulMod<P>(x, rhs.val());
65         return *this;
66     }
67
68     constexpr ModIntBase &operator+=(const ModIntBase &rhs) & {
69         x = norm(x + rhs.x);
70         return *this;
71     }
72
73     constexpr ModIntBase &operator-=(const ModIntBase &rhs) & {
74         x = norm(x - rhs.x);
75         return *this;
76     }
77
78     constexpr ModIntBase &operator/=(const ModIntBase &rhs) & {
79         return *this *= rhs.inv();
80     }
81
82     friend constexpr ModIntBase operator*(ModIntBase lhs, const ModIntBase &rhs) {
83         lhs *= rhs;
84         return lhs;
85     }
86
87     friend constexpr ModIntBase operator+(ModIntBase lhs, const ModIntBase &rhs) {
88         lhs += rhs;
89         return lhs;
90     }
91
92     friend constexpr ModIntBase operator-(ModIntBase lhs, const ModIntBase &rhs) {
93         lhs -= rhs;
94         return lhs;
95     }

```



```

95     }
96
97     friend constexpr ModIntBase operator/(ModIntBase lhs, const ModIntBase &rhs) {
98         lhs /= rhs;
99         return lhs;
100    }
101
102    friend constexpr std::ostream &operator<<(std::ostream &os, const ModIntBase &a) {
103        return os << a.val();
104    }
105
106    friend constexpr bool operator==(ModIntBase lhs, ModIntBase rhs) {
107        return lhs.val() == rhs.val();
108    }
109
110    friend constexpr bool operator!=(ModIntBase lhs, ModIntBase rhs) {
111        return lhs.val() != rhs.val();
112    }
113
114    friend constexpr bool operator<(ModIntBase lhs, ModIntBase rhs) {
115        return lhs.val() < rhs.val();
116    }
117
118 private:
119     U x;
120 };
121
122 template <u32 P>
123 using ModInt = ModIntBase<u32, P>;
124
125 template <u64 P>
126 using ModInt64 = ModIntBase<u64, P>;
127
128 constexpr u32 P = 998244353;
129 using Z = ModInt<P>;

```

5.53 06 - 状压 RMQ (RMQ)

Listing 79: ds/06-RMQ.cpp

```

1  /** 状压RMQ (RMQ)
2   *   2023-03-02: https://atcoder.jp/contests/joi2022ho/submissions/39351739
3   *   2023-09-04: https://qoj.ac/submission/163598
4   */
5  template<class T,
6          class Cmp = std::less<T>>
7  struct RMQ {
8      const Cmp cmp = Cmp();
9      static constexpr unsigned B = 64;
10     using u64 = unsigned long long;
11     int n;
12     std::vector<std::vector<T>>> a;
13     std::vector<T> pre, suf, ini;
14     std::vector<u64> stk;
15     RMQ() {}
16     RMQ(const std::vector<T> &v) {
17         init(v);
18     }
19     void init(const std::vector<T> &v) {
20         n = v.size();
21         pre = suf = ini = v;
22         stk.resize(n);
23         if (!n) {
24             return;

```

```

25     }
26     const int M = (n - 1) / B + 1;
27     const int lg = std::__lg(M);
28     a.assign(lg + 1, std::vector<T>(M));
29     for (int i = 0; i < M; i++) {
30         a[0][i] = v[i * B];
31         for (int j = 1; j < B && i * B + j < n; j++) {
32             a[0][i] = std::min(a[0][i], v[i * B + j], cmp);
33         }
34     }
35     for (int i = 1; i < n; i++) {
36         if (i % B) {
37             pre[i] = std::min(pre[i], pre[i - 1], cmp);
38         }
39     }
40     for (int i = n - 2; i >= 0; i--) {
41         if (i % B != B - 1) {
42             suf[i] = std::min(suf[i], suf[i + 1], cmp);
43         }
44     }
45     for (int j = 0; j < lg; j++) {
46         for (int i = 0; i + (2 << j) <= M; i++) {
47             a[j + 1][i] = std::min(a[j][i], a[j][i + (1 << j)], cmp);
48         }
49     }
50     for (int i = 0; i < M; i++) {
51         const int l = i * B;
52         const int r = std::min(1U * n, l + B);
53         u64 s = 0;
54         for (int j = l; j < r; j++) {
55             while (s && cmp(v[j], v[std::__lg(s) + l])) {
56                 s ^= 1ULL << std::__lg(s);
57             }
58             s |= 1ULL << (j - l);
59             stk[j] = s;
60         }
61     }
62 }
63 T operator()(int l, int r) {
64     if (l / B != (r - 1) / B) {
65         T ans = std::min(suf[l], pre[r - 1], cmp);
66         l = l / B + 1;
67         r = r / B;
68         if (l < r) {
69             int k = std::__lg(r - l);
70             ans = std::min({ans, a[k][l], a[k][r - (1 << k)]}, cmp);
71         }
72         return ans;
73     } else {
74         int x = B * (l / B);
75         return ini[__builtin_ctzll(stk[r - 1] >> (l - x)) + l];
76     }
77 }
78 };

```

5.54 07A - Splay

Listing 80: ds/07A-Splay.cpp

```

1 struct Node {
2     Node *l = nullptr;
3     Node *r = nullptr;
4     int cnt = 0;

```

```

5     i64 sum = 0;
6 };
7
8 Node *add(Node *t, int l, int r, int p, int v) {
9     Node *x = new Node;
10    if (t) {
11        *x = *t;
12    }
13    x->cnt += 1;
14    x->sum += v;
15    if (r - l == 1) {
16        return x;
17    }
18    int m = (l + r) / 2;
19    if (p < m) {
20        x->l = add(x->l, l, m, p, v);
21    } else {
22        x->r = add(x->r, m, r, p, v);
23    }
24    return x;
25 }
26
27 int find(Node *tl, Node *tr, int l, int r, int x) {
28     if (r <= x) {
29         return -1;
30     }
31     if (l >= x) {
32         int cnt = (tr ? tr->cnt : 0) - (tl ? tl->cnt : 0);
33         if (cnt == 0) {
34             return -1;
35         }
36         if (r - l == 1) {
37             return l;
38         }
39     }
40     int m = (l + r) / 2;
41     int res = find(tl ? tl->l : tl, tr ? tr->l : tr, l, m, x);
42     if (res == -1) {
43         res = find(tl ? tl->r : tl, tr ? tr->r : tr, m, r, x);
44     }
45     return res;
46 }
47
48 std::pair<int, i64> getNode(Node *t, int l, int r, int x, int y) {
49     if (l >= y || r <= x || !t) {
50         return {0, 0LL};
51     }
52     if (l >= x && r <= y) {
53         return {t->cnt, t->sum};
54     }
55     int m = (l + r) / 2;
56     auto [cl, sl] = get(t->l, l, m, x, y);
57     auto [cr, sr] = get(t->r, m, r, x, y);
58     return {cl + cr, sl + sr};
59 }
60
61 struct Tree {
62     int add = 0;
63     int val = 0;
64     int id = 0;
65     Tree *ch[2] = {};
66     Tree *p = nullptr;
67 };
68

```

