**Stanford University ACM Team Notebook (2011-12)**

**Table of Contents**

**Combinatorial optimization**

1. [Sparse max-flow (C++)](http://stanford.edu/~liszt90/acm/notebook.html" \l "file1)
2. [Min-cost max-flow (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file2)
3. [Push-relabel max-flow (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file3)
4. [Min-cost matching (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file4)
5. [Max bipartite matching (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file5)
6. [Global min cut (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file6)

**Geometry**

1. [Convex hull (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file7)
2. [Miscellaneous geometry (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file8)
3. [Java geometry (Java)](http://stanford.edu/~liszt90/acm/notebook.html#file9)
4. [3D geometry (Java)](http://stanford.edu/~liszt90/acm/notebook.html#file10)
5. [Slow Delaunay triangulation (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file11)

**Numerical algorithms**

1. [Number theoretic algorithms (modular, Chinese remainder, linear Diophantine) (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file12)
2. [Systems of linear equations, matrix inverse, determinant (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file13)
3. [Reduced row echelon form, matrix rank (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file14)
4. [Fast Fourier transform (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file15)
5. [Simplex algorithm (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file16)

**Graph algorithms**

1. [Fast Dijkstra's algorithm (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file17)
2. [Strongly connected components (C)](http://stanford.edu/~liszt90/acm/notebook.html#file18)

**Data structures**

1. [Suffix arrays (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file19)
2. [Binary Indexed Tree](http://stanford.edu/~liszt90/acm/notebook.html#file20)
3. [Union-Find Set (C/C++)](http://stanford.edu/~liszt90/acm/notebook.html#file21)
4. [KD-tree (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file22)

**Miscellaneous**

1. [Longest increasing subsequence (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file23)
2. [Dates (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file24)
3. [Regular expressions (Java)](http://stanford.edu/~liszt90/acm/notebook.html#file25)
4. [Prime numbers (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file26)
5. [Knuth-Morris-Pratt (C++)](http://stanford.edu/~liszt90/acm/notebook.html#file27)

**Dinic.cc 1/27**

*// Adjacency list implementation of Dinic's blocking flow algorithm.*

*// This is very fast in practice, and only loses to push-relabel flow.*

*//*

*// Running time:*

*// O(|V|^2 |E|)*

*//*

*// INPUT:*

*// - graph, constructed using AddEdge()*

*// - source*

*// - sink*

*//*

*// OUTPUT:*

*// - maximum flow value*

*// - To obtain the actual flow values, look at all edges with*

*// capacity > 0 (zero capacity edges are residual edges).*

#**include** **<cmath>**

#**include** **<vector>**

#**include** **<iostream>**

#**include** **<queue>**

using namespace std;

**const** **int** INF = 2000000000;

**struct** Edge {

**int** from, to, cap, flow, index;

Edge(**int** from, **int** to, **int** cap, **int** flow, **int** index) :

from(from), to(to), cap(cap), flow(flow), index(index) {}

};

**struct** Dinic {

**int** N;

vector<vector<Edge> > G;

vector<Edge \*> dad;

vector<**int**> Q;

Dinic(**int** N) : N(N), G(N), dad(N), Q(N) {}

**void** AddEdge(**int** from, **int** to, **int** cap) {

G[from].push\_back(Edge(from, to, cap, 0, G[to].size()));

**if** (from == to) G[from].back().index++;

G[to].push\_back(Edge(to, from, 0, 0, G[from].size() - 1));

}

**long** **long** BlockingFlow(**int** s, **int** t) {

fill(dad.begin(), dad.end(), (Edge \*) NULL);

dad[s] = &G[0][0] - 1;

**int** head = 0, tail = 0;

Q[tail++] = s;

**while** (head < tail) {

**int** x = Q[head++];

**for** (**int** i = 0; i < G[x].size(); i++) {

Edge &e = G[x][i];

**if** (!dad[e.to] && e.cap - e.flow > 0) {

dad[e.to] = &G[x][i];

Q[tail++] = e.to;

}

}

}

**if** (!dad[t]) **return** 0;

**long** **long** totflow = 0;

**for** (**int** i = 0; i < G[t].size(); i++) {

Edge \*start = &G[G[t][i].to][G[t][i].index];

**int** amt = INF;

**for** (Edge \*e = start; amt && e != dad[s]; e = dad[e->from]) {

**if** (!e) { amt = 0; **break**; }

amt = min(amt, e->cap - e->flow);

}

**if** (amt == 0) **continue**;

**for** (Edge \*e = start; amt && e != dad[s]; e = dad[e->from]) {

e->flow += amt;

G[e->to][e->index].flow -= amt;

}

totflow += amt;

}

**return** totflow;

}

**long** **long** GetMaxFlow(**int** s, **int** t) {

**long** **long** totflow = 0;

**while** (**long** **long** flow = BlockingFlow(s, t))

totflow += flow;

**return** totflow;

}

};

**MinCostMaxFlow.cc 2/27**

*// Implementation of min cost max flow algorithm using adjacency*

*// matrix (Edmonds and Karp 1972). This implementation keeps track of*

*// forward and reverse edges separately (so you can set cap[i][j] !=*

*// cap[j][i]). For a regular max flow, set all edge costs to 0.*

*//*

*// Running time, O(|V|^2) cost per augmentation*

*// max flow: O(|V|^3) augmentations*

*// min cost max flow: O(|V|^4 \* MAX\_EDGE\_COST) augmentations*

*//*

*// INPUT:*

*// - graph, constructed using AddEdge()*

*// - source*

*// - sink*

*//*

*// OUTPUT:*

*// - (maximum flow value, minimum cost value)*

*// - To obtain the actual flow, look at positive values only.*

#**include** **<cmath>**

#**include** **<vector>**

#**include** **<iostream>**

using namespace std;

**typedef** vector<**int**> VI;

**typedef** vector<VI> VVI;

**typedef** **long** **long** L;

**typedef** vector<L> VL;

**typedef** vector<VL> VVL;

**typedef** pair<**int**, **int**> PII;

**typedef** vector<PII> VPII;

**const** L INF = numeric\_limits<L>::max() / 4;

**struct** MinCostMaxFlow {

**int** N;

VVL cap, flow, cost;

VI found;

VL dist, pi, width;

VPII dad;

MinCostMaxFlow(**int** N) :

N(N), cap(N, VL(N)), flow(N, VL(N)), cost(N, VL(N)),

found(N), dist(N), pi(N), width(N), dad(N) {}

**void** AddEdge(**int** from, **int** to, L cap, L cost) {

**this**->cap[from][to] = cap;

**this**->cost[from][to] = cost;

}

**void** Relax(**int** s, **int** k, L cap, L cost, **int** dir) {

L val = dist[s] + pi[s] - pi[k] + cost;

**if** (cap && val < dist[k]) {

dist[k] = val;

dad[k] = make\_pair(s, dir);

width[k] = min(cap, width[s]);

}

}

L Dijkstra(**int** s, **int** t) {

fill(found.begin(), found.end(), false);

fill(dist.begin(), dist.end(), INF);

fill(width.begin(), width.end(), 0);

dist[s] = 0;

width[s] = INF;

**while** (s != -1) {

**int** best = -1;

found[s] = true;

**for** (**int** k = 0; k < N; k++) {

**if** (found[k]) **continue**;

Relax(s, k, cap[s][k] - flow[s][k], cost[s][k], 1);

Relax(s, k, flow[k][s], -cost[k][s], -1);

**if** (best == -1 || dist[k] < dist[best]) best = k;

}

s = best;

}

**for** (**int** k = 0; k < N; k++)

pi[k] = min(pi[k] + dist[k], INF);

**return** width[t];

}

pair<L, L> GetMaxFlow(**int** s, **int** t) {

L totflow = 0, totcost = 0;

**while** (L amt = Dijkstra(s, t)) {

totflow += amt;

**for** (**int** x = t; x != s; x = dad[x].first) {

**if** (dad[x].second == 1) {

flow[dad[x].first][x] += amt;

totcost += amt \* cost[dad[x].first][x];

} **else** {

flow[x][dad[x].first] -= amt;

totcost -= amt \* cost[x][dad[x].first];

}

}

}

**return** make\_pair(totflow, totcost);

}

};

**PushRelabel.cc 3/27**

*// Adjacency list implementation of FIFO push relabel maximum flow*

*// with the gap relabeling heuristic. This implementation is*

*// significantly faster than straight Ford-Fulkerson. It solves*

*// random problems with 10000 vertices and 1000000 edges in a few*

*// seconds, though it is possible to construct test cases that*

*// achieve the worst-case.*

*//*

*// Running time:*

*// O(|V|^3)*

*//*

*// INPUT:*

*// - graph, constructed using AddEdge()*

*// - source*

*// - sink*

*//*

*// OUTPUT:*

*// - maximum flow value*

*// - To obtain the actual flow values, look at all edges with*

*// capacity > 0 (zero capacity edges are residual edges).*

#**include** **<cmath>**

#**include** **<vector>**

#**include** **<iostream>**

#**include** **<queue>**

using namespace std;

**typedef** **long** **long** LL;

**struct** Edge {

**int** from, to, cap, flow, index;

Edge(**int** from, **int** to, **int** cap, **int** flow, **int** index) :

from(from), to(to), cap(cap), flow(flow), index(index) {}

};

**struct** PushRelabel {

**int** N;

vector<vector<Edge> > G;

vector<LL> excess;

vector<**int**> dist, active, count;

queue<**int**> Q;

PushRelabel(**int** N) : N(N), G(N), excess(N), dist(N), active(N), count(2\*N) {}

**void** AddEdge(**int** from, **int** to, **int** cap) {

G[from].push\_back(Edge(from, to, cap, 0, G[to].size()));

**if** (from == to) G[from].back().index++;

G[to].push\_back(Edge(to, from, 0, 0, G[from].size() - 1));

}

**void** Enqueue(**int** v) {

**if** (!active[v] && excess[v] > 0) { active[v] = true; Q.push(v); }

}

**void** Push(Edge &e) {

**int** amt = **int**(min(excess[e.from], LL(e.cap - e.flow)));

**if** (dist[e.from] <= dist[e.to] || amt == 0) **return**;

e.flow += amt;

G[e.to][e.index].flow -= amt;

excess[e.to] += amt;

excess[e.from] -= amt;

Enqueue(e.to);

}

**void** Gap(**int** k) {

**for** (**int** v = 0; v < N; v++) {

**if** (dist[v] < k) **continue**;

count[dist[v]]--;

dist[v] = max(dist[v], N+1);

count[dist[v]]++;

Enqueue(v);

}

}

**void** Relabel(**int** v) {

count[dist[v]]--;

dist[v] = 2\*N;

**for** (**int** i = 0; i < G[v].size(); i++)

**if** (G[v][i].cap - G[v][i].flow > 0)

dist[v] = min(dist[v], dist[G[v][i].to] + 1);

count[dist[v]]++;

Enqueue(v);

}

**void** Discharge(**int** v) {

**for** (**int** i = 0; excess[v] > 0 && i < G[v].size(); i++) Push(G[v][i]);

**if** (excess[v] > 0) {

**if** (count[dist[v]] == 1)

Gap(dist[v]);

**else**

Relabel(v);

