Contents

1 Basic

1.1 vimrc

```
colo ron
syn on
se ai ar nu rnu
se mouse=a bs=2 ts=4 sw=4 ttm=100
au BufNewFile *.cpp 0r ~/default.cpp | :1,$-7 fo
filetype indent on
```

1.2 IncreaseStackSize

```
//stack resize
asm( "mov %0,%%esp\n" ::"g"(mem+10000000) );
//change esp to rsp if 64-bit system

//stack resize (linux)
#include <sys/resource.h>
void increase_stack_size() {
  const rlim_t ks = 64*1024*1024;
  struct rlimit rl;
  int res=getrlimit(RLIMIT_STACK, &rl);
  if(res==0){
    if(rl.rlim_cur<ks){
      rl.rlim_cur=ks;
      res=setrlimit(RLIMIT_STACK, &rl);
    }
  }
}
```

1.3 Default Code

```
#include<bits/stdc++.h>
using namespace std;
#define F first
#define S second
#define pb push_back
#define MP make_pair
#define ALL(x) begin(x),end(x)
#define SZ(x) ((int)(x).size())
typedef long long LL;
typedef double D;
typedef long double LDB;
typedef pair<int, int> PII;
typedef pair<LL, LL> PLL;
#define IOS ios_base::sync_with_stdio(0); cin.tie(0)
const int MXN = (int)1e6 + 7;
int main(){
  return 0;
}
```

2 Data Structure

2.1 Bigint

```
struct Bigint{
  static const int LEN = 60;
  static const int BIGMOD = 10000;

  int s;
  int vl, v[LEN];
  //  vector<int> v;
  Bigint() : s(1) { vl = 0; }
  Bigint(long long a) {
    s = 1; vl = 0;
    if (a < 0) { s = -1; a = -a; }
    while (a) {
      push_back(a % BIGMOD);
      a /= BIGMOD;
    }
  }
  Bigint(string str) {
    s = 1; vl = 0;
    int stPos = 0, num = 0;
    if (!str.empty() && str[0] == '-') {
```

```
    stPos = 1;
    s = -1;
  }
  for (int i=SZ(str)-1, q=1; i>=stPos; i--) {
    num += (str[i] - '0') * q;
    if ((q *= 10) >= BIGMOD) {
      push_back(num);
      num = 0; q = 1;
    }
  }
  if (num) push_back(num);
  n();
}

int len() const {
  return vl;
  //    return SZ(v);
}
bool empty() const { return len() == 0; }
void push_back(int x) {
  v[vl++] = x;
  //    v.PB(x);
}
void pop_back() {
  vl--;
  //    v.pop_back();
}
int back() const {
  return v[vl-1];
  //    return v.back();
}
void n() {
  while (!empty() && !back()) pop_back();
}
void resize(int nl) {
  vl = nl;
  fill(v, v+vl, 0);
  //    v.resize(nl);
  //    fill(ALL(v), 0);
}

void print() const {
  if (empty()) { putchar('0'); return; }
  if (s == -1) putchar('-');
  printf("%d", back());
  for (int i=len()-2; i>=0; i--) printf("%.4d",v[i]);
}
friend std::ostream& operator << (std::ostream& out,
    const Bigint &a) {
  if (a.empty()) { out << "0"; return out; }
  if (a.s == -1) out << "-";
  out << a.back();
  for (int i=a.len()-2; i>=0; i--) {
    char str[10];
    snprintf(str, 5, "%.4d", a.v[i]);
    out << str;
  }
  return out;
}

int cp3(const Bigint &b)const {
  if (s != b.s) return s - b.s;
  if (s == -1) return -(-*this).cp3(-b);
  if (len() != b.len()) return len()-b.len();//int
  for (int i=len()-1; i>=0; i--)
    if (v[i]!=b.v[i]) return v[i]-b.v[i];
  return 0;
}

bool operator < (const Bigint &b)const{ return cp3(b)
    <0; }
bool operator <= (const Bigint &b)const{ return cp3(b
    )<=0; }
bool operator == (const Bigint &b)const{ return cp3(b
    )==0; }
bool operator != (const Bigint &b)const{ return cp3(b
    )!=0; }
bool operator > (const Bigint &b)const{ return cp3(b)
    >0; }
bool operator >= (const Bigint &b)const{ return cp3(b
    )>=0; }

Bigint operator - () const {
  Bigint r = (*this);
  r.s = -r.s;
  return r;
}
Bigint operator + (const Bigint &b) const {
  if (s == -1) return -(-(*this)+(-b));
  if (b.s == -1) return (*this)-(-b);
  Bigint r;
  int nl = max(len(), b.len());
  r.resize(nl + 1);
  for (int i=0; i<nl; i++) {
    if (i < len()) r.v[i] += v[i];
    if (i < b.len()) r.v[i] += b.v[i];
    if(r.v[i] >= BIGMOD) {
      r.v[i+1] += r.v[i] / BIGMOD;
      r.v[i] %= BIGMOD;
    }
  }
  r.n();
  return r;
}
Bigint operator - (const Bigint &b) const {
  if (s == -1) return -(-(*this)-(-b));
  if (b.s == -1) return (*this)+(-b);
  if ((*this) < b) return -(b-(*this));
  Bigint r;
  r.resize(len());
  for (int i=0; i<len(); i++) {
    r.v[i] += v[i];
    if (i < b.len()) r.v[i] -= b.v[i];
    if (r.v[i] < 0) {
      r.v[i] += BIGMOD;
      r.v[i+1]--;
    }
  }
  r.n();
  return r;
}
Bigint operator * (const Bigint &b) {
  Bigint r;
  r.resize(len() + b.len() + 1);
  r.s = s * b.s;
  for (int i=0; i<len(); i++) {
    for (int j=0; j<b.len(); j++) {
      r.v[i+j] += v[i] * b.v[j];
      if(r.v[i+j] >= BIGMOD) {
        r.v[i+j+1] += r.v[i+j] / BIGMOD;
        r.v[i+j] %= BIGMOD;
      }
    }
  }
  r.n();
  return r;
}
Bigint operator / (const Bigint &b) {
  Bigint r;
  r.resize(max(1, len()-b.len()+1));
  int oriS = s;
  Bigint b2 = b; // b2 = abs(b)
  s = b2.s = r.s = 1;
  for (int i=r.len()-1; i>=0; i--) {
    int d=0, u=BIGMOD-1;
    while(d<u) {
      int m = (d+u+1)>>1;
      r.v[i] = m;
      if((r*b2) > (*this)) u = m-1;
      else d = m;
    }
    r.v[i] = d;
  }
  s = oriS;
  r.s = s * b.s;
  r.n();
  return r;
}
Bigint operator % (const Bigint &b) {
  return (*this)-(*this)/b*b;
}
};
```

2.2 unordered_map

```
struct Key {
  int first,second;
  Key () {}
  Key (int _x, int _y) : first(_x),  second(_y) {}
  bool operator == (const Key &b) const {
```

```
    return tie(F,S) == tie(b.F,b.S);
  }
};
struct KeyHasher {
  size_t operator()(const Key& k) const {
    return k.first + k.second*100000;
  }
};

typedef unordered_map<Key,int,KeyHasher> map_t;

int main(int argc, char** argv){
  map_t mp;
  for (int i=0; i<10; i++)
    mp[Key(i,0)] = i+1;
  for (int i=0; i<10; i++)
    printf("%d\n", mp[Key(i,0)]);

  return 0;
}
```

2.3 extc__heap

```
#include <bits/extc++.h>
typedef __gnu_pbds::priority_queue<int> heap_t;
heap_t a,b;

int main() {
  a.clear();
  b.clear();
  a.push(1);
  a.push(3);
  b.push(2);
  b.push(4);
  assert(a.top() == 3);
  assert(b.top() == 4);
  // merge two heap
  a.join(b);
  assert(a.top() == 4);
  assert(b.empty());

  return 0;
}
```

2.4 extc__balance__tree

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace std;
using namespace __gnu_pbds;
typedef tree<int,null_type,less<int>,rb_tree_tag,
    tree_order_statistics_node_update> set_t;
typedef cc_hash_table<int,int> umap_t;

int main()
{
  // Insert some entries into s.
  set_t s;
  s.insert(12);
  s.insert(505);

  // The order of the keys should be: 12, 505.
  assert(*s.find_by_order(0) == 12);
  assert(s.find_by_order(2) == end(s));

  // The order of the keys should be: 12, 505.
  assert(s.order_of_key(12) == 0);
  assert(s.order_of_key(505) == 1);

  // Erase an entry.
  s.erase(12);

  // The order of the keys should be: 505.
  assert(*s.find_by_order(0) == 505);

  // The order of the keys should be: 505.
  assert(s.order_of_key(505) == 0);
}
```

2.5 Heavy Light Decomposition(PEC ver.)