```

69 int pos(Tree *t) {
70     return t->p->ch[1] == t;
71 }
72
73 void add(Tree *t, int v) {
74     t->val += v;
75     t->add += v;
76 }
77
78 void push(Tree *t) {
79     if (t->ch[0]) {
80         add(t->ch[0], t->add);
81     }
82     if (t->ch[1]) {
83         add(t->ch[1], t->add);
84     }
85     t->add = 0;
86 }
87
88 void rotate(Tree *t) {
89     Tree *q = t->p;
90     int x = !pos(t);
91     q->ch[!x] = t->ch[x];
92     if (t->ch[x]) t->ch[x]->p = q;
93     t->p = q->p;
94     if (q->p) q->p->ch[pos(q)] = t;
95     t->ch[x] = q;
96     q->p = t;
97 }
98
99 void splay(Tree *t) {
100     std::vector<Tree *> s;
101     for (Tree *i = t; i->p; i = i->p) s.push_back(i->p);
102     while (!s.empty()) {
103         push(s.back());
104         s.pop_back();
105     }
106     push(t);
107     while (t->p) {
108         if (t->p->p) {
109             if (pos(t) == pos(t->p)) rotate(t->p);
110             else rotate(t);
111         }
112         rotate(t);
113     }
114 }
115
116 void insert(Tree *t, Tree *x, Tree *p = nullptr) {
117     if (!t) {
118         t = x;
119         x->p = p;
120         return;
121     }
122
123     push(t);
124     if (x->val < t->val) {
125         insert(t->ch[0], x, t);
126     } else {
127         insert(t->ch[1], x, t);
128     }
129 }
130
131 void dfs(Tree *t) {

```

```

132     if (!t) {
133         return;
134     }
135     push(t);
136     dfs(t->ch[0]);
137     std::cerr << t->val << "_";
138     dfs(t->ch[1]);
139 }
140
141 std::pair<Tree *, Tree *> split(Tree *t, int x) {
142     if (!t) {
143         return {t, t};
144     }
145     Tree *v = nullptr;
146     Tree *j = t;
147     for (Tree *i = t; i; ) {
148         push(i);
149         j = i;
150         if (i->val >= x) {
151             v = i;
152             i = i->ch[0];
153         } else {
154             i = i->ch[1];
155         }
156     }
157
158     splay(j);
159     if (!v) {
160         return {j, nullptr};
161     }
162
163     splay(v);
164
165     Tree *u = v->ch[0];
166     if (u) {
167         v->ch[0] = u->p = nullptr;
168     }
169     // std::cerr << "split " << x << "\n";
170     // dfs(u);
171     // std::cerr << "\n";
172     // dfs(v);
173     // std::cerr << "\n";
174     return {u, v};
175 }
176
177 Tree *merge(Tree *l, Tree *r) {
178     if (!l) {
179         return r;
180     }
181     if (!r) {
182         return l;
183     }
184     Tree *i = l;
185     while (i->ch[1]) {
186         i = i->ch[1];
187     }
188     splay(i);
189     i->ch[1] = r;
190     r->p = i;
191     return i;
192 }

```

5.55 07B - Splay

Listing 81: ds/07B-Splay.cpp

```

1 struct Node {
2     Node *ch[2], *p;
3     bool rev;
4     int siz = 1;
5     Node() : ch{nullptr, nullptr}, p(nullptr), rev(false) {}
6 };
7 void reverse(Node *t) {
8     if (t) {
9         std::swap(t->ch[0], t->ch[1]);
10        t->rev ^= 1;
11    }
12 }
13 void push(Node *t) {
14     if (t->rev) {
15         reverse(t->ch[0]);
16         reverse(t->ch[1]);
17         t->rev = false;
18     }
19 }
20 void pull(Node *t) {
21     t->siz = (t->ch[0] ? t->ch[0]->siz : 0) + 1 + (t->ch[1] ? t->ch[1]->siz : 0);
22 }
23 bool isroot(Node *t) {
24     return t->p == nullptr || (t->p->ch[0] != t && t->p->ch[1] != t);
25 }
26 int pos(Node *t) {
27     return t->p->ch[1] == t;
28 }
29 void pushAll(Node *t) {
30     if (!isroot(t)) {
31         pushAll(t->p);
32     }
33     push(t);
34 }
35 void rotate(Node *t) {
36     Node *q = t->p;
37     int x = !pos(t);
38     q->ch[!x] = t->ch[x];
39     if (t->ch[x]) {
40         t->ch[x]->p = q;
41     }
42     t->p = q->p;
43     if (!isroot(q)) {
44         q->p->ch[pos(q)] = t;
45     }
46     t->ch[x] = q;
47     q->p = t;
48     pull(q);
49 }
50 void splay(Node *t) {
51     pushAll(t);
52     while (!isroot(t)) {
53         if (!isroot(t->p)) {
54             if (pos(t) == pos(t->p)) {
55                 rotate(t->p);
56             } else {
57                 rotate(t);
58             }
59         }
60         rotate(t);
61     }
62     pull(t);

```

```

63 }
64 void access(Node *t) {
65     for (Node *i = t, *q = nullptr; i; q = i, i = i->p) {
66         splay(i);
67         i->ch[1] = q;
68         pull(i);
69     }
70     splay(t);
71 }
72 void makeroot(Node *t) {
73     access(t);
74     reverse(t);
75 }
76 void link(Node *x, Node *y) {
77     makeroot(x);
78     x->p = y;
79 }
80 void split(Node *x, Node *y) {
81     makeroot(x);
82     access(y);
83 }
84 void cut(Node *x, Node *y) {
85     split(x, y);
86     x->p = y->ch[0] = nullptr;
87     pull(y);
88 }
89 int dist(Node *x, Node *y) {
90     split(x, y);
91     return y->siz - 1;
92 }

```

5.56 07C - Splay

Listing 82: ds/07C-Splay.cpp

```

1 struct Matrix : std::array<std::array<i64, 4>, 4> {
2     Matrix(i64 v = 0) {
3         for (int i = 0; i < 4; i++) {
4             for (int j = 0; j < 4; j++) {
5                 (*this)[i][j] = (i == j ? v : inf);
6             }
7         }
8     }
9 };
10
11 Matrix operator*(const Matrix &a, const Matrix &b) {
12     Matrix c(inf);
13     for (int i = 0; i < 3; i++) {
14         for (int j = 0; j < 3; j++) {
15             for (int k = 0; k < 4; k++) {
16                 c[i][k] = std::min(c[i][k], a[i][j] + b[j][k]);
17             }
18         }
19         c[i][3] = std::min(c[i][3], a[i][3]);
20     }
21     c[3][3] = 0;
22     return c;
23 }
24
25 struct Node {
26     Node *ch[2], *p;
27     i64 sumg = 0;
28     i64 sumh = 0;

```

```

29     i64 sumb = 0;
30     i64 g = 0;
31     i64 h = 0;
32     i64 b = 0;
33     Matrix mat;
34     Matrix prd;
35     std::array<i64, 4> ans{};
36     Node() : ch{nullptr, nullptr}, p(nullptr) {}
37
38     void update() {
39         mat = Matrix(0);
40         mat[0][0] = b + h - g + sumg;
41         mat[1][1] = mat[1][2] = mat[1][3] = h + sumh;
42         mat[2][0] = mat[2][1] = mat[2][2] = mat[2][3] = b + h + sumb;
43         mat[3][3] = 0;
44     }
45 };
46 void push(Node *t) {
47 }
48 void pull(Node *t) {
49     t->prd = (t->ch[0] ? t->ch[0]->prd : Matrix()) * t->mat * (t->ch[1] ? t->ch[1]->prd : Matrix());
50 }
51 bool isroot(Node *t) {
52     return t->p == nullptr || (t->p->ch[0] != t && t->p->ch[1] != t);
53 }
54 int pos(Node *t) {
55     return t->p->ch[1] == t;
56 }
57 void pushAll(Node *t) {
58     if (!isroot(t)) {
59         pushAll(t->p);
60     }
61     push(t);
62 }
63 void rotate(Node *t) {
64     Node *q = t->p;
65     int x = !pos(t);
66     q->ch[!x] = t->ch[x];
67     if (t->ch[x]) {
68         t->ch[x]->p = q;
69     }
70     t->p = q->p;
71     if (!isroot(q)) {
72         q->p->ch[pos(q)] = t;
73     }
74     t->ch[x] = q;
75     q->p = t;
76     pull(q);
77 }
78 void splay(Node *t) {
79     pushAll(t);
80     while (!isroot(t)) {
81         if (!isroot(t->p)) {
82             if (pos(t) == pos(t->p)) {
83                 rotate(t->p);
84             } else {
85                 rotate(t);
86             }
87         }
88         rotate(t);
89     }
90     pull(t);
91 }
92

```



