

Contents

1	src/geom/basic.hpp	2
2	src/numtheory/diophantine.hpp	3
3	src/numtheory/basic.hpp	5
4	src/graph/spanningtree.hpp	6
5	src/graph/maxflow.hpp	7
6	src/string/suffixarray.hpp	9
7	src/string/z.hpp	12
8	src/boilerplate.hpp	13
9	src/game/nim.hpp	14
10	src/datastruct/querysegtree.hpp	15
11	src/datastruct/bindtree.hpp	17
12	src/datastruct/unionfind.hpp	18

1 src/geom/basic.hpp

```
#pragma once
#include "boilerplate.hpp"

// WARNING: be careful with overflows and accuracy. Check what the code does.

/// Return true iff points a, b, c are CCW oriented.
bool ccw(V a, V b, V c) {
    return ((c - a) * conj(b - a)).imag() > 0;
}

/// Return true iff points a, b, c are collinear.
/// NOTE: doesn't make much sense with non-integer COORD_TYPE.
bool collinear(V a, V b, V c) {
    return ((c - a) * conj(b - a)).imag() == 0;
}

/// Check whether segments [a, b] and [c, d] intersect.
/// The segments must not be collinear. Doesn't handle edge cases (endpoint of
/// a segment on the other segment) consistently.
bool intersects(V a, V b, V c, V d) {
    return ccw(a, d, b) != ccw(a, c, b) && ccw(c, a, d) != ccw(c, b, d);
}

/// Interpolate between points a and b with parameter t.
V interpolate(VC t, V a, V b) {
    return a + t * (b - a);
}

/// Return interpolation parameter between a and b of projection of v to the
/// line defined by a and b.
/// NOTE: no rounding behavior specified for integers.
VC projectionParam(V v, V a, V b) {
    return ((v - a) / (b - a)).real();
}
```

2 src/numtheory/diophantine.hpp

```
#pragma once
#include "boilerplate.hpp"

struct DiophantineSolution {
    Z x;
    Z y;
    Z dx;
    Z dy;
};

void assign(Z& a, Z& b, Z aval, Z bval) {
    a = aval;
    b = bval;
}

/// Solve linear diophantine equation  $ax + by = c$ . If there is no solution
/// (iff  $\gcd(a, b)$  does not divide  $c$ ), fails. Returns structure containing
/// a solution  $(x, y)$ , all solutions are  $(x + t * dx, y + t * dy)$ , for all
/// integers  $t$ .  $a$  and  $b$  must be nonzero.
DiophantineSolution solveLinearDiophantine(Z a, Z b, Z c) {
    if(a == 0 || b == 0) fail();

    Z A = a;
    Z B = b;

    // NOTE: the following chunk only if you need negative a,b,c.
    Z as = 1;
    Z bs = 1;
    if(a < 0) {
        a = -a;
        as = -as;
    }
    if(b < 0) {
        b = -b;
        bs = -bs;
    }
    if(c < 0) {
        c = -c;
        as = -as;
        bs = -bs;
    }

    Z x = 0, y = 1, lx = 1, ly = 0;
    while(b != 0) {
        Z q = a / b;
        assign(a, b, b, a % b);
        assign(x, lx, lx - q * x, x);
        assign(y, ly, ly - q * y, y);
    }
}
```

```
if(c % a != 0) fail();
Z coef = c / a;

DiophantineSolution ret = {as * coef * lx, bs * coef * ly, B / a, -A / a};
return ret;
}
```

3 src/numtheory/basic.hpp

```
#pragma once
#include "boilerplate.hpp"

Z gcd_(Z a, Z b) {
    if(a == 0) return b;
    return gcd_(b % a, a);
}

/// Return the greatest common divisor of two integers. Returns 0 if a and b
/// are zero, otherwise result is always positive.
Z gcd(Z a, Z b) {
    return gcd_(abs(a), abs(b));
}

/// Return lookup table of primes in [0, n[. (1 for prime, 0 for non-prime).
vector<char> genPrimeTable(int n) {
    vector<char> ret(n, 1);
    if(n > 0) ret[0] = 0;
    if(n > 1) ret[1] = 0;
    for(int i = 2; i * i <= n; ++i) {
        int x = i * i;
        while(x < n) {
            ret[x] = 0;
            x += i;
        }
    }
    return ret;
}
```

