1 Data Structure

1.1 DSU

```cpp
class DSU{
public:
    DSU(int n ){
        this->n = n;
        reset();
    }
    int n;
    vector<int> boss;
    vector<int> rank;
    vector<int> size;
    void reset(){
        this->boss.resize(n);
        this->rank.resize(n,0);
        this->size.resize(n,0);
        for(int i =0;i<n;i++){
            boss[i] = i;
        }
    }
    int find(int x){
        if(boss[x]!= x){
            boss[x] = find(boss[x]);
        }
        return boss[x];
    }
    int get_size(int x){
        return size[find(x)];
    }
    void merge(int x, int y){
        int a = find(x);
        int b = find(y);
        if(a!=b){
            if(rank[a]<rank[b]){
                boss[a] = b;
                size[b] += size[a];
            }else if (rank[a]<rank[b]){
                boss[b] = a;
                size[a] += size[b];
            }else{
                boss[a] = b;
                size[b] += size[a];
                rank[b]++;
            }
        }
    }
    bool aresame(int a,int b){
        return find(a)==find(b);
    }
};
```

1.2 Monotonic Queue

```cpp
class Monotonic_queue{
private:
    deque<int> qu;
public:
    void push(int n){
        while(!qu.empty()&&qu.back()<n){
            qu.pop_back();
        }
        qu.push_back(n);
    }
    int max(){
        return qu.front();
    }
    int min(){
        return qu.back();
    }
    int  size(){
        return qu.size();
    }
    void pop(){
        qu.pop_front();
    }
};
```

1.3 BIT

```cpp
class BIT{
public:
    vector<int> bit;
    int N;
    BIT(int n){
        this->N = n;
        this->bit.resize(n);
    }
    void update(int x,int d){
        while(x<=N){
            bit[x] +=d;
            x +=x&(-x);// lowest bit in x;
        }
    }
    int query(int x){
        int res = 0;
        while(x){
            res+= bit[x];
            x -= x& -x;
        }
        return res;
    }
};
```

1.4 Treap

```cpp
// 區間加值、反轉、rotate、刪除、插入元素、求區間
// srand(time(0))
class Treap {
  private:
    struct Node {
        int pri = rand(), size = 1;
        ll val, mn, inc = 0; bool rev = 0;
        Node *lc = 0, *rc = 0;
        Node(ll v) { val = mn = v; }
    };
    Node* root = 0;
    void rev(Node* t) {
        if (!t) return;
        swap(t->lc, t->rc), t->rev ^= 1;
    }
    void update(Node* t, ll v) {
        if (!t) return;
        t->val += v, t->inc += v, t->mn += v;
    }
    void push(Node* t) {
        if (t->rev) rev(t->lc), rev(t->rc), t->rev = 0;
        update(t->lc, t->inc), update(t->rc, t->inc);
        t->inc = 0;
    }
    void pull(Node* t) {
        t->size = 1 + size(t->lc) + size(t->rc);
        t->mn = t->val;
        if (t->lc) t->mn = min(t->mn, t->lc->mn);
        if (t->rc) t->mn = min(t->mn, t->rc->mn);
    }
    void discard(Node* t) { // 看要不要釋放記憶體
        if (!t) return;
        discard(t->lc), discard(t->rc);
        delete t;
    }
    void split(Node* t, Node*& a, Node*& b, int k) {
        if (!t) return a = b = 0, void();
        push(t);
        if (size(t->lc) < k) {
            a = t;
            split(t->rc, a->rc, b, k - size(t->lc) - 1);
            pull(a);
        } else {
            b = t;
            split(t->lc, a, b->lc, k);
            pull(b);
        }
    }
    Node* merge(Node* a, Node* b) {
        if (!a || !b) return a ? a : b;
        if (a->pri > b->pri) {
            push(a);
            a->rc = merge(a->rc, b);
            pull(a);
            return a;
        } else {
            push(b);
            b->lc = merge(a, b->lc);
            pull(b);
            return b;
        }
    }
    inline int size(Node* t) { return t ? t->size : 0; }
  public:
    int size() { return size(root); }
    void add(int l, int r, ll val) {
        Node *a, *b, *c, *d;
        split(root, a, b, r);
        split(a, c, d, l - 1);
        update(d, val);
        root = merge(merge(c, d), b);
    }
    // 反轉區間 [l, r]
    void reverse(int l, int r) {
        Node *a, *b, *c, *d;
        split(root, a, b, r);
        split(a, c, d, l - 1);
        swap(d->lc, d->rc);
```

```
        d->rev ^= 1;
        root = merge(merge(c, d), b);
    }
    // 區間 [l, r] 向右 rotate k 次， k < 0 表向左 rotate
    void rotate(int l, int r, int k) {
        int len = r - l + 1;
        Node *a, *b, *c, *d, *e, *f;
        split(root, a, b, r);
        split(a, c, d, l - 1);
        k = (k + len) % len;
        split(d, e, f, len - k);
        root = merge(merge(c, merge(f, e)), b);
    }
    // 插入一個元素 val 使其 index = i <= size
    void insert(int i, ll val) {
        if (i == size() + 1) {
            push_back(val); return;
        }
        assert(i <= size());
        Node *a, *b;
        split(root, a, b, i - 1);
        root = merge(merge(a, new Node(val)), b);
    }
    void push_back(ll val) {
        root = merge(root, new Node(val));
    }
    void remove(int l, int r) {
        int len = r - l + 1;
        Node *a, *b, *c, *d;
        split(root, a, b, l - 1);
        split(b, c, d, len);
        discard(c); // 看你要不要釋放記憶體
        root = merge(a, d);
    }
    ll minn(int l, int r) {
        Node *a, *b, *c, *d;
        split(root, a, b, r);
        split(a, c, d, l - 1);
        int ans = d->mn;
        root = merge(merge(c, d), b);
        return ans;
    }
};
```

1.5 Segment Tree

```
class SegmentTree{
private:
    const int n;
    const vl arr;
    // vl st;
    vl summ;
    vl minn;
    vl maxx;
    vl tag;
    void pull(int l,int r,int v){
        if(r-l==1)
            return;
        // st[v]=st[2*v+1]+st[2*v+2];
        int mid=(l+r)/2;
        push(l,mid,2*v+1);
        push(mid,r,2*v+2);
        summ[v]=summ[2*v+1]+summ[2*v+2];
        // minn[v]=min(minn[2*v+1],minn[2*v+2]);
        // maxx[v]=max(maxx[2*v+1],minn[2*v+2]);
    }
    void push(int l,int r,int v){
        summ[v]+=tag[v]*(r-l);
        if(r-l==1)
            return tag[v]=0,void();
        tag[2*v+1]+=tag[v];
        tag[2*v+2]+=tag[v];
        tag[v]=0;
    }
    void build(int l,int r,int v=0){
        if(r-l==1){
            summ[v]=arr[l];
            // summ[v]=minn[v]=maxx[v]=arr[l];
            return;
        }
        int mid=(l+r)/2;
        build(l,mid,2*v+1);
        build(mid,r,2*v+2);
        pull(l,r,v);
    }

public:
    SegmentTree(vl&_arr,int _n):arr(_arr),n(_n){
        assert(arr.size()==n);
        summ.assign(4*n,0);
        // minn.assign(4*n,1e9);
        // maxx.assign(4*n,-1e9);
        tag.assign(4*n,0);
        build(0,arr.size());
    }
    void modify(int x,int val,int l,int r,int v=0){

    }
    // query sum
    loli query(int L,int R,int l,int r,int v=0){
        // dbn(L,R,l,r,v)
        push(l,r,v);
        if(l==L && R==r){
            return summ[v];
            return minn[v];
            return maxx[v];
        }
        int mid=(l+r)/2;
        if(R<=mid)
            return query(L,R,l,mid,2*v+1);
        else if(mid<=L)
            return query(L,R,mid,r,2*v+2);
        else
            return query(L,mid,l,mid,2*v+1)+query(mid,R,mid,r
                ,2*v+2);
    }
    // plus `val` to every element in [L,R)
    void update(int L,int R,loli val,int l,int r,int v=0){
        // dbn(L,R,l,r,v)
        push(l,r,v);
        if(l==L && R==r){
            tag[v]+=val;
            push(l,r,v);
            return;
        }
        int mid=(l+r)/2;
        if(R<=mid)
            update(L,R,val,l,mid,2*v+1);
        else if(mid<=L)
            update(L,R,val,mid,r,2*v+2);
        else
            update(L,mid,val,l,mid,2*v+1),update(mid,R,val,
                mid,r,2*v+2);
        pull(l,r,v);
    }
};

void solve(){
    int n,q;
    cin>>n>>q;
    vl arr(n);
    for(auto&x:arr)
        cin>>x;
    SegmentTree st(arr,n);
    while(q--){
        int op=0;
        // str op;
        cin>>op;
        if(op&1){
            loli l,r,val;
            cin>>l>>r>>val;
            assert(r>=1);
            st.update(l-1,r,val,0,n);
            // loli k,u;
            // cin>>k>>u;
            // st.update(k-1,k,u-arr[k-1],0,n);
            // arr[k-1]=u;
        }else{
            int x,y;
            cin>>x>>y;
            assert(y>=x);
            cout<<st.query(x-1,y,0,n)<<endl;
        }
    }
}
```

1.6 Sparse Table

```
int a[N], sp[__lg(N) + 1][N]{};
void init(int n) { //0-based
  for (int i = 0; i < n; ++i) {
    sp[0][i] = a[i];
  }
  for (int i = 0; i < __lg(n); ++i) {
    for (int j = 0; j+(1<<i) < n; ++j) {
      sp[i + 1][j] = max(sp[i][j], sp[i][j+(1<<i)]);
    }
  }
}
int query(int l, int r) { //[l, r]
  int p = __lg(r - l + 1);
  return max(sp[p][l], sp[p][r-(1<<p)+1]);
}
```

1.7 Monotonic Stack

```
vector<int> monotonic_stack(vector<int> nums){
    int n = nums.size();
```

```
    vector<int> res(n);
    stack<int>  st;
    for(int i = n-1;i>=0;i--){
        while(!st.empty() && st.top()<=nums[i]){
            st.pop();
        }
        if(st.empty())res[i] = -1;
        else res[i] = st.top();
        st.push(nums[i]);
    }
    return res;
}
```