```

93 std::array<i64, 4> get(Node *t) {
94     std::array<i64, 4> ans;
95     ans.fill(0);
96     ans[3] = 0;
97     for (int i = 0; i < 3; i++) {
98         for (int j = 0; j < 4; j++) {
99             ans[i] = std::min(ans[i], t->prd[i][j]);
100         }
101     }
102     return ans;
103 }
104
105 void access(Node *t) {
106     std::array<i64, 4> old{};
107     for (Node *i = t, *q = nullptr; i; q = i, i = i->p) {
108         splay(i);
109         if (i->ch[1]) {
110             auto res = get(i->ch[1]);
111             i->sumg += res[0];
112             i->sumh += std::min({res[1], res[2], res[3]});
113             i->sumb += std::min({res[0], res[1], res[2], res[3]});
114         }
115         i->ch[1] = q;
116         i->sumg -= old[0];
117         i->sumh -= std::min({old[1], old[2], old[3]});
118         i->sumb -= std::min({old[0], old[1], old[2], old[3]});
119         old = get(i);
120         i->update();
121         pull(i);
122     }
123     splay(t);
124 }
125 ...
126
127 ```cpp
128 /** Splay
129  * 2024-06-24: https://cf.dianhsu.com/gym/105229/submission/267199687?version=1.5
130  */
131 constexpr int D = 27;
132 struct Info {
133     int up[D][2]{};
134     int down[D][2]{};
135     int t = 0;
136     i64 ans = 0;
137 };
138
139 Info operator+(const Info &a, const Info &b) {
140     Info c;
141     c.t = a.t ^ b.t;
142     c.ans = a.ans + b.ans;
143     for (int i = 0; i < D; i++) {
144         for (int j = 0; j < 2; j++) {
145             c.ans += (1LL << i) * a.down[i][j] * b.up[i][j ^ 1];
146             c.up[i][j] += a.up[i][j] + b.up[i][j ^ (a.t >> i & 1)];
147             c.down[i][j] += b.down[i][j] + a.down[i][j ^ (b.t >> i & 1)];
148         }
149     }
150     return c;
151 }
152 struct Node {
153     Node *ch[2], *p;
154     Info val;
155     Info tot;
156     int cnt[D][2];

```

```

157     i64 pair[D][2];
158     i64 sum;
159     Node() : ch{nullptr, nullptr}, p(nullptr), cnt{}, pair{}, sum{} {}
160 };
161 void pull(Node *t) {
162     t->tot = (t->ch[0] ? t->ch[0]->tot : Info{}) + t->val + (t->ch[1] ? t->ch[1]->tot : Info{});
163 }
164 bool isroot(Node *t) {
165     return t->p == nullptr || (t->p->ch[0] != t && t->p->ch[1] != t);
166 }
167 int pos(Node *t) {
168     return t->p->ch[1] == t;
169 }
170 void rotate(Node *t) {
171     Node *q = t->p;
172     int x = !pos(t);
173     q->ch[!x] = t->ch[x];
174     if (t->ch[x]) {
175         t->ch[x]->p = q;
176     }
177     t->p = q->p;
178     if (!isroot(q)) {
179         q->p->ch[pos(q)] = t;
180     }
181     t->ch[x] = q;
182     q->p = t;
183     pull(q);
184 }
185 void update(Node *t) {
186     t->val.ans = t->val.t + t->sum;
187     for (int i = 0; i < D; i++) {
188         t->val.ans += (1LL << i) * t->pair[i][t->val.t >> i & 1];
189         for (int j = 0; j < 2; j++) {
190             t->val.up[i][j] = t->cnt[i][j ^ (t->val.t >> i & 1)];
191             t->val.down[i][j] = t->cnt[i][j ^ (t->val.t >> i & 1)];
192         }
193         t->val.up[i][t->val.t >> i & 1]++;
194         t->val.down[i][t->val.t >> i & 1]++;
195     }
196     pull(t);
197 }
198 void splay(Node *t) {
199     while (!isroot(t)) {
200         if (!isroot(t->p)) {
201             if (pos(t) == pos(t->p)) {
202                 rotate(t->p);
203             } else {
204                 rotate(t);
205             }
206         }
207         rotate(t);
208     }
209     pull(t);
210 }
211 void add(Node *t, Info s) {
212     for (int i = 0; i < D; i++) {
213         for (int x = 0; x < 2; x++) {
214             t->pair[i][x] += s.up[i][1 ^ x];
215             for (int j = 0; j < 2; j++) {
216                 t->pair[i][x] += t->cnt[i][j] * s.up[i][j ^ 1 ^ x];
217             }
218         }
219         for (int j = 0; j < 2; j++) {

```

```

220         t->cnt[i][j] += s.up[i][j];
221     }
222 }
223 t->sum += s.ans;
224 }
225 void del(Node *t, Info s) {
226     t->sum -= s.ans;
227     for (int i = 0; i < D; i++) {
228         for (int j = 0; j < 2; j++) {
229             t->cnt[i][j] -= s.up[i][j];
230         }
231         for (int x = 0; x < 2; x++) {
232             for (int j = 0; j < 2; j++) {
233                 t->pair[i][x] -= t->cnt[i][j] * s.up[i][j ^ 1 ^ x];
234             }
235             t->pair[i][x] -= s.up[i][1 ^ x];
236         }
237     }
238 }
239 void access(Node *t, int v) {
240     Info lst;
241     for (Node *i = t, *q = nullptr; i; q = i, i = i->p) {
242         splay(i);
243         if (i->ch[1]) {
244             add(i, i->ch[1]->tot);
245         }
246         i->ch[1] = q;
247         if (q) {
248             del(i, lst);
249         } else {
250             i->val.t = v;
251         }
252         lst = i->tot;
253         update(i);
254     }
255     splay(t);
256 }

```

5.57 08A - 其他平衡树

Listing 83: ds/08A-Mysterious-Balanced-Tree.cpp

```

1 struct Node {
2     Node *l = nullptr;
3     Node *r = nullptr;
4     int sum = 0;
5     int sumodd = 0;
6
7     Node(Node *t) {
8         if (t) {
9             *this = *t;
10        }
11    }
12 };
13
14 Node *add(Node *t, int l, int r, int x, int v) {
15     t = new Node(t);
16     t->sum += v;
17     t->sumodd += (x % 2) * v;
18     if (r - l == 1) {
19         return t;
20     }
21     int m = (l + r) / 2;

```