4 src/graph/spanningtree.hpp

```
#pragma once
#include "boilerplate.hpp"

#include "datastruct/unionfind.hpp"

/// Find the minimum spanning tree of a graph with vertices 0,...,n-1 and
/// edges given by (weight, (vertex1, vertex2)) using Kruskal algorithm.
/// If the input graph is not connected, the result consists of spanning trees
/// for each component. The return value is a pair of the resulting forest and
/// its total weight.
/// Weight type may be replaced with any number type.
pair<vector<vector<int> >, double> kruskal(
    int n,
    vector<pair<double, pair<int, int> > > edges
) {
    sort(edges.begin(), edges.end());

    vector<vector<int> > span(n);
    double weight = 0.0;
    UnionFind c(n);
    for(int i = 0; i < edges.size(); ++i) {
        int v1 = edges[i].second.first;
        int v2 = edges[i].second.second;
        if(c.find(v1) != c.find(v2)) {
            c.merge(v1, v2);
            span[v1].push_back(v2);
            span[v2].push_back(v1);
            weight += edges[i].first;
        }
    }

    return pair<vector<vector<int> >, double>(span, weight);
}
```

5 src/graph/maxflow.hpp

```
#pragma once
#include "boilerplate.hpp"

/// Edmonds-Karp algorithm for computing max flow in a graph. Edges are given
/// with addEdge(source, destination, capacity), and maxFlow computes the
/// maximum flow, populating the flow fields of the edges.
struct EdmondsKarp {
    struct Edge {
        int dest;
        Z cap; // Remaining capacity in the edge.
        Z flow; // Flow through the edge. >= 0 in normal edges, <= 0 in
                // backwards edges.
        int back; // Corresponding backwards edge.
    };

    EdmondsKarp(int n) : G(n) { }

    void addEdge(int src, int dest, Z cap) {
        if(src == dest) return;
        Edge e1 = {dest, cap, 0, (int)G[dest].size()};
        Edge e2 = {src, 0, 0, (int)G[src].size()};
        G[src].push_back(e1);
        G[dest].push_back(e2);
    }

    Z maxFlow(int s, int t) {
        if(s == t) fail();

        Z ret = 0;

        typedef pair<int, int> P;
        vector<P> parent;
        while(true) {
            parent.clear();
            parent.resize(G.size(), P(-1, -1));

            queue<int> Q;
            Q.push(s);
            parent[s] = P(s, -1);

            while(!Q.empty()) {
                int v = Q.front();
                Q.pop();

                if(v == t) break;

                for(int i = 0; i < G[v].size(); ++i) {
                    if(G[v][i].flow == G[v][i].cap) continue;
                    int x = G[v][i].dest;
                    if(parent[x].first != -1) continue;
```

```

        parent[x] = P(v, i);
        Q.push(x);
    }
}

if(parent[t].first == -1) break;

Z a = -1;
int v = t;
while(v != s) {
    P p = parent[v];
    Z rem = G[p.first][p.second].cap - G[p.first][p.second].flow;
    if(a < 0 || rem < a) a = rem;
    v = p.first;
}
ret += a;
v = t;
while(v != s) {
    P p = parent[v];
    G[p.first][p.second].flow += a;
    G[v][G[p.first][p.second].back].flow -= a;
    v = p.first;
}

return ret;
}

vector<vector<Edge> > G;
};

```


6 src/string/suffixarray.hpp

```
#pragma once
#include "boilerplate.hpp"

struct Elem {
    int ind;
    int parts[2];
};

/// Construct suffix array of string S: starting indices of suffices of S
/// appended with value that compares less to all other values.
vector<int> constructSuffixArray(const vector<Z>& S) {
    int n = S.size();

    vector<pair<Z, int> > by_char;
    for(int i = 0; i < n; ++i) {
        by_char.push_back(pair<Z, int>(S[i], i));
    }
    sort(by_char.begin(), by_char.end());

    vector<Elem> T(n + 1);
    vector<Elem> T2(n + 1);
    vector<int> tmp(n + 2);
    T[0].ind = n;
    for(int i = 0; i < n; ++i) {
        T[i + 1].ind = by_char[i].second;
    }

    int t = 1;
    while(true) {
        cout << "t = " << t << "\n";
        for(int i = 0; i <= n; ++i) {
            cout << " ";
            for(int j = T[i].ind; j < T[i].ind + t; ++j) {
                if(j < S.size()) {
                    cout << (char)S[j];
                } else {
                    cout << "$";
                }
            }
            cout << "\n";
        }

        for(int i = 0; i <= n; ++i) {
            tmp[T[i].ind] = i;
        }
        if(t == 1) {
            for(int i = 1; i <= n; ++i) {
                if(
                    S[tmp[i]] == S[tmp[i - 1]]
                ) {