}

}

LL GetMaxFlow(**int** s, **int** t) {

count[0] = N-1;

count[N] = 1;

dist[s] = N;

active[s] = active[t] = true;

**for** (**int** i = 0; i < G[s].size(); i++) {

excess[s] += G[s][i].cap;

Push(G[s][i]);

}

**while** (!Q.empty()) {

**int** v = Q.front();

Q.pop();

active[v] = false;

Discharge(v);

}

LL totflow = 0;

**for** (**int** i = 0; i < G[s].size(); i++) totflow += G[s][i].flow;

**return** totflow;

}

};

**MinCostMatching.cc 4/27**

*///////////////////////////////////////////////////////////////////////////*

*// Min cost bipartite matching via shortest augmenting paths*

*//*

*// This is an O(n^3) implementation of a shortest augmenting path*

*// algorithm for finding min cost perfect matchings in dense*

*// graphs. In practice, it solves 1000x1000 problems in around 1*

*// second.*

*//*

*// cost[i][j] = cost for pairing left node i with right node j*

*// Lmate[i] = index of right node that left node i pairs with*

*// Rmate[j] = index of left node that right node j pairs with*

*//*

*// The values in cost[i][j] may be positive or negative. To perform*

*// maximization, simply negate the cost[][] matrix.*

*///////////////////////////////////////////////////////////////////////////*

#**include** **<algorithm>**

#**include** **<cstdio>**

#**include** **<cmath>**

#**include** **<vector>**

using namespace std;

**typedef** vector<**double**> VD;

**typedef** vector<VD> VVD;

**typedef** vector<**int**> VI;

**double** **MinCostMatching**(**const** VVD &cost, VI &Lmate, VI &Rmate) {

**int** n = **int**(cost.size());

*// construct dual feasible solution*

VD u(n);

VD v(n);

**for** (**int** i = 0; i < n; i++) {

u[i] = cost[i][0];

**for** (**int** j = 1; j < n; j++) u[i] = min(u[i], cost[i][j]);

}

**for** (**int** j = 0; j < n; j++) {

v[j] = cost[0][j] - u[0];

**for** (**int** i = 1; i < n; i++) v[j] = min(v[j], cost[i][j] - u[i]);

}

*// construct primal solution satisfying complementary slackness*

Lmate = VI(n, -1);

Rmate = VI(n, -1);

**int** mated = 0;

**for** (**int** i = 0; i < n; i++) {

**for** (**int** j = 0; j < n; j++) {

**if** (Rmate[j] != -1) **continue**;

**if** (fabs(cost[i][j] - u[i] - v[j]) < 1e-10) {

Lmate[i] = j;

Rmate[j] = i;

mated++;

**break**;

}

}

}

VD dist(n);

VI dad(n);

VI seen(n);

*// repeat until primal solution is feasible*

**while** (mated < n) {

*// find an unmatched left node*

**int** s = 0;

**while** (Lmate[s] != -1) s++;

*// initialize Dijkstra*

fill(dad.begin(), dad.end(), -1);

fill(seen.begin(), seen.end(), 0);

**for** (**int** k = 0; k < n; k++)

dist[k] = cost[s][k] - u[s] - v[k];

**int** j = 0;

**while** (true) {

*// find closest*

j = -1;

**for** (**int** k = 0; k < n; k++) {

**if** (seen[k]) **continue**;

**if** (j == -1 || dist[k] < dist[j]) j = k;

}

seen[j] = 1;

*// termination condition*

**if** (Rmate[j] == -1) **break**;

*// relax neighbors*

**const** **int** i = Rmate[j];

**for** (**int** k = 0; k < n; k++) {

**if** (seen[k]) **continue**;

**const** **double** new\_dist = dist[j] + cost[i][k] - u[i] - v[k];

**if** (dist[k] > new\_dist) {

dist[k] = new\_dist;

dad[k] = j;

}

}

}

*// update dual variables*

**for** (**int** k = 0; k < n; k++) {

**if** (k == j || !seen[k]) **continue**;

**const** **int** i = Rmate[k];

v[k] += dist[k] - dist[j];

u[i] -= dist[k] - dist[j];

}

u[s] += dist[j];

*// augment along path*

**while** (dad[j] >= 0) {

**const** **int** d = dad[j];

Rmate[j] = Rmate[d];

Lmate[Rmate[j]] = j;

j = d;

}

Rmate[j] = s;

Lmate[s] = j;

mated++;

}

**double** value = 0;

**for** (**int** i = 0; i < n; i++)

value += cost[i][Lmate[i]];

**return** value;

}

**MaxBipartiteMatching.cc 5/27**

*// This code performs maximum bipartite matching.*

*//*

*// Running time: O(|E| |V|) -- often much faster in practice*

*//*

*// INPUT: w[i][j] = edge between row node i and column node j*

*// OUTPUT: mr[i] = assignment for row node i, -1 if unassigned*

*// mc[j] = assignment for column node j, -1 if unassigned*

*// function returns number of matches made*

#**include** **<vector>**

using namespace std;

**typedef** vector<**int**> VI;

**typedef** vector<VI> VVI;

**bool** **FindMatch**(**int** i, **const** VVI &w, VI &mr, VI &mc, VI &seen) {

**for** (**int** j = 0; j < w[i].size(); j++) {

**if** (w[i][j] && !seen[j]) {

seen[j] = true;

**if** (mc[j] < 0 || FindMatch(mc[j], w, mr, mc, seen)) {

mr[i] = j;

mc[j] = i;

**return** true;

}

}

}

**return** false;

}

**int** **BipartiteMatching**(**const** VVI &w, VI &mr, VI &mc) {

mr = VI(w.size(), -1);

mc = VI(w[0].size(), -1);

**int** ct = 0;

**for** (**int** i = 0; i < w.size(); i++) {

VI seen(w[0].size());

**if** (FindMatch(i, w, mr, mc, seen)) ct++;

}

**return** ct;

}

**MinCut.cc 6/27**

*// Adjacency matrix implementation of Stoer-Wagner min cut algorithm.*

*//*

*// Running time:*

*// O(|V|^3)*

*//*

*// INPUT:*

*// - graph, constructed using AddEdge()*

*//*

*// OUTPUT:*

*// - (min cut value, nodes in half of min cut)*

#**include** **<cmath>**

#**include** **<vector>**

#**include** **<iostream>**

using namespace std;

**typedef** vector<**int**> VI;

**typedef** vector<VI> VVI;

**const** **int** INF = 1000000000;

pair<**int**, VI> GetMinCut(VVI &weights) {

**int** N = weights.size();

VI used(N), cut, best\_cut;

**int** best\_weight = -1;

**for** (**int** phase = N-1; phase >= 0; phase--) {

VI w = weights[0];

VI added = used;

**int** prev, last = 0;

**for** (**int** i = 0; i < phase; i++) {

prev = last;

last = -1;

**for** (**int** j = 1; j < N; j++)

**if** (!added[j] && (last == -1 || w[j] > w[last])) last = j;

**if** (i == phase-1) {

**for** (**int** j = 0; j < N; j++) weights[prev][j] += weights[last][j];

**for** (**int** j = 0; j < N; j++) weights[j][prev] = weights[prev][j];

used[last] = true;

cut.push\_back(last);

**if** (best\_weight == -1 || w[last] < best\_weight) {

best\_cut = cut;

best\_weight = w[last];

}

} **else** {

**for** (**int** j = 0; j < N; j++)

w[j] += weights[last][j];

added[last] = true;

}

}

}

**return** make\_pair(best\_weight, best\_cut);

}

**ConvexHull.cc 7/27**

*// Compute the 2D convex hull of a set of points using the monotone chain*

*// algorithm. Eliminate redundant points from the hull if REMOVE\_REDUNDANT is*

*// #defined.*

*//*

*// Running time: O(n log n)*

*//*

*// INPUT: a vector of input points, unordered.*

*// OUTPUT: a vector of points in the convex hull, counterclockwise, starting*

*// with bottommost/leftmost point*

#**include** **<cstdio>**

#**include** **<cassert>**

#**include** **<vector>**

#**include** **<algorithm>**

#**include** **<cmath>**

using namespace std;

#**define** REMOVE\_REDUNDANT

**typedef** **double** T;

**const** T EPS = 1e-7;

**struct** PT {

T x, y;

PT() {}

PT(T x, T y) : x(x), y(y) {}

**bool** **operator**<(**const** PT &rhs) **const** { **return** make\_pair(y,x) < make\_pair(rhs.y,rhs.x); }

**bool** **operator**==(**const** PT &rhs) **const** { **return** make\_pair(y,x) == make\_pair(rhs.y,rhs.x); }

};

T cross(PT p, PT q) { **return** p.x\*q.y-p.y\*q.x; }

T area2(PT a, PT b, PT c) { **return** cross(a,b) + cross(b,c) + cross(c,a); }

#**ifdef** REMOVE\_REDUNDANT

**bool** **between**(**const** PT &a, **const** PT &b, **const** PT &c) {

**return** (fabs(area2(a,b,c)) < EPS && (a.x-b.x)\*(c.x-b.x) <= 0 && (a.y-b.y)\*(c.y-b.y) <= 0);

}

#**endif**

**void** **ConvexHull**(vector<PT> &pts) {

sort(pts.begin(), pts.end());

pts.erase(unique(pts.begin(), pts.end()), pts.end());

vector<PT> up, dn;

**for** (**int** i = 0; i < pts.size(); i++) {

**while** (up.size() > 1 && area2(up[up.size()-2], up.back(), pts[i]) >= 0) up.pop\_back();

**while** (dn.size() > 1 && area2(dn[dn.size()-2], dn.back(), pts[i]) <= 0) dn.pop\_back();

up.push\_back(pts[i]);

dn.push\_back(pts[i]);

}

pts = dn;

**for** (**int** i = (**int**) up.size() - 2; i >= 1; i--) pts.push\_back(up[i]);

#**ifdef** REMOVE\_REDUNDANT

**if** (pts.size() <= 2) **return**;

dn.clear();

dn.push\_back(pts[0]);

dn.push\_back(pts[1]);

**for** (**int** i = 2; i < pts.size(); i++) {

**if** (between(dn[dn.size()-2], dn[dn.size()-1], pts[i])) dn.pop\_back();

dn.push\_back(pts[i]);

}

**if** (dn.size() >= 3 && between(dn.back(), dn[0], dn[1])) {

dn[0] = dn.back();

dn.pop\_back();

}

pts = dn;

#**endif**

}

**Geometry.cc 8/27**

*// C++ routines for computational geometry.*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<cmath>**

#**include** **<cassert>**

using namespace std;

**double** INF = 1e100;

**double** EPS = 1e-12;

**struct** PT {

**double** x, y;

PT() {}

PT(**double** x, **double** y) : x(x), y(y) {}

PT(**const** PT &p) : x(p.x), y(p.y) {}

PT **operator** + (**const** PT &p) **const** { **return** PT(x+p.x, y+p.y); }

PT **operator** - (**const** PT &p) **const** { **return** PT(x-p.x, y-p.y); }

PT **operator** \* (**double** c) **const** { **return** PT(x\*c, y\*c ); }

PT **operator** / (**double** c) **const** { **return** PT(x/c, y/c ); }

};