```

22     if (x < m) {
23         t->l = add(t->l, l, m, x, v);
24     } else {
25         t->r = add(t->r, m, r, x, v);
26     }
27     return t;
28 }
29
30 int query1(Node *t1, Node *t2, int l, int r, int k) {
31     if (r - l == 1) {
32         return l;
33     }
34     int m = (l + r) / 2;
35     int odd = (t1 && t1->r ? t1->r->sumodd : 0) - (t2 && t2->r ? t2->r->sumodd : 0);
36     int cnt = (t1 && t1->r ? t1->r->sum : 0) - (t2 && t2->r ? t2->r->sum : 0);
37     if (odd > 0 || cnt > k) {
38         return query1(t1 ? t1->r : t1, t2 ? t2->r : t2, m, r, k);
39     } else {
40         return query1(t1 ? t1->l : t1, t2 ? t2->l : t2, l, m, k - cnt);
41     }
42 }
43
44 std::array<int, 3> query2(Node *t1, Node *t2, int l, int r, int k) {
45     if (r - l == 1) {
46         int cnt = (t1 ? t1->sumodd : 0) - (t2 ? t2->sumodd : 0);
47         return {l, cnt, k};
48     }
49     int m = (l + r) / 2;
50     int cnt = (t1 && t1->r ? t1->r->sumodd : 0) - (t2 && t2->r ? t2->r->sumodd : 0);
51     if (cnt > k) {
52         return query2(t1 ? t1->r : t1, t2 ? t2->r : t2, m, r, k);
53     } else {
54         return query2(t1 ? t1->l : t1, t2 ? t2->l : t2, l, m, k - cnt);
55     }
56 }

```

5.58 08B - 其他平衡树

Listing 84: ds/08B-Mysterious-Balanced-Tree.cpp

```

1 struct Node {
2     Node *l = nullptr;
3     Node *r = nullptr;
4     int cnt = 0;
5 };
6
7 Node *add(Node *t, int l, int r, int x) {
8     if (t) {
9         t = new Node(*t);
10    } else {
11        t = new Node;
12    }
13    t->cnt += 1;
14    if (r - l == 1) {
15        return t;
16    }
17    int m = (l + r) / 2;
18    if (x < m) {
19        t->l = add(t->l, l, m, x);
20    } else {
21        t->r = add(t->r, m, r, x);
22    }
23    return t;

```

```

24 }
25
26 int query(Node *t1, Node *t2, int l, int r, int x) {
27     int cnt = (t2 ? t2->cnt : 0) - (t1 ? t1->cnt : 0);
28     if (cnt == 0 || l >= x) {
29         return -1;
30     }
31     if (r - l == 1) {
32         return l;
33     }
34     int m = (l + r) / 2;
35     int res = query(t1 ? t1->r : t1, t2 ? t2->r : t2, m, r, x);
36     if (res == -1) {
37         res = query(t1 ? t1->l : t1, t2 ? t2->l : t2, l, m, x);
38     }
39     return res;
40 }

```

5.59 08C - 其他平衡树

Listing 85: ds/08C-Mysterious-Balanced-Tree.cpp

```

1 struct Info {
2     int imp = 0;
3     int id = 0;
4 };
5
6 Info operator+(Info a, Info b) {
7     return {std::max(a.imp, b.imp), 0};
8 }
9
10 struct Node {
11     int w = rng();
12     Info info;
13     Info sum;
14     int siz = 1;
15     Node *l = nullptr;
16     Node *r = nullptr;
17 };
18
19 void pull(Node *t) {
20     t->sum = t->info;
21     t->siz = 1;
22     if (t->l) {
23         t->sum = t->l->sum + t->sum;
24         t->siz += t->l->siz;
25     }
26     if (t->r) {
27         t->sum = t->sum + t->r->sum;
28         t->siz += t->r->siz;
29     }
30 }
31
32 std::pair<Node *, Node *> splitAt(Node *t, int p) {
33     if (!t) {
34         return {t, t};
35     }
36     if (p <= (t->l ? t->l->siz : 0)) {
37         auto [l, r] = splitAt(t->l, p);
38         t->l = r;
39         pull(t);
40         return {l, t};
41     } else {
42         auto [l, r] = splitAt(t->r, p - 1 - (t->l ? t->l->siz : 0));

```

```

43     t->r = l;
44     pull(t);
45     return {t, r};
46 }
47 }
48
49 void insertAt(Node *t, int p, Node *x) {
50     if (!t) {
51         t = x;
52         return;
53     }
54     if (x->w < t->w) {
55         auto [l, r] = splitAt(t, p);
56         t = x;
57         t->l = l;
58         t->r = r;
59         pull(t);
60         return;
61     }
62     if (p <= (t->l ? t->l->siz : 0)) {
63         insertAt(t->l, p, x);
64     } else {
65         insertAt(t->r, p - 1 - (t->l ? t->l->siz : 0), x);
66     }
67     pull(t);
68 }
69
70 Node *merge(Node *a, Node *b) {
71     if (!a) {
72         return b;
73     }
74     if (!b) {
75         return a;
76     }
77
78     if (a->w < b->w) {
79         a->r = merge(a->r, b);
80         pull(a);
81         return a;
82     } else {
83         b->l = merge(a, b->l);
84         pull(b);
85         return b;
86     }
87 }
88
89 int query(Node *t, int v) {
90     if (!t) {
91         return 0;
92     }
93     if (t->sum.imp < v) {
94         return t->siz;
95     }
96     int res = query(t->r, v);
97     if (res != (t->r ? t->r->siz : 0)) {
98         return res;
99     }
100     if (t->info.imp > v) {
101         return res;
102     }
103     return res + 1 + query(t->l, v);
104 }
105
106 void dfs(Node *t) {

```

```

107     if (!t) {
108         return;
109     }
110     dfs(t->l);
111     std::cout << t->info.id << "_";
112     dfs(t->r);
113 }

```

5.60 08D - 其他平衡树

Listing 86: ds/08D-Mysterious-Balanced-Tree.cpp

```

1  struct Node {
2      Node *l = nullptr;
3      Node *r = nullptr;
4      int cnt = 0;
5      int cntnew = 0;
6  };
7
8  Node *add(int l, int r, int x, int isnew) {
9      Node *t = new Node;
10     t->cnt = 1;
11     t->cntnew = isnew;
12     if (r - l == 1) {
13         return t;
14     }
15     int m = (l + r) / 2;
16     if (x < m) {
17         t->l = add(l, m, x, isnew);
18     } else {
19         t->r = add(m, r, x, isnew);
20     }
21     return t;
22 }
23
24 struct Info {
25     Node *t = nullptr;
26     int psum = 0;
27     bool rev = false;
28 };
29
30 void pull(Node *t) {
31     t->cnt = (t->l ? t->l->cnt : 0) + (t->r ? t->r->cnt : 0);
32     t->cntnew = (t->l ? t->l->cntnew : 0) + (t->r ? t->r->cntnew : 0);
33 }
34
35 std::pair<Node *, Node *> split(Node *t, int l, int r, int x, bool rev) {
36     if (!t) {
37         return {t, t};
38     }
39     if (x == 0) {
40         return {nullptr, t};
41     }
42     if (x == t->cnt) {
43         return {t, nullptr};
44     }
45     if (r - l == 1) {
46         Node *t2 = new Node;
47         t2->cnt = t->cnt - x;
48         t->cnt = x;
49         return {t, t2};
50     }
51     Node *t2 = new Node;
52     int m = (l + r) / 2;

```