```
#define REP(i, s, e) for(int i = (s); i <= (e); i++)
#define REPD(i, s, e) for(int i = (s); i >= (e); i--)
const int MAXN = 100010;
const int LOG  = 19;
struct HLD{
  int n;
  vector<int> g[MAXN];
  int sz[MAXN], dep[MAXN];
  int ts, tid[MAXN], tdi[MAXN], tl[MAXN], tr[MAXN];
  //  ts : timestamp , useless after yutruli
  //  tid[ u ] : pos. of node u in the seq.
  //  tdi[ i ] : node at pos i of the seq.
  //  tl , tr[ u ] : subtree interval in the seq. of
      node u
  int prt[MAXN][LOG], head[MAXN];
  // head[ u ] : head of the chain contains u
  void dfssz(int u, int p){
    dep[u] = dep[p] + 1;
    prt[u][0] = p; sz[u] = 1; head[u] = u;
    for(int& v:g[u]) if(v != p){
      dep[v] = dep[u] + 1;
      dfssz(v, u);
      sz[u] += sz[v];
    }
  }
  void dfshl(int u){
    ts++;
    tid[u] = tl[u] = tr[u] = ts;
    tdi[tid[u]] = u;
    sort(ALL(g[u]),
         [&](int a, int b){return sz[a] > sz[b];});
    bool flag = 1;
    for(int& v:g[u]) if(v != prt[u][0]){
      if(flag) head[v] = head[u], flag = 0;
      dfshl(v);
      tr[u] = tr[v];
    }
  }
  inline int lca(int a, int b){
    if(dep[a] > dep[b]) swap(a, b);
    int diff = dep[b] - dep[a];
    REPD(k, LOG-1, 0) if(diff & (1<<k)){
      b = prt[b][k];
    }
    if(a == b) return a;
    REPD(k, LOG-1, 0) if(prt[a][k] != prt[b][k]){
      a = prt[a][k]; b = prt[b][k];
    }
    return prt[a][0];
  }
  void init( int _n ){
    n = _n; REP( i , 1 , n ) g[ i ].clear();
  }
  void addEdge( int u , int v ){
    g[ u ].push_back( v );
    g[ v ].push_back( u );
  }
  void yutruli(){
    dfssz(1, 0);
    ts = 0;
    dfshl(1);
    REP(k, 1, LOG-1) REP(i, 1, n)
      prt[i][k] = prt[prt[i][k-1]][k-1];
  }
  vector< PII > getPath( int u , int v ){
    vector< PII > res;
    while( tid[ u ] < tid[ head[ v ] ] ){
      res.push_back( PII(tid[ head[ v ] ] , tid[ v ]) )
          ;
      v = prt[ head[ v ] ][ 0 ];
    }
    res.push_back( PII( tid[ u ] , tid[ v ] ) );
    reverse( ALL( res ) );
    return res;
    /* res : list of intervals from u to v
     * u must be ancestor of v
     * usage :
     * vector< PII >& path = tree.getPath( u , v )
     * for( PII tp : path ) {
     *   int l , r;tie( l , r ) = tp;
     *   upd( l , r );
     *   uu = tree.tdi[ l ] , vv = tree.tdi[ r ];
     *   uu ~> vv is a heavy path on tree
     * }
```

```
    */
  }
} tree;
```

2.6 Disjoint Set

```
struct DisjointSet {
  // save() is like recursive
  // undo() is like return
  int n, fa[MXN], sz[MXN];
  vector<pair<int*,int>> h;
  vector<int> sp;
  void init(int tn) {
    n=tn;
    for (int i=0; i<n; i++) {
      fa[i]=i;
      sz[i]=1;
    }
    sp.clear(); h.clear();
  }
  void assign(int *k, int v) {
    h.PB({k, *k});
    *k=v;
  }
  void save() { sp.PB(SZ(h)); }
  void undo() {
    assert(!sp.empty());
    int last=sp.back(); sp.pop_back();
    while (SZ(h)!=last) {
      auto x=h.back(); h.pop_back();
      *x.F=x.S;
    }
  }
  int f(int x) {
    while (fa[x]!=x) x=fa[x];
    return x;
  }
  void uni(int x, int y) {
    x=f(x); y=f(y);
    if (x==y) return ;
    if (sz[x]<sz[y]) swap(x, y);
    assign(&sz[x], sz[x]+sz[y]);
    assign(&fa[y], x);
  }
}djs;
```

2.7 Treap

```
const int MEM = 16000004;
struct Treap {
  static Treap nil, mem[MEM], *pmem;
  Treap *l, *r;
  char val;
  int size;
  Treap () : l(&nil), r(&nil), size(0) {}
  Treap (char _val) :
    l(&nil), r(&nil), val(_val), size(1) {}
} Treap::nil, Treap::mem[MEM], *Treap::pmem = Treap::
    mem;

int size(const Treap *t) { return t->size; }
void pull(Treap *t) {
  if (!size(t)) return;
  t->size = size(t->l) + size(t->r) + 1;
}
Treap* merge(Treap *a, Treap *b) {
  if (!size(a)) return b;
  if (!size(b)) return a;
  Treap *t;
  if (rand() % (size(a) + size(b)) < size(a)) {
    t = new (Treap::pmem++) Treap(*a);
    t->r = merge(a->r, b);
  } else {
    t = new (Treap::pmem++) Treap(*b);
    t->l = merge(a, b->l);
  }
  pull(t);
  return t;
}
void split(Treap *t, int k, Treap *&a, Treap *&b) {
  if (!size(t)) a = b = &Treap::nil;
  else if (size(t->l) + 1 <= k) {
    a = new (Treap::pmem++) Treap(*t);
    split(t->r, k - size(t->l) - 1, a->r, b);
    pull(a);
  } else {
    b = new (Treap::pmem++) Treap(*t);
    split(t->l, k, a, b->l);
    pull(b);
  }
}

int nv;
Treap *rt[50005];

void print(const Treap *t) {
  if (!size(t)) return;
  print(t->l);
  cout << t->val;
  print(t->r);
}

int main(int argc, char** argv) {
  IOS;
  rt[nv=0] = &Treap::nil;
  Treap::pmem = Treap::mem;
  int Q, cmd, p, c, v;
  string s;
  cin >> Q;
  while (Q--) {
    cin >> cmd;
    if (cmd == 1) {
      // insert string s after position p
      cin >> p >> s;
      Treap *tl, *tr;
      split(rt[nv], p, tl, tr);
      for (int i=0; i<SZ(s); i++)
        tl = merge(tl, new (Treap::pmem++) Treap(s[i]))
            ;
      rt[++nv] = merge(tl, tr);
    } else if (cmd == 2) {
      // remove c characters starting at position
      Treap *tl, *tm, *tr;
      cin >> p >> c;
      split(rt[nv], p-1, tl, tm);
      split(tm, c, tm, tr);
      rt[++nv] = merge(tl, tr);
    } else if (cmd == 3) {
      // print c characters starting at position p, in
          version v
      Treap *tl, *tm, *tr;
      cin >> v >> p >> c;
      split(rt[v], p-1, tl, tm);
      split(tm, c, tm, tr);
      print(tm);
      cout << "\n";
    }
  }
  return 0;
}
```

3 Graph

3.1 BCC Edge

```
struct BccEdge {
  static const int MXN = 100005;
  struct Edge { int v,eid; };
  int n,m,step,par[MXN],dfn[MXN],low[MXN];
  vector<Edge> E[MXN];
  DisjointSet djs;
  void init(int _n) {
    n = _n; m = 0;
    for (int i=0; i<n; i++) E[i].clear();
    djs.init(n);
  }
  void add_edge(int u, int v) {
    E[u].PB({v, m});
    E[v].PB({u, m});
    m++;
  }
  void DFS(int u, int f, int f_eid) {
    par[u] = f;
    dfn[u] = low[u] = step++;
```

```
    for (auto it:E[u]) {
      if (it.eid == f_eid) continue;
      int v = it.v;
      if (dfn[v] == -1) {
        DFS(v, u, it.eid);
        low[u] = min(low[u], low[v]);
      } else {
        low[u] = min(low[u], dfn[v]);
      }
    }
  }
  void solve() {
    step = 0;
    memset(dfn, -1, sizeof(int)*n);
    for (int i=0; i<n; i++) {
      if (dfn[i] == -1) DFS(i, i, -1);
    }
    djs.init(n);
    for (int i=0; i<n; i++) {
      if (low[i] < dfn[i]) djs.uni(i, par[i]);
    }
  }
}graph;
```

3.2 BCC Vertex