**double** **dot**(PT p, PT q) { **return** p.x\*q.x+p.y\*q.y; }

**double** **dist2**(PT p, PT q) { **return** dot(p-q,p-q); }

**double** **cross**(PT p, PT q) { **return** p.x\*q.y-p.y\*q.x; }

ostream &**operator**<<(ostream &os, **const** PT &p) {

os << **"("** << p.x << **","** << p.y << **")"**;

}

*// rotate a point CCW or CW around the origin*

PT **RotateCCW90**(PT p) { **return** PT(-p.y,p.x); }

PT **RotateCW90**(PT p) { **return** PT(p.y,-p.x); }

PT **RotateCCW**(PT p, **double** t) {

**return** PT(p.x\*cos(t)-p.y\*sin(t), p.x\*sin(t)+p.y\*cos(t));

}

*// project point c onto line through a and b*

*// assuming a != b*

PT **ProjectPointLine**(PT a, PT b, PT c) {

**return** a + (b-a)\*dot(c-a, b-a)/dot(b-a, b-a);

}

*// project point c onto line segment through a and b*

PT **ProjectPointSegment**(PT a, PT b, PT c) {

**double** r = dot(b-a,b-a);

**if** (fabs(r) < EPS) **return** a;

r = dot(c-a, b-a)/r;

**if** (r < 0) **return** a;

**if** (r > 1) **return** b;

**return** a + (b-a)\*r;

}

*// compute distance from c to segment between a and b*

**double** **DistancePointSegment**(PT a, PT b, PT c) {

**return** sqrt(dist2(c, ProjectPointSegment(a, b, c)));

}

*// compute distance between point (x,y,z) and plane ax+by+cz=d*

**double** **DistancePointPlane**(**double** x, **double** y, **double** z,

**double** a, **double** b, **double** c, **double** d)

{

**return** fabs(a\*x+b\*y+c\*z-d)/sqrt(a\*a+b\*b+c\*c);

}

*// determine if lines from a to b and c to d are parallel or collinear*

**bool** **LinesParallel**(PT a, PT b, PT c, PT d) {

**return** fabs(cross(b-a, c-d)) < EPS;

}

**bool** **LinesCollinear**(PT a, PT b, PT c, PT d) {

**return** LinesParallel(a, b, c, d)

&& fabs(cross(a-b, a-c)) < EPS

&& fabs(cross(c-d, c-a)) < EPS;

}

*// determine if line segment from a to b intersects with*

*// line segment from c to d*

**bool** **SegmentsIntersect**(PT a, PT b, PT c, PT d) {

**if** (LinesCollinear(a, b, c, d)) {

**if** (dist2(a, c) < EPS || dist2(a, d) < EPS ||

dist2(b, c) < EPS || dist2(b, d) < EPS) **return** true;

**if** (dot(c-a, c-b) > 0 && dot(d-a, d-b) > 0 && dot(c-b, d-b) > 0)

**return** false;

**return** true;

}

**if** (cross(d-a, b-a) \* cross(c-a, b-a) > 0) **return** false;

**if** (cross(a-c, d-c) \* cross(b-c, d-c) > 0) **return** false;

**return** true;

}

*// compute intersection of line passing through a and b*

*// with line passing through c and d, assuming that unique*

*// intersection exists; for segment intersection, check if*

*// segments intersect first*

PT **ComputeLineIntersection**(PT a, PT b, PT c, PT d) {

b=b-a; d=c-d; c=c-a;

assert(dot(b, b) > EPS && dot(d, d) > EPS);

**return** a + b\*cross(c, d)/cross(b, d);

}

*// compute center of circle given three points*

PT **ComputeCircleCenter**(PT a, PT b, PT c) {

b=(a+b)/2;

c=(a+c)/2;

**return** ComputeLineIntersection(b, b+RotateCW90(a-b), c, c+RotateCW90(a-c));

}

*// determine if point is in a possibly non-convex polygon (by William*

*// Randolph Franklin); returns 1 for strictly interior points, 0 for*

*// strictly exterior points, and 0 or 1 for the remaining points.*

*// Note that it is possible to convert this into an \*exact\* test using*

*// integer arithmetic by taking care of the division appropriately*

*// (making sure to deal with signs properly) and then by writing exact*

*// tests for checking point on polygon boundary*

**bool** **PointInPolygon**(**const** vector<PT> &p, PT q) {

**bool** c = 0;

**for** (**int** i = 0; i < p.size(); i++){

**int** j = (i+1)%p.size();

**if** ((p[i].y <= q.y && q.y < p[j].y ||

p[j].y <= q.y && q.y < p[i].y) &&

q.x < p[i].x + (p[j].x - p[i].x) \* (q.y - p[i].y) / (p[j].y - p[i].y))

c = !c;

}

**return** c;

}

*// determine if point is on the boundary of a polygon*

**bool** **PointOnPolygon**(**const** vector<PT> &p, PT q) {

**for** (**int** i = 0; i < p.size(); i++)

**if** (dist2(ProjectPointSegment(p[i], p[(i+1)%p.size()], q), q) < EPS)

**return** true;

**return** false;

}

*// compute intersection of line through points a and b with*

*// circle centered at c with radius r > 0*

vector<PT> CircleLineIntersection(PT a, PT b, PT c, **double** r) {

vector<PT> ret;

b = b-a;

a = a-c;

**double** A = dot(b, b);

**double** B = dot(a, b);

**double** C = dot(a, a) - r\*r;

**double** D = B\*B - A\*C;

**if** (D < -EPS) **return** ret;

ret.push\_back(c+a+b\*(-B+sqrt(D+EPS))/A);

**if** (D > EPS)

ret.push\_back(c+a+b\*(-B-sqrt(D))/A);

**return** ret;

}

*// compute intersection of circle centered at a with radius r*

*// with circle centered at b with radius R*

vector<PT> CircleCircleIntersection(PT a, PT b, **double** r, **double** R) {

vector<PT> ret;

**double** d = sqrt(dist2(a, b));

**if** (d > r+R || d+min(r, R) < max(r, R)) **return** ret;

**double** x = (d\*d-R\*R+r\*r)/(2\*d);

**double** y = sqrt(r\*r-x\*x);

PT v = (b-a)/d;

ret.push\_back(a+v\*x + RotateCCW90(v)\*y);

**if** (y > 0)

ret.push\_back(a+v\*x - RotateCCW90(v)\*y);

**return** ret;

}

*// This code computes the area or centroid of a (possibly nonconvex)*

*// polygon, assuming that the coordinates are listed in a clockwise or*

*// counterclockwise fashion. Note that the centroid is often known as*

*// the "center of gravity" or "center of mass".*

**double** **ComputeSignedArea**(**const** vector<PT> &p) {

**double** area = 0;

**for**(**int** i = 0; i < p.size(); i++) {

**int** j = (i+1) % p.size();

area += p[i].x\*p[j].y - p[j].x\*p[i].y;

}

**return** area / 2.0;

}

**double** **ComputeArea**(**const** vector<PT> &p) {

**return** fabs(ComputeSignedArea(p));

}

PT **ComputeCentroid**(**const** vector<PT> &p) {

PT c(0,0);

**double** scale = 6.0 \* ComputeSignedArea(p);

**for** (**int** i = 0; i < p.size(); i++){

**int** j = (i+1) % p.size();

c = c + (p[i]+p[j])\*(p[i].x\*p[j].y - p[j].x\*p[i].y);

}

**return** c / scale;

}

*// tests whether or not a given polygon (in CW or CCW order) is simple*

**bool** **IsSimple**(**const** vector<PT> &p) {

**for** (**int** i = 0; i < p.size(); i++) {

**for** (**int** k = i+1; k < p.size(); k++) {

**int** j = (i+1) % p.size();

**int** l = (k+1) % p.size();

**if** (i == l || j == k) **continue**;

**if** (SegmentsIntersect(p[i], p[j], p[k], p[l]))

**return** false;

}

}

**return** true;

}

**int** **main**() {

*// expected: (-5,2)*

cerr << RotateCCW90(PT(2,5)) << endl;

*// expected: (5,-2)*

cerr << RotateCW90(PT(2,5)) << endl;

*// expected: (-5,2)*

cerr << RotateCCW(PT(2,5),M\_PI/2) << endl;

*// expected: (5,2)*

cerr << ProjectPointLine(PT(-5,-2), PT(10,4), PT(3,7)) << endl;

*// expected: (5,2) (7.5,3) (2.5,1)*

cerr << ProjectPointSegment(PT(-5,-2), PT(10,4), PT(3,7)) << **" "**

<< ProjectPointSegment(PT(7.5,3), PT(10,4), PT(3,7)) << **" "**

<< ProjectPointSegment(PT(-5,-2), PT(2.5,1), PT(3,7)) << endl;

*// expected: 6.78903*

cerr << DistancePointPlane(4,-4,3,2,-2,5,-8) << endl;

*// expected: 1 0 1*

cerr << LinesParallel(PT(1,1), PT(3,5), PT(2,1), PT(4,5)) << **" "**

<< LinesParallel(PT(1,1), PT(3,5), PT(2,0), PT(4,5)) << **" "**

<< LinesParallel(PT(1,1), PT(3,5), PT(5,9), PT(7,13)) << endl;

*// expected: 0 0 1*

cerr << LinesCollinear(PT(1,1), PT(3,5), PT(2,1), PT(4,5)) << **" "**

<< LinesCollinear(PT(1,1), PT(3,5), PT(2,0), PT(4,5)) << **" "**

<< LinesCollinear(PT(1,1), PT(3,5), PT(5,9), PT(7,13)) << endl;

*// expected: 1 1 1 0*

cerr << SegmentsIntersect(PT(0,0), PT(2,4), PT(3,1), PT(-1,3)) << **" "**

<< SegmentsIntersect(PT(0,0), PT(2,4), PT(4,3), PT(0,5)) << **" "**

<< SegmentsIntersect(PT(0,0), PT(2,4), PT(2,-1), PT(-2,1)) << **" "**

<< SegmentsIntersect(PT(0,0), PT(2,4), PT(5,5), PT(1,7)) << endl;

*// expected: (1,2)*

cerr << ComputeLineIntersection(PT(0,0), PT(2,4), PT(3,1), PT(-1,3)) << endl;

*// expected: (1,1)*

cerr << ComputeCircleCenter(PT(-3,4), PT(6,1), PT(4,5)) << endl;

vector<PT> v;

v.push\_back(PT(0,0));

v.push\_back(PT(5,0));

v.push\_back(PT(5,5));

v.push\_back(PT(0,5));

*// expected: 1 1 1 0 0*

cerr << PointInPolygon(v, PT(2,2)) << **" "**

<< PointInPolygon(v, PT(2,0)) << **" "**

<< PointInPolygon(v, PT(0,2)) << **" "**

<< PointInPolygon(v, PT(5,2)) << **" "**

<< PointInPolygon(v, PT(2,5)) << endl;

*// expected: 0 1 1 1 1*

cerr << PointOnPolygon(v, PT(2,2)) << **" "**

<< PointOnPolygon(v, PT(2,0)) << **" "**

<< PointOnPolygon(v, PT(0,2)) << **" "**

<< PointOnPolygon(v, PT(5,2)) << **" "**

<< PointOnPolygon(v, PT(2,5)) << endl;