2 Flow

2.1 Dinic

```
#define maxn 2005
#define INF 0x3f3f3f3f
struct MaxFlow{
    struct edge{
        int  to, cap, flow,rev;
        edge( int v, int c, int f,int r) :  to(v), cap(c),
             flow(f),rev(r) {}
      };
    vector<edge> G[maxn];
    int s,t,dis[maxn],cur[maxn],vis[maxn];
    void add_edge(int from,int to,int cap){
        G[from].push_back(edge(to,cap,0,G[to].size()));
        G[to].push_back(edge(from,0,0,G[from].size()-1));
    }
    bool bfs(){
        memset(dis, -1, sizeof(dis));
        queue<int> qu;
        qu.push(s);
        dis[s] = 0;
        while (!qu.empty()) {
            int from = qu.front();
            qu.pop();
            for (auto &e: G[from]) {
                if (dis[e.to]==-1 && e.cap != e.flow) {
                    dis[e.to] = dis[from] + 1;
                    qu.push(e.to);
                }
            }
        }
        return dis[t]!=-1;
    }
    int dfs(int from,int cap){
        if(from==t ||cap==0)return cap;
        for(int &i = cur[from];i<G[from].size();i++){
            edge &e = G[from][i];
            if(dis[e.to]==dis[from]+1 && e.flow!=e.cap){
                int df = dfs(e.to,min(e.cap-e.flow,cap));
                if(df){
                    e.flow+=df;
                    G[e.to][e.rev].flow-=df;
                    return df;
                }
            }
        }
        dis[from] = -1;
        return 0;
    }
    int Maxflow(int s,int t){
        this->s = s,this->t =t;
        int flow = 0;
        int df;
        while(bfs()){
            memset(cur,0,sizeof(cur));
            while(df = dfs(s,INF)){
                flow +=df;
            }
        }
        return flow;
    }
};
int main(){
    int n = 4,m = 6;
    MaxFlow maxflow;
    for(int i =0;i<m;i++){
        int a,b,cap;
        cin >>a>>b>>cap;
        maxflow.add_edge(a,b,cap);
    }
    cout << maxflow.Maxflow(1,3)<<endl;;
}
```

3 Formula

3.1 formula

3.1.1 Pick 公式

給定頂點坐標均是整點的簡單多邊形，面積 = 內部格點數 + 邊上格點數/2-1

3.1.2 圖論

1. 對於平面圖，$F = E - V + C + 1$，C 是連通分 數
2. 對於平面圖，$E \leq 3V - 6$
3. 對於連通圖 G，最大獨立點集的大小設為 I(G)，最大匹配大小設為 M(G)，最小點覆蓋設為 Cv(G)，最小邊覆蓋設為 Ce(G)。對於任意連通圖：
   (a) $I(G) + Cv(G) = |V|$
   (b) $M(G) + Ce(G) = |V|$
4. 對於連通二分圖：
   (a) $I(G) = Cv(G)$
   (b) $M(G) = Ce(G)$
5. 最大權閉合圖：
   (a) $C(u, v) = \infty, (u, v) \in E$
   (b) $C(S, v) = W_v, W_v > 0$
   (c) $C(v, T) = -W_v, W_v < 0$
   (d) ans=$\sum_{W_v>0} W_v - flow(S, T)$
6. 最大密度子圖：
   (a) 求 $max\left(\frac{W_e+W_v}{|V'|}\right), e \in E', v \in V'$
   (b) $U = \sum_{v \in V} 2W_v + \sum_{e \in E} W_e$
   (c) $C(u, v) = W_{(u,v)}, (u, v) \in E$，雙向邊
   (d) $C(S, v) = U, v \in V$
   (e) $D_u = \sum_{(u,v) \in E} W_{(u,v)}$
   (f) $C(v, T) = U + 2g - D_v - 2W_v, v \in V$
   (g) 二分搜 g：
   $l = 0, r = U, eps = 1/n^2$
   if$((U \times |V| - flow(S, T))/2 > 0)$ $l = mid$
   else $r = mid$
   (h) ans=$min\_cut(S, T)$
   (i) $|E| = 0$ 要特殊判斷
7. 弦圖：
   (a) 點數大於 3 的環都要有一條弦
   (b) 完美消除序 從後往前依次給每個點染色，給每個點染上可以染的最小顏色
   (c) 最大團大小 = 色數
   (d) 最大獨立集：完美消除序 從前往後能選就選
   (e) 最小團覆蓋：最大獨立集的點和他延伸的邊構成
   (f) 區間圖是弦圖
   (g) 區間圖的完美消除序 ：將區間按造又端點由小到大排序
   (h) 區間圖染色：用線段樹做

3.1.3 dinic 特殊圖複雜度

1. 單位流：$O\left(min\left(V^{3/2}, E^{1/2}\right) E\right)$
2. 二分圖：$O\left(V^{1/2} E\right)$

3.1.4 0-1 分數規劃

$x_i = \{0, 1\}$，x_i 可能會有其他限制，求 $max\left(\frac{\sum B_i x_i}{\sum C_i x_i}\right)$

1. $D(i, g) = B_i - g \times C_i$
2. $f(g) = \sum D(i, g) x_i$
3. $f(g) = 0$ 時 g 為最佳解，$f(g) < 0$ 沒有意義
4. 因為 $f(g)$ 單調可以二分搜 g
5. 或用 Dinkelbach 通常比較快

```
binary_search(){
  while(r-l>eps){
    g=(l+r)/2;
    for(i:所有元素)D[i]=B[i]-g*C[i];//D(i,g)
    找出一組合法x[i]使f(g)最大;
    if(f(g)>0) l=g;
    else r=g;
  }
  Ans = r;
}
Dinkelbach(){
  g=任意 態(通常設為0);
  do{
    Ans=g;
    for(i:所有元素)D[i]=B[i]-g*C[i];//D(i,g)
    找出一組合法x[i]使f(g)最大;
    p=0,q=0;
    for(i:所有元素)
      if(x[i])p+=B[i],q+=C[i];
    g=p/q;//  新解，注意q=0的情況
  }while(abs(Ans-g)>EPS);
  return Ans;
}
```

3.1.5 學長公式

1. $\sum_{d|n}\phi(n)=n$
2. $g(n)=\sum_{d|n}f(d) => f(n)=\sum_{d|n}\mu(d)\times g(n/d)$
3. Harmonic series $H_n=\ln(n)+\gamma+1/(2n)-1/(12n^2)+1/(120n^4)$
4. $\gamma=0.57721566490153286060651209008240243104215$
5. 格雷碼 $=n\oplus(n>>1)$
6. $SG(A+B)=SG(A)\oplus SG(B)$
7. 旋轉矩陣 $M(\theta)=\begin{pmatrix}cos\theta & -sin\theta\\ sin\theta & cos\theta\end{pmatrix}$

3.1.6 基本數論

1. $\sum_{d|n}\mu(n)=[n==1]$
2. $g(m)=\sum_{d|m}f(d)\Leftrightarrow f(m)=\sum_{d|m}\mu(d)\times g(m/d)$
3. $\sum_{i=1}^{n}\sum_{j=1}^{m}$ 互質數 $=\sum\mu(d)\lfloor\frac{n}{d}\rfloor\lfloor\frac{m}{d}\rfloor$
4. $\sum_{i=1}^{n}\sum_{j=1}^{n}lcm(i,j)=n\sum_{d|n}d\times\phi(d)$

3.1.7 排組公式

1. k 卡特 $\frac{C_n^{kn}}{n(k-1)+1}$，$C_m^n=\frac{n!}{m!(n-m)!}$
2. $H(n,m)\cong x_1+x_2\ldots+x_n=k, num=C_k^{n+k-1}$
3. Stirling number of 2^{nd}, n 人分 k 組方法數目
   (a) $S(0,0)=S(n,n)=1$
   (b) $S(n,0)=0$
   (c) $S(n,k)=kS(n-1,k)+S(n-1,k-1)$
4. Bell number, n 人分任意多組方法數目
   (a) $B_0=1$
   (b) $B_n=\sum_{i=0}^{n}S(n,i)$
   (c) $B_{n+1}=\sum_{k=0}^{n}C_k^nB_k$
   (d) $B_{p+n}\equiv B_n+B_{n+1}modp$, p is prime
   (e) $B_{p^m+n}\equiv mB_n+B_{n+1}modp$, p is prime
   (f) From $B_0:1,1,2,5,15,52,203,877,4140,21147,115975$
5. Derangement, 錯排, 沒有人在自己位置上
   (a) $D_n=n!(1-\frac{1}{1!}+\frac{1}{2!}-\frac{1}{3!}\ldots+(-1)^n\frac{1}{n!})$
   (b) $D_n=(n-1)(D_{n-1}+D_{n-2}), D_0=1, D_1=0$
   (c) From $D_0:1,0,1,2,9,44,265,1854,14833,133496$
6. Binomial Equality
   (a) $\sum_k\binom{r}{m+k}\binom{s}{n-k}=\binom{r+s}{m+n}$
   (b) $\sum_k\binom{l}{m+k}\binom{s}{n+k}=\binom{l+s}{l-m+n}$
   (c) $\sum_k\binom{l}{m+k}\binom{s+k}{n}(-1)^k=(-1)^{l+m}\binom{s-m}{n-l}$
   (d) $\sum_{k\le l}\binom{l-k}{m}\binom{s}{k-n}(-1)^k=(-1)^{l+m}\binom{s-m-1}{l-n-m}$
   (e) $\sum_{0\le k\le l}\binom{l-k}{m}\binom{q+k}{n}=\binom{l+q+1}{m+n+1}$
   (f) $\binom{r}{k}=(-1)^k\binom{k-r-1}{k}$
   (g) $\binom{r}{m}\binom{m}{k}=\binom{r}{k}\binom{r-k}{m-k}$
   (h) $\sum_{k\le n}\binom{r+k}{k}=\binom{r+n+1}{n}$
   (i) $\sum_{0\le k\le n}\binom{k}{m}=\binom{n+1}{m+1}$
   (j) $\sum_{k\le m}\binom{m+r}{k}x^ky^k=\sum_{k\le m}\binom{-r}{k}(-x)^k(x+y)^{m-k}$