```
struct BccVertex {
  int n,nBcc,step,root,dfn[MXN],low[MXN];
  vector<int> E[MXN], ap;
  vector<PII> bcc[MXN];
  int top;
  PII stk[MXN];
  void init(int _n) {
    n = _n;
    nBcc = step = 0;
    for (int i=0; i<n; i++) E[i].clear();
  }
  void add_edge(int u, int v) {
    E[u].PB(v);
    E[v].PB(u);
  }
  void DFS(int u, int f) {
    dfn[u] = low[u] = step++;
    int son = 0;
    for (auto v:E[u]) {
      if (v == f) continue;
      if (dfn[v] == -1) {
        son++;
        stk[top++] = {u,v};
        DFS(v,u);
        if (low[v] >= dfn[u]) {
          if(v != root) ap.PB(v);
          do {
            assert(top > 0);
            bcc[nBcc].PB(stk[--top]);
          } while (stk[top] != PII(u,v));
          nBcc++;
        }
        low[u] = min(low[u], low[v]);
      } else {
        if (dfn[v] < dfn[u]) stk[top++] = PII(u,v);
        low[u] = min(low[u],dfn[v]);
      }
    }
    if (u == root && son > 1) ap.PB(u);
  }
  // return the edges of each bcc;
  vector<vector<PII>> solve() {
    vector<vector<PII>> res;
    for (int i=0; i<n; i++) {
      dfn[i] = low[i] = -1;
    }
    ap.clear();
    for (int i=0; i<n; i++) {
      if (dfn[i] == -1) {
        top = 0;
        root = i;
        DFS(i,i);
      }
    }
    for(int i = 0; i < nBcc; i ++){
    res.PB(bcc[i]);
    bcc[i].clear();
  }
    return res;
  }
}graph;
```

3.3 Strongly Connected Components

```
struct Scc{
  int n, nScc, vst[MXN], bln[MXN];
  vector<int> E[MXN], rE[MXN], vec;
  void init(int _n){
    n = _n;
    for (int i=0; i<n; i++){
      E[i].clear();
      rE[i].clear();
    }
  }
  void add_edge(int u, int v){
    E[u].PB(v);
    rE[v].PB(u);
  }
  void DFS(int u){
    vst[u]=1;
    for (auto v : E[u])
      if (!vst[v]) DFS(v);
    vec.PB(u);
  }
  void rDFS(int u){
    vst[u] = 1;
    bln[u] = nScc;
    for (auto v : rE[u])
      if (!vst[v]) rDFS(v);
  }
  void solve(){
    nScc = 0;
    vec.clear();
    for (int i=0; i<n; i++) vst[i] = 0;
    for (int i=0; i<n; i++)
      if (!vst[i]) DFS(i);
    reverse(vec.begin(),vec.end());
    for (int i=0; i<n; i++) vst[i] = 0;
    for (auto v : vec){
      if (!vst[v]){
        rDFS(v);
        nScc++;
      }
    }
  }
};
```

3.4 Heavy Light Decomposition

```
struct HLD{
  int n;
  vector<int>edge[MXN];
  int siz[MXN], dep[MXN];
  int cntp, re[MXN], in[MXN], out[MXN];
  int prt[MAXN][20], head[MAXN];
  void pre(int u, int pa){
    dep[u] = dep[pa] + 1;
    prt[0][u] = pa; siz[u] = 1; head[u] = u;
    for(int v : edge[u]){
      if( v == pa ) continue;
      pre(v, u);
      siz[u] += siz[v];
    }
    return ;
  }
  void dfs(int u){
    cntp++;
    in[u] = cntp;
    re[ cntp ] = u;
    sort(ALL(g[u]), [&](int a, int b){ return siz[a] >
        siz[b] });
    bool f = 1;
    for(int &v : edge[u]) if(v != prt[0][u]){
      if(f) head[v] = head[u], f = 0;
      dfs(v);
    }
    out[u] = cntp;
  }
  void addEdge(int u, int v){
    edge[u].pb(v);
```

```
    edge[v].pb(u);
  }
  void init(int _n){
    n = _n;
    rep1(i, 1, n+1) edge[i].clear();
  }
  void solve(){
    pre(1, 0);
    cntp = 0;
    dfs(1);
    rep1(i, 1, 20) rep1(j, 1, n+1){
      prt[i][j] = prt[i-1][ prt[i-1][j] ];
    }
  }
  vector< PII >getpath( int u, int v ){
    vector<PII> res;
    while( in[u] < in[ head[v] ] ){
      res.pb( MP(in[ head[v] ], in[v]) );
      v = prt[ head[v] ][0];
    }
    res.pb( MP(in[u], in[v]) );
    reverse( ALL(res) );
    return res;
  }
}tree;
```

3.5 Maximum Clique

```
class MaxClique {
public:
    static const int MV = 210;

    int V;
    int el[MV][MV/30+1];
    int dp[MV];
    int ans;
    int s[MV][MV/30+1];
    vector<int> sol;

    void init(int v) {
        V = v; ans = 0;
        FZ(el); FZ(dp);
    }

    /* Zero Base */
    void addEdge(int u, int v) {
        if(u > v) swap(u, v);
        if(u == v) return;
        el[u][v/32] |= (1<<(v%32));
    }

    bool dfs(int v, int k) {
        int c = 0, d = 0;
        for(int i=0; i<(V+31)/32; i++) {
            s[k][i] = el[v][i];
            if(k != 1) s[k][i] &= s[k-1][i];
            c += __builtin_popcount(s[k][i]);
        }
        if(c == 0) {
            if(k > ans) {
                ans = k;
                sol.clear();
                sol.push_back(v);
                return 1;
            }
            return 0;
        }
        for(int i=0; i<(V+31)/32; i++) {
            for(int a = s[k][i]; a ; d++) {
                if(k + (c-d) <= ans) return 0;
                int lb = a&(-a), lg = 0;
                a ^= lb;
                while(lb!=1) {
                    lb = (unsigned int)(lb) >> 1;
                    lg ++;
                }
                int u = i*32 + lg;
                if(k + dp[u] <= ans) return 0;
                if(dfs(u, k+1)) {
                    sol.push_back(v);
                    return 1;
                }
            }
        }
        return 0;
    }

    int solve() {
        for(int i=V-1; i>=0; i--) {
            dfs(i, 1);
            dp[i] = ans;
        }
        return ans;
    }
};
```

3.6 MinimumMeanCycle

```
/* minimum mean cycle */
const int MAXE = 1805;
const int MAXN = 35;
const double inf = 1029384756;
const double eps = 1e-6;
struct Edge {
  int v,u;
  double c;
};
int n,m,prv[MAXN][MAXN], prve[MAXN][MAXN], vst[MAXN];
Edge e[MAXE];
vector<int> edgeID, cycle, rho;
double d[MAXN][MAXN];
inline void bellman_ford() {
  for(int i=0; i<n; i++) d[0][i]=0;
  for(int i=0; i<n; i++) {
    fill(d[i+1], d[i+1]+n, inf);
    for(int j=0; j<m; j++) {
      int v = e[j].v, u = e[j].u;
      if(d[i][v]<inf && d[i+1][u]>d[i][v]+e[j].c) {
        d[i+1][u] = d[i][v]+e[j].c;
        prv[i+1][u] = v;
        prve[i+1][u] = j;
      }
    }
  }
}
double karp_mmc() {
  // returns inf if no cycle, mmc otherwise
  double mmc=inf;
  int st = -1;
  bellman_ford();
  for(int i=0; i<n; i++) {
    double avg=-inf;
    for(int k=0; k<n; k++) {
      if(d[n][i]<inf-eps) avg=max(avg,(d[n][i]-d[k][i])
          /(n-k));
      else avg=max(avg,inf);
    }
    if (avg < mmc) tie(mmc, st) = tie(avg, i);
  }
  for(int i=0; i<n; i++) vst[i] = 0;
  edgeID.clear(); cycle.clear(); rho.clear();
  for (int i=n; !vst[st]; st=prv[i--][st]) {
    vst[st]++;
    edgeID.PB(prve[i][st]);
    rho.PB(st);
  }
  while (vst[st] != 2) {
    int v = rho.back(); rho.pop_back();
    cycle.PB(v);
    vst[v]++;
  }
  reverse(ALL(edgeID));
  edgeID.resize(SZ(cycle));
  return mmc;
}
```

4 Flow

4.1 Dinic

```
struct Dinic{
  static const int MXN = 10000;
  struct Edge{ int v,f,re; };
```

```
  int n,s,t,level[MXN];
  vector<Edge> E[MXN];
  void init(int _n, int _s, int _t){
    n = _n; s = _s; t = _t;
    for (int i=0; i<n; i++) E[i].clear();
  }
  void add_edge(int u, int v, int f){
    E[u].PB({v,f,SZ(E[v])});
    E[v].PB({u,0,SZ(E[u])-1});
  }
  bool BFS(){
    for (int i=0; i<n; i++) level[i] = -1;
    queue<int> que;
    que.push(s);
    level[s] = 0;
    while (!que.empty()){
      int u = que.front(); que.pop();
      for (auto it : E[u]){
        if (it.f > 0 && level[it.v] == -1){
          level[it.v] = level[u]+1;
          que.push(it.v);
        }
      }
    }
    return level[t] != -1;
  }
  int DFS(int u, int nf){
    if (u == t) return nf;
    int res = 0;
    for (auto &it : E[u]){
      if (it.f > 0 && level[it.v] == level[u]+1){
        int tf = DFS(it.v, min(nf,it.f));
        res += tf; nf -= tf; it.f -= tf;
        E[it.v][it.re].f += tf;
        if (nf == 0) return res;
      }
    }
    if (!res) level[u] = -1;
    return res;
  }
  int flow(int res=0){
    while ( BFS() )
      res += DFS(s,2147483647);
    return res;
  }
}flow;
```

4.2 Cost Flow