*// expected: (1,6)*

*// (5,4) (4,5)*

*// blank line*

*// (4,5) (5,4)*

*// blank line*

*// (4,5) (5,4)*

vector<PT> u = CircleLineIntersection(PT(0,6), PT(2,6), PT(1,1), 5);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

u = CircleLineIntersection(PT(0,9), PT(9,0), PT(1,1), 5);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

u = CircleCircleIntersection(PT(1,1), PT(10,10), 5, 5);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

u = CircleCircleIntersection(PT(1,1), PT(8,8), 5, 5);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

u = CircleCircleIntersection(PT(1,1), PT(4.5,4.5), 10, sqrt(2.0)/2.0);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

u = CircleCircleIntersection(PT(1,1), PT(4.5,4.5), 5, sqrt(2.0)/2.0);

**for** (**int** i = 0; i < u.size(); i++) cerr << u[i] << **" "**; cerr << endl;

*// area should be 5.0*

*// centroid should be (1.1666666, 1.166666)*

PT pa[] = { PT(0,0), PT(5,0), PT(1,1), PT(0,5) };

vector<PT> p(pa, pa+4);

PT c = ComputeCentroid(p);

cerr << **"Area: "** << ComputeArea(p) << endl;

cerr << **"Centroid: "** << c << endl;

**return** 0;

}

**JavaGeometry.java 9/27**

*// In this example, we read an input file containing three lines, each*

*// containing an even number of doubles, separated by commas. The first two*

*// lines represent the coordinates of two polygons, given in counterclockwise*

*// (or clockwise) order, which we will call "A" and "B". The last line*

*// contains a list of points, p[1], p[2], ...*

*//*

*// Our goal is to determine:*

*// (1) whether B - A is a single closed shape (as opposed to multiple shapes)*

*// (2) the area of B - A*

*// (3) whether each p[i] is in the interior of B - A*

*//*

*// INPUT:*

*// 0 0 10 0 0 10*

*// 0 0 10 10 10 0*

*// 8 6*

*// 5 1*

*//*

*// OUTPUT:*

*// The area is singular.*

*// The area is 25.0*

*// Point belongs to the area.*

*// Point does not belong to the area.*

**import** java.util.\*;

**import** java.awt.geom.\*;

**import** java.io.\*;

**public** **class** JavaGeometry {

*// make an array of doubles from a string*

**static** **double**[] readPoints(String s) {

String[] arr = s.trim().split(**"\\s++"**);

**double**[] ret = **new** **double**[arr.length];

**for** (**int** i = 0; i < arr.length; i++) ret[i] = Double.parseDouble(arr[i]);

**return** ret;

}

*// make an Area object from the coordinates of a polygon*

**static** Area makeArea(**double**[] pts) {

Path2D.Double p = **new** Path2D.Double();

p.moveTo(pts[0], pts[1]);

**for** (**int** i = 2; i < pts.length; i += 2) p.lineTo(pts[i], pts[i+1]);

p.closePath();

**return** **new** Area(p);

}

*// compute area of polygon*

**static** **double** computePolygonArea(ArrayList<Point2D.Double> points) {

Point2D.Double[] pts = points.toArray(**new** Point2D.Double[points.size()]);

**double** area = 0;

**for** (**int** i = 0; i < pts.length; i++){

**int** j = (i+1) % pts.length;

area += pts[i].x \* pts[j].y - pts[j].x \* pts[i].y;

}

**return** Math.abs(area)/2;

}

*// compute the area of an Area object containing several disjoint polygons*

**static** **double** computeArea(Area area) {

**double** totArea = 0;

PathIterator iter = area.getPathIterator(**null**);

ArrayList<Point2D.Double> points = **new** ArrayList<Point2D.Double>();

**while** (!iter.isDone()) {

**double**[] buffer = **new** **double**[6];

**switch** (iter.currentSegment(buffer)) {

**case** PathIterator.SEG\_MOVETO:

**case** PathIterator.SEG\_LINETO:

points.add(**new** Point2D.Double(buffer[0], buffer[1]));

**break**;

**case** PathIterator.SEG\_CLOSE:

totArea += computePolygonArea(points);

points.clear();

**break**;

}

iter.next();

}

**return** totArea;

}

*// notice that the main() throws an Exception -- necessary to*

*// avoid wrapping the Scanner object for file reading in a*

*// try { ... } catch block.*

**public** **static** **void** main(String args[]) **throws** Exception {

Scanner scanner = **new** Scanner(**new** File(**"input.txt"**));

*// also,*

*// Scanner scanner = new Scanner (System.in);*

**double**[] pointsA = readPoints(scanner.nextLine());

**double**[] pointsB = readPoints(scanner.nextLine());

Area areaA = makeArea(pointsA);

Area areaB = makeArea(pointsB);

areaB.subtract(areaA);

*// also,*

*// areaB.exclusiveOr (areaA);*

*// areaB.add (areaA);*

*// areaB.intersect (areaA);*

*// (1) determine whether B - A is a single closed shape (as*

*// opposed to multiple shapes)*

**boolean** isSingle = areaB.isSingular();

*// also,*

*// areaB.isEmpty();*

**if** (isSingle)

System.out.println(**"The area is singular."**);

**else**

System.out.println(**"The area is not singular."**);

*// (2) compute the area of B - A*

System.out.println(**"The area is "** + computeArea(areaB) + **"."**);

*// (3) determine whether each p[i] is in the interior of B - A*

**while** (scanner.hasNextDouble()) {

**double** x = scanner.nextDouble();

assert(scanner.hasNextDouble());

**double** y = scanner.nextDouble();

**if** (areaB.contains(x,y)) {

System.out.println (**"Point belongs to the area."**);

} **else** {

System.out.println (**"Point does not belong to the area."**);

}

}

*// Finally, some useful things we didn't use in this example:*

*//*

*// Ellipse2D.Double ellipse = new Ellipse2D.Double (double x, double y,*

*// double w, double h);*

*//*

*// creates an ellipse inscribed in box with bottom-left corner (x,y)*

*// and upper-right corner (x+y,w+h)*

*//*

*// Rectangle2D.Double rect = new Rectangle2D.Double (double x, double y,*

*// double w, double h);*

*//*

*// creates a box with bottom-left corner (x,y) and upper-right*

*// corner (x+y,w+h)*

*//*

*// Each of these can be embedded in an Area object (e.g., new Area (rect)).*

}

}

**Geom3D.java 10/27**

**public** **class** Geom3D {

*// distance from point (x, y, z) to plane aX + bY + cZ + d = 0*

**public** **static** **double** ptPlaneDist(**double** x, **double** y, **double** z,

**double** a, **double** b, **double** c, **double** d) {

**return** Math.abs(a\*x + b\*y + c\*z + d) / Math.sqrt(a\*a + b\*b + c\*c);

}

*// distance between parallel planes aX + bY + cZ + d1 = 0 and*

*// aX + bY + cZ + d2 = 0*

**public** **static** **double** planePlaneDist(**double** a, **double** b, **double** c,

**double** d1, **double** d2) {

**return** Math.abs(d1 - d2) / Math.sqrt(a\*a + b\*b + c\*c);

}

*// distance from point (px, py, pz) to line (x1, y1, z1)-(x2, y2, z2)*

*// (or ray, or segment; in the case of the ray, the endpoint is the*

*// first point)*

**public** **static** **final** **int** LINE = 0;

**public** **static** **final** **int** SEGMENT = 1;

**public** **static** **final** **int** RAY = 2;

**public** **static** **double** ptLineDistSq(**double** x1, **double** y1, **double** z1,

**double** x2, **double** y2, **double** z2, **double** px, **double** py, **double** pz,

**int** type) {

**double** pd2 = (x1-x2)\*(x1-x2) + (y1-y2)\*(y1-y2) + (z1-z2)\*(z1-z2);

**double** x, y, z;

**if** (pd2 == 0) {

x = x1;

y = y1;

z = z1;

} **else** {

**double** u = ((px-x1)\*(x2-x1) + (py-y1)\*(y2-y1) + (pz-z1)\*(z2-z1)) / pd2;

x = x1 + u \* (x2 - x1);

y = y1 + u \* (y2 - y1);

z = z1 + u \* (z2 - z1);

**if** (type != LINE && u < 0) {

x = x1;

y = y1;

z = z1;

}

**if** (type == SEGMENT && u > 1.0) {

x = x2;

y = y2;

z = z2;

}

}

**return** (x-px)\*(x-px) + (y-py)\*(y-py) + (z-pz)\*(z-pz);

}

**public** **static** **double** ptLineDist(**double** x1, **double** y1, **double** z1,

**double** x2, **double** y2, **double** z2, **double** px, **double** py, **double** pz,

**int** type) {

**return** Math.sqrt(ptLineDistSq(x1, y1, z1, x2, y2, z2, px, py, pz, type));

}

}

**Delaunay.cc 11/27**

*// Slow but simple Delaunay triangulation. Does not handle*

*// degenerate cases (from O'Rourke, Computational Geometry in C)*

*//*

*// Running time: O(n^4)*

*//*

*// INPUT: x[] = x-coordinates*

*// y[] = y-coordinates*

*//*

*// OUTPUT: triples = a vector containing m triples of indices*

*// corresponding to triangle vertices*

#**include<vector>**

using namespace std;

**typedef** **double** T;

**struct** triple {

**int** i, j, k;

triple() {}

triple(**int** i, **int** j, **int** k) : i(i), j(j), k(k) {}

};

vector<triple> delaunayTriangulation(vector<T>& x, vector<T>& y) {

**int** n = x.size();

vector<T> z(n);

vector<triple> ret;

**for** (**int** i = 0; i < n; i++)

z[i] = x[i] \* x[i] + y[i] \* y[i];

**for** (**int** i = 0; i < n-2; i++) {

**for** (**int** j = i+1; j < n; j++) {

**for** (**int** k = i+1; k < n; k++) {

**if** (j == k) **continue**;

**double** xn = (y[j]-y[i])\*(z[k]-z[i]) - (y[k]-y[i])\*(z[j]-z[i]);

**double** yn = (x[k]-x[i])\*(z[j]-z[i]) - (x[j]-x[i])\*(z[k]-z[i]);

**double** zn = (x[j]-x[i])\*(y[k]-y[i]) - (x[k]-x[i])\*(y[j]-y[i]);

**bool** flag = zn < 0;

**for** (**int** m = 0; flag && m < n; m++)

flag = flag && ((x[m]-x[i])\*xn +

(y[m]-y[i])\*yn +

(z[m]-z[i])\*zn <= 0);

**if** (flag) ret.push\_back(triple(i, j, k));

}

}

}

**return** ret;

}

**int** **main**()

{

T xs[]={0, 0, 1, 0.9};

T ys[]={0, 1, 0, 0.9};

vector<T> x(&xs[0], &xs[4]), y(&ys[0], &ys[4]);

vector<triple> tri = delaunayTriangulation(x, y);

*//expected: 0 1 3*

*// 0 3 2*

**int** i;

**for**(i = 0; i < tri.size(); i++)

printf(**"%d %d %d\n"**, tri[i].i, tri[i].j, tri[i].k);

**return** 0;

}

**Euclid.cc 12/27**

*// This is a collection of useful code for solving problems that*

*// involve modular linear equations. Note that all of the*

*// algorithms described here work on nonnegative integers.*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<algorithm>**

using namespace std;