3.1.8 冪次, 冪次和

1. $a^b\%P=a^{b\%\varphi(p)+\varphi(p)}, b\ge\varphi(p)$
2. $1^3+2^3+3^3+\ldots+n^3=\frac{n^4}{4}+\frac{n^3}{2}+\frac{n^2}{4}$
3. $1^4+2^4+3^4+\ldots+n^4=\frac{n^5}{5}+\frac{n^4}{2}+\frac{n^3}{3}-\frac{n}{30}$
4. $1^5+2^5+3^5+\ldots+n^5=\frac{n^6}{6}+\frac{n^5}{2}+\frac{5n^4}{12}-\frac{n^2}{12}$
5. $0^k+1^k+2^k+\ldots+n^k=P(k), P(k)=\frac{(n+1)^{k+1}-\sum_{i=0}^{k-1}C_i^{k+1}P(i)}{k+1}, P(0)=n+1$
6. $\sum_{k=0}^{m-1}k^n=\frac{1}{n+1}\sum_{k=0}^{n}C_k^{n+1}B_km^{n+1-k}$
7. $\sum_{j=0}^{m}C_j^{m+1}B_j=0, B_0=1$
8. 除 $B_1=-1/2$，剩下的奇數項都是 0
9. $B_2=1/6, B_4=-1/30, B_6=1/42, B_8=-1/30, B_{10}=5/66, B_{12}=-691/2730, B_{14}=7/6, B_{16}=-3617/510, B_{18}=43867/798, B_{20}=-174611/330,$

3.1.9 Burnside's lemma

1. $|X/G|=\frac{1}{|G|}\sum_{g\in G}|X^g|$
2. $X^g=t^{c(g)}$
3. G 表示有幾種轉法，X^g 表示在那種轉法下，有幾種是會保持對稱的，t 是顏色數，$c(g)$ 是循環節不動的面數。
4. 正立方體塗三顏色，轉 0 有 3^6 個元素不變，轉 90 有 6 種，每種有 3^3 不變，180 有 3×3^4，120(角) 有 8×3^2，180(邊) 有 6×3^3，全部 $\frac{1}{24}(3^6+6\times3^3+3\times3^4+8\times3^2+6\times3^3)=57$

3.1.10 Count on a tree

1. Rooted tree: $s_{n+1}=\frac{1}{n}\sum_{i=1}^{n}(i\times a_i\times\sum_{j=1}^{\lfloor n/i\rfloor}a_{n+1-i\times j})$
2. Unrooted tree:
   (a) Odd:$a_n-\sum_{i=1}^{n/2}a_ia_{n-i}$
   (b) Even:$Odd+\frac{1}{2}a_{n/2}(a_{n/2}+1)$
3. Spanning Tree
   (a) 完全圖 n^{n-2}
   (b) 一般圖 (Kirchhoff's theorem) $M[i][i]=degree(V_i), M[i][j]=-1$, if have $E(i,j)$, 0 if no edge. delete any one row and col in A, $ans=det(A)$

4 Geometry

4.1 Sort by Angle

```
bool cmp(pii a, pii b) {
#define is_neg(k) (k.y < 0 || (k.y == 0 && k.x < 0));
  int A = is_neg(a), B = is_neg(b);
  if (A != B)
    return A < B;
  if (cross(a, b) == 0)
    return (a.x*a.x + a.y*a.y) < (b.x*b.x + b.y*b.y);
  return cross(a, b) > 0;
}
```