```
typedef pair<long long, long long> pll;
struct CostFlow {
  static const int MXN = 205;
  static const long long INF = 102938475610293847LL;
  struct Edge {
    int v, r;
    long long f, c;
  };
  int n, s, t, prv[MXN], prvL[MXN], inq[MXN];
  long long dis[MXN], fl, cost;
  vector<Edge> E[MXN];
  void init(int _n, int _s, int _t) {
    n = _n; s = _s; t = _t;
    for (int i=0; i<n; i++) E[i].clear();
    fl = cost = 0;
  }
  void add_edge(int u, int v, long long f, long long c)
      {
    E[u].PB({v, SZ(E[v])  , f,  c});
    E[v].PB({u, SZ(E[u])-1, 0, -c});
  }
  pll flow() {
    while (true) {
      for (int i=0; i<n; i++) {
        dis[i] = INF;
        inq[i] = 0;
      }
      dis[s] = 0;
      queue<int> que;
      que.push(s);
      while (!que.empty()) {
        int u = que.front(); que.pop();
        inq[u] = 0;
        for (int i=0; i<SZ(E[u]); i++) {
          int v = E[u][i].v;
          long long w = E[u][i].c;
          if (E[u][i].f > 0 && dis[v] > dis[u] + w) {
            prv[v] = u; prvL[v] = i;
            dis[v] = dis[u] + w;
            if (!inq[v]) {
              inq[v] = 1;
              que.push(v);
            }
          }
        }
      }
      if (dis[t] == INF) break;
      long long tf = INF;
      for (int v=t, u, l; v!=s; v=u) {
        u=prv[v]; l=prvL[v];
        tf = min(tf, E[u][l].f);
      }
      for (int v=t, u, l; v!=s; v=u) {
        u=prv[v]; l=prvL[v];
        E[u][l].f -= tf;
        E[v][E[u][l].r].f += tf;
      }
      cost += tf * dis[t];
      fl += tf;
    }
    return {fl, cost};
  }
}flow;
```

4.3 Kuhn Munkres

```
struct KM{
// Maximum Bipartite Weighted Matching (Perfect Match)
  static const int MXN = 650;
  static const int INF = 2147483647; // long long
  int n,match[MXN],vx[MXN],vy[MXN];
  int edge[MXN][MXN],lx[MXN],ly[MXN],slack[MXN];
  // ^^^^ long long
  void init(int _n){
    n = _n;
    for (int i=0; i<n; i++)
      for (int j=0; j<n; j++)
        edge[i][j] = 0;
  }
  void add_edge(int x, int y, int w){ // long long
    edge[x][y] = w;
  }
  bool DFS(int x){
    vx[x] = 1;
    for (int y=0; y<n; y++){
      if (vy[y]) continue;
      if (lx[x]+ly[y] > edge[x][y]){
        slack[y] = min(slack[y], lx[x]+ly[y]-edge[x][y
            ]);
      } else {
        vy[y] = 1;
        if (match[y] == -1 || DFS(match[y])){
          match[y] = x;
          return true;
        }
      }
    }
    return false;
  }
  int solve(){
    fill(match,match+n,-1);
    fill(lx,lx+n,-INF);
    fill(ly,ly+n,0);
    for (int i=0; i<n; i++)
      for (int j=0; j<n; j++)
        lx[i] = max(lx[i], edge[i][j]);
    for (int i=0; i<n; i++){
      fill(slack,slack+n,INF);
      while (true){
        fill(vx,vx+n,0);
        fill(vy,vy+n,0);
        if ( DFS(i) ) break;
        int d = INF; // long long
        for (int j=0; j<n; j++)
          if (!vy[j]) d = min(d, slack[j]);
        for (int j=0; j<n; j++){
          if (vx[j]) lx[j] -= d;
          if (vy[j]) ly[j] += d;
          else slack[j] -= d;
```

```
      }
    }
  }
  int res=0;
  for (int i=0; i<n; i++)
    res += edge[match[i]][i];
  return res;
 }
}graph;
```

4.4 Maximum Simple Graph Matching

```
struct GenMatch { // 1-base
  static const int MAXN = 514;
  int V;
  bool el[MAXN][MAXN];
  int pr[MAXN];
  bool inq[MAXN],inp[MAXN],inb[MAXN];
  queue<int> qe;
  int st,ed;
  int nb;
  int bk[MAXN],djs[MAXN];
  int ans;
  void init(int _V) {
    V = _V;
    for(int i = 0; i <= V; i++) {
      for(int j = 0; j <= V; j++) el[i][j] = 0;
      pr[i] = bk[i] = djs[i] = 0;
      inq[i] = inp[i] = inb[i] = 0;
    }
    ans = 0;
  }
  void add_edge(int u, int v) {
    el[u][v] = el[v][u] = 1;
  }
  int lca(int u,int v) {
    for(int i = 0; i <= V; i++) inp[i] = 0;
    while(1) {
      u = djs[u];
      inp[u] = true;
      if(u == st) break;
      u = bk[pr[u]];
    }
    while(1) {
      v = djs[v];
      if(inp[v]) return v;
      v = bk[pr[v]];
    }
    return v;
  }
  void upd(int u) {
    int v;
    while(djs[u] != nb) {
      v = pr[u];
      inb[djs[u]] = inb[djs[v]] = true;
      u = bk[v];
      if(djs[u] != nb) bk[u] = v;
    }
  }
  void blo(int u,int v) {
    nb = lca(u,v);
    for (int i=0; i<=V; i++) inb[i] = 0;
    upd(u); upd(v);
    if(djs[u] != nb) bk[u] = v;
    if(djs[v] != nb) bk[v] = u;
    for(int tu = 1; tu <= V; tu++)
      if(inb[djs[tu]]) {
        djs[tu] = nb;
        if(!inq[tu]){
          qe.push(tu);
          inq[tu] = 1;
        }
      }
  }
  void flow() {
    for(int i = 1; i <= V; i++) {
      inq[i] = 0;
      bk[i] = 0;
      djs[i] = i;
    }

    while(qe.size()) qe.pop();
    qe.push(st);
    inq[st] = 1;
    ed = 0;
    while(qe.size()) {
      int u = qe.front(); qe.pop();
      for(int v = 1; v <= V; v++)
        if(el[u][v] && (djs[u] != djs[v]) && (pr[u] !=
            v)) {
          if((v == st) || ((pr[v] > 0) && bk[pr[v]] >
              0))
            blo(u,v);
          else if(bk[v] == 0) {
            bk[v] = u;
            if(pr[v] > 0) {
              if(!inq[pr[v]]) qe.push(pr[v]);
            } else {
              ed = v;
              return;
            }
          }
        }
    }
  }
  void aug() {
    int u,v,w;
    u = ed;
    while(u > 0) {
      v = bk[u];
      w = pr[v];
      pr[v] = u;
      pr[u] = v;
      u = w;
    }
  }
  int solve() {
    for(int i = 0; i <= V; i++) pr[i] = 0;
    for(int u = 1; u <= V; u++)
      if(pr[u] == 0) {
        st = u;
        flow();
        if(ed > 0) {
          aug();
          ans ++;
        }
      }
    return ans;
  }
}G;

int main() {
  G.init(V);
  for(int i=0; i<E; i++) {
    int u, v;
    cin >> u >> v;
    G.add_edge(u, v);
  }
  cout << G.solve() << endl;
}
```

4.5 Minimum Weight Matching (Clique version)

```
struct Graph {
  // Minimum General Weighted Matching (Perfect Match)
      0-base
  static const int MXN = 105;

  int n, edge[MXN][MXN];
  int match[MXN],dis[MXN],onstk[MXN];
  vector<int> stk;

  void init(int _n) {
    n = _n;
    for (int i=0; i<n; i++)
      for (int j=0; j<n; j++)
        edge[i][j] = 0;
  }
  void add_edge(int u, int v, int w) {
    edge[u][v] = edge[v][u] = w;
  }
  bool SPFA(int u){
    if (onstk[u]) return true;
    stk.PB(u);
    onstk[u] = 1;
    for (int v=0; v<n; v++){
```

```
      if (u != v && match[u] != v && !onstk[v]){
        int m = match[v];
        if (dis[m] > dis[u] - edge[v][m] + edge[u][v]){
          dis[m] = dis[u] - edge[v][m] + edge[u][v];
          onstk[v] = 1;
          stk.PB(v);
          if (SPFA(m)) return true;
          stk.pop_back();
          onstk[v] = 0;
        }
      }
    }
    onstk[u] = 0;
    stk.pop_back();
    return false;
  }

  int solve() {
    // find a match
    for (int i=0; i<n; i+=2){
      match[i] = i+1;
      match[i+1] = i;
    }
    while (true){
      int found = 0;
      for (int i=0; i<n; i++)
        dis[i] = onstk[i] = 0;
      for (int i=0; i<n; i++){
        stk.clear();
        if (!onstk[i] && SPFA(i)){
          found = 1;
          while (SZ(stk)>=2){
            int u = stk.back(); stk.pop_back();
            int v = stk.back(); stk.pop_back();
            match[u] = v;
            match[v] = u;
          }
        }
      }
      if (!found) break;
    }
    int ret = 0;
    for (int i=0; i<n; i++)
      ret += edge[i][match[i]];
    ret /= 2;
    return ret;
  }
}graph;
```

5 Math

5.1 ax+by=gcd