```

53     if (!rev) {
54         if (t->l && x <= t->l->cnt) {
55             std::tie(t->l, t2->l) = split(t->l, l, m, x, rev);
56             t2->r = t->r;
57             t->r = nullptr;
58         } else {
59             std::tie(t->r, t2->r) = split(t->r, m, r, x - (t->l ? t->l->cnt : 0), rev);
60         }
61     } else {
62         if (t->r && x <= t->r->cnt) {
63             std::tie(t->r, t2->r) = split(t->r, m, r, x, rev);
64             t2->l = t->l;
65             t->l = nullptr;
66         } else {
67             std::tie(t->l, t2->l) = split(t->l, l, m, x - (t->r ? t->r->cnt : 0), rev);
68         }
69     }
70     pull(t);
71     pull(t2);
72     return {t, t2};
73 }
74
75 Node *merge(Node *t1, Node *t2, int l, int r) {
76     if (!t1) {
77         return t2;
78     }
79     if (!t2) {
80         return t1;
81     }
82     if (r - l == 1) {
83         t1->cnt += t2->cnt;
84         t1->cntnew += t2->cntnew;
85         delete t2;
86         return t1;
87     }
88     int m = (l + r) / 2;
89     t1->l = merge(t1->l, t2->l, l, m);
90     t1->r = merge(t1->r, t2->r, m, r);
91     delete t2;
92     pull(t1);
93     return t1;
94 }

```

5.61 09 - 分数四则运算 (Frac)

Listing 87: ds/09-Frac.cpp

```

1  template<class T>
2  struct Frac {
3      T num;
4      T den;
5      Frac(T num_, T den_) : num(num_), den(den_) {
6          if (den < 0) {
7              den = -den;
8              num = -num;
9          }
10     }
11     Frac() : Frac(0, 1) {}
12     Frac(T num_) : Frac(num_, 1) {}
13     explicit operator double() const {
14         return 1. * num / den;
15     }
16     Frac &operator+=(const Frac &rhs) {
17         num = num * rhs.den + rhs.num * den;

```



```

18     den *= rhs.den;
19     return *this;
20 }
21 Frac &operator--(const Frac &rhs) {
22     num = num * rhs.den - rhs.num * den;
23     den *= rhs.den;
24     return *this;
25 }
26 Frac &operator*=(const Frac &rhs) {
27     num *= rhs.num;
28     den *= rhs.den;
29     return *this;
30 }
31 Frac &operator/=(const Frac &rhs) {
32     num *= rhs.den;
33     den *= rhs.num;
34     if (den < 0) {
35         num = -num;
36         den = -den;
37     }
38     return *this;
39 }
40 friend Frac operator+(Frac lhs, const Frac &rhs) {
41     return lhs += rhs;
42 }
43 friend Frac operator-(Frac lhs, const Frac &rhs) {
44     return lhs -= rhs;
45 }
46 friend Frac operator*(Frac lhs, const Frac &rhs) {
47     return lhs *= rhs;
48 }
49 friend Frac operator/(Frac lhs, const Frac &rhs) {
50     return lhs /= rhs;
51 }
52 friend Frac operator~(const Frac &a) {
53     return Frac(-a.num, a.den);
54 }
55 friend bool operator==(const Frac &lhs, const Frac &rhs) {
56     return lhs.num * rhs.den == rhs.num * lhs.den;
57 }
58 friend bool operator!=(const Frac &lhs, const Frac &rhs) {
59     return lhs.num * rhs.den != rhs.num * lhs.den;
60 }
61 friend bool operator<(const Frac &lhs, const Frac &rhs) {
62     return lhs.num * rhs.den < rhs.num * lhs.den;
63 }
64 friend bool operator>(const Frac &lhs, const Frac &rhs) {
65     return lhs.num * rhs.den > rhs.num * lhs.den;
66 }
67 friend bool operator<=(const Frac &lhs, const Frac &rhs) {
68     return lhs.num * rhs.den <= rhs.num * lhs.den;
69 }
70 friend bool operator>=(const Frac &lhs, const Frac &rhs) {
71     return lhs.num * rhs.den >= rhs.num * lhs.den;
72 }
73 friend std::ostream &operator<<(std::ostream &os, Frac x) {
74     T g = std::gcd(x.num, x.den);
75     if (x.den == g) {
76         return os << x.num / g;
77     } else {
78         return os << x.num / g << "/" << x.den / g;
79     }
80 }
81 };

```

5.62 10 - 线性基 (Basis)

Listing 88: ds/10-Basis.cpp

```

1 struct Basis {
2     int a[20] {};
3     int t[20] {};
4
5     Basis() {
6         std::fill(t, t + 20, -1);
7     }
8
9     void add(int x, int y = 1E9) {
10         for (int i = 0; i < 20; i++) {
11             if (x >> i & 1) {
12                 if (y > t[i]) {
13                     std::swap(a[i], x);
14                     std::swap(t[i], y);
15                 }
16                 x ^= a[i];
17             }
18         }
19     }
20
21     bool query(int x, int y = 0) {
22         for (int i = 0; i < 20; i++) {
23             if ((x >> i & 1) && t[i] >= y) {
24                 x ^= a[i];
25             }
26         }
27         return x == 0;
28     }
29 };

```

5.63 143 - 高精度 (BigInt)

Listing 89: ds/143-BigInt.cpp

```

1 /** 高精度 (BigInt)
2  * 2023-09-11: https://qoj.ac/submission/176420
3  **/
4 constexpr int N = 1000;
5
6 struct BigInt {
7     int a[N];
8     BigInt(int x = 0) : a{} {
9         for (int i = 0; x; i++) {
10             a[i] = x % 10;
11             x /= 10;
12         }
13     }
14     BigInt &operator*=(int x) {
15         for (int i = 0; i < N; i++) {
16             a[i] *= x;
17         }
18         for (int i = 0; i < N - 1; i++) {
19             a[i + 1] += a[i] / 10;
20             a[i] %= 10;
21         }
22         return *this;
23     }
24     BigInt &operator/=(int x) {
25         for (int i = N - 1; i >= 0; i--) {
26             if (i) {

```

```

27         a[i - 1] += a[i] % x * 10;
28     }
29     a[i] /= x;
30 }
31 return *this;
32 }
33 BigInt &operator+=(const BigInt &x) {
34     for (int i = 0; i < N; i++) {
35         a[i] += x.a[i];
36         if (a[i] >= 10) {
37             a[i + 1] += 1;
38             a[i] -= 10;
39         }
40     }
41     return *this;
42 }
43 };
44
45 std::ostream &operator<<(std::ostream &o, const BigInt &a) {
46     int t = N - 1;
47     while (a.a[t] == 0) {
48         t--;
49     }
50     for (int i = t; i >= 0; i--) {
51         o << a.a[i];
52     }
53     return o;
54 }

```

6 Watashi 代码库 (备用)

6.1 $O(n \log n) - O(1)$ RMQ

Listing 90: **rmq.cpp**

```

1  #include <algorithm> // copy
2  #include <climits>   // CHAR_BIT
3
4  using namespace std;
5
6  template <typename T>
7  struct RMQ {
8      int n;
9      vector<T> e;
10     vector<vector<int>> rmq;
11
12     static const int INT_BIT = sizeof(4) * CHAR_BIT;
13     static inline int LG2(int i) { return INT_BIT - 1 - __builtin_clz(i); }
14     static inline int BIN(int i) { return 1 << i; }
15
16     int cmp(int l, int r) const {
17         return e[l] <= e[r] ? l : r;
18     }
19
20     void init(int n, const T e[]) {
21         this->n = n;
22         vector<T>(e, e + n).swap(this->e);
23
24         int m = 1;
25         while (BIN(m) <= n) {
26             ++m;
27         }
28         vector<vector<int>>(m, vector<int>(n)).swap(rmq);
29

```