```

```

        tmp[i] = tmp[i - 1];
    }
} else {
    for(int i = 1; i <= n; ++i) {
        if(
            T[tmp[i]].parts[0] == T[tmp[i - 1]].parts[0] &&
            T[tmp[i]].parts[1] == T[tmp[i - 1]].parts[1]
        ) {
            tmp[i] = tmp[i - 1];
        }
    }
}

if(t > n) {
    tmp.resize(n + 1);
    return tmp;
}

for(int i = 0; i <= n; ++i) {
    T[i].ind = i;
    T[i].parts[0] = (i + t > n) ? 0 : tmp[i + t];
    T[i].parts[1] = tmp[i];
}

for(int s = 0; s < 2; ++s) {
    fill(tmp.begin(), tmp.end(), 0);
    for(int i = 0; i <= n; ++i) {
        ++tmp[T[i].parts[s] + 1];
    }
    for(int i = 1; i < n + 2; ++i) {
        tmp[i] += tmp[i - 1];
    }

    for(int i = 0; i <= n; ++i) {
        T2[tmp[T[i].parts[s]]++] = T[i];
    }

    swap(T, T2);
    cout << "X t = " << 2 * t << "\n";
    for(int i = 0; i <= n; ++i) {
        cout << " ";
        for(int j = T[i].ind; j < T[i].ind + 2 * t; ++j) {
            if(j < S.size()) {
                cout << (char)S[j];
            } else {
                cout << "$";
            }
        }
        cout << "\n";
    }
}
}

```

```
    }  
    t *= 2;  
}
```

7 src/string/z.hpp

```
#pragma once
#include "boilerplate.hpp"

/// Return vector containing for each position i the length of the longest
/// substring that is also a prefix of the string.
vector<int> zAlgorithm(const vector<int>& S) {
    int n = S.size();
    vector<int> ret(n, 0);

    int L = 0;
    int R = 0;
    for(int i = 1; i < n; ++i) {
        if(i > R) {
            L = i;
            R = i;
            while(R < n && S[R - L] == S[R]) ++R;
            ret[i] = R - L;
            --R;
        } else if(ret[i - L] < R - i + 1) {
            ret[i] = ret[i - L];
        } else {
            L = i;
            while(R < n && S[R - L] == S[R]) ++R;
            ret[i] = R - L;
            --R;
        }
    }

    return ret;
}
```

8 src/boilerplate.hpp

```
#pragma once

// Boilerplate required by other modules.

using namespace std;

#include <algorithm> // abs, binary_search, copy, equal_range, lower_bound, max,
                  // merge, min, upper_bound, sort, swap, ...
#include <bitset>    // bitset
#include <complex>   // complex
#include <climits>   // INT_MAX, INT_MIN, ...
#include <cstdlib>   // exit
#include <deque>     // deque
#include <iostream>  // cin, cout, cerr
#include <list>      // list
#include <map>       // map
#include <queue>     // queue, priority_queue
#include <set>       // set
#include <stack>     // stack
#include <string>    // string
#include <sstream>   // stringstream
#include <vector>    // vector

// Complex number/vector type for geometry.
#ifdef COORD_TYPE
    typedef COORD_TYPE VC;
#else
    typedef double VC;
#endif
typedef complex<VC> V;

// Integer type used for integers apart from indices.
#ifdef INT_TYPE
    typedef INT_TYPE Z;
#else
    typedef int Z;
#endif

const double PI = 4 * atan(1);

void fail(string msg) {
    cerr << "FAIL: " << msg << "\n";
    abort();
}

void fail() {
    cerr << "FAIL\n";
    abort();
}
```