```
typedef pair<int, int> pii;

pii gcd(int a, int b){
  if(b == 0) return make_pair(1, 0);
  else{
    int p = a / b;
    pii q = gcd(b, a % b);
    return make_pair(q.second, q.first - q.second * p);
  }
}
```

5.2 Segmented Sieve

```
bool sieve[MXN];
void linear_sieve(){
  vector<int> prime;
  for(int i=2; i< MXN; ++i){
    if(!sieve[i]) prime.push_back(i);
    for(int j = 0; i*prime[j] < N; ++j){
      sieve[i*prime[j]] = true;
      if(i % prime[j] == 0) break;
    }
  }
}
```

5.3 Fast Fourier Transform

```
struct cp{
    double a,b;
    cp(){};
    cp(double _a, double _b){
        a = _a, b = _b;
    }
    cp operator +(const cp &o){ return cp(a+o.a, b+o.b)
        ; }
    cp operator -(const cp &o){ return cp(a-o.a, b-o.b)
        ; }
    cp operator *(const cp &o){ return cp(a*o.a-b*o.b,
        b*o.a+a*o.b); }
    cp operator *(const double &o){ return cp(a*o, b*o)
        ; }
    cp operator !(){ return cp(a, -b); }
}w[MXN];
int pos[MXN];
void fft_init(int len){
    int j = 0;
    while((1<<j) < len) j++;
    j--;
    rep(i, len) pos[i] = pos[i>>1]>>1 | ((i&1)<<j);
    return ;
}
void fft(cp *x, int len, int sta){
    rep(i, len) if(i < pos[i]) swap(x[i], x[pos[i]]);
    w[0] = cp(1,0);
    for(unsigned i = 2; i <= len; i <<= 1){
        cp g = cp(cos(2*PI/i), sin(2*PI/i)*sta);
        for(int j = i>>1; j >= 0; j -= 2) w[j] = w[j
            >>1];
        for(int j = 1; j < (i>>1); j += 2) w[j] = w[j
            -1]*g;
        for(int j = 0; j < len; j += i){
            cp *a = x+j, *b = a+(i>>1);
            rep(l, i>>1){
                cp o = b[l]*w[l];
                b[l] = a[l]-o;
                a[l] = a[l]+o;
            }
        }
    }
  if(sta == -1) rep(i, len) x[i].a /= len, x[i].b /=
      len;
    return ;
}
cp xt[MXN], yt[MXN], zt[MXN];
LL st[3][MXN];
void FFT(int a, int b, int l1, int l2, int c){
    int len = 1;
    while(len <= (l1+l2)>>1) len <<= 1;
    fft_init(len);
    rep1(i, l1>>1, len) xt[i].a = xt[i].b = 0;
    rep(i, l1) (i&1 ? xt[i>>1].b : xt[i>>1].a) = st[a][
        i];
    fft(xt, len, 1);

    rep1(i, l2>>1, len) yt[i].a = yt[i].b = 0;
    rep(i, l1) (i&1 ? yt[i>>1].b : yt[i>>1].a) = st[b][
        i];
    fft(yt, len, 1);


    rep(i, len>>1){
        int j = len - 1&len - i;
        zt[i] = xt[i]*yt[i] - (xt[i]-!xt[j])*(yt[i]-!yt
            [j])*(w[i]+cp(1,0))*0.25;
    }
    rep1(i, len>>1, len){
        int j = len - 1&len - i;
        zt[i] = xt[i]*yt[i] - (xt[i]-!xt[j])*(yt[i]-!yt
            [j])*(cp(1,0)-w[i^len>>1])*0.25;
    }
    fft(zt, len, -1);
    rep(i, l1 + l2 - 1){
        if(i&1) st[c][i] = (LL)(zt[i>>1].b+0.5);
        else st[c][i] = (LL)(zt[i>>1].a+0.5);
    }
    return ;
}
```

5.4 FFT (Pec.ver)

```
// const int MAXN = 262144;
// (must be 2^k)
// before any usage, run pre_fft() first
typedef long double ld;
typedef complex<ld> cplx;
const ld PI = acosl(-1);
const cplx I(0, 1);
cplx omega[MAXN+1];
void pre_fft(){
  for(int i=0; i<=MAXN; i++)
    omega[i] = exp(i * 2 * PI / MAXN * I);
}
// n must be 2^k
void fft(int n, cplx a[], bool inv=false){
  int basic = MAXN / n;
  int theta = basic;
  for (int m = n; m >= 2; m >>= 1) {
    int mh = m >> 1;
    for (int i = 0; i < mh; i++) {
      cplx w = omega[inv ? MAXN-(i*theta%MAXN)
                         : i*theta%MAXN];
      for (int j = i; j < n; j += m) {
        int k = j + mh;
        cplx x = a[j] - a[k];
        a[j] += a[k];
        a[k] = w * x;
      }
    }
    theta = (theta * 2) % MAXN;
  }
  int i = 0;
  for (int j = 1; j < n - 1; j++) {
    for (int k = n >> 1; k > (i ^= k); k >>= 1);
    if (j < i) swap(a[i], a[j]);
  }
  if(inv) for (i = 0; i < n; i++) a[i] /= n;
}
```

5.5 Gauss Elimination

```
const int MAX = 300;
const double EPS = 1e-8;

double mat[MAX][MAX];
void Gauss(int n) {
  for(int i=0; i<n; i++) {
    bool ok = 0;
    for(int j=i; j<n; j++) {
      if(fabs(mat[j][i]) > EPS) {
        swap(mat[j], mat[i]);
        ok = 1;
        break;
      }
    }
    if(!ok) continue;

    double fs = mat[i][i];
    for(int j=i+1; j<n; j++) {
      double r = mat[j][i] / fs;
      for(int k=i; k<n; k++) {
        mat[j][k] -= mat[i][k] * r;
      }
    }
  }
}
```

5.6 Matrix

```
struct Mat{
  int n, m;
  LL a[MXN][MXN];
  void init(int _n, int _m){
    n = _n, m = _m;
    rep1(i, 1, n+1) rep1(j, 1, m+1){
      a[i][j] = 0;
    }
  }
  Mat operator *(const Mat & p2){
    Mat res; res.init(n, p2.m);
    rep1(i, 1, n+1) rep1(j, 1, m+1) rep1(k, 1, p2.m+1){
      res.a[i][k] = (res.a[i][k] + a[i][j]*p2.a[j][k])%
          mod;
    }
    return res;
  }
  Mat operator ^(const LL & p2){
    LL t = p2 - 1;
    Mat res = *this, x = *this;
    while(t){
      if(t & 1){
        res = res*x;
      }
      t >>= 1;
      x = x*x;
    }
    return res;
  }
};
```

5.7 Miller Rabin

```
// n < 4,759,123,141        3 :  2, 7, 61
// n < 1,122,004,669,633    4 :  2, 13, 23, 1662803
// n < 3,474,749,660,383          6 :  pirmes <= 13
// n < 2^64                       7 :
// 2, 325, 9375, 28178, 450775, 9780504, 1795265022
// Make sure testing integer is in range [2, n-2] if
// you want to use magic.
long long mult(LL a, LL b, LL mod){
  a %= mod, b %= mod;
  LL res = 0;
  while(b){
    if(b & 1) res = (res + a) % mod;
    b >>= 1;
    a = (a<<1)%mod;
  }
  return res;
}
long long power(long long x,long long p,long long mod){
  long long s=1,m=x;
  while(p) {
    if(p&1) s=mult(s,m,mod);
    p>>=1;
    m=mult(m,m,mod);
  }
  return s;
}
bool witness(long long a,long long n,long long u,int t)
    {
  long long x=power(a,u,n);
  for(int i=0;i<t;i++) {
    long long nx=mult(x,x,n);
    if(nx==1&&x!=1&&x!=n-1) return 1;
    x=nx;
  }
  return x!=1;
}
bool miller_rabin(long long n,int s=100) {
  // iterate s times of witness on n
  // return 1 if prime, 0 otherwise
  if(n<2) return 0;
  if(!(n&1)) return n==2;
  long long u=n-1;
  int t=0;
  // n-1 = u*2^t
  while(!(u&1)) {
    u>>=1;
    t++;
  }
  while(s--) {
    long long a=randll()%(n-1)+1;
    if(witness(a,n,u,t)) return 0;
  }
  return 1;
}
```

5.8 Pollard Rho

```
// does not work when n is prime
long long modit(long long x,long long mod) {
  if(x>=mod) x-=mod;
```