**typedef** vector<**int**> VI;

**typedef** pair<**int**,**int**> PII;

*// return a % b (positive value)*

**int** **mod**(**int** a, **int** b) {

**return** ((a%b)+b)%b;

}

*// computes gcd(a,b)*

**int** **gcd**(**int** a, **int** b) {

**int** tmp;

**while**(b){a%=b; tmp=a; a=b; b=tmp;}

**return** a;

}

*// computes lcm(a,b)*

**int** **lcm**(**int** a, **int** b) {

**return** a/gcd(a,b)\*b;

}

*// returns d = gcd(a,b); finds x,y such that d = ax + by*

**int** **extended\_euclid**(**int** a, **int** b, **int** &x, **int** &y) {

**int** xx = y = 0;

**int** yy = x = 1;

**while** (b) {

**int** q = a/b;

**int** t = b; b = a%b; a = t;

t = xx; xx = x-q\*xx; x = t;

t = yy; yy = y-q\*yy; y = t;

}

**return** a;

}

*// finds all solutions to ax = b (mod n)*

VI **modular\_linear\_equation\_solver**(**int** a, **int** b, **int** n) {

**int** x, y;

VI solutions;

**int** d = extended\_euclid(a, n, x, y);

**if** (!(b%d)) {

x = mod (x\*(b/d), n);

**for** (**int** i = 0; i < d; i++)

solutions.push\_back(mod(x + i\*(n/d), n));

}

**return** solutions;

}

*// computes b such that ab = 1 (mod n), returns -1 on failure*

**int** **mod\_inverse**(**int** a, **int** n) {

**int** x, y;

**int** d = extended\_euclid(a, n, x, y);

**if** (d > 1) **return** -1;

**return** mod(x,n);

}

*// Chinese remainder theorem (special case): find z such that*

*// z % x = a, z % y = b. Here, z is unique modulo M = lcm(x,y).*

*// Return (z,M). On failure, M = -1.*

PII **chinese\_remainder\_theorem**(**int** x, **int** a, **int** y, **int** b) {

**int** s, t;

**int** d = extended\_euclid(x, y, s, t);

**if** (a%d != b%d) **return** make\_pair(0, -1);

**return** make\_pair(mod(s\*b\*x+t\*a\*y,x\*y)/d, x\*y/d);

}

*// Chinese remainder theorem: find z such that*

*// z % x[i] = a[i] for all i. Note that the solution is*

*// unique modulo M = lcm\_i (x[i]). Return (z,M). On*

*// failure, M = -1. Note that we do not require the a[i]'s*

*// to be relatively prime.*

PII **chinese\_remainder\_theorem**(**const** VI &x, **const** VI &a) {

PII ret = make\_pair(a[0], x[0]);

**for** (**int** i = 1; i < x.size(); i++) {

ret = chinese\_remainder\_theorem(ret.second, ret.first, x[i], a[i]);

**if** (ret.second == -1) **break**;

}

**return** ret;

}

*// computes x and y such that ax + by = c; on failure, x = y =-1*

**void** **linear\_diophantine**(**int** a, **int** b, **int** c, **int** &x, **int** &y) {

**int** d = gcd(a,b);

**if** (c%d) {

x = y = -1;

} **else** {

x = c/d \* mod\_inverse(a/d, b/d);

y = (c-a\*x)/b;

}

}

**int** **main**() {

*// expected: 2*

cout << gcd(14, 30) << endl;

*// expected: 2 -2 1*

**int** x, y;

**int** d = extended\_euclid(14, 30, x, y);

cout << d << **" "** << x << **" "** << y << endl;

*// expected: 95 45*

VI sols = modular\_linear\_equation\_solver(14, 30, 100);

**for** (**int** i = 0; i < (**int**) sols.size(); i++) cout << sols[i] << **" "**;

cout << endl;

*// expected: 8*

cout << mod\_inverse(8, 9) << endl;

*// expected: 23 56*

*// 11 12*

**int** xs[] = {3, 5, 7, 4, 6};

**int** as[] = {2, 3, 2, 3, 5};

PII ret = chinese\_remainder\_theorem(VI (xs, xs+3), VI(as, as+3));

cout << ret.first << **" "** << ret.second << endl;

ret = chinese\_remainder\_theorem (VI(xs+3, xs+5), VI(as+3, as+5));

cout << ret.first << **" "** << ret.second << endl;

*// expected: 5 -15*

linear\_diophantine(7, 2, 5, x, y);

cout << x << **" "** << y << endl;

}

**GaussJordan.cc 13/27**

*// Gauss-Jordan elimination with full pivoting.*

*//*

*// Uses:*

*// (1) solving systems of linear equations (AX=B)*

*// (2) inverting matrices (AX=I)*

*// (3) computing determinants of square matrices*

*//*

*// Running time: O(n^3)*

*//*

*// INPUT: a[][] = an nxn matrix*

*// b[][] = an nxm matrix*

*//*

*// OUTPUT: X = an nxm matrix (stored in b[][])*

*// A^{-1} = an nxn matrix (stored in a[][])*

*// returns determinant of a[][]*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<cmath>**

using namespace std;

**const** **double** EPS = 1e-10;

**typedef** vector<**int**> VI;

**typedef** **double** T;

**typedef** vector<T> VT;

**typedef** vector<VT> VVT;

T GaussJordan(VVT &a, VVT &b) {

**const** **int** n = a.size();

**const** **int** m = b[0].size();

VI irow(n), icol(n), ipiv(n);

T det = 1;

**for** (**int** i = 0; i < n; i++) {

**int** pj = -1, pk = -1;

**for** (**int** j = 0; j < n; j++) **if** (!ipiv[j])

**for** (**int** k = 0; k < n; k++) **if** (!ipiv[k])

**if** (pj == -1 || fabs(a[j][k]) > fabs(a[pj][pk])) { pj = j; pk = k; }

**if** (fabs(a[pj][pk]) < EPS) { cerr << **"Matrix is singular."** << endl; exit(0); }

ipiv[pk]++;

swap(a[pj], a[pk]);

swap(b[pj], b[pk]);

**if** (pj != pk) det \*= -1;

irow[i] = pj;

icol[i] = pk;

T c = 1.0 / a[pk][pk];

det \*= a[pk][pk];

a[pk][pk] = 1.0;

**for** (**int** p = 0; p < n; p++) a[pk][p] \*= c;

**for** (**int** p = 0; p < m; p++) b[pk][p] \*= c;

**for** (**int** p = 0; p < n; p++) **if** (p != pk) {

c = a[p][pk];

a[p][pk] = 0;

**for** (**int** q = 0; q < n; q++) a[p][q] -= a[pk][q] \* c;

**for** (**int** q = 0; q < m; q++) b[p][q] -= b[pk][q] \* c;

}

}

**for** (**int** p = n-1; p >= 0; p--) **if** (irow[p] != icol[p]) {

**for** (**int** k = 0; k < n; k++) swap(a[k][irow[p]], a[k][icol[p]]);

}

**return** det;

}

**int** **main**() {

**const** **int** n = 4;

**const** **int** m = 2;

**double** A[n][n] = { {1,2,3,4},{1,0,1,0},{5,3,2,4},{6,1,4,6} };

**double** B[n][m] = { {1,2},{4,3},{5,6},{8,7} };

VVT a(n), b(n);

**for** (**int** i = 0; i < n; i++) {

a[i] = VT(A[i], A[i] + n);

b[i] = VT(B[i], B[i] + m);

}

**double** det = GaussJordan(a, b);

*// expected: 60*

cout << **"Determinant: "** << det << endl;

*// expected: -0.233333 0.166667 0.133333 0.0666667*

*// 0.166667 0.166667 0.333333 -0.333333*

*// 0.233333 0.833333 -0.133333 -0.0666667*

*// 0.05 -0.75 -0.1 0.2*

cout << **"Inverse: "** << endl;

**for** (**int** i = 0; i < n; i++) {

**for** (**int** j = 0; j < n; j++)

cout << a[i][j] << **' '**;

cout << endl;

}

*// expected: 1.63333 1.3*

*// -0.166667 0.5*

*// 2.36667 1.7*

*// -1.85 -1.35*

cout << **"Solution: "** << endl;

**for** (**int** i = 0; i < n; i++) {

**for** (**int** j = 0; j < m; j++)

cout << b[i][j] << **' '**;

cout << endl;

}

}

**ReducedRowEchelonForm.cc 14/27**

*// Reduced row echelon form via Gauss-Jordan elimination*

*// with partial pivoting. This can be used for computing*

*// the rank of a matrix.*

*//*

*// Running time: O(n^3)*

*//*

*// INPUT: a[][] = an nxn matrix*

*//*

*// OUTPUT: rref[][] = an nxm matrix (stored in a[][])*

*// returns rank of a[][]*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<cmath>**

using namespace std;

**const** **double** EPSILON = 1e-10;

**typedef** **double** T;

**typedef** vector<T> VT;

**typedef** vector<VT> VVT;

**int** **rref**(VVT &a) {

**int** n = a.size();

**int** m = a[0].size();

**int** r = 0;

**for** (**int** c = 0; c < m; c++) {

**int** j = r;

**for** (**int** i = r+1; i < n; i++)

**if** (fabs(a[i][c]) > fabs(a[j][c])) j = i;

**if** (fabs(a[j][c]) < EPSILON) **continue**;

swap(a[j], a[r]);

T s = 1.0 / a[r][c];

**for** (**int** j = 0; j < m; j++) a[r][j] \*= s;

**for** (**int** i = 0; i < n; i++) **if** (i != r) {

T t = a[i][c];

**for** (**int** j = 0; j < m; j++) a[i][j] -= t \* a[r][j];

}

r++;

}

**return** r;

}

**int** **main**(){

**const** **int** n = 5;

**const** **int** m = 4;

**double** A[n][m] = { {16,2,3,13},{5,11,10,8},{9,7,6,12},{4,14,15,1},{13,21,21,13} };

VVT a(n);

**for** (**int** i = 0; i < n; i++)

a[i] = VT(A[i], A[i] + n);

**int** rank = rref (a);

*// expected: 4*

cout << **"Rank: "** << rank << endl;

*// expected: 1 0 0 1*

*// 0 1 0 3*

*// 0 0 1 -3*

*// 0 0 0 2.78206e-15*

*// 0 0 0 3.22398e-15*

cout << **"rref: "** << endl;

**for** (**int** i = 0; i < 5; i++){

**for** (**int** j = 0; j < 4; j++)

cout << a[i][j] << **' '**;

cout << endl;

}

}

**FFT\_new.cpp 15/27**

#**include** **<cassert>**

#**include** **<cstdio>**

#**include** **<cmath>**

**struct** cpx

{

cpx(){}

cpx(**double** aa):a(aa){}

cpx(**double** aa, **double** bb):a(aa),b(bb){}

**double** a;

**double** b;

**double** modsq(**void**) **const**

{

**return** a \* a + b \* b;

}

cpx bar(**void**) **const**

{

**return** cpx(a, -b);

}

};

cpx **operator** +(cpx a, cpx b)

{

**return** cpx(a.a + b.a, a.b + b.b);

}

cpx **operator** \*(cpx a, cpx b)

{

**return** cpx(a.a \* b.a - a.b \* b.b, a.a \* b.b + a.b \* b.a);

}

cpx **operator** /(cpx a, cpx b)

{

cpx r = a \* b.bar();