4.2 Geometry

```
const double PI=atan2(0.0,-1.0);
template<typename T>
struct point{
  T x,y;
  point(){}
  point(const T&x,const T&y):x(x),y(y){}
  point operator+(const point &b)const{
    return point(x+b.x,y+b.y); }
  point operator-(const point &b)const{
    return point(x-b.x,y-b.y); }
  point operator*(const T &b)const{
    return point(x*b,y*b); }
  point operator/(const T &b)const{
    return point(x/b,y/b); }
  bool operator==(const point &b)const{
    return x==b.x&&y==b.y; }
  T dot(const point &b)const{
    return x*b.x+y*b.y; }
  T cross(const point &b)const{
    return x*b.y-y*b.x; }
  point normal()const{//求法向
    return point(-y,x); }
  T abs2()const{//向  長度的平方
    return dot(*this); }
  T rad(const point &b)const{//  向  的弧度
return fabs(atan2(fabs(cross(b)),dot(b))); }
  T getA()const{//對x軸的弧度
    T A=atan2(y,x);//超過180度會變負的
    if(A<=-PI/2)A+=PI*2;
    return A;
  }
};
template<typename T>
struct line{
  line(){}
  point<T> p1,p2;
  T a,b,c;//ax+by+c=0
  line(const point<T>&x,const point<T>&y):p1(x),p2(y){}
  void pton(){//轉成一般式
    a=p1.y-p2.y;
    b=p2.x-p1.x;
    c=-a*p1.x-b*p1.y;
  }
  T ori(const point<T> &p)const{//點和有向直線的關係，>0左邊、=0在線上<0右邊
    return (p2-p1).cross(p-p1);
  }
  T btw(const point<T> &p)const{//點投影  在線段上<=0
    return (p1-p).dot(p2-p);
  }
  bool point_on_segment(const point<T>&p)const{//點是否在線段上
    return ori(p)==0&&btw(p)<=0;
  }
  T dis2(const point<T> &p,bool is_segment=0)const{//點跟直線/線段的距離平方
    point<T> v=p2-p1,v1=p-p1;
    if(is_segment){
      point<T> v2=p-p2;
      if(v.dot(v1)<=0)return v1.abs2();
      if(v.dot(v2)>=0)return v2.abs2();
```

```
    }
    T tmp=v.cross(v1);
    return tmp*tmp/v.abs2();
  }
  T seg_dis2(const line<T> &l)const{//  線段距離平方
    return min({dis2(l.p1,1),dis2(l.p2,1),l.dis2(p1,1),l.dis2
        (p2,1)});
  }
  point<T> projection(const point<T> &p)const{//點對直線的投
      影
    point<T> n=(p2-p1).normal();
    return p-n*(p-p1).dot(n)/n.abs2();
  }
  point<T> mirror(const point<T> &p)const{
    //點對直線的鏡射，要先呼叫pton轉成一般式
    point<T> R;
    T d=a*a+b*b;
    R.x=(b*b*p.x-a*a*p.x-2*a*b*p.y-2*a*c)/d;
    R.y=(a*a*p.y-b*b*p.y-2*a*b*p.x-2*b*c)/d;
    return R;
  }
  bool equal(const line &l)const{//直線相等
    return ori(l.p1)==0&&ori(l.p2)==0;
  }
  bool parallel(const line &l)const{
    return (p1-p2).cross(l.p1-l.p2)==0;
  }
  bool cross_seg(const line &l)const{
    return (p2-p1).cross(l.p1-p1)*(p2-p1).cross(l.p2-p1)<=0;
        //直線是否交線段
  }
  int line_intersect(const line &l)const{//直線相交情況，-1無
      限多點、1交於一點、0不相交
    return parallel(l)?(ori(l.p1)==0?-1:0):1;
  }
  int seg_intersect(const line &l)const{
    T c1=ori(l.p1), c2=ori(l.p2);
    T c3=l.ori(p1), c4=l.ori(p2);
    if(c1==0&&c2==0){//共線
      bool b1=btw(l.p1)>=0,b2=btw(l.p2)>=0;
      T a3=l.btw(p1),a4=l.btw(p2);
      if(b1&&b2&&a3==0&&a4>=0) return 2;
      if(b1&&b2&&a3>=0&&a4==0) return 3;
      if(b1&&b2&&a3>=0&&a4>=0) return 0;
      return -1;//無限交點
    }else if(c1*c2<=0&&c3*c4<=0)return 1;
    return 0;//不相交
  }
  point<T> line_intersection(const line &l)const{/*直線交點*/
    point<T> a=p2-p1,b=l.p2-l.p1,s=l.p1-p1;
    //if(a.cross(b)==0)return INF;
    return p1+a*(s.cross(b)/a.cross(b));
  }
  point<T> seg_intersection(const line &l)const{//線段交點
    int res=seg_intersect(l);
    if(res<=0) assert(0);
    if(res==2) return p1;
    if(res==3) return p2;
    return line_intersection(l);
  }
};
template<typename T>
struct polygon{
  polygon(){}
  vector<point<T> > p;//逆時針順序
  T area()const{//面積
    T ans=0;
    for(int i=p.size()-1,j=0;j<(int)p.size();i=j++)
      ans+=p[i].cross(p[j]);
    return ans/2;
  }
  point<T> center_of_mass()const{//重心
    T cx=0,cy=0,w=0;
    for(int i=p.size()-1,j=0;j<(int)p.size();i=j++){
      T a=p[i].cross(p[j]);
      cx+=(p[i].x+p[j].x)*a;
      cy+=(p[i].y+p[j].y)*a;
      w+=a;
    }
    return point<T>(cx/3/w,cy/3/w);
  }
  char ahas(const point<T>& t)const{//點是否在簡單多邊形內，
      是的話回傳1、在邊上回傳-1、否則回傳0
    bool c=0;
    for(int i=0,j=p.size()-1;i<p.size();j=i++)
      if(line<T>(p[i],p[j]).point_on_segment(t))return -1;
      else if((p[i].y>t.y)!=(p[j].y>t.y)&&
      t.x<(p[j].x-p[i].x)*(t.y-p[i].y)/(p[j].y-p[i].y)+p[i].x
          )
        c=!c;
    return c;
  }
  char point_in_convex(const point<T>&x)const{
    int l=1,r=(int)p.size()-2;
    while(l<=r){//點是否在凸多邊形內，是的話回傳1、在邊上回傳
        -1、否則回傳0
      int mid=(l+r)/2;
      T a1=(p[mid]-p[0]).cross(x-p[0]);
      T a2=(p[mid+1]-p[0]).cross(x-p[0]);
      if(a1>=0&&a2<=0){
        T res=(p[mid+1]-p[mid]).cross(x-p[mid]);
        return res>0?1:(res>=0?-1:0);
      }else if(a1<0)r=mid-1;
      else l=mid+1;
    }
    return 0;
  }
  vector<T> getA()const{//凸包邊對x軸的夾角
    vector<T>res;//一定是遞增的
    for(size_t i=0;i<p.size();++i)
      res.push_back((p[(i+1)%p.size()]-p[i]).getA());
    return res;
  }
  bool line_intersect(const vector<T>&A,const line<T> &l)
      const{//O(logN)
    int f1=upper_bound(A.begin(),A.end(),(l.p1-l.p2).getA())-
        A.begin();
    int f2=upper_bound(A.begin(),A.end(),(l.p2-l.p1).getA())-
        A.begin();
    return l.cross_seg(line<T>(p[f1],p[f2]));
  }
  polygon cut(const line<T> &l)const{//凸包對直線切割，得到直
      線l左側的凸包
    polygon ans;
    for(int n=p.size(),i=n-1,j=0;j<n;i=j++){
      if(l.ori(p[i])>=0){
        ans.p.push_back(p[i]);
        if(l.ori(p[j])<0)
          ans.p.push_back(l.line_intersection(line<T>(p[i],p[
              j])));
      }else if(l.ori(p[j])>0)
        ans.p.push_back(l.line_intersection(line<T>(p[i],p[j
            ])));
    }
    return ans;
  }
  static bool graham_cmp(const point<T>& a,const point<T>& b)
      {//凸包排序函數
    return (a.x<b.x)||(a.x==b.x&&a.y<b.y);
  }
  void graham(vector<point<T> > &s){//凸包
    sort(s.begin(),s.end(),graham_cmp);
    p.resize(s.size()+1);
    int m=0;
    for(size_t i=0;i<s.size();++i){
      while(m>=2&&(p[m-1]-p[m-2]).cross(s[i]-p[m-2])<=0)--m;
      p[m++]=s[i];
    }
    for(int i=s.size()-2,t=m+1;i>=0;--i){
      while(m>=t&&(p[m-1]-p[m-2]).cross(s[i]-p[m-2])<=0)--m;
      p[m++]=s[i];
    }
    if(s.size()>1)--m;
    p.resize(m);
  }
  T diam(){//直徑
    int n=p.size(),t=1;
    T ans=0;p.push_back(p[0]);
    for(int i=0;i<n;i++){
      point<T> now=p[i+1]-p[i];
      while(now.cross(p[t+1]-p[i])>now.cross(p[t]-p[i]))t=(t
          +1)%n;
      ans=max(ans,(p[i]-p[t]).abs2());
    }
    return p.pop_back(),ans;
  }
  T min_cover_rectangle(){//最小覆蓋矩形
    int n=p.size(),t=1,r=1,l;
    if(n<3)return 0;//也可以做最小周長矩形
    T ans=1e99;p.push_back(p[0]);
    for(int i=0;i<n;i++){
      point<T> now=p[i+1]-p[i];
      while(now.cross(p[t+1]-p[i])>now.cross(p[t]-p[i]))t=(t
          +1)%n;
      while(now.dot(p[r+1]-p[i])>now.dot(p[r]-p[i]))r=(r+1)%n
          ;
      if(!i)l=r;
      while(now.dot(p[l+1]-p[i])<=now.dot(p[l]-p[i]))l=(l+1)%
          n;
      T d=now.abs2();
      T tmp=now.cross(p[t]-p[i])*(now.dot(p[r]-p[i])-now.dot(
          p[l]-p[i]))/d;
      ans=min(ans,tmp);
    }
    return p.pop_back(),ans;
  }
  T dis2(polygon &pl){//凸包最近距離平方
    vector<point<T> > &P=p,&Q=pl.p;
    int n=P.size(),m=Q.size(),l=0,r=0;
  for(int i=0;i<n;++i)if(P[i].y<P[l].y)l=i;
  for(int i=0;i<m;++i)if(Q[i].y<Q[r].y)r=i;
    P.push_back(P[0]),Q.push_back(Q[0]);
    T ans=1e99;
```

```
    for(int i=0;i<n;++i){
      while((P[l]-P[l+1]).cross(Q[r+1]-Q[r])<0)r=(r+1)%m;
      ans=min(ans,line<T>(P[l],P[l+1]).seg_dis2(line<T>(Q[r],
          Q[r+1])));
      l=(l+1)%n;
    }
    return P.pop_back(),Q.pop_back(),ans;
  }
  static char sign(const point<T>&t){
    return (t.y==0?t.x:t.y)<0;
  }
  static bool angle_cmp(const line<T>& A,const line<T>& B){
    point<T> a=A.p2-A.p1,b=B.p2-B.p1;
    return sign(a)<sign(b)||(sign(a)==sign(b)&&a.cross(b)>0);
  }
  int halfplane_intersection(vector<line<T> > &s){//半平面交
    sort(s.begin(),s.end(),angle_cmp);//線段左側為該線段半平
        面
    int L,R,n=s.size();
    vector<point<T> > px(n);
    vector<line<T> > q(n);
    q[L=R=0]=s[0];
    for(int i=1;i<n;++i){
      while(L<R&&s[i].ori(px[R-1])<=0)--R;
      while(L<R&&s[i].ori(px[L])<=0)++L;
      q[++R]=s[i];
      if(q[R].parallel(q[R-1])){
        --R;
        if(q[R].ori(s[i].p1)>0)q[R]=s[i];
      }
      if(L<R)px[R-1]=q[R-1].line_intersection(q[R]);
    }
    while(L<R&&q[L].ori(px[R-1])<=0)--R;
    p.clear();
    if(R-L<=1)return 0;
    px[R]=q[R].line_intersection(q[L]);
    for(int i=L;i<=R;++i)p.push_back(px[i]);
    return R-L+1;
  }
};
template<typename T>
struct triangle{
  point<T> a,b,c;
  triangle(){}
  triangle(const point<T> &a,const point<T> &b,const point<T>
      &c):a(a),b(b),c(c){}
  T area()const{
    T t=(b-a).cross(c-a)/2;
    return t>0?t:-t;
  }
  point<T> barycenter()const{//重心
    return (a+b+c)/3;
  }
  point<T> circumcenter()const{//外心
    static line<T> u,v;
    u.p1=(a+b)/2;
    u.p2=point<T>(u.p1.x-a.y+b.y,u.p1.y+a.x-b.x);
    v.p1=(a+c)/2;
    v.p2=point<T>(v.p1.x-a.y+c.y,v.p1.y+a.x-c.x);
    return u.line_intersection(v);
  }
  point<T> incenter()const{//內心
    T A=sqrt((b-c).abs2()),B=sqrt((a-c).abs2()),C=sqrt((a-b).
        abs2());
    return point<T>(A*a.x+B*b.x+C*c.x,A*a.y+B*b.y+C*c.y)/(A+B
        +C);
  }
  point<T> perpencenter()const{//垂心
    return barycenter()*3-circumcenter()*2;
  }
};
template<typename T>
struct point3D{
  T x,y,z;
  point3D(){}
  point3D(const T&x,const T&y,const T&z):x(x),y(y),z(z){}
  point3D operator+(const point3D &b)const{
    return point3D(x+b.x,y+b.y,z+b.z);}
  point3D operator-(const point3D &b)const{
    return point3D(x-b.x,y-b.y,z-b.z);}
  point3D operator*(const T &b)const{
    return point3D(x*b,y*b,z*b);}
  point3D operator/(const T &b)const{
    return point3D(x/b,y/b,z/b);}
  bool operator==(const point3D &b)const{
    return x==b.x&&y==b.y&&z==b.z;}
  T dot(const point3D &b)const{
    return x*b.x+y*b.y+z*b.z;}
  point3D cross(const point3D &b)const{
    return point3D(y*b.z-z*b.y,z*b.x-x*b.z,x*b.y-y*b.x);}
  T abs2()const{//向  長度的平方
    return dot(*this);}
  T area2(const point3D &b)const{//和b、原點圍成面積的平方
    return cross(b).abs2()/4;}
};
template<typename T>
struct line3D{
  point3D<T> p1,p2;
  line3D(){}
  line3D(const point3D<T> &p1,const point3D<T> &p2):p1(p1),p2
      (p2){}
  T dis2(const point3D<T> &p,bool is_segment=0)const{//點跟直
      線/線段的距離平方
    point3D<T> v=p2-p1,v1=p-p1;
    if(is_segment){
      point3D<T> v2=p-p2;
      if(v.dot(v1)<=0)return v1.abs2();
      if(v.dot(v2)>=0)return v2.abs2();
    }
    point3D<T> tmp=v.cross(v1);
    return tmp.abs2()/v.abs2();
  }
  pair<point3D<T>,point3D<T> > closest_pair(const line3D<T> &
      l)const{
    point3D<T> v1=(p1-p2),v2=(l.p1-l.p2);
    point3D<T> N=v1.cross(v2),ab(p1-l.p1);
    //if(N.abs2()==0)return NULL;平  或重合
    T tmp=N.dot(ab),ans=tmp*tmp/N.abs2();//最近點對距離
    point3D<T> d1=p2-p1,d2=l.p2-l.p1,D=d1.cross(d2),G=l.p1-p1
        ;
    T t1=(G.cross(d2)).dot(D)/D.abs2();
    T t2=(G.cross(d1)).dot(D)/D.abs2();
    return make_pair(p1+d1*t1,l.p1+d2*t2);
  }
  bool same_side(const point3D<T> &a,const point3D<T> &b)
      const{
    return (p2-p1).cross(a-p1).dot((p2-p1).cross(b-p1))>0;
  }
};
template<typename T>
struct plane{
  point3D<T> p0,n;//平面上的點和法向
  plane(){}
  plane(const point3D<T> &p0,const point3D<T> &n):p0(p0),n(n)
      {}
  T dis2(const point3D<T> &p)const{//點到平面距離的平方
    T tmp=(p-p0).dot(n);
    return tmp*tmp/n.abs2();
  }
  point3D<T> projection(const point3D<T> &p)const{
    return p-n*(p-p0).dot(n)/n.abs2();
  }
  point3D<T> line_intersection(const line3D<T> &l)const{
    T tmp=n.dot(l.p2-l.p1);//等於0表示平  或重合該平面
    return l.p1+(l.p2-l.p1)*(n.dot(p0-l.p1)/tmp);
  }
  line3D<T> plane_intersection(const plane &pl)const{
    point3D<T> e=n.cross(pl.n),v=n.cross(e);
    T tmp=pl.n.dot(v);//等於0表示平  或重合該平面
    point3D<T> q=p0+(v*(pl.n.dot(pl.p0-p0))/tmp);
    return line3D<T>(q,q+e);
  }
};
template<typename T>
struct triangle3D{
  point3D<T> a,b,c;
  triangle3D(){}
  triangle3D(const point3D<T> &a,const point3D<T> &b,const
      point3D<T> &c):a(a),b(b),c(c){}
  bool point_in(const point3D<T> &p)const{//點在該平面上的投
      影在三角形中
    return line3D<T>(b,c).same_side(p,a)&&line3D<T>(a,c).
        same_side(p,b)&&line3D<T>(a,b).same_side(p,c);
  }
};
template<typename T>
struct tetrahedron{//四面體
  point3D<T> a,b,c,d;
  tetrahedron(){}
  tetrahedron(const point3D<T> &a,const point3D<T> &b,const
      point3D<T> &c,const point3D<T> &d):a(a),b(b),c(c),d(d)
      {}
  T volume6()const{//體積的六倍
    return (d-a).dot((b-a).cross(c-a));
  }
  point3D<T> centroid()const{
    return (a+b+c+d)/4;
  }
  bool point_in(const point3D<T> &p)const{
    return triangle3D<T>(a,b,c).point_in(p)&&triangle3D<T>(c,
        d,a).point_in(p);
  }
};
template<typename T>
struct convexhull3D{
  static const int MAXN=1005;
  struct face{
    int a,b,c;
    face(int a,int b,int c):a(a),b(b),c(c){}
  };
  vector<point3D<T>> pt;
  vector<face> ans;
  int fid[MAXN][MAXN];
```

```
  void build(){
    int n=pt.size();
    ans.clear();
    memset(fid,0,sizeof(fid));
    ans.emplace_back(0,1,2);//注意不能共線
    ans.emplace_back(2,1,0);
    int ftop = 0;
    for(int i=3, ftop=1; i<n; ++i,++ftop){
      vector<face> next;
      for(auto &f:ans){
        T d=(pt[i]-pt[f.a]).dot((pt[f.b]-pt[f.a]).cross(pt[f.
            c]-pt[f.a]));
        if(d<=0) next.push_back(f);
        int ff=0;
        if(d>0) ff=ftop;
        else if(d<0) ff=-ftop;
        fid[f.a][f.b]=fid[f.b][f.c]=fid[f.c][f.a]=ff;
      }
      for(auto &f:ans){
        if(fid[f.a][f.b]>0 && fid[f.a][f.b]!=fid[f.b][f.a])
          next.emplace_back(f.a,f.b,i);
        if(fid[f.b][f.c]>0 && fid[f.b][f.c]!=fid[f.c][f.b])
          next.emplace_back(f.b,f.c,i);
        if(fid[f.c][f.a]>0 && fid[f.c][f.a]!=fid[f.a][f.c])
          next.emplace_back(f.c,f.a,i);
      }
      ans=next;
    }
  }
  point3D<T> centroid()const{
    point3D<T> res(0,0,0);
    T vol=0;
    for(auto &f:ans){
      T tmp=pt[f.a].dot(pt[f.b].cross(pt[f.c]));
      res=res+(pt[f.a]+pt[f.b]+pt[f.c])*tmp;
      vol+=tmp;
    }
    return res/(vol*4);
  }
};
```