9 src/game/nim.hpp

```
#pragma once
#include "boilerplate.hpp"

/// In the Nim game, there are heaps of coins with  $h[i]$  coins in  $i$ :th heap.
/// The players remove any positive number of coins from one heap in turns.
/// The player who removes the last coin wins. The function returns a pair
/// consisting of the index of the heap and the number of coins to remove
/// to win, or pair (-1, -1) if there is no winning strategy.
pair<int, Z> solveNim(const vector<Z>& h) {
    Z nim = 0;
    for(int i = 0; i < h.size(); ++i) {
        nim ^= h[i];
    }

    if(nim == 0) return pair<int, Z>(-1, -1);

    for(int i = 0; i < h.size(); ++i) {
        if((nim ^ h[i]) < h[i]) return pair<int, Z>(i, h[i] - (nim ^ h[i]));
    }

    fail();
    return pair<int, Z>(-2, -2);
}
```

10 src/datastruct/querysegtree.hpp

```
#pragma once
#include "boilerplate.hpp"

/// Array [0, n[ -> Z with fast queries of A[i] (x) A[i + 1] (x) ... (x) A[j - 1]
/// for given i, j where (x) is the associative operator 'oper' (implement).
struct QuerySegmentTree {
    /// The associative operator to use. To be implemented by the user.
    static Z oper(Z a, Z b); // { return <result>; }

    QuerySegmentTree(vector<int> src) {
        N = 1;
        while(N < src.size()) N *= 2;
        tree.resize(2 * N);
        copy(src.begin(), src.end(), tree.begin() + N);
        for(int x = N - 1; x != 0; --x) {
            tree[x] = oper(tree[2 * x], tree[2 * x + 1]);
        }
    }

    /// Query A[x] (x) A[x + 1] (x) ... (x) A[y - 1].
    Z query(int x, int y) {
        x += N;
        y += N;

        if(x == y) fail();
        if(x + 1 == y) return tree[x];

        Z a = tree[x];
        Z b = tree[--y];
        while(x / 2 != y / 2) {
            if(x % 2 == 0) a = oper(a, tree[x + 1]);
            if(y % 2 == 1) b = oper(tree[y - 1], b);

            x /= 2;
            y /= 2;
        }
        return oper(a, b);
    }

    /// Set A[x] to val.
    void set(int x, Z val) {
        x += N;
        tree[x] = val;
        x /= 2;
        while(x != 0) {
            tree[x] = oper(tree[2 * x], tree[2 * x + 1]);
            x /= 2;
        }
    }
}
```

```
int N;  
vector<Z> tree;  
};
```


11 src/datastruct/bindtree.hpp

```
#pragma once
#include "boilerplate.hpp"

/// Array [0, n[ -> Z with fast query of sums [0, x[.
/// Initially set to zero.
struct BinIndexedTree {
    BinIndexedTree(int n) : n(n), tree(n + 1, 0) { }

    /// Add x to i:th value, 0 <= i < n.
    void change(int i, Z x) {
        ++i;
        while(i <= n) {
            tree[i] += x;
            i += (i & -i);
        }
    }

    /// Get sum of elements [0, i[, 0 <= i <= n.
    Z sum(int i) {
        Z ret = 0;
        while(i != 0) {
            ret += tree[i];
            i -= (i & -i);
        }
        return ret;
    }

    int n;
    vector<Z> tree;
};
```

12 src/datastruct/unionfind.hpp

```
#pragma once
#include "boilerplate.hpp"

/// Data structure containing a subdivision of set  $0, \dots, n-1$ . Each set has a
/// representative element of the set, and two sets can be merged fast.
/// Initially each element is in its own set.
struct UnionFind {
    UnionFind(int n) : parent(n) {
        for(int i = 0; i < n; ++i) {
            parent[i] = i;
        }
    }

    /// Find the representative element for set containing x.
    int find(int x) {
        if(parent[x] != x) {
            parent[x] = find(parent[x]);
        }
        return parent[x];
    }

    /// Merge sets containing x and y.
    void merge(int x, int y) {
        x = find(x);
        y = find(y);
        parent[x] = y;
    }

    vector<int> parent;
};
```