**return** cpx(r.a / b.modsq(), r.b / b.modsq());

}

cpx **EXP**(**double** theta)

{

**return** cpx(cos(theta),sin(theta));

}

**const** **double** two\_pi = 4 \* acos(0);

*// in: input array*

*// out: output array*

*// step: {SET TO 1} (used internally)*

*// size: length of the input/output {MUST BE A POWER OF 2}*

*// dir: either plus or minus one (direction of the FFT)*

*// RESULT: out[k] = \sum\_{j=0}^{size - 1} in[j] \* exp(dir \* 2pi \* i \* j \* k / size)*

**void** **FFT**(cpx \*in, cpx \*out, **int** step, **int** size, **int** dir)

{

**if**(size < 1) **return**;

**if**(size == 1)

{

out[0] = in[0];

**return**;

}

FFT(in, out, step \* 2, size / 2, dir);

FFT(in + step, out + size / 2, step \* 2, size / 2, dir);

**for**(**int** i = 0 ; i < size / 2 ; i++)

{

cpx even = out[i];

cpx odd = out[i + size / 2];

out[i] = even + EXP(dir \* two\_pi \* i / size) \* odd;

out[i + size / 2] = even + EXP(dir \* two\_pi \* (i + size / 2) / size) \* odd;

}

}

*// Usage:*

*// f[0...N-1] and g[0..N-1] are numbers*

*// Want to compute the convolution h, defined by*

*// h[n] = sum of f[k]g[n-k] (k = 0, ..., N-1).*

*// Here, the index is cyclic; f[-1] = f[N-1], f[-2] = f[N-2], etc.*

*// Let F[0...N-1] be FFT(f), and similarly, define G and H.*

*// The convolution theorem says H[n] = F[n]G[n] (element-wise product).*

*// To compute h[] in O(N log N) time, do the following:*

*// 1. Compute F and G (pass dir = 1 as the argument).*

*// 2. Get H by element-wise multiplying F and G.*

*// 3. Get h by taking the inverse FFT (use dir = -1 as the argument)*

*// and \*dividing by N\*. DO NOT FORGET THIS SCALING FACTOR.*

**int** **main**(**void**)

{

printf(**"If rows come in identical pairs, then everything works.\n"**);

cpx a[8] = {0, 1, cpx(1,3), cpx(0,5), 1, 0, 2, 0};

cpx b[8] = {1, cpx(0,-2), cpx(0,1), 3, -1, -3, 1, -2};

cpx A[8];

cpx B[8];

FFT(a, A, 1, 8, 1);

FFT(b, B, 1, 8, 1);

**for**(**int** i = 0 ; i < 8 ; i++)

{

printf(**"%7.2lf%7.2lf"**, A[i].a, A[i].b);

}

printf(**"\n"**);

**for**(**int** i = 0 ; i < 8 ; i++)

{

cpx Ai(0,0);

**for**(**int** j = 0 ; j < 8 ; j++)

{

Ai = Ai + a[j] \* EXP(j \* i \* two\_pi / 8);

}

printf(**"%7.2lf%7.2lf"**, Ai.a, Ai.b);

}

printf(**"\n"**);

cpx AB[8];

**for**(**int** i = 0 ; i < 8 ; i++)

AB[i] = A[i] \* B[i];

cpx aconvb[8];

FFT(AB, aconvb, 1, 8, -1);

**for**(**int** i = 0 ; i < 8 ; i++)

aconvb[i] = aconvb[i] / 8;

**for**(**int** i = 0 ; i < 8 ; i++)

{

printf(**"%7.2lf%7.2lf"**, aconvb[i].a, aconvb[i].b);

}

printf(**"\n"**);

**for**(**int** i = 0 ; i < 8 ; i++)

{

cpx aconvbi(0,0);

**for**(**int** j = 0 ; j < 8 ; j++)

{

aconvbi = aconvbi + a[j] \* b[(8 + i - j) % 8];

}

printf(**"%7.2lf%7.2lf"**, aconvbi.a, aconvbi.b);

}

printf(**"\n"**);

**return** 0;

}

**Simplex.cc 16/27**

*// Two-phase simplex algorithm for solving linear programs of the form*

*//*

*// maximize c^T x*

*// subject to Ax <= b*

*// x >= 0*

*//*

*// INPUT: A -- an m x n matrix*

*// b -- an m-dimensional vector*

*// c -- an n-dimensional vector*

*// x -- a vector where the optimal solution will be stored*

*//*

*// OUTPUT: value of the optimal solution (infinity if unbounded*

*// above, nan if infeasible)*

*//*

*// To use this code, create an LPSolver object with A, b, and c as*

*// arguments. Then, call Solve(x).*

#**include** **<iostream>**

#**include** **<iomanip>**

#**include** **<vector>**

#**include** **<cmath>**

#**include** **<limits>**

using namespace std;

**typedef** **long** **double** DOUBLE;

**typedef** vector<DOUBLE> VD;

**typedef** vector<VD> VVD;

**typedef** vector<**int**> VI;

**const** DOUBLE EPS = 1e-9;

**struct** LPSolver {

**int** m, n;

VI B, N;

VVD D;

LPSolver(**const** VVD &A, **const** VD &b, **const** VD &c) :

m(b.size()), n(c.size()), N(n+1), B(m), D(m+2, VD(n+2)) {

**for** (**int** i = 0; i < m; i++) **for** (**int** j = 0; j < n; j++) D[i][j] = A[i][j];

**for** (**int** i = 0; i < m; i++) { B[i] = n+i; D[i][n] = -1; D[i][n+1] = b[i]; }

**for** (**int** j = 0; j < n; j++) { N[j] = j; D[m][j] = -c[j]; }

N[n] = -1; D[m+1][n] = 1;

}

**void** Pivot(**int** r, **int** s) {

**for** (**int** i = 0; i < m+2; i++) **if** (i != r)

**for** (**int** j = 0; j < n+2; j++) **if** (j != s)

D[i][j] -= D[r][j] \* D[i][s] / D[r][s];

**for** (**int** j = 0; j < n+2; j++) **if** (j != s) D[r][j] /= D[r][s];

**for** (**int** i = 0; i < m+2; i++) **if** (i != r) D[i][s] /= -D[r][s];

D[r][s] = 1.0 / D[r][s];

swap(B[r], N[s]);

}

**bool** Simplex(**int** phase) {

**int** x = phase == 1 ? m+1 : m;

**while** (true) {

**int** s = -1;

**for** (**int** j = 0; j <= n; j++) {

**if** (phase == 2 && N[j] == -1) **continue**;

**if** (s == -1 || D[x][j] < D[x][s] || D[x][j] == D[x][s] && N[j] < N[s]) s = j;

}

**if** (D[x][s] >= -EPS) **return** true;

**int** r = -1;

**for** (**int** i = 0; i < m; i++) {

**if** (D[i][s] <= 0) **continue**;

**if** (r == -1 || D[i][n+1] / D[i][s] < D[r][n+1] / D[r][s] ||

D[i][n+1] / D[i][s] == D[r][n+1] / D[r][s] && B[i] < B[r]) r = i;

}

**if** (r == -1) **return** false;

Pivot(r, s);

}

}

DOUBLE Solve(VD &x) {

**int** r = 0;

**for** (**int** i = 1; i < m; i++) **if** (D[i][n+1] < D[r][n+1]) r = i;

**if** (D[r][n+1] <= -EPS) {

Pivot(r, n);

**if** (!Simplex(1) || D[m+1][n+1] < -EPS) **return** -numeric\_limits<DOUBLE>::infinity();

**for** (**int** i = 0; i < m; i++) **if** (B[i] == -1) {

**int** s = -1;

**for** (**int** j = 0; j <= n; j++)

**if** (s == -1 || D[i][j] < D[i][s] || D[i][j] == D[i][s] && N[j] < N[s]) s = j;

Pivot(i, s);

}

}

**if** (!Simplex(2)) **return** numeric\_limits<DOUBLE>::infinity();

x = VD(n);

**for** (**int** i = 0; i < m; i++) **if** (B[i] < n) x[B[i]] = D[i][n+1];

**return** D[m][n+1];

}

};

**int** **main**() {

**const** **int** m = 4;

**const** **int** n = 3;

DOUBLE \_A[m][n] = {

{ 6, -1, 0 },

{ -1, -5, 0 },

{ 1, 5, 1 },

{ -1, -5, -1 }

};

DOUBLE \_b[m] = { 10, -4, 5, -5 };

DOUBLE \_c[n] = { 1, -1, 0 };

VVD A(m);

VD b(\_b, \_b + m);

VD c(\_c, \_c + n);

**for** (**int** i = 0; i < m; i++) A[i] = VD(\_A[i], \_A[i] + n);

LPSolver solver(A, b, c);

VD x;

DOUBLE value = solver.Solve(x);

cerr << **"VALUE: "**<< value << endl;

cerr << **"SOLUTION:"**;

**for** (size\_t i = 0; i < x.size(); i++) cerr << **" "** << x[i];

cerr << endl;

**return** 0;

}

**FastDijkstra.cc 17/27**

*// Implementation of Dijkstra's algorithm using adjacency lists*

*// and priority queue for efficiency.*

*//*

*// Running time: O(|E| log |V|)*

#**include** **<queue>**

#**include** **<stdio.h>**

using namespace std;

**const** **int** INF = 2000000000;

**typedef** pair<**int**,**int**> PII;

**int** **main**(){

**int** N, s, t;

scanf (**"%d%d%d"**, &N, &s, &t);

vector<vector<PII> > edges(N);

**for** (**int** i = 0; i < N; i++){

**int** M;

scanf (**"%d"**, &M);

**for** (**int** j = 0; j < M; j++){

**int** vertex, dist;

scanf (**"%d%d"**, &vertex, &dist);

edges[i].push\_back (make\_pair (dist, vertex)); *// note order of arguments here*

}

}

*// use priority queue in which top element has the "smallest" priority*

priority\_queue<PII, vector<PII>, greater<PII> > Q;

vector<**int**> dist(N, INF), dad(N, -1);

Q.push (make\_pair (0, s));

dist[s] = 0;

**while** (!Q.empty()){

PII p = Q.top();

**if** (p.second == t) **break**;

Q.pop();

**int** here = p.second;

**for** (vector<PII>::iterator it=edges[here].begin(); it!=edges[here].end(); it++){

**if** (dist[here] + it->first < dist[it->second]){

dist[it->second] = dist[here] + it->first;

dad[it->second] = here;

Q.push (make\_pair (dist[it->second], it->second));

}

}

}

printf (**"%d\n"**, dist[t]);

**if** (dist[t] < INF)

**for**(**int** i=t;i!=-1;i=dad[i])

printf (**"%d%c"**, i, (i==s?**'\n'**:**' '**));

**return** 0;

}

**SCC.cc 18/27**

#**include<memory.h>**

**struct** edge{**int** e, nxt;};

**int** V, E;

edge e[MAXE], er[MAXE];

**int** sp[MAXV], spr[MAXV];

**int** group\_cnt, group\_num[MAXV];

**bool** v[MAXV];

**int** stk[MAXV];

**void** **fill\_forward**(**int** x)

{

**int** i;

v[x]=true;

**for**(i=sp[x];i;i=e[i].nxt) **if**(!v[e[i].e]) fill\_forward(e[i].e);

stk[++stk[0]]=x;