4.3 Convex Hull

```
using pdd = pair<double, double>;
#define F first
#define S second
pdd operator-(pdd a, pdd b) {
  return {a.F - b.F, a.S - b.S};
}
double cross(pdd a, pdd b) {
  return a.F * b.S - a.S * b.F;
}
void solve() {
  int n;
  cin >> n;
  vector<pdd> pnts;
  for (int i = 0; i < n; ++i) {
    double x, y;
    cin >> x >> y;
    pnts.push_back(x, y);
  }
  sort(iter(pnts));
  vector<pdd> hull;
  for (int i = 0; i < 2; ++i) {
    int t = hull.size();
    for (pdd j: pnts) {
      while(hull.size() - t >= 2 && cross(j - hull[hull.size
          () - 2], hull.back() - hull[hull.size() - 2]) >=
          0)
        hull.pop_back();
      hull.push_back(j);
    }
    hull.pop_back();
    reverse(iter(pnts));
  }
  double area = 0;
  for (int i=0; i < hull.size(); ++i){
    area += cross(hull[i], hull[(i + 1) % hull.size()]);
  }
  area /= 2.0;
}
```

4.4 Point in Polygon

```
const ll inf = 2000000000;
struct Point {
  ll x, y;
  Point(ll x = 0, ll y = 0):x(x), y(y){}
  Point operator+(const Point p) const {
    return Point(x + p.x, y + p.y); }
  Point operator-(const Point p) const {
    return Point(x - p.x, y - p.y); }
  ll operator*(const Point p) const { //dot
    return x * p.x + y * p.y; }
  ll operator^(const Point p) const { //cross
    return x * p.y - y * p.x; }
};
bool onseg(Point a, Point b, Point o) {
  return ((a - o) ^ (b - o)) == 0 && ((a - o) * (b - o)) <=
      0;
}
int ori(Point a, Point b, Point o) {
  ll w = (a - o) ^ (b - o);
  return (w ? (w > 0 ? 1 : -1) : 0);
}
bool inters(Point a, Point b, Point c, Point d) {
  if (onseg(a, b, c) || onseg(a, b, d)) return 1;
  if (onseg(c, d, a) || onseg(c, d, b)) return 1;
  if (ori(a, b, c) * ori(a, b, d) < 0 && ori(c, d, a) * ori(c
      , d, b) < 0) return 1;
  return 0;
}
Point poly[maxn];
void solve(int n, Point p) {
  poly[n] = poly[0];
  int cnt = 0;
  for (int i = 0; i < n; ++i) {
    if (onseg(poly[i], poly[i + 1], p)) {
      cnt = -1;
      break;
    }
    if (inters(poly[i], poly[i + 1], p, Point(inf, p.y))) {
      ++cnt;
    }
    Point hi = (poly[i].y > poly[i + 1].y ? poly[i] : poly[i
        + 1]);
    if (hi.y == p.y && hi.x > p.x) {
      --cnt;
    }
  }
  if (cnt < 0)
    cout << "BOUNDARY\n";
  else if (cnt % 2)
    cout << "INSIDE\n";
  else
    cout << "OUTSIDE\n";
}
```

4.5 MinCoveringCircle

```
double dis(pdd a, pdd b) {
  double dx = a.x - b.x, dy = a.y - b.y;
  return sqrt(dx*dx + dy*dy);
}
double sq(double x) {
  return x * x;
}
pdd excenter(pdd p1, pdd p2, pdd p3) {
  double a1 = p1.x - p2.x, a2 = p1.x - p3.x;
  double b1 = p1.y - p2.y, b2 = p1.y - p3.y;
  double c1 = (sq(p1.x) - sq(p2.x) + sq(p1.y) - sq(p2.y)) /
      2;
  double c2 = (sq(p1.x) - sq(p3.x) + sq(p1.y) - sq(p3.y)) /
      2;
  double dd = a1*b2 - a2*b1;
  return {(c1*b2 - c2*b1) / dd, (a1*c2 - a2*c1) / dd};
}
void solve(pdd a[], int n) {
  shuffle(a, a + n, rng);
  pdd center = a[0];
  double r = 0;
  for (int i = 1; i < n; ++i) {
    if (dis(center, a[i]) <= r) continue;
    center = a[i], r = 0;
    for (int j = 0; j < i; ++j) {
      if (dis(center, a[j]) <= r) continue;
      center.x = (a[i].x + a[j].x) / 2;
      center.y = (a[i].y + a[j].y) / 2;
      r = dis(center, a[i]);
      for (int k = 0; k < j; ++k) {
        if (dis(center, a[k]) <= r) continue;
        center = excenter(a[i], a[j], a[k]);
        r = dis(center, a[i]);
      }
    }
  }
  cout << fixed << setprecision(10) << r << '\n';
  cout << center.x << ' ' << center.y << '\n';
}
```

5 Graph

5.1 Bipartite Matching

```cpp
const int MAXN = 100;

struct Bipartite_matching{
    int mx[MAXN], my[MAXN], vy[MAXN]; //matchX, matchY, visitY
    vector<int> edge[MAXN]; //adjcent list;
    int x_cnt;
    bool dfs(int x){
        for(auto y: edge[x]){ //對 x 可以碰到的邊進  檢查
            if(vy[y] == 1) continue; //避免遞迴 error

            vy[y] = 1;
            if(my[y] == -1 || dfs(my[y])){ //分析 3
                mx[x] = y;
                my[y] = x;
                return true;
            }
        }
        return false; //分析 4
    }

    int bipartite_matching(){
        memset(mx, -1, sizeof(mx)); //分析 1,2
        memset(my, -1, sizeof(my));
        int ans = 0;
        for(int i = 0; i < x_cnt; i++){  //對每一個 x 節點進 DFS(最大匹配)
            memset(vy, 0, sizeof(vy));
            if(dfs(i)) ans++;
        }
        return ans;
    }
    vector<vector<int>> get_match(){
        vector<vector<int>> res;
        for(int i =0 ;i<x_cnt;i++){
            if(mx[i]!=-1){
                res.push_back({i,mx[i]});
            }
        }
        return res;
    }
    void add_edge(int i,int j){
        edge[i].push_back(j);
    }
    void init(int x){
        x_cnt = x;
    }
};
int main(){
    int n,m;
    Bipartite_matching bm;
    for(int i = 0;i<m;i++){
        int a , b;cin >>a>>b;
        bm.add_edge(a,b);
    }
    bm.init(n);
    cout << bm.bipartite_matching()<<endl;
    auto match = bm.get_match();
    for(auto t: match){
        cout << t[0]<<" "<<t[1]<<endl;
    }

}
```

5.2 Tarjan SCC

```cpp
const int n = 16;
vector<vector<int>> graph;
int visit[n], low[n],t = 0;
int st[n], top =0;
bool instack[n];
int contract[n]; // 每個點收縮到的點
vector<vector<int>> block;
void dfs(int x,int parent){
    // cout <<x<<endl;
    visit[x] = low[x] = ++t;
  st[top++] = x;
  instack[x] = true;
    for(auto to: graph[x]){
        if(!visit[to])
            dfs(to,x);

        if(instack[to])
            low[x] = min(low[x],low[to]);
    }
    if(visit[x]==low[x]){ //scc 裡最早拜訪的
        int j;
        block.push_back({});
        do{
            j = st[--top];
            instack[j] = false;
            block[block.size()-1].push_back(j);
            contract[j] =x;
        }while(j!=x);
    }
}
int main(){
    for(int i =0;i<n;i++){
        if (!visit[i])
      dfs(i, i);
    }
    for(auto t: block){
        for(auto x:t){
            cout << x <<" ";
        }cout <<endl;
    }
}
```