```

30     for (int i = 0; i < n; ++i) {
31         rmq[0][i] = i;
32     }
33     for (int i = 0; BIN(i + 1) <= n; ++i) {
34         for (int j = 0; j + BIN(i + 1) <= n; ++j) {
35             rmq[i + 1][j] = cmp(rmq[i][j], rmq[i][j + BIN(i)]);
36         }
37     }
38 }
39
40 int index(int l, int r) const {
41     int b = LG2(r - l);
42     return cmp(rmq[b][l], rmq[b][r - (1 << b)]);
43 }
44
45 T value(int l, int r) const {
46     return e[index(l, r)];
47 }
48 };

```

6.2 $O(n \log n) - O(\log n)$ LCA

Listing 91: lca.cpp

```

1  #include <algorithm>
2  #include <cstdio>
3  #include <vector>
4
5  using namespace std;
6
7  const int MAXM = 16;
8  const int MAXN = 1 << MAXM;
9
10 // LCA
11 struct LCA {
12     vector<int> e[MAXN];
13     int d[MAXN], p[MAXN][MAXM];
14
15     void dfs_(int v, int f) {
16         p[v][0] = f;
17         for (int i = 1; i < MAXM; ++i) {
18             p[v][i] = p[p[v][i - 1]][i - 1];
19         }
20         for (int i = 0; i < (int)e[v].size(); ++i) {
21             int w = e[v][i];
22             if (w != f) {
23                 d[w] = d[v] + 1;
24                 dfs_(w, v);
25             }
26         }
27     }
28
29     int up_(int v, int m) {
30         for (int i = 0; i < MAXM; ++i) {
31             if (m & (1 << i)) {
32                 v = p[v][i];
33             }
34         }
35         return v;
36     }
37
38     int lca(int a, int b) {
39         if (d[a] > d[b]) {
40             swap(a, b);

```

```

41     }
42     b = up_(b, d[b] - d[a]);
43     if (a == b) {
44         return a;
45     } else {
46         for (int i = MAXM - 1; i >= 0; --i) {
47             if (p[a][i] != p[b][i]) {
48                 a = p[a][i];
49                 b = p[b][i];
50             }
51         }
52         return p[a][0];
53     }
54 }
55
56 void init(int n) {
57     for (int i = 0; i < n; ++i) {
58         e[i].clear();
59     }
60 }
61
62 void add(int a, int b) {
63     e[a].push_back(b);
64     e[b].push_back(a);
65 }
66
67 void build() {
68     d[0] = 0;
69     dfs_(0, 0);
70 }
71 } lca;

```

6.3 树状数组

Listing 92: **bit.cpp**

```

1  #include <vector>
2
3  using namespace std;
4
5  template<typename T = int>
6  struct BIT {
7      vector<T> a;
8
9      void init(int n) {
10         vector<T>(n + 1).swap(a);
11     }
12
13     void add(int i, T v) {
14         for (int j = i + 1; j < (int)a.size(); j = (j | (j - 1)) + 1) {
15             a[j] += v;
16         }
17     }
18
19     // [0, i)
20     T sum(int i) const {
21         T ret = T();
22         for (int j = i; j > 0; j = j & (j - 1)) {
23             ret += a[j];
24         }
25         return ret;
26     }
27
28     T get(int i) const {

```

```

29     return sum(i + 1) - sum(i);
30 }
31
32 void set(int i, T v) {
33     add(i, v - get(i));
34 }
35 };

```

6.4 并查集

Listing 93: union-find.cpp

```

1  #include <vector>
2
3  using namespace std;
4
5  struct DisjointSet {
6      vector<int> p;
7
8      void init(int n) {
9          p.resize(n);
10         for (int i = 0; i < n; ++i) {
11             p[i] = i;
12         }
13     }
14
15     int getp(int i) {
16         return i == p[i] ? i : (p[i] = getp(p[i]));
17     }
18
19     bool setp(int i, int j) {
20         i = getp(i);
21         j = getp(j);
22         p[i] = j;
23         return i != j;
24     }
25 };

```

6.5 轻重权树剖分

Listing 94: chain-decomp.cpp

```

1  #include <cstdio>
2  #include <vector>
3  #include <algorithm>
4
5  using namespace std;
6
7  const int MAXM = 16;
8  const int MAXN = 1 << MAXM;
9
10 // Heavy-Light Decomposition
11 struct TreeDecomposition {
12     vector<int> e[MAXN], c[MAXN];
13     int s[MAXN];    // subtree size
14     int p[MAXN];    // parent id
15     int r[MAXN];    // chain root id
16     int t[MAXN];    // timestamp, index used in segtree
17     int ts;
18
19     void dfs_(int v, int f) {
20         p[v] = f;
21         s[v] = 1;
22         for (int i = 0; i < (int)e[v].size(); ++i) {

```

```

23     int w = e[v][i];
24     if (w != f) {
25         dfs_(w, v);
26         s[v] += s[w];
27     }
28 }
29 }
30
31 void decomp_(int v, int f, int k) {
32     t[v] = ts++;
33     c[k].push_back(v);
34     r[v] = k;
35
36     int x = 0, y = -1;
37     for (int i = 0; i < (int)e[v].size(); ++i) {
38         int w = e[v][i];
39         if (w != f) {
40             if (s[w] > x) {
41                 x = s[w];
42                 y = w;
43             }
44         }
45     }
46     if (y != -1) {
47         decomp_(y, v, k);
48     }
49
50     for (int i = 0; i < (int)e[v].size(); ++i) {
51         int w = e[v][i];
52         if (w != f && w != y) {
53             decomp_(w, v, w);
54         }
55     }
56 }
57
58 void init(int n) {
59     for (int i = 0; i < n; ++i) {
60         e[i].clear();
61     }
62 }
63
64 void add(int a, int b) {
65     e[a].push_back(b);
66     e[b].push_back(a);
67 }
68
69 void build() { // !!
70     ts = 0;
71     dfs_(0, 0);
72     decomp_(0, 0, 0);
73 }
74 } hld;

```

6.6 强连通分量

Listing 95: scc.cpp

```

1  #include <algorithm>
2  #include <stack>
3  #include <vector>
4
5  using namespace std;
6
7  struct SCCTarjan {

```

```

8     int n;
9     vector<vector<int>> e;
10
11     vector<int> id;
12     vector<vector<int>> scc;
13
14     void init(int n) {
15         this->n = n;
16         vector<vector<int>>(n).swap(e);
17         id.resize(n);
18         dfn.resize(n);
19         low.resize(n);
20     }
21
22     void add(int a, int b) {
23         e[a].push_back(b);
24     }
25
26     vector<int> dfn, low;
27     int timestamp;
28     stack<int> s;
29
30     void dfs(int v) {
31         dfn[v] = timestamp++;
32         low[v] = dfn[v];
33         s.push(v);
34         for (vector<int>::const_iterator w = e[v].begin(); w != e[v].end(); ++w) {
35             if (dfn[*w] == -1) {
36                 dfs(*w);
37                 low[v] = min(low[v], low[*w]);
38             } else if (dfn[*w] != -2) {
39                 low[v] = min(low[v], dfn[*w]);
40             }
41         }
42
43         if (low[v] == dfn[v]) {
44             vector<int> t;
45             do {
46                 int w = s.top();
47                 s.pop();
48                 id[w] = (int)scc.size();
49                 t.push_back(w);
50                 dfn[w] = -2;
51             } while (t.back() != v);
52             scc.push_back(t);
53         }
54     }
55
56     int gao() {
57         scc.clear();
58         stack<int>().swap(s);
59         timestamp = 0;
60
61         fill(dfn.begin(), dfn.end(), -1);
62         for (int i = 0; i < n; ++i) {
63             if (dfn[i] == -1) {
64                 dfs(i);
65             }
66         }
67         return (int)scc.size();
68     }
69 };

```


6.7 双连通分量

Listing 96: bcc.cpp