}

**void** **fill\_backward**(**int** x)

{

**int** i;

v[x]=false;

group\_num[x]=group\_cnt;

**for**(i=spr[x];i;i=er[i].nxt) **if**(v[er[i].e]) fill\_backward(er[i].e);

}

**void** **add\_edge**(**int** v1, **int** v2) *//add edge v1->v2*

{

e [++E].e=v2; e [E].nxt=sp [v1]; sp [v1]=E;

er[ E].e=v1; er[E].nxt=spr[v2]; spr[v2]=E;

}

**void** **SCC**()

{

**int** i;

stk[0]=0;

memset(v, false, **sizeof**(v));

**for**(i=1;i<=V;i++) **if**(!v[i]) fill\_forward(i);

group\_cnt=0;

**for**(i=stk[0];i>=1;i--) **if**(v[stk[i]]){group\_cnt++; fill\_backward(stk[i]);}

}

**SuffixArray.cc 19/27**

*// Suffix array construction in O(L log^2 L) time. Routine for*

*// computing the length of the longest common prefix of any two*

*// suffixes in O(log L) time.*

*//*

*// INPUT: string s*

*//*

*// OUTPUT: array suffix[] such that suffix[i] = index (from 0 to L-1)*

*// of substring s[i...L-1] in the list of sorted suffixes.*

*// That is, if we take the inverse of the permutation suffix[],*

*// we get the actual suffix array.*

#**include** **<vector>**

#**include** **<iostream>**

#**include** **<string>**

using namespace std;

**struct** SuffixArray {

**const** **int** L;

string s;

vector<vector<**int**> > P;

vector<pair<pair<**int**,**int**>,**int**> > M;

SuffixArray(**const** string &s) : L(s.length()), s(s), P(1, vector<**int**>(L, 0)), M(L) {

**for** (**int** i = 0; i < L; i++) P[0][i] = **int**(s[i]);

**for** (**int** skip = 1, level = 1; skip < L; skip \*= 2, level++) {

P.push\_back(vector<**int**>(L, 0));

**for** (**int** i = 0; i < L; i++)

M[i] = make\_pair(make\_pair(P[level-1][i], i + skip < L ? P[level-1][i + skip] : -1000), i);

sort(M.begin(), M.end());

**for** (**int** i = 0; i < L; i++)

P[level][M[i].second] = (i > 0 && M[i].first == M[i-1].first) ? P[level][M[i-1].second] : i;

}

}

vector<**int**> GetSuffixArray() { **return** P.back(); }

*// returns the length of the longest common prefix of s[i...L-1] and s[j...L-1]*

**int** LongestCommonPrefix(**int** i, **int** j) {

**int** len = 0;

**if** (i == j) **return** L - i;

**for** (**int** k = P.size() - 1; k >= 0 && i < L && j < L; k--) {

**if** (P[k][i] == P[k][j]) {

i += 1 << k;

j += 1 << k;

len += 1 << k;

}

}

**return** len;

}

};

**int** **main**() {

*// bobocel is the 0'th suffix*

*// obocel is the 5'th suffix*

*// bocel is the 1'st suffix*

*// ocel is the 6'th suffix*

*// cel is the 2'nd suffix*

*// el is the 3'rd suffix*

*// l is the 4'th suffix*

SuffixArray suffix(**"bobocel"**);

vector<**int**> v = suffix.GetSuffixArray();

*// Expected output: 0 5 1 6 2 3 4*

*// 2*

**for** (**int** i = 0; i < v.size(); i++) cout << v[i] << **" "**;

cout << endl;

cout << suffix.LongestCommonPrefix(0, 2) << endl;

}

**BIT.cc 20/27**

#**include** **<iostream>**

using namespace std;

#**define** LOGSZ 17

**int** tree[(1<<LOGSZ)+1];

**int** N = (1<<LOGSZ);

*// add v to value at x*

**void** **set**(**int** x, **int** v) {

**while**(x <= N) {

tree[x] += v;

x += (x & -x);

}

}

*// get cumulative sum up to and including x*

**int** **get**(**int** x) {

**int** res = 0;

**while**(x) {

res += tree[x];

x -= (x & -x);

}

**return** res;

}

*// get largest value with cumulative sum less than or equal to x;*

*// for smallest, pass x-1 and add 1 to result*

**int** **getind**(**int** x) {

**int** idx = 0, mask = N;

**while**(mask && idx < N) {

**int** t = idx + mask;

**if**(x >= tree[t]) {

idx = t;

x -= tree[t];

}

mask >>= 1;

}

**return** idx;

}

**UnionFind.cc 21/27**

*//union-find set: the vector/array contains the parent of each node*

**int** **find**(vector <**int**>& C, **int** x){**return** (C[x]==x) ? x : C[x]=find(C, C[x]);} *//C++*

**int** **find**(**int** x){**return** (C[x]==x)?**x**:C[x]=find(C[x]);} *//C*

**KDTree.cc 22/27**

*// --------------------------------------------------------------------------*

*// A straightforward, but probably sub-optimal KD-tree implmentation that's*

*// probably good enough for most things (current it's a 2D-tree)*

*//*

*// - constructs from n points in O(n lg^2 n) time*

*// - handles nearest-neighbor query in O(lg n) if points are well distributed*

*// - worst case for nearest-neighbor may be linear in pathological case*

*//*

*// Sonny Chan, Stanford University, April 2009*

*// --------------------------------------------------------------------------*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<limits>**

#**include** **<cstdlib>**

using namespace std;

*// number type for coordinates, and its maximum value*

**typedef** **long** **long** ntype;

**const** ntype sentry = numeric\_limits<ntype>::max();

*// point structure for 2D-tree, can be extended to 3D*

**struct** point {

ntype x, y;

point(ntype xx = 0, ntype yy = 0) : x(xx), y(yy) {}

};

**bool** **operator**==(**const** point &a, **const** point &b)

{

**return** a.x == b.x && a.y == b.y;

}

*// sorts points on x-coordinate*

**bool** **on\_x**(**const** point &a, **const** point &b)

{

**return** a.x < b.x;

}

*// sorts points on y-coordinate*

**bool** **on\_y**(**const** point &a, **const** point &b)

{

**return** a.y < b.y;

}

*// squared distance between points*

ntype **pdist2**(**const** point &a, **const** point &b)

{

ntype dx = a.x-b.x, dy = a.y-b.y;

**return** dx\*dx + dy\*dy;

}

*// bounding box for a set of points*

**struct** bbox

{

ntype x0, x1, y0, y1;

bbox() : x0(sentry), x1(-sentry), y0(sentry), y1(-sentry) {}

*// computes bounding box from a bunch of points*

**void** compute(**const** vector<point> &v) {

**for** (**int** i = 0; i < v.size(); ++i) {

x0 = min(x0, v[i].x); x1 = max(x1, v[i].x);

y0 = min(y0, v[i].y); y1 = max(y1, v[i].y);

}

}

*// squared distance between a point and this bbox, 0 if inside*

ntype distance(**const** point &p) {

**if** (p.x < x0) {

**if** (p.y < y0) **return** pdist2(point(x0, y0), p);

**else** **if** (p.y > y1) **return** pdist2(point(x0, y1), p);

**else** **return** pdist2(point(x0, p.y), p);

}

**else** **if** (p.x > x1) {

**if** (p.y < y0) **return** pdist2(point(x1, y0), p);

**else** **if** (p.y > y1) **return** pdist2(point(x1, y1), p);

**else** **return** pdist2(point(x1, p.y), p);

}

**else** {

**if** (p.y < y0) **return** pdist2(point(p.x, y0), p);

**else** **if** (p.y > y1) **return** pdist2(point(p.x, y1), p);

**else** **return** 0;

}

}

};

*// stores a single node of the kd-tree, either internal or leaf*

**struct** kdnode

{

**bool** leaf; *// true if this is a leaf node (has one point)*

point pt; *// the single point of this is a leaf*

bbox bound; *// bounding box for set of points in children*

kdnode \*first, \*second; *// two children of this kd-node*

kdnode() : leaf(false), first(0), second(0) {}

~kdnode() { **if** (first) **delete** first; **if** (second) **delete** second; }

*// intersect a point with this node (returns squared distance)*

ntype intersect(**const** point &p) {

**return** bound.distance(p);

}

*// recursively builds a kd-tree from a given cloud of points*

**void** construct(vector<point> &vp)

{

*// compute bounding box for points at this node*

bound.compute(vp);

*// if we're down to one point, then we're a leaf node*

**if** (vp.size() == 1) {

leaf = true;

pt = vp[0];

}

**else** {

*// split on x if the bbox is wider than high (not best heuristic...)*

**if** (bound.x1-bound.x0 >= bound.y1-bound.y0)

sort(vp.begin(), vp.end(), on\_x);

*// otherwise split on y-coordinate*

**else**

sort(vp.begin(), vp.end(), on\_y);

*// divide by taking half the array for each child*

*// (not best performance if many duplicates in the middle)*

**int** half = vp.size()/2;

vector<point> vl(vp.begin(), vp.begin()+half);

vector<point> vr(vp.begin()+half, vp.end());

first = **new** kdnode(); first->construct(vl);

second = **new** kdnode(); second->construct(vr);

}

}

};

*// simple kd-tree class to hold the tree and handle queries*

**struct** kdtree

{

kdnode \*root;

*// constructs a kd-tree from a points (copied here, as it sorts them)*

kdtree(**const** vector<point> &vp) {

vector<point> v(vp.begin(), vp.end());

root = **new** kdnode();

root->construct(v);

}

~kdtree() { **delete** root; }

*// recursive search method returns squared distance to nearest point*

ntype search(kdnode \*node, **const** point &p)

{

**if** (node->leaf) {

*// commented special case tells a point not to find itself*

*// if (p == node->pt) return sentry;*

*// else*

**return** pdist2(p, node->pt);

}

ntype bfirst = node->first->intersect(p);

ntype bsecond = node->second->intersect(p);

*// choose the side with the closest bounding box to search first*

*// (note that the other side is also searched if needed)*

**if** (bfirst < bsecond) {

ntype best = search(node->first, p);

**if** (bsecond < best)

best = min(best, search(node->second, p));

**return** best;

}

**else** {

ntype best = search(node->second, p);

**if** (bfirst < best)

best = min(best, search(node->first, p));

**return** best;

}

}

*// squared distance to the nearest*

ntype nearest(**const** point &p) {

**return** search(root, p);

}

};

*// --------------------------------------------------------------------------*

*// some basic test code here*

**int** **main**()

{

*// generate some random points for a kd-tree*

vector<point> vp;

**for** (**int** i = 0; i < 100000; ++i) {

vp.push\_back(point(rand()%100000, rand()%100000));

}

kdtree tree(vp);

*// query some points*

**for** (**int** i = 0; i < 10; ++i) {

point q(rand()%100000, rand()%100000);

cout << **"Closest squared distance to ("** << q.x << **", "** << q.y << **")"**

<< **" is "** << tree.nearest(q) << endl;

}

**return** 0;

}

*// --------------------------------------------------------------------------*

**LongestIncreasingSubsequence.cc 23/27**

*// Given a list of numbers of length n, this routine extracts a*

*// longest increasing subsequence.*

*//*

*// Running time: O(n log n)*

*//*

*// INPUT: a vector of integers*

*// OUTPUT: a vector containing the longest increasing subsequence*

#**include** **<iostream>**

#**include** **<vector>**

#**include** **<algorithm>**

using namespace std;