5.3 Bridge

```cpp
const int n = 9;
vector<vector<int>> graph;
vector<int> visit(n, 0);
vector<int> trace(n, 0);
vector<vector<int>> bridge;
int t = 0;
void dfs(int x, int parent){
    visit[x] = ++t;
    trace[x] = x; // 最高祖先預設為自己
    for (auto to : graph[x]){
        if (visit[to]){ // back edge
            if (to != parent){
                trace[x] = to;
            }
        }
        else{ // treeedge
            dfs(to, x);
            if (visit[trace[to]] < visit[trace[x]])
                trace[x] = trace[to];

            // 子樹回不到祖先暨自身。
            if (visit[trace[to]] > visit[x])
                bridge.push_back({x, to});
        }
    }
}//call for()dfs(i,-1)
int main(){
    for(int i =0;i<9;i++){
        if(!visit[i])
            dfs(i,-1);
    }
    for(auto x: bridge){
        cout << x[0]<<" "<< x[1]<<endl;
    }
}
```

5.4 2 SAT

```cpp
class TwoSAT{
public:
    TwoSAT(int n) : n(n), graph(2 * n), visited(2 * n, false) {}
    void addClause(int a, int b) {// 0-base;
        a *=2;
        b *=2;
        // Add implications (~a => b) and (~b => a)
        graph[a ^ 1].push_back(b);
        graph[b ^ 1].push_back(a);
    }
    bool solve() {// Find SCCs and check for contradictions
        for (int i = 0; i < 2 * n; ++i) {
            if (!visited[i]) {
                dfs1(i);
            }
        }
        reverse(processingOrder.begin(), processingOrder.end());//topological sort
        for (int i = 0; i < 2 * n; ++i) {
            visited[i] = false;
        }
        for (int node : processingOrder) {
            if (!visited[node]) {
                scc.clear();
                dfs2(node);
                if (!checkSCCConsistency()) {
                    return false;
                }
            }
        }

        return true;
    }

private:
    int n;
    vector<vector<int>> graph;
    vector<bool> visited;
    vector<int> processingOrder;
```

```
    vector<int> scc;

    void dfs1(int node) {
        visited[node] = true;
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs1(neighbor);
            }
        }
        processingOrder.push_back(node);
    }

    void dfs2(int node) {
        visited[node] = true;
        scc.push_back(node);
        for (int neighbor : graph[node]) {
            if (!visited[neighbor]) {
                dfs2(neighbor);
            }
        }
    }

    bool checkSCCConsistency() {
        for (int node : scc) {
            if (find(scc.begin(), scc.end(), node ^ 1) != scc
                 .end()) {
                return false; // Contradiction found in the
                     same SCC
            }
        }
        return true;
    }
};
int main() {
    int n, m;// Number of variables and clauses
    TwoSAT twoSat(n);
    for (int i = 0; i < m; ++i) {
        int a, b;
        twoSat.addClause(a, b);
    }
    if (twoSat.solve()) {
        cout << "Satisfiable" << endl;
    } else {
        cout << "Unsatisfiable" << endl;
    }
}
```

5.5 Kosaraju 2DFS

```
const int n = 16;
vector<vector<int>> graph;
vector<vector<int>> reverse_graph;
int visit[n];
int contract[n]; // 每個點收縮到的點
vector<vector<int>> block;
vector<int> finish;//fake topological sort
// need graph and reverse praph
void dfs1(int x){
    visit[x] = true;
    for(auto to:graph[x]){
        if(!visit[to]){
            dfs1(to);
        }
    }
    finish.push_back(x);
}
void dfs2(int x,int c){
    contract[x] = c;
    block[c].push_back(x);
    visit[x] = true;
    for(auto to:reverse_graph[x]){
        if(!visit[to]){
            dfs2(to,c);
        }
    }
}
int main(){
    graph = {};
    reverse_graph = {};

    for(int i =0;i<n;i++){
        if (!visit[i])
      dfs1(i);
    }
    int c =0;
    memset(visit,0,sizeof(visit));
    for(int i =  n-1;i>=0;i--){
        if(!visit[finish[i]]){
            block.push_back({});
            dfs2(finish[i],c++);
        }
    }
    for(auto t: block){
        for(auto x:t){
            cout << x <<" ";
        }cout <<endl;
    }
}
```

5.6 Dijkstra

```
#define maxn 200005
vector<int> dis(maxn,-1);
vector<int> parent(maxn,-1);
vector<bool> vis(maxn,false);
vector<vector<pair<int,int>>> graph;
void dijsktra(int source){
    dis[source] =0 ;

    priority_queue<pair<int,int>,vector<pair<int,int>>,
         greater<pair<int,int>>> pq;
    pq.push({0,source});
    while(!pq.empty()){
        int from  = pq.top().second;
        pq.pop();
        // cout <<vis[from]<<endl;
        if(vis[from])continue;
        vis[from] = true;
        for(auto next : graph[from]){
            int to = next.second;
            int weight = next.first;
            // cout <<from<<' ' <<to<<' ' <<weight;
            if(dis[from]+weight< dis[to] || dis[to]==-1){
                dis[to] = dis[from]+weight;
                parent[to] = from;
                pq.push({dis[from]+weight,to});
            }
        }
    }
}
int main(){
    int startpoint;
    dijsktra(startpoint);
    //dis and parent
}
```

5.7 Floyd Warshall

```
#define maxn 2005
vector<vector<int>> dis(maxn,vector<int>(maxn,9999999));
vector<vector<int>> mid(maxn,vector<int>(maxn,-1));
vector<vector<pair<int,int>>> graph;

void floyd_warshall(int n ){ // n is n nodes
  for(int i =0;i<n;i++){
        for(auto path:graph[i]){
            dis[i][path.second] = path.first;
        }
    }
  for (int i=0; i<n; i++)
    dis[i][i] = 0;
  for (int k=0; k<n; k++){
    for (int i=0; i<n; i++){
      for (int j=0; j<n; j++){
        if (dis[i][k] + dis[k][j] < dis[i][j] || dis[i][j
             ]==-1){
          dis[i][j] = dis[i][k] + dis[k][j];
          mid[i][j] = k;  // 由i點走到j點經過  k點
        }
            }
        }
    }
}
void find_path(int s, int t){   // 印出最短  徑
  if (mid[s][t] == -1) return;  // 沒有中繼點就結束
  find_path(s, mid[s][t]);    // 前半段最短  徑
  cout << mid[s][t];       // 中繼點
  find_path(mid[s][t], t);    // 後半段最短  徑
}
int main(){
    int n;
    floyd_warshall(n);
    for(int i =0;i<4;i++){
        for(int j = 0 ; j <4;j++)
            cout << dis[i][j]<<" ";
        cout << endl;
    }
    find_path(0,2);
}
```

5.8 Articulation Vertex

```
const int n = 9;
int t = 0;
vector<int> disc(n, -1);         // Discovery time
```

```
vector<int> low(n, -1);          // Low time
vector<int> parent_array(n, -1); // Parent in DFS tree
vector<bool> visited(n, false);
vector<bool> is_articulation(n, false);
vector<vector<int>> graph;
void dfs_articulation(int node, int parent){
    visited[node] = true;
    disc[node] = t;
    low[node] = t;
    t++;
    int children = 0;

    for (int neighbor : graph[node])
    {
        if (!visited[neighbor])
        {
            children++;
            parent_array[neighbor] = node;
            dfs_articulation(neighbor, node);
            low[node] = min(low[node], low[neighbor]);

            if (low[neighbor] >= disc[node] && parent != -1)
            {
                is_articulation[node] = true;
            }
        }
        else if (neighbor != parent)
        {
            low[node] = min(low[node], disc[neighbor]);
        }
    }

    if (parent == -1 && children > 1)
    {
        is_articulation[node] = true;
    }
}//call for() dfs(i,-1)
int main(){
    for (int i = 0; i < n; ++i) {
        if (!visited[i]) {
            dfs_articulation(i, -1);
        }
    }
    cout << "Articulation Points: ";
    for (int i = 0; i < n; ++i) {
        if (is_articulation[i]) {
            cout << i << " ";
        }
    }cout << endl;
}
```

5.9 Topological Sort

```
vector<vector<int>> graph;
vector<int> visit(10,0);
vector<int> order;
int n;
bool cycle;   // 記錄DFS的過程中是否偵測到環
void DFS(int i){ //reverse(order) is topo
  if (visit[i] == 1) {cycle = true; return;}
  if (visit[i] == 2) return;
  visit[i] = 1;
  for(auto to :graph[i])
      DFS(to);
  visit[i] = 2;
    order.push_back(i);
}//for() if(!vis[i])DFS(i)
int main() {
  for (int i=0; i<n; ++i){
    if (!visit[i])
      DFS(i);
    }
  if (cycle)
    cout << "圖上有環";
  else
    for (int i=n-1; i>=0; --i)
      cout << order[i];
}
```

5.10 Closest Pair

```
template<typename _IT=point<T>* >
T cloest_pair(_IT L, _IT R){
  if(R-L <= 1) return INF;
  _IT mid = L+(R-L)/2;
  T x = mid->x;
  T d = min(cloest_pair(L,mid),cloest_pair(mid,R));
  inplace_merge(L, mid, R, ycmp);
  static vector<point> b; b.clear();
  for(auto u=L;u<R;++u){
    if((u->x-x)*(u->x-x)>=d) continue;
    for(auto v=b.rbegin();v!=b.rend();++v){
      T dx=u->x-v->x, dy=u->y-v->y;
      if(dy*dy>=d) break;
      d=min(d,dx*dx+dy*dy);
    }
    b.push_back(*u);
  }
  return d;
}
T closest_pair(vector<point<T>> &v){
  sort(v.begin(),v.end(),xcmp);
  return closest_pair(v.begin(),v.end());
}
```

5.11 Planar

```
class Graph {
public:
    int V;
    vector<vector<int>> adj;
    Graph(int vertices) : V(vertices), adj(vertices) {}
    void addEdge(int u, int v) {
        adj[u].push_back(v);
        adj[v].push_back(u);
    }
};

bool containsSubgraph(const Graph& graph, const vector<int>&
     subgraph) {
    unordered_set<int> subgraphVertices(subgraph.begin(),
         subgraph.end());
    for (int vertex : subgraphVertices) {
        for (int neighbor : graph.adj[vertex]) {
            if (subgraphVertices.count(neighbor) == 0) {
                bool found = true;
                for (int v : subgraph) {
                    if (v != vertex && v != neighbor) {
                        if (graph.adj[v].size() < 3) {
                            found = false;
                            break;
                        }
                    }
                }
                if (found)
                    return true;
            }
        }
    }
    return false;
}

bool isPlanar(const Graph& graph) {
    // Subgraphs isomorphic to K  and K ,
    vector<int> k5 = {0, 1, 2, 3, 4};       // Vertices of K
    vector<int> k33a = {0, 1, 2};           // Vertices of K
          ,  (part A)
    vector<int> k33b = {3, 4, 5};           // Vertices of K
          ,  (part B)

    if (containsSubgraph(graph, k5) || containsSubgraph(graph
         , k33a) || containsSubgraph(graph, k33b)) {
        return false; // The graph is non-planar
    }
    return true; // The graph is planar
}
int main() {
    int vertices, edges;
    Graph graph(vertices);
    for (int i = 0; i < edges; ++i) {
        int u, v;cin >> u >> v;
        graph.addEdge(u, v);
    }
    if (isPlanar(graph)) {
        cout << "The graph is planar." << endl;
    } else {
        cout << "The graph is non-planar." << endl;
    }
}
```