```

1  #include <algorithm>
2  #include <stack>
3  #include <utility>
4  #include <vector>
5
6  using namespace std;
7
8  // TODO: cannot handle duplicate edges
9  struct Tarjan {
10     int n;
11     vector<vector<int>> e;
12
13     vector<int> cut;
14     vector<pair<int, int>> bridge;
15     vector<vector<pair<int, int>>> bcc;
16
17     void init(int n) {
18         this->n = n;
19         e.clear();
20         e.resize(n);
21         dfn.resize(n);
22         low.resize(n);
23     }
24
25     void add(int a, int b) {
26         // assert(find(e[a].begin(), e[a].end(), b) == e[a].end());
27         e[a].push_back(b);
28         e[b].push_back(a);
29     }
30
31     vector<int> dfn, low;
32     int timestamp;
33     stack<pair<int, int>> s;
34
35     void dfs(int v, int p) {
36         int part = p == -1 ? 0 : 1;
37         dfn[v] = low[v] = timestamp++;
38         for (vector<int>::const_iterator w = e[v].begin(); w != e[v].end(); ++w) {
39             pair<int, int> f = make_pair(min(v, *w), max(v, *w));
40             if (dfn[*w] == -1) {
41                 s.push(f);
42                 dfs(*w, v);
43                 low[v] = min(low[v], low[*w]);
44                 if (dfn[v] <= low[*w]) {
45                     // articulation point
46                     if (++part == 2) {
47                         cut.push_back(v);
48                     }
49                     // articulation edge
50                     if (dfn[v] < low[*w]) {
51                         bridge.push_back(f);
52                     }
53                     // biconnected component (2-vertex-connected)
54                     vector<pair<int, int>> t;
55                     do {
56                         t.push_back(s.top());
57                         s.pop();
58                     } while (t.back() != f);
59                     bcc.push_back(t);
60                 }

```

```

61         } else if (*w != p && dfn[*w] < dfn[v]) {
62             s.push(f);
63             low[v] = min(low[v], dfn[*w]);
64         }
65     }
66 }
67
68 void gao() {
69     cut.clear();
70     bridge.clear();
71     bcc.clear();
72
73     timestamp = 0;
74     stack<pair<int, int>>().swap(s);
75     fill(dfn.begin(), dfn.end(), -1);
76
77     for (int i = 0; i < n; ++i) {
78         if (dfn[i] == -1) {
79             dfs(i, -1);
80         }
81     }
82 }
83 };
84
85 struct BridgeBlockTree {
86     Tarjan<MAXN> bcc;
87     DisjointSet<MAXN> ds;
88     vector<int> e[MAXN];
89
90     void init(int n) {
91         bcc.init(n);
92         ds.init(n);
93     }
94
95     void add(int a, int b) {
96         bcc.add(a, b);
97     }
98
99     void gao() {
100         bcc.gao();
101         for (const auto &i : bcc.bcc) {
102             if (i.size() > 1) {
103                 for (const auto &j : i) {
104                     ds.setp(j.first, j.second);
105                 }
106             }
107         }
108         for (const auto &i : bcc.bridge) {
109             int a = ds.getp(i.first);
110             int b = ds.getp(i.second);
111             e[a].push_back(b);
112             e[b].push_back(a);
113         }
114     }
115
116     int id(int v) {
117         return ds.getp(v);
118     }
119 };

```

6.8 二分图匹配

Listing 97: bimatch.cpp

```

1 // maximum matchings in bipartite graphs
2 // maximum cardinality bipartite matching
3 //  $O(|V||E|)$ , generally fast
4
5 #include <algorithm>
6 #include <string>
7 #include <vector>
8
9 using namespace std;
10
11 struct Hungarian {
12     int nx, ny;
13     vector<int> mx, my;
14     vector<vector<int>> e;
15
16     void init(int nx, int ny) {
17         this->nx = nx;
18         this->ny = ny;
19         mx.resize(nx);
20         my.resize(ny);
21         e.clear();
22         e.resize(nx);
23         mark.resize(nx);
24     }
25
26     void add(int a, int b) {
27         e[a].push_back(b);
28     }
29
30     // vector<bool> is evil!!!
31     basic_string<bool> mark;
32
33     bool augment(int i) {
34         if (!mark[i]) {
35             mark[i] = true;
36             for (vector<int>::const_iterator j = e[i].begin(); j != e[i].end(); ++j) {
37                 if (my[*j] == -1 || augment(my[*j])) {
38                     mx[i] = *j;
39                     my[*j] = i;
40                     return true;
41                 }
42             }
43         }
44         return false;
45     }
46
47     int gao() {
48         int ret = 0;
49         fill(mx.begin(), mx.end(), -1);
50         fill(my.begin(), my.end(), -1);
51         for (int i = 0; i < nx; ++i) {
52             fill(mark.begin(), mark.end(), false);
53             if (augment(i)) {
54                 ++ret;
55             }
56         }
57         return ret;
58     }
59 };

```

6.9 最小费用最大流

Listing 98: flow.cpp

```

1  #include <algorithm>
2  #include <cstdio>
3  #include <limits>
4  #include <queue>
5  #include <vector>
6
7  using namespace std;
8
9  template <int MAXN, typename T = int, typename S = T>
10 struct MinCostMaxFlow {
11     struct NegativeCostCircuitExistsException {
12     };
13
14     struct Edge {
15         int v;
16         T c;
17         S w;
18         int b;
19         Edge(int v, T c, S w, int b) : v(v), c(c), w(w), b(b) {}
20     };
21
22     int n, source, sink;
23     vector<Edge> e[MAXN];
24
25     void init(int n, int source, int sink) {
26         this->n = n;
27         this->source = source;
28         this->sink = sink;
29         for (int i = 0; i < n; ++i) {
30             e[i].clear();
31         }
32     }
33
34     void addEdge(int a, int b, T c, S w) {
35         e[a].push_back(Edge(b, c, w, e[b].size()));
36         e[b].push_back(Edge(a, 0, -w, e[a].size() - 1)); // TODO
37     }
38
39     bool mark[MAXN];
40     T maxc[MAXN];
41     S minw[MAXN];
42     int dist[MAXN];
43     Edge *prev[MAXN];
44
45     bool _spfa() {
46         queue<int> q;
47         fill(mark, mark + n, false);
48         fill(maxc, maxc + n, 0);
49         fill(minw, minw + n, numeric_limits<S>::max());
50         fill(dist, dist + n, 0);
51         fill(prev, prev + n, (Edge *)NULL);
52         mark[source] = true;
53         maxc[source] = numeric_limits<S>::max();
54         minw[source] = 0;
55
56         q.push(source);
57         while (!q.empty()) {
58             int cur = q.front();
59             mark[cur] = false;
60             q.pop();
61             for (typename vector<Edge>::iterator it = e[cur].begin(); it != e[cur].end(); ++it) {
62                 T c = min(maxc[cur], it->c);
63                 if (c == 0) {

```