```
  //if(x<0) x+=mod;
  return x;
}
long long mult(long long x,long long y,long long mod) {
  long long s=0,m=x%mod;
  while(y) {
    if(y&1) s=modit(s+m,mod);
    y>>=1;
    m=modit(m+m,mod);
  }
  return s;
}
long long f(long long x,long long mod) {
  return modit(mult(x,x,mod)+1,mod);
}
long long pollard_rho(long long n) {
  if(!(n&1)) return 2;
  while (true) {
    long long y=2, x=rand()%(n-1)+1, res=1;
    for (int sz=2; res==1; sz*=2) {
      for (int i=0; i<sz && res<=1; i++) {
        x = f(x, n);
        res = __gcd(abs(x-y), n);
      }
      y = x;
    }
    if (res!=0 && res!=n) return res;
  }
}
```

5.9 Theorem

5.9.1 Lucas' Theorem

For non-negative integer n, m and prime p, $\binom{m}{n} \equiv \prod_{i=0}^{k} \binom{m_i}{n_i} \pmod{p}$ where m_i is the i-th digit of m in base p.

5.9.2 Sum of Two Squares Thm (Legendre)

For a given positive integer n, let
$D_1 = (\#$ of positive integers d dividing N that $1 \equiv d \pmod 4)$
$D_3 = (\#$ of positive integers d dividing N that $3 \equiv d \pmod 4)$
then n can be written as a sum of two squares in exactly $R(n) = 4(D_1 - D_3)$ ways.

5.9.3 Difference of D1-D3 Thm

let $n = 2^t \cdot (p_1^{e_1} \cdot ... \cdot p_r^{e_r}) \cdots (q_1^{f_1} \cdot ... \cdot q_s^{f_s})$
where p_i, q_i are primes and $1 \equiv p_i \pmod 4, 3 \equiv q_i \pmod 4$
then $D_1 - D_3 = \begin{cases} (e_1+1)(e_2+1)...(e_r+1), & \text{if } f_i \text{ all even} \\ 0, & \text{if any } f_i \text{ is odd} \end{cases}$

5.9.4 Krush–Kuhn–Tucker Conditions

Stationarity
For maximizing $f(x)$: $\nabla f(x^*) = \sum_{i=1}^{m} \mu_i \nabla g_i(x^*) + \sum_{j=1}^{l} \lambda_j \nabla h_j(x^*)$
For minimizing $f(x)$: $-\nabla f(x^*) = \sum_{i=1}^{m} \mu_i \nabla g_i(x^*) + \sum_{j=1}^{l} \lambda_j \nabla h_j(x^*)$

Primal feasibility
$g_i(x^*) \leq 0, \text{ for all } i = 1, \ldots, m$
$h_j(x^*) = 0, \text{ for all } j = 1, \ldots, l$

Dual feasibility
$\mu_i \geq 0, \text{ for all } i = 1, \ldots, m$

Complementary slackness
$\mu_i g_i(x^*) = 0, \text{for all } i = 1, \ldots, m$

5.9.5 Chinese remainder theorem

$x \equiv r_i \mod p_i$
$N = \prod p_i$
$N_i = N/p_i$
$x \equiv \sum r_i N_i (N_i)_{p_i}^{-1} \mod N$

6 Geometry

6.1 Point operators

```
#define x first
#define y second

#define cpdd const pdd
struct pdd : pair<double, double> {
    using pair<double, double>::pair;

    pdd operator + (cpdd &p) const {
        return {x+p.x, y+p.y};
    }

    pdd operator - () const {
        return {-x, -y};
    }

    pdd operator - (cpdd &p) const {
        return (*this) + (-p);
    }

    pdd operator * (double f) const {
        return {f*x, f*y};
    }

    double operator * (cpdd &p) const {
        return x*p.x + y*p.y;
    }
};

double abs(cpdd &p) { return hypot(p.x, p.y); }
double arg(cpdd &p) { return atan2(p.y, p.x); }
double cross(cpdd &p, cpdd &q) { return p.x*q.y - p.y*q
    .x; }
double cross(cpdd &p, cpdd &q, cpdd &o) { return cross(
    p-o, q-o); }
pdd operator * (double f, cpdd &p) { return p*f; } //
    !! Not f*p !!
```

6.2 Intersection of two circles

```
using ld = double;
vector<pdd> interCircle(pdd o1, double r1, pdd o2,
    double r2) {
  ld d2 = (o1 - o2) * (o1 - o2);
  ld d = sqrt(d2);
  if (d < abs(r1-r2)) return {};
  if (d > r1+r2) return {};
  pdd u = 0.5*(o1+o2) + ((r2*r2-r1*r1)/(2*d2))*(o1-o2);
  double A = sqrt((r1+r2+d) * (r1-r2+d) * (r1+r2-d) *
      (-r1+r2+d));
  pdd v = A / (2*d2) * pdd(o1.S-o2.S, -o1.F+o2.F);
  return {u+v, u-v};
}
```

6.3 Intersection of two lines

```
const double EPS = 1e-9;

pdd interPnt(pdd p1, pdd p2, pdd q1, pdd q2, bool &res)
    {
  double f1 = cross(p2, q1, p1);
  double f2 = -cross(p2, q2, p1);
  double f = (f1 + f2);

  if(fabs(f) < EPS) {
    res = false;
    return {};
    }

  res = true;
  return (f2 / f) * q1 + (f1 / f) * q2;
}
```

6.4 Circle cover

```
typedef double type;
typedef pair<type,type> Pt;
typedef pair<Pt,Pt> Line;
typedef pair<Pt,type> Circle;
#define X first
```

```
#define Y second
#define O first
#define R second
Pt operator+( const Pt& p1 , const Pt& p2 ){
  return { p1.X + p2.X , p1.Y + p2.Y };
}
Pt operator-( const Pt& p1 , const Pt& p2 ){
  return { p1.X - p2.X , p1.Y - p2.Y };
}
Pt operator*( const Pt& tp , const type& tk ){
  return { tp.X * tk , tp.Y * tk };
}
Pt operator/( const Pt& tp , const type& tk ){
  return { tp.X / tk , tp.Y / tk };
}
type operator*( const Pt& p1 , const Pt& p2 ){
  return p1.X * p2.X + p1.Y * p2.Y;
}
type operator^( const Pt& p1 , const Pt& p2 ){
  return p1.X * p2.Y - p1.Y * p2.X;
}
type norm2( const Pt& tp ){
  return tp * tp;
}
double norm( const Pt& tp ){
  return sqrt( norm2( tp ) );
}
Pt perp( const Pt& tp ){
  return { tp.Y , -tp.X };
}

#define N 1021
struct CircleCover{
  int C; Circ c[ N ];
  bool g[ N ][ N ], overlap[ N ][ N ];
  // Area[i] : area covered by at least i circles
  D Area[ N ];
  void init( int _C ){ C = _C; }
  bool CCinter( Circ& a , Circ& b , Pt& p1 , Pt& p2 ){
    Pt o1 = a.O , o2 = b.O;
    D r1 = a.R , r2 = b.R;
    if( norm( o1 - o2 ) > r1 + r2 ) return {};
    if( norm( o1 - o2 ) < max(r1, r2) - min(r1, r2) )
        return {};
    D d2 = ( o1 - o2 ) * ( o1 - o2 );
    D d = sqrt(d2);
    if( d > r1 + r2 ) return false;
    Pt u=(o1+o2)*0.5 + (o1-o2)*((r2*r2-r1*r1)/(2*d2));
    D A=sqrt((r1+r2+d)*(r1-r2+d)*(r1+r2-d)*(-r1+r2+d));
    Pt v=Pt( o1.Y-o2.Y , -o1.X + o2.X ) * A / (2*d2);
    p1 = u + v; p2 = u - v;
    return true;
  }
  struct Teve {
    Pt p; D ang; int add;
    Teve() {}
    Teve(Pt _a, D _b, int _c):p(_a), ang(_b), add(_c){}
    bool operator<(const Teve &a)const
    {return ang < a.ang;}
  }eve[ N * 2 ];
  // strict: x = 0, otherwise x = -1
  bool disjuct( Circ& a, Circ &b, int x )
  {return sign( norm( a.O - b.O ) - a.R - b.R ) > x;}
  bool contain( Circ& a, Circ &b, int x )
  {return sign( a.R - b.R - norm( a.O - b.O ) ) > x;}
  bool contain(int i, int j){
    /* c[j] is non-strictly in c[i]. */
    return (sign(c[i].R - c[j].R) > 0 ||
            (sign(c[i].R - c[j].R) == 0 && i < j) ) &&
                contain(c[i], c[j], -1);
  }
  void solve(){
    for( int i = 0 ; i <= C + 1 ; i ++ )
      Area[ i ] = 0;
    for( int i = 0 ; i < C ; i ++ )
      for( int j = 0 ; j < C ; j ++ )
        overlap[i][j] = contain(i, j);
    for( int i = 0 ; i < C ; i ++ )
      for( int j = 0 ; j < C ; j ++ )
        g[i][j] = !(overlap[i][j] || overlap[j][i] ||
                    disjuct(c[i], c[j], -1));
    for( int i = 0 ; i < C ; i ++ ){
      int E = 0, cnt = 1;
      for( int j = 0 ; j < C ; j ++ )
        if( j != i && overlap[j][i] )
          cnt ++;
      for( int j = 0 ; j < C ; j ++ )
        if( i != j && g[i][j] ){
          Pt aa, bb;
          CCinter(c[i], c[j], aa, bb);
          D A=atan2(aa.Y - c[i].O.Y, aa.X - c[i].O.X);
          D B=atan2(bb.Y - c[i].O.Y, bb.X - c[i].O.X);
          eve[E ++] = Teve(bb, B, 1);
          eve[E ++] = Teve(aa, A, -1);
          if(B > A) cnt ++;
        }
      if( E == 0 ) Area[ cnt ] += pi * c[i].R * c[i].R;
      else{
        sort( eve , eve + E );
        eve[E] = eve[0];
        for( int j = 0 ; j < E ; j ++ ){
          cnt += eve[j].add;
          Area[cnt] += (eve[j].p ^ eve[j + 1].p) * .5;
          D theta = eve[j + 1].ang - eve[j].ang;
          if (theta < 0) theta += 2. * pi;
          Area[cnt] +=
            (theta - sin(theta)) * c[i].R*c[i].R * .5;
        }
      }
    }
  }
};
```

6.5 Half Plane Intersection