5.12 Heavy Light Decomposition

```
int dep[N], pa[N], sz[N], nxt[N];
int id[N], rt[N];
int dfs(int u, int lst, int d = 0) {
  dep[u] = d;
  pa[u] = lst;
  sz[u] = 1;
  nxt[u] = -1;
  for (int v: g[u]) {
    if (v == lst) continue;
    sz[u] += dfs(v, u, d + 1);
    if (nxt[u] == -1 || sz[v] > sz[nxt[u]]) {
      nxt[u] = v;
    }
```

```
  }
  return sz[u];
}
int tn = 0;
void mapId(int u, int lst, int root) {
  id[u] = ++tn;
  rt[u] = root;
  if (~nxt[u]) mapId(nxt[u], u, root);
  for (int v: g[u]) {
    if (v == lst || v == nxt[u]) continue;
    mapId(v, u, v);
  }
}
void solve() {
  while (rt[a] != rt[b]) {
    if (dep[rt[a]] > dep[rt[b]]) swap(a, b);
    //...
    b = pa[rt[b]];
  }
  if (a != b) {
    if (id[a] > id[b]) swap(a, b);
    //...
  } else {
    //...
  }
}
```

5.13 Centroid Decomposition

```
int sz[maxn]{};
bool ok[maxn]{};
int get_subtree_size(int u, int lst) {
  sz[u] = 1;
  for (int v: g[u]) {
    if (v == lst || ok[v]) continue;
    sz[u] += get_subtree_size(v, u);
  }
  return sz[u];
}
int get_centroid(int u, int lst, int tree_size) {
  for (int v: g[u]) {
    if (v == lst || ok[v]) continue;
    if (2 * sz[v] >= tree_size) {
      return get_centroid(v, u, tree_size);
    }
  }
  return u;
}
void centroid_decomp(int u = 1) { //1-based
  int centroid = get_centroid(u, u, get_subtree_size(u, u));
  //...
  ok[centroid] = 1;
  for (int v: g[centroid]) if (!ok[v]) {
    centroid_decomp(v);
  }
}
```

6 Math

6.1 fpow

```
ll fpow(ll b, ll p, ll mod) {
  ll res = 1;
  while (p) {
    if (p & 1) res = res * b % mod;
    b = b * b % mod, p >>= 1;
  }
  return res;
}
```

6.2 modinv

```
// 解 (ax == 1) mod p ，p 必須是質數，a 是正整數。
ll modinv(ll a, ll p) {
    if (p == 1) return 0;
    ll pp = p, y = 0, x = 1;
    while (a > 1) {
        ll q = a / p, t = p;
        p = a % p, a = t, t = y, y = x - q * y, x = t;
    }
    if (x < 0) x += pp;
    return x;
}
// 解 (ax == b) mod p ，p 必須是質數，a 和 b 是正整數。
ll modinv(ll a, ll b, ll p) {
    ll ret = modinv(a, p);
    return ret * b % p;
}
```

6.3 PollardRho

```
// does not work when n is prime
ll f(ll x,ll mod){ return add(mul(x,x,mod),1,mod); }
ll pollard_rho(ll n){
  if(!(n&1)) return 2;
  while(1){
    ll y=2,x=rand()%(n-1)+1,res=1;
    for(int sz=2;res==1;y=x,sz*=2)
      for(int i=0;i<sz&&res<=1;++i)
        x=f(x,n),res=__gcd(abs(x-y),n);
    if(res!=0&&res!=n) return res;
  }
}
```

6.4 extGCD

```
int extgcd(int a,int b,int &x,int &y){//a*x +b*y = 1
    if(b==0){
        x = 1;
        y = 0;
        return a;  //到達遞歸邊界開始向上一層返回
    }
    int r = extgcd(b,a%b,x,y);
    int temp=y;     //把x y變成上一層的
    y = x - (a / b) * y;
    x = temp;
    return r;      //得到a b的最大公因數
}
int main(){
    int a = 55,b = 80;
    int x,y;//a*x+b*y = 1;
    int GCD = extgcd(a,b,x,y);
}
```

6.5 random

```
inline int ran(){
  static int x = 20167122;
  return x = (x * 0xdefaced + 1) & INT_MAX;
}
```

6.6 EulerTotientFunction

```
ll phi[maxn];
for (int i = 0; i < maxn; ++i) {
  phi[i] = i;
}
for (int i = 2; i < maxn; ++i) if (phi[i] == i) {
  phi[i] = i - 1; //prime
  for (int j = 2; i*j < maxn; ++j) { //overflow
    phi[i*j] = (phi[i*j] / i) * (i - 1);
  }
}
```

6.7 FFT

```
//OI Wiki
#include <complex>
using cd = complex<double>;
const double PI = acos(-1);
void change(vector<cd> &y) {
  vector<int> rev(y.size());
  for (int i = 0; i < y.size(); ++i) {
    rev[i] = rev[i >> 1] >> 1;
    if (i & 1) {
      rev[i] |= y.size() >> 1;
    }
  }
  for (int i = 0; i < y.size(); ++i) {
    if (i < rev[i]) {
      swap(y[i], y[rev[i]]);
    }
  }
}
void fft(vector<cd> &y, bool inv) {
  change(y);
  for (int h = 2; h <= y.size(); h <<= 1) {
```

```
    cd wn(cos(2 * PI / h), sin(2 * PI / h));
    for (int j = 0; j < y.size(); j += h) {
      cd w(1, 0);
      for (int k = j; k < j + h / 2; ++k) {
        cd u = y[k];
        cd t = w * y[k + h / 2];
        y[k] = u + t;
        y[k + h / 2] = u - t;
        w = w * wn;
      }
    }
  }
  if (inv) {
    reverse(begin(y) + 1, end(y));
    for (int i = 0; i < y.size(); ++i) {
      y[i] /= y.size();
    }
  }
}
void solve() {
  int n;
  int m = 1 << (__lg(n) + 1); //power of 2
  vector<cd> a(m), b(m);
  //...
  fft(a, 0);
  fft(b, 0);
  vector<cd> c(m);
  for (int i = 0; i < m; ++i) {
    c[i] = a[i] * b[i];
  }
  fft(c, 1);
  for (auto p: c) {
    int ans = int(p.real() + 0.25);
  }
}
```

6.8 MillerRabin

```
// 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

//From jacky860226
typedef long long LL;
inline LL mul(LL a,LL b,LL m){//a*b%m
    return (a%m)*(b%m)%m;
}
/*LL mul(LL a,LL b,LL m){//a*b%m
    a %= m, b %= m;
    LL y = (LL)((double)a*b/m+0.5); //fast for m < 2^58
    LL r = (a*b-y*m)%m;
    return r<0 ? r+m : r;
}*/
template<typename T> T
pow(T a,T b,T mod) { //a^b%mod
    T ans = 1;
    while(b) {
        if(b&1) ans = mul(ans,a,mod);
        a = mul(a,a,mod);
        b >>= 1;
    } return ans;
}
template<typename T>
bool isprime(T n, int num) { //num = 3,7
    int sprp[3] = {2,7,61}; //int範圍可解
    //int llsprp[7] =
         {2,325,9375,28178,450775,9780504,1795265022}; //至少
         unsigned long long範圍
    if(n==2) return true;
    if(n<2 || n%2==0) return false;
    //n-1 = u * 2^t
    int t = 0;  T u = n-1;
    while(u%2==0) u >>= 1, t++;
    for(int i=0; i<num; i++) {
        T a = sprp[i]%n;
        if(a==0 || a==1 || a==n-1) continue;
        T x = pow(a,u,n);
        if(x==1 || x==n-1) continue;
        for(int j=1; j<t; j++) {
            x = mul(x,x,n);
            if(x==1) return false;
            if(x==n-1) break;
        }
        if(x!=n-1) return false;
    } return true;
}
```

6.9 mu

```
int mu[MAXN];
bool isnp[MAXN];
vector<int> primes;
void init(int n)
{
    mu[1] = 1;
    for (int i = 2; i <= n; i++)
    {
        if (!isnp[i])
            primes.push_back(i), mu[i] = -1; // 质数为-1
        for (int p : primes)
        {
            if (p * i > n)
                break;
            isnp[p * i] = 1;
            if (i % p == 0)
            {
                mu[p * i] = 0; // 有平方因数为0
                break;
            }
            else
                mu[p * i] = mu[p] * mu[i]; // 互质，  用积性
                     函数性质
        }
    }
}
```

7 Misc

7.1 pbds

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;

template<typename T>
using ordered_set = tree<T, null_type, less<T>, rb_tree_tag,
     tree_order_statistics_node_update>;

int32_t main() {
  ordered_set<int64_t> rbt;
  // .insert(x); .erase(x)
  // .lower_bound(x); .upper_bound(x): iter
  // .find_by_order(k): find k-th small value(iter)
  // .order_of_key(x): return x is k-th big
  // .join(rbt2): merge with no mutiple same element
  // .split(key, rbt2): rbt keeps value <= key, others to
       rbt2
}
```

7.2 Misc

```
mt19937 rng(chrono::steady_clock::now().time_since_epoch().
     count());
int randint(int lb, int ub) {
  return uniform_int_distribution<int>(lb, ub)(rng);
} //static unsigned x = 19; ++(x *= 0xdefaced);

#define SECs ((double)clock() / CLOCKS_PER_SEC)

struct KeyHasher {
  size_t operator()(const Key& k) const {
    return k.first + k.second * 100000;
} };
typedef unordered_map<Key,int,KeyHasher> map_t;