```

64         continue;
65     }
66
67     int v = it->v;
68     S w = minw[cur] + it->w;
69     if (minw[v] > w || (minw[v] == w && maxc[v] < c)) { // TODO
70         maxc[v] = c;
71         minw[v] = w;
72         dist[v] = dist[cur] + 1;
73         if (dist[v] >= n) {
74             return false;
75         }
76         prev[v] = &*it;
77         if (!mark[v]) {
78             mark[v] = true;
79             q.push(v);
80         }
81     }
82 }
83 }
84 return true;
85 }
86
87 pair<T, S> gao() {
88     T sumc = 0;
89     S sumw = 0;
90     while (true) {
91         if (!_spfa()) {
92             throw NegativeCostCircuitExistsException();
93         } else if (maxc[sink] == 0) {
94             break;
95         } else {
96             T c = maxc[sink];
97             sumc += c;
98             sumw += c * minw[sink];
99
100             int cur = sink;
101             while (cur != source) {
102                 Edge *e1 = prev[cur];
103                 e1->c -= c;
104                 Edge *e2 = &e[e1->v][e1->b];
105                 e2->c += c;
106                 cur = e2->v;
107             }
108         }
109     }
110     return make_pair(sumc, sumw);
111 }
112 };

```

6.10 AhoCorasick 自动机

Listing 99: ac-automata.cpp

```

1  #include <algorithm>
2  #include <queue>
3
4  using namespace std;
5
6  struct AhoCorasick {
7      static const int NONE = 0;
8      static const int MAXN = 1024;
9      static const int CHARSET = 26;
10
11      int end;

```

```

12     int tag[MAXN];
13     int fail[MAXN];
14     int trie[MAXN][CHARSET];
15
16     void init() {
17         tag[0] = NONE;
18         fill(trie[0], trie[0] + CHARSET, -1);
19         end = 1;
20     }
21
22     int add(int m, const int *s) {
23         int p = 0;
24         for (int i = 0; i < m; ++i) {
25             if (trie[p][*s] == -1) {
26                 tag[end] = NONE;
27                 fill(trie[end], trie[end] + CHARSET, -1);
28                 trie[p][*s] = end++;
29             }
30             p = trie[p][*s];
31             ++s;
32         }
33         return p;
34     }
35
36     void build(void) { // !!
37         queue<int> bfs;
38         fail[0] = 0;
39         for (int i = 0; i < CHARSET; ++i) {
40             if (trie[0][i] != -1) {
41                 fail[trie[0][i]] = 0;
42                 bfs.push(trie[0][i]);
43             } else {
44                 trie[0][i] = 0;
45             }
46         }
47         while (!bfs.empty()) {
48             int p = bfs.front();
49             tag[p] |= tag[fail[p]];
50             bfs.pop();
51             for (int i = 0; i < CHARSET; ++i) {
52                 if (trie[p][i] != -1) {
53                     fail[trie[p][i]] = trie[fail[p]][i];
54                     bfs.push(trie[p][i]);
55                 } else {
56                     trie[p][i] = trie[fail[p]][i];
57                 }
58             }
59         }
60     }
61 } ac;

```

6.11 后缀数组

Listing 100: sa.cpp

```

1  #include <algorithm>
2  #include <utility>
3  #include <vector>
4  using namespace std;
5
6  struct SuffixArray {
7      vector<int> sa, rank, height;
8
9      template <typename T>

```

```

10 void init(int n, const T a[]) {
11     sa.resize(n);
12     rank.resize(n);
13
14     vector<pair<T, int>> assoc(n);
15     for (int i = 0; i < n; ++i) {
16         assoc[i] = make_pair(a[i], i);
17     }
18     sort(assoc.begin(), assoc.end());
19     for (int i = 0; i < n; ++i) {
20         sa[i] = assoc[i].second;
21         if (i == 0 || assoc[i].first != assoc[i - 1].first) {
22             rank[sa[i]] = i;
23         } else {
24             rank[sa[i]] = rank[sa[i - 1]];
25         }
26     }
27
28     vector<int> tmp(n), cnt(n);
29     vector<pair<int, int>> suffix(n);
30     for (int m = 1; m < n; m <= 1) {
31         // snd
32         for (int i = 0; i < m; ++i) {
33             tmp[i] = n - m + i;
34         }
35         for (int i = 0, j = m; i < n; ++i) {
36             if (sa[i] >= m) {
37                 tmp[j++] = sa[i] - m;
38             }
39         }
40         // fst
41         fill(cnt.begin(), cnt.end(), 0);
42         for (int i = 0; i < n; ++i) {
43             ++cnt[rank[i]];
44         }
45         partial_sum(cnt.begin(), cnt.end(), cnt.begin());
46         for (int i = n - 1; i >= 0; --i) {
47             sa[--cnt[rank[tmp[i]]]] = tmp[i];
48         }
49         //
50         for (int i = 0; i < n; ++i) {
51             suffix[i] = make_pair(rank[i], i + m < n ? rank[i + m] : numeric_limits<int>::min());
52         }
53         for (int i = 0; i < n; ++i) {
54             if (i == 0 || suffix[sa[i]] != suffix[sa[i - 1]]) {
55                 rank[sa[i]] = i;
56             } else {
57                 rank[sa[i]] = rank[sa[i - 1]];
58             }
59         }
60     }
61
62     height.resize(n);
63     for (int i = 0, z = 0; i < n; ++i) {
64         if (rank[i] == 0) {
65             height[0] = z = 0;
66         } else {
67             int x = i, y = sa[rank[i] - 1];
68             z = max(0, z - 1);
69             while (x + z < n && y + z < n && a[x + z] == a[y + z]) {
70                 ++z;
71             }
72             height[rank[i]] = z;
73         }
74     }
75 }

```

```

74     }
75   }
76 };

```

6.12 LU 分解

Listing 101: **lu.cpp**

```

1  const int MAXN = 128;
2  const double EPS = 1e-10;
3
4  void LU(int n, double a[MAXN][MAXN], int r[MAXN], int c[MAXN]) {
5      for (int i = 0; i < n; ++i) {
6          r[i] = c[i] = i;
7      }
8      for (int k = 0; k < n; ++k) {
9          int ii = k, jj = k;
10         for (int i = k; i < n; ++i) {
11             for (int j = k; j < n; ++j) {
12                 if (fabs(a[i][j]) > fabs(a[ii][jj])) {
13                     ii = i;
14                     jj = j;
15                 }
16             }
17         }
18         swap(r[k], r[ii]);
19         swap(c[k], c[jj]);
20         for (int i = 0; i < n; ++i) {
21             swap(a[i][k], a[i][jj]);
22         }
23         for (int j = 0; j < n; ++j) {
24             swap(a[k][j], a[ii][j]);
25         }
26         if (fabs(a[k][k]) < EPS) {
27             continue;
28         }
29         for (int i = k + 1; i < n; ++i) {
30             a[i][k] = a[i][k] / a[k][k];
31             for (int j = k + 1; j < n; ++j) {
32                 a[i][j] -= a[i][k] * a[k][j];
33             }
34         }
35     }
36 }
37
38 void solve(int n, double a[MAXN][MAXN], int r[MAXN], int c[MAXN], double b[MAXN]) {
39     static double x[MAXN];
40     for (int i = 0; i < n; ++i) {
41         x[i] = b[r[i]];
42     }
43     for (int i = 0; i < n; ++i) {
44         for (int j = 0; j < i; ++j) {
45             x[i] -= a[i][j] * x[j];
46         }
47     }
48     for (int i = n - 1; i >= 0; --i) {
49         for (int j = n - 1; j > i; --j) {
50             x[i] -= a[i][j] * x[j];
51         }
52         if (fabs(a[i][i]) >= EPS) {
53             x[i] /= a[i][i];
54         } // else assert(fabs(x[i]) < EPS);
55     }

```



```
56     for (int i = 0; i < n; ++i) {  
57         b[c[i]] = x[i];  
58     }  
59 }  
60  
61 // LU(n - 1, a, r, c);  
62 // solve(n - 1, a, r, c, b);
```

7 对一类问题的处理方法