```
const double EPS = 1e-9;

pdd interPnt(Line l1, Line l2, bool &res){
    pdd p1, p2, q1, q2;
    tie(p1, p2) = l1;
    tie(q1, q2) = l2;
  double f1 = cross(p2, q1, p1);
    double f2 = -cross(p2, q2, p1);
  double f = (f1 + f2);

    if(fabs(f) < EPS) {
        res = false;
        return {0, 0};
    }

    res = true;
  return (f2 / f) * q1 + (f1 / f) * q2;
}

bool isin(Line l0, Line l1, Line l2) {
    // Check inter(l1, l2) in l0
    bool res;
    pdd p = interPnt(l1, l2, res);
    return cross(l0.S, p, l0.F) > EPS;
}

/* If no solution, check: 1. ret.size() < 3
 * Or more precisely, 2. interPnt(ret[0], ret[1])
 * in all the lines. (use (l.S - l.F).cross(p - l.F) >
     0
 */
vector<Line> halfPlaneInter(vector<Line> lines) {
    int sz = lines.size();
    vector<double> ata(sz), ord(sz);
    for (int i=0; i<sz; i++) {
        ord[i] = i;
        pdd d = lines[i].S - lines[i].F;
        ata[i] = atan2(d.y, d.x);
    }
    sort(ALL(ord), [&](int i, int j) {
        if (abs(ata[i] - ata[j]) < EPS) {
            return cross(lines[i].S, lines[j].S, lines[
                i].F) < 0;
        }
        return ata[i] < ata[j];
    });
    vector<Line> fin;
    for (int i=0; i<sz; i++) {
        if (!i or fabs(ata[ord[i]] - ata[ord[i-1]]) >
            EPS) {
            fin.PB(lines[ord[i]]);
        }
    }

    deque<Line> dq;
```

```
    for (int i=0; i<SZ(fin); i++) {
        while(SZ(dq) >= 2 and
              not isin(fin[i], dq[SZ(dq)-2], dq[SZ(dq)
                  -1])) {
            dq.pop_back();
        }
        while(SZ(dq) >= 2 and
              not isin(fin[i], dq[0], dq[1])) {
            dq.pop_front();
        }
        dq.push_back(fin[i]);
    }

    while (SZ(dq) >= 3 and
           not isin(dq[0], dq[SZ(dq)-2], dq[SZ(dq)-1]))
                {
        dq.pop_back();
    }

    while (SZ(dq) >= 3 and
           not isin(dq[SZ(dq)-1], dq[0], dq[1])) {
        dq.pop_front();
    }
    vector<Line> res(ALL(dq));
    return res;
}
```

6.6 dao point

```
typedef double Type;
struct Point{
  Type x, y;
  Point(){};
  Point(Type _x, Type _y){
    x = _x, y = _y;
  }
  void read(){
    scanf("%lf %lf", &x, &y);
  }
  Point operator +(const Point & P2){
    return Point(x + P2.x, y + P2.y);
  }
  Point operator -(const Point & P2){
    return Point(x - P2.x, y - P2.y);
  }
  Point operator *(const Type & Len){
    return Point(x*Len, y*Len);
  }
  Type operator *(const Point & P2){
    return x*P2.x + y*P2.y;
  }
  Type operator ^(const Point & P2){
    return x*P2.y - y*P2.x;
  }
  Type dis(){
    return x*x+y*y;
  }
};
struct Line{
  Point s, e;
  Line(){};
  Line(Point _s, Point _e){
    s = _s, e = _e;
  }
  void read(){
    s.read(); e.read();
  }
};
```

6.7 dao inter

```
Point inter(Line l1, Line l2){
  Type v1 = (l1.s - l1.e) ^ (l2.s - l1.e);
  Type v2 = (l1.s - l1.e) ^ (l1.e - l2.e);
  Type v3 = (v1 + v2);
  if(v3 + eps > 0 && v3 - eps < 0) return Point(nan("")
      , nan(""));
  return l2.s*(v2/v3) + l2.e*(v1/v3);
}
```

6.8 dao 2D convex hull

```
int ori(Point s, Point e, Point P){
  Type val = (s - e)^(P - e);
  if(fabs(val) < eps) return 0;
  else if(val > 0) return 1;
  else return -1;
}
bool cmp(Point a, Point b){
  if(a.x != b.x) return a.x < b.x;
  return a.y < b.y;
}
vector<Point> convex_hull(vector<Point> pt){
  sort(pt.begin(), pt.end(), cmp);
  int top=0;
  vector<Point> stk(2*pt.size());
  for (int i=0; i<(int)pt.size(); i++){
    while (top >= 2 && ori(stk[top-2],stk[top-1],pt[i])
        >= 0)
      top--;
    stk[top++] = pt[i];
  }
  for (int i=pt.size()-2, t=top+1; i>=0; i--){
    while (top >= t && ori(stk[top-2],stk[top-1],pt[i])
        >= 0)
      top--;
    stk[top++] = pt[i];
  }
  stk.resize(top-1);
  return stk;
}
```

6.9 Minimum Covering Circle

```
struct Mcc{
  // return pair of center and r^2
  static const int MAXN = 1000100;
  int n;
  pdd p[MAXN],cen;
  double r2;

  void init(int _n, pdd _p[]){
    n = _n;
    memcpy(p,_p,sizeof(pdd)*n);
  }
  double sqr(double a){ return a*a; }
  double abs2(pdd a){ return a*a; }
  pdd center(pdd p0, pdd p1, pdd p2) {
    pdd a = p1-p0;
    pdd b = p2-p0;
    double c1=abs2(a)*0.5;
    double c2=abs2(b)*0.5;
    double d = a % b;
    double x = p0.x + (c1 * b.y - c2 * a.y) / d;
    double y = p0.y + (a.x * c2 - b.x * c1) / d;
    return pdd(x,y);
  }

  pair<pdd,double> solve(){
    random_shuffle(p,p+n);
    r2=0;
    for (int i=0; i<n; i++){
      if (abs2(cen-p[i]) <= r2) continue;
      cen = p[i];
      r2 = 0;
      for (int j=0; j<i; j++){
        if (abs2(cen-p[j]) <= r2) continue;
        cen = 0.5 * (p[i]+p[j]);
        r2 = abs2(cen-p[j]);
        for (int k=0; k<j; k++){
          if (abs2(cen-p[k]) <= r2) continue;
          cen = center(p[i],p[j],p[k]);
          r2 = abs2(cen-p[k]);
        }
      }
    }
    return {cen,r2};
  }
}mcc;
```

7 Stringology

7.1 Suffix Array

```
const int MAX = 1020304;
int ct[MAX], he[MAX], rk[MAX], sa[MAX], tsa[MAX], tp[
    MAX][2];

void suffix_array(char *ip){

  int len = strlen(ip);
  int alp = 256;

  memset(ct, 0, sizeof(ct));
  for(int i=0;i<len;i++) ct[ip[i]+1]++;
  for(int i=1;i<alp;i++) ct[i]+=ct[i-1];
  for(int i=0;i<len;i++) rk[i]=ct[ip[i]];

  for(int i=1;i<len;i*=2){
    for(int j=0;j<len;j++){
      if(j+i>=len) tp[j][1]=0;
      else tp[j][1]=rk[j+i]+1;

      tp[j][0]=rk[j];
    }
    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][1]+1]++;
    for(int j=1;j<len+2;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++) tsa[ct[tp[j][1]]++]=j;

    memset(ct, 0, sizeof(ct));
    for(int j=0;j<len;j++) ct[tp[j][0]+1]++;
    for(int j=1;j<len+1;j++) ct[j]+=ct[j-1];
    for(int j=0;j<len;j++) sa[ct[tp[tsa[j]][0]]++]=tsa[
        j];

    rk[sa[0]]=0;
    for(int j=1;j<len;j++){
      if( tp[sa[j]][0] == tp[sa[j-1]][0] &&
        tp[sa[j]][1] == tp[sa[j-1]][1] )
        rk[sa[j]] = rk[sa[j-1]];
      else
        rk[sa[j]] = j;
    }
  }

  for(int i=0,h=0;i<len;i++){
    if(rk[i]==0) h=0;
    else{
      int j=sa[rk[i]-1];
      h=max(0,h-1);
      for(;ip[i+h]==ip[j+h];h++);
    }
    he[rk[i]]=h;
  }
}
```

7.2 Suffix Array (SAIS TWT514)