**typedef** vector<**int**> VI;

**typedef** pair<**int**,**int**> PII;

**typedef** vector<PII> VPII;

#**define** STRICTLY\_INCREASNG

VI **LongestIncreasingSubsequence**(VI v) {

VPII best;

VI dad(v.size(), -1);

**for** (**int** i = 0; i < v.size(); i++) {

#**ifdef** STRICTLY\_INCREASNG

PII item = make\_pair(v[i], 0);

VPII::iterator it = lower\_bound(best.begin(), best.end(), item);

item.second = i;

#**else**

PII item = make\_pair(v[i], i);

VPII::iterator it = upper\_bound(best.begin(), best.end(), item);

#**endif**

**if** (it == best.end()) {

dad[i] = (best.size() == 0 ? -1 : best.back().second);

best.push\_back(item);

} **else** {

dad[i] = dad[it->second];

\*it = item;

}

}

VI ret;

**for** (**int** i = best.back().second; i >= 0; i = dad[i])

ret.push\_back(v[i]);

reverse(ret.begin(), ret.end());

**return** ret;

}

**Dates.cc 24/27**

*// Routines for performing computations on dates. In these routines,*

*// months are expressed as integers from 1 to 12, days are expressed*

*// as integers from 1 to 31, and years are expressed as 4-digit*

*// integers.*

#**include** **<iostream>**

#**include** **<string>**

using namespace std;

string dayOfWeek[] = {**"Mon"**, **"Tue"**, **"Wed"**, **"Thu"**, **"Fri"**, **"Sat"**, **"Sun"**};

*// converts Gregorian date to integer (Julian day number)*

**int** **dateToInt** (**int** m, **int** d, **int** y){

**return**

1461 \* (y + 4800 + (m - 14) / 12) / 4 +

367 \* (m - 2 - (m - 14) / 12 \* 12) / 12 -

3 \* ((y + 4900 + (m - 14) / 12) / 100) / 4 +

d - 32075;

}

*// converts integer (Julian day number) to Gregorian date: month/day/year*

**void** **intToDate** (**int** jd, **int** &m, **int** &d, **int** &y){

**int** x, n, i, j;

x = jd + 68569;

n = 4 \* x / 146097;

x -= (146097 \* n + 3) / 4;

i = (4000 \* (x + 1)) / 1461001;

x -= 1461 \* i / 4 - 31;

j = 80 \* x / 2447;

d = x - 2447 \* j / 80;

x = j / 11;

m = j + 2 - 12 \* x;

y = 100 \* (n - 49) + i + x;

}

*// converts integer (Julian day number) to day of week*

string **intToDay** (**int** jd){

**return** dayOfWeek[jd % 7];

}

**int** **main** (**int** argc, **char** \*\*argv){

**int** jd = dateToInt (3, 24, 2004);

**int** m, d, y;

intToDate (jd, m, d, y);

string day = intToDay (jd);

*// expected output:*

*// 2453089*

*// 3/24/2004*

*// Wed*

cout << jd << endl

<< m << **"/"** << d << **"/"** << y << endl

<< day << endl;

}

**LogLan.java 25/27**

*// Code which demonstrates the use of Java's regular expression libraries.*

*// This is a solution for*

*//*

*// Loglan: a logical language*

*// http://acm.uva.es/p/v1/134.html*

*//*

*// In this problem, we are given a regular language, whose rules can be*

*// inferred directly from the code. For each sentence in the input, we must*

*// determine whether the sentence matches the regular expression or not. The*

*// code consists of (1) building the regular expression (which is fairly*

*// complex) and (2) using the regex to match sentences.*

**import** java.util.\*;

**import** java.util.regex.\*;

**public** **class** LogLan {

**public** **static** String BuildRegex (){

String space = **" +"**;

String A = **"([aeiou])"**;

String C = **"([a-z&&[^aeiou]])"**;

String MOD = **"(g"** + A + **")"**;

String BA = **"(b"** + A + **")"**;

String DA = **"(d"** + A + **")"**;

String LA = **"(l"** + A + **")"**;

String NAM = **"([a-z]\*"** + C + **")"**;

String PREDA = **"("** + C + C + A + C + A + **"|"** + C + A + C + C + A + **")"**;

String predstring = **"("** + PREDA + **"("** + space + PREDA + **")\*)"**;

String predname = **"("** + LA + space + predstring + **"|"** + NAM + **")"**;

String preds = **"("** + predstring + **"("** + space + A + space + predstring + **")\*)"**;

String predclaim = **"("** + predname + space + BA + space + preds + **"|"** + DA + space +

preds + **")"**;

String verbpred = **"("** + MOD + space + predstring + **")"**;

String statement = **"("** + predname + space + verbpred + space + predname + **"|"** +

predname + space + verbpred + **")"**;

String sentence = **"("** + statement + **"|"** + predclaim + **")"**;

**return** **"^"** + sentence + **"$"**;

}

**public** **static** **void** main (String args[]){

String regex = BuildRegex();

Pattern pattern = Pattern.compile (regex);

Scanner s = **new** Scanner(System.in);

**while** (**true**) {

*// In this problem, each sentence consists of multiple lines, where the last*

*// line is terminated by a period. The code below reads lines until*

*// encountering a line whose final character is a '.'. Note the use of*

*//*

*// s.length() to get length of string*

*// s.charAt() to extract characters from a Java string*

*// s.trim() to remove whitespace from the beginning and end of Java string*

*//*

*// Other useful String manipulation methods include*

*//*

*// s.compareTo(t) < 0 if s < t, lexicographically*

*// s.indexOf("apple") returns index of first occurrence of "apple" in s*

*// s.lastIndexOf("apple") returns index of last occurrence of "apple" in s*

*// s.replace(c,d) replaces occurrences of character c with d*

*// s.startsWith("apple) returns (s.indexOf("apple") == 0)*

*// s.toLowerCase() / s.toUpperCase() returns a new lower/uppercased string*

*//*

*// Integer.parseInt(s) converts s to an integer (32-bit)*

*// Long.parseLong(s) converts s to a long (64-bit)*

*// Double.parseDouble(s) converts s to a double*

String sentence = **""**;

**while** (**true**){

sentence = (sentence + **" "** + s.nextLine()).trim();

**if** (sentence.equals(**"#"**)) **return**;

**if** (sentence.charAt(sentence.length()-1) == **'.'**) **break**;

}

*// now, we remove the period, and match the regular expression*

String removed\_period = sentence.substring(0, sentence.length()-1).trim();

**if** (pattern.matcher (removed\_period).find()){

System.out.println (**"Good"**);

} **else** {

System.out.println (**"Bad!"**);

}

}

}

}

**Primes.cc 26/27**

*// O(sqrt(x)) Exhaustive Primality Test*

#**include** **<cmath>**

#**define** EPS 1e-7

**typedef** **long** **long** LL;

**bool** **IsPrimeSlow** (LL x)

{

**if**(x<=1) **return** false;

**if**(x<=3) **return** true;

**if** (!(x%2) || !(x%3)) **return** false;

LL s=(LL)(sqrt((**double**)(x))+EPS);

**for**(LL i=5;i<=s;i+=6)

{

**if** (!(x%i) || !(x%(i+2))) **return** false;

}

**return** true;

}

*// Primes less than 1000:*

*// 2 3 5 7 11 13 17 19 23 29 31 37*

*// 41 43 47 53 59 61 67 71 73 79 83 89*

*// 97 101 103 107 109 113 127 131 137 139 149 151*

*// 157 163 167 173 179 181 191 193 197 199 211 223*

*// 227 229 233 239 241 251 257 263 269 271 277 281*

*// 283 293 307 311 313 317 331 337 347 349 353 359*

*// 367 373 379 383 389 397 401 409 419 421 431 433*

*// 439 443 449 457 461 463 467 479 487 491 499 503*

*// 509 521 523 541 547 557 563 569 571 577 587 593*

*// 599 601 607 613 617 619 631 641 643 647 653 659*

*// 661 673 677 683 691 701 709 719 727 733 739 743*

*// 751 757 761 769 773 787 797 809 811 821 823 827*

*// 829 839 853 857 859 863 877 881 883 887 907 911*

*// 919 929 937 941 947 953 967 971 977 983 991 997*

*// Other primes:*

*// The largest prime smaller than 10 is 7.*

*// The largest prime smaller than 100 is 97.*

*// The largest prime smaller than 1000 is 997.*

*// The largest prime smaller than 10000 is 9973.*

*// The largest prime smaller than 100000 is 99991.*

*// The largest prime smaller than 1000000 is 999983.*

*// The largest prime smaller than 10000000 is 9999991.*

*// The largest prime smaller than 100000000 is 99999989.*

*// The largest prime smaller than 1000000000 is 999999937.*

*// The largest prime smaller than 10000000000 is 9999999967.*

*// The largest prime smaller than 100000000000 is 99999999977.*

*// The largest prime smaller than 1000000000000 is 999999999989.*

*// The largest prime smaller than 10000000000000 is 9999999999971.*

*// The largest prime smaller than 100000000000000 is 99999999999973.*

*// The largest prime smaller than 1000000000000000 is 999999999999989.*

*// The largest prime smaller than 10000000000000000 is 9999999999999937.*

*// The largest prime smaller than 100000000000000000 is 99999999999999997.*

*// The largest prime smaller than 1000000000000000000 is 999999999999999989.*

**KMP.cpp 27/27**

*/\**

*Searches for the string w in the string s (of length k). Returns the*

*0-based index of the first match (k if no match is found). Algorithm*

*runs in O(k) time.*

*\*/*

#**include** **<iostream>**

#**include** **<string>**

#**include** **<vector>**

using namespace std;

**typedef** vector<**int**> VI;

**void** **buildTable**(string& w, VI& t)

{

t = VI(w.length());

**int** i = 2, j = 0;

t[0] = -1; t[1] = 0;

**while**(i < w.length())

{

**if**(w[i-1] == w[j]) { t[i] = j+1; i++; j++; }

**else** **if**(j > 0) j = t[j];

**else** { t[i] = 0; i++; }

}

}

**int** **KMP**(string& s, string& w)

{

**int** m = 0, i = 0;

VI t;

buildTable(w, t);

**while**(m+i < s.length())

{

**if**(w[i] == s[m+i])

{

i++;

**if**(i == w.length()) **return** m;

}

**else**

{

m += i-t[i];

**if**(i > 0) i = t[i];

}

}

**return** s.length();

}

**int** **main**()

{

string a = (string) **"The example above illustrates the general technique for assembling "**+

**"the table with a minimum of fuss. The principle is that of the overall search: "**+

**"most of the work was already done in getting to the current position, so very "**+

**"little needs to be done in leaving it. The only minor complication is that the "**+

**"logic which is correct late in the string erroneously gives non-proper "**+

**"substrings at the beginning. This necessitates some initialization code."**;

string b = **"table"**;

**int** p = KMP(a, b);

cout << p << **": "** << a.substr(p, b.length()) << **" "** << b << endl;

}

*Generated by [GNU enscript 1.6.1](http://www.iki.fi/~mtr/genscript/).*