__lg
__gcd

__builtin_popcount  // 二進位有幾個1
__builtin_clz       // 左起第一個1之前0的個數
__builtin_parity    // 1的個數的奇偶性
```

7.3 Mo'sAlgorithm

```
struct Query {
  int L, R;
  //...
};
vector<Query> query;
void solve() { //K = n / sqrt(q)
  sort(iter(query), [&](Query &a, Query &b) {
    if (a.L / K != b.L / K) return a.L < b.L;
    return a.L / K % 2 ? a.R < b.R : a.R > b.R;
```

```
  });
  int L = 0, R = 0;
  for (auto x: query) {
    while (R < x.R) add(arr[++R]);
    while (L > x.L) add(arr[--L]);
    while (R > x.R) sub(arr[R--]);
    while (L < x.L) sub(arr[L++]);
    //...
  }
}
```

7.4 bit

```
int __builtin_ffs(unsigned int x)
int __builtin_ffsl(unsigned long)
int __builtin_ffsll(unsigned long long)
返回右起第一個1的位置
Returns one plus the index of the least significant 1-bit of
    x, or if x is zero, returns zero.

int __builtin_clz(unsigned int x)
int __builtin_clzl(unsigned long)
int __builtin_clzll(unsigned long long)
返回左起第一個1之前0的個數
Returns the number of leading 0-bits in x, starting at the
    most significant bit position. If x is 0, the result is
    undefined.

int __builtin_ctz(unsigned int x)
int __builtin_ctzl(unsigned long)
int __builtin_ctzll(unsigned long long)
返回右起第一個1之後的0的個數
Returns the number of trailing 0-bits in x, starting at the
    least significant bit position. If x is 0, the result is
    undefined.

int __builtin_popcount(unsigned int x)
int __builtin_popcountl(unsigned long)
int __builtin_popcountll(unsigned long long)
返回1的個數
Returns the number of 1-bits in x.

int __builtin_parity(unsigned int x)
int __builtin_parityl(unsigned long)
int __builtin_parityll(unsigned long long)
返回1的個數的奇偶性(1的個數 mod 2的值)
Returns the parity of x, i.e. the number of 1-bits in x
    modulo 2.
```

8 String

8.1 Hashing

```
const ll P = 401, M = 998244353;

ll hashes[10005], modp[10005];
ll hashp(string s, bool saveval) {
  ll val = 0;
  int index = 0;
  for (char c: s) {
    val = ((val * P) % M + c) % M;
    if (saveval) hashes[index++] = val;
  }
  return val;
}
void init(int base, int exp) {
  ll b = 1;
  modp[0] = 1;
  for (int i = 0; i < exp; i++) {
    b = (b * base) % M;
    modp[i + 1] = b;
  }
}
ll subseq(int l, int r) { //[l, r]
  if (l == 0) return hashes[r];
  return ((hashes[r] - hashes[l-1] * modp[r-l+1]) % M + M) %
      M;
}
```

8.2 Trie

```
struct node {
  int ch[26]{};
  int cnt = 0;
};
struct Trie {
  vector<node> t;
  void init() {
    t.clear();
    t.emplace_back(node());
  }
  void insert(string s) {
    int ptr = 0;
    for (char i: s) {
      if (!t[ptr].ch[i - 'a']) {
        t[ptr].ch[i - 'a'] = (int)t.size();
        t.emplace_back(node());
      }
      ptr = t[ptr].ch[i - 'a'];
    }
    t[ptr].cnt++;
  }
} trie;
```

8.3 Zvalue

```
vector<int> Zvalue(string &s) { //t + # + s
  vector<int> Z(s.size());
  int x = 0, y = 0;
  for (int i=0; i<s.size(); ++i) {
    Z[i] = max(0, min(y - i + 1, Z[i - x]));
    while (i + Z[i] < s.size() && s[Z[i]] == s[i + Z[i]])
      x = i, y = i + Z[i], ++Z[i];
  }
  return Z;
}
```

8.4 KMP

```
int F[maxn]{};
vector<int> match(string& s, string& t) {
  int p = F[0] = -1;
  for (int i = 1; i < t.size(); ++i) {
    while (p != -1 && t[p + 1] != t[i]) p = F[p];
    if (t[p + 1] == t[i]) ++p;
    F[i] = p;
  }
  p = -1;
  vector<int> v;
  for (int i = 0; i < s.size(); ++i) {
    while (p != -1 && t[p + 1] != s[i]) p = F[p];
    if (t[p + 1] == s[i]) ++p;
    if (p == t.size() - 1) v.push_back(i - p), p = F[p];
  }
  return v; //0-based
}
```

8.5 Manacher

```
int z[maxn * 2]{};
int manacher(string& s) {
  string t = "#";
  for (char c: s) t += c, t += '#';
  int l = 0, r = 0, ans = 0; //l: mid, r: right
  for (int i = 1; i < t.size(); ++i) {
    z[i] = (r > i ? min(z[2 * l - i], r - i) : 1);
    while (i - z[i] >= 0 && i + z[i] < t.size()) {
      if (t[i - z[i]] == t[i + z[i]])
        ++z[i];
      else
        break;
    }
    if (i + z[i] > r) r = i + z[i], l = i;
  }
  for (int i = 1; i < t.size(); ++i) ans = max(ans, z[i] - 1)
      ;
  string res;
  for (int i = 1; i < t.size(); ++i) if (ans == z[i] - 1) {
    for (int j = i - ans + 1; j < i + ans; ++j) if (t[j] != '
        #') {
      res += t[j];
    }
    break;
  }
  return ans;
}
```

9 Tree

9.1 LCA

```cpp
int n, logn,t=0;
vector<vector<int>> graph;
vector<vector<int>> ancestor;
vector<int> tin, tout;
void dfs(int x){
    tin[x] = t++;
  for(auto y:graph[x]){
        if(y!= ancestor[x][0]){
            ancestor[y][0] = x;
            dfs(y);
        }
    }
    tout[x] = t++;
}
bool is_ancestor(int x, int y){
  return tin[x] <= tin[y] && tout[x] >= tout[y];
}
void table(){
  for (int i=1; i<logn; i++)// 上  輩祖先、上四輩祖先、上八輩祖先、……
    for (int x=0; x<n; ++x)
      ancestor[x][i] = ancestor[ancestor[x][i-1]][i-1];
}

int kth_ancestor(int x, int k){
  for (int i=0; i<logn; i++)// k拆解成二進位位數，找到第k祖先。不斷上升逼近之。
    if (k & (1<<i))
      x = ancestor[x][i];
  return x;
}

void rooted_tree(int root){// build the tree with root at "root"
  ancestor[root][0] = root;
  dfs(root);
  table();
}
int LCA(int x,int y){
    if (is_ancestor(x, y)) return x;
  if (is_ancestor(y, x)) return y;
    for (int i=logn-1; i>=0; i--)
    if (!is_ancestor(ancestor[x][i], y))
      x = ancestor[x][i];
  return ancestor[x][0];
}
int main(){
    graph = {
        {1,2},
        {3},
        {5,6},
        {7},
        {},
        {},
        {},
        {8},
        {4},
    };
    n = 9;
    logn = ceil(log2(n));
    ancestor.resize(n,vector<int>(logn));
    tin.resize(n);
    tout.resize(n);

    rooted_tree(0);
    while(true){
        int a,b;
        cin >>a>>b;
        cout <<LCA(a,b)<<endl;;
    }
}
int main(){
    n = 9;
    logn = ceil(log2(n));
    ancestor.resize(n,vector<int>(logn));
    tin.resize(n);
    tout.resize(n);
    rooted_tree(0);
    while(true){
        int a,b;
        cin >>a>>b;
        cout <<LCA(a,b)<<endl;;
    }
}
```

9.2 Diameter

```cpp
vector<vector<int>> graph;
int diameter = 0;
int dfs(int start, int parent){
    int h1 = 0, h2 = 0;
    for (auto child : graph[start]){
        if (child != parent){
            int h = dfs(child, start) + 1;
            if (h > h1){
                h2 = h1;
                h1 = h;
            }
            else if (h > h2){
                h2 = h;
            }
        }
    }
    diameter = max(diameter, h1 + h2);
    return h1;
}
// call diameter
int main(){
    dfs(0,-1);
    cout << diameter<<endl;
}
```

9.3 Radius

```cpp
// Perform DFS to find the farthest node and its distance from the given node
pair<int, int> dfs(int node, int distance, vector<bool> & visited, const vector<vector<int>> &adj_list){
    visited[node] = true;
    int max_distance = distance;
    int farthest_node = node;

    for (int neighbor : adj_list[node]){
        if (!visited[neighbor]){
            auto result = dfs(neighbor, distance + 1, visited, adj_list);
            if (result.first > max_distance){
                max_distance = result.first;
                farthest_node = result.second;
            }
        }
    }

    return make_pair(max_distance, farthest_node);
}

// Calculate the radius of the tree using DFS
int tree_radius(const vector<vector<int>> &adj_list){
    int num_nodes = adj_list.size();
    vector<bool> visited(num_nodes, false);

    // Find the farthest node from the root (node 0)
    auto farthest_result = dfs(0, 0, visited, adj_list);

    // Reset visited array
    fill(visited.begin(), visited.end(), false);

    // Calculate the distance from the farthest node
    int radius = dfs(farthest_result.second, 0, visited, adj_list).first;

    return radius;
}
int main() {
    vector<vector<int>> adj_list;
    int radius = tree_radius(adj_list);
    cout << "Tree radius: " << radius << endl;
    return 0;
}
```

9.4 Spanning Tree

```cpp
const int V = 100, E = 1000;
struct Edge {int a, b, c;} e[E];  // edge list
bool operator<(Edge e1, Edge e2) {return e1.c < e2.c;}

int p[V];
void init() {for (int i=0; i<V; ++i) p[i] = i;}
int find(int x) {return x == p[x] ? x : (p[x] = find(p[x]));}
void merge(int x, int y) {p[find(x)] = find(y);}

void Kruskal(){
  init();
  sort(e, e+E);
  int i, j;
  for (i = 0, j = 0; i < V-1 && j < E; ++i){
    while (find(e[j].a) == find(e[j].b)) j++;
    merge(e[j].a, e[j].b);
    cout << "起點：" << e[j].a<< "終點：" << e[j].b<< "權重：" << e[j].c;
    j++;
  }
  if (i == V-1) cout << "得到最小生成樹";
  else          cout << "得到最小生成森  ";
}
```

NYCU_Segmentree Codebook

Contents