```
struct SA{
#define REP(i,n) for ( int i=0; i<int(n); i++ )
#define REP1(i,a,b) for ( int i=(a); i<=int(b); i++ )
    static const int MXN = 300010;
    bool _t[MXN*2];
    int _s[MXN*2], _sa[MXN*2], _c[MXN*2], x[MXN], _p[
        MXN], _q[MXN*2], hei[MXN], r[MXN];
    int operator [] (int i){ return _sa[i]; }
    void build(int *s, int n, int m){
        memcpy(_s, s, sizeof(int) * n);
        sais(_s, _sa, _p, _q, _t, _c, n, m);
        mkhei(n);
    }
    void mkhei(int n){
        REP(i,n) r[_sa[i]] = i;
        hei[0] = 0;
        REP(i,n) if(r[i]) {
            int ans = i>0 ? max(hei[r[i-1]] - 1, 0) :
                0;
            while(_s[i+ans] == _s[_sa[r[i]-1]+ans]) ans
                ++;
            hei[r[i]] = ans;
        }
    }
    void sais(int *s, int *sa, int *p, int *q, bool *t,
         int *c, int n, int z){
        bool uniq = t[n-1] = true, neq;
        int nn = 0, nmxz = -1, *nsa = sa + n, *ns = s +
             n, lst = -1;
#define MS0(x,n) memset((x),0,n*sizeof(*(x)))
#define MAGIC(XD) MS0(sa, n); \
        memcpy(x, c, sizeof(int) * z); \
        XD; \
        memcpy(x + 1, c, sizeof(int) * (z - 1)); \
        REP(i,n) if(sa[i] && !t[sa[i]-1]) sa[x[s[sa[i
            ]-1]]++] = sa[i]-1; \
        memcpy(x, c, sizeof(int) * z); \
        for(int i = n - 1; i >= 0; i--) if(sa[i] && t[
            sa[i]-1]) sa[--x[s[sa[i]-1]]] = sa[i]-1;
        MS0(c, z);
        REP(i,n) uniq &= ++c[s[i]] < 2;
        REP(i,z-1) c[i+1] += c[i];
        if (uniq) { REP(i,n) sa[--c[s[i]]] = i; return;
             }
        for(int i = n - 2; i >= 0; i--) t[i] = (s[i]==s
            [i+1] ? t[i+1] : s[i]<s[i+1]);
        MAGIC(REP1(i,1,n-1) if(t[i] && !t[i-1]) sa[--x[
            s[i]]]=p[q[i]=nn++]=i);
        REP(i, n) if (sa[i] && t[sa[i]] && !t[sa[i]-1])
             {
            neq=lst<0||memcmp(s+sa[i],s+lst,(p[q[sa[i
                ]]+1]-sa[i])*sizeof(int));
            ns[q[lst=sa[i]]]=nmxz+=neq;
        }
        sais(ns, nsa, p + nn, q + n, t + n, c + z, nn,
            nmxz + 1);
        MAGIC(for(int i = nn - 1; i >= 0; i--) sa[--x[s
            [p[nsa[i]]]]] = p[nsa[i]]);
    }
}sa;

void suffix_array(int* ip, int len) {
    // should padding a zero in the back
    // s is int array, n is array length
    // s[0..n-1] != 0, and s[n] = 0
    // resulting SA will be length n+1
    ip[len++] = 0;
    sa.build(ip, len, 128);
    // original 1-base
    for (int i=0; i<l; i++) {
        hei[i] = sa.hei[i + 1];
        sa[i] = sa._sa[i + 1];
    }
}
```

7.3 Aho-Corasick Algorithm

```
struct ACautomata{
  struct Node{
    int cnt,dp;
    Node *go[26], *fail;
    Node (){
      cnt = 0;
      dp = -1;
      memset(go,0,sizeof(go));
      fail = 0;
    }
  };

  Node *root, pool[1048576];
  int nMem;

  Node* new_Node(){
    pool[nMem] = Node();
    return &pool[nMem++];
  }
  void init(){
    nMem = 0;
    root = new_Node();
  }
  void add(const string &str){
    insert(root,str,0);
  }
  void insert(Node *cur, const string &str, int pos){
    if (pos >= (int)str.size()){
      cur->cnt++;
      return;
```

```
    }
    int c = str[pos]-'a';
    if (cur->go[c] == 0){
      cur->go[c] = new_Node();
    }
    insert(cur->go[c],str,pos+1);
  }
  void make_fail(){
    queue<Node*> que;
    que.push(root);
    while (!que.empty()){
      Node* fr=que.front();
      que.pop();
      for (int i=0; i<26; i++){
        if (fr->go[i]){
          Node *ptr = fr->fail;
          while (ptr && !ptr->go[i]) ptr = ptr->fail;
          if (!ptr) fr->go[i]->fail = root;
          else fr->go[i]->fail = ptr->go[i];
          que.push(fr->go[i]);
        }
      }
    }
  }
};
```

7.4 KMP

```
#include<bits/stdc++.h>
using namespace std;

void build_fail_function(string B, int *fail) {
    int len = B.length(), pos;
    pos = fail[0] = -1;
    for (int i = 1; i < len; i ++) {
        while (pos != -1 and B[pos + 1] != B[i])
            pos = fail[pos];
        if (B[pos + 1] == B[i]) pos ++;
        fail[i] = pos;
    }
}

void match(string A, string B, int *fail) {
    int lenA = A.length(), lenB = B.length();
    int pos = -1;
    for (int i = 0; i < lenA; i ++) {
        while (pos != -1 and B[pos + 1] != A[i])
            pos = fail[pos];

        if (B[pos + 1] == A[i]) pos ++;

        if (pos == lenB - 1) {
            // Match ! A[i - lenB + 1, i] = B
            pos = fail[pos];
        }
    }
}
```

7.5 Z value

```
void Zval(const char *s, int len, int *z) {
    z[0] = 0;
    for (int b=0, i=1; i<len; i++) {
        z[i] = max(min(z[i-b], z[b] + b - i), 0);
        while (s[i + z[i]] == s[z[i]]) z[i] ++;
        if (i+z[i] > b+z[b]) b=i;
    }
}
```

7.6 Z value (palindrome ver.)

```
void Zpal(const char *s, int len, int *z) {
    // Only odd palindrome len is considered
    // z[i] means that the longest odd palindrom
        centered at
    // i is [i-z[i] .. i+z[i]]
    z[0] = 0;
    for (int b=0, i=1; i<len; i++) {
        if (z[b] + b >= i) z[i] = min(z[2*b-i], b+z[b]-
            i);
        else z[i] = 0;
        while (i+z[i]+1 < len and i-z[i]-1 >= 0 and
               s[i+z[i]+1] == s[i-z[i]-1]) z[i] ++;
        if (z[i] + i > z[b] + b) b = i;
    }
}
```

7.7 Lexicographically Smallest Rotation

```
string mcp(string s){
  int n = s.length();
  s += s;
  int i=0, j=1;
  while (i<n && j<n){
    int k = 0;
    while (k < n && s[i+k] == s[j+k]) k++;
    if (s[i+k] <= s[j+k]) j += k+1;
    else i += k+1;
    if (i == j) j++;
  }
  int ans = i < n ? i : j;
  return s.substr(ans, n);
}
```

7.8 Suffix Automaton

```
// par : fail link
// val : a topological order ( useful for DP )
// go[x] : automata edge ( x is integer in [0,26) )

struct SAM{
  struct State{
    int par, go[26], val;
    State () : par(0), val(0){ FZ(go); }
    State (int _val) : par(0), val(_val){ FZ(go); }
  };
  vector<State> vec;
  int root, tail;

  void init(int arr[], int len){
    vec.resize(2);
    vec[0] = vec[1] = State(0);
    root = tail = 1;
    for (int i=0; i<len; i++)
      extend(arr[i]);
  }
  void extend(int w){
    int p = tail, np = vec.size();
    vec.PB(State(vec[p].val+1));
    for ( ; p && vec[p].go[w]==0; p=vec[p].par)
      vec[p].go[w] = np;
    if (p == 0){
      vec[np].par = root;
    } else {
      if (vec[vec[p].go[w]].val == vec[p].val+1){
        vec[np].par = vec[p].go[w];
      } else {
        int q = vec[p].go[w], r = vec.size();
        vec.PB(vec[q]);
        vec[r].val = vec[p].val+1;
        vec[q].par = vec[np].par = r;
        for ( ; p && vec[p].go[w] == q; p=vec[p].par)
          vec[p].go[w] = r;
      }
    }
    tail = np;
  }
};
```