Data Structures and Algorithms for competitive programming

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Contents

1 Graphs

Traversal

BFS

```
int dist[MX_N];
vector<int> adjList[MX_N];

int main(){
    for(int i = 0; i < MX_N; i++)
        dist[i]=INF;
    queue<int> q;
    q.push(0);
    dist[0] = 0;
    while(!q.empty()){
        int u = q.front(); q.pop();
        int d = dist[u];
        for(int i : adjList[u]){
            if(dist[i]==INF){
                dist[i]=d+1;
                q.push(i);
            }
        }
    }
    return 0;
}
```

Dijkstras

```
struct path {
    int u,d;
    path(int _u, int _d) : u(_u), d(_d) {}
    path(){}
    bool operator < (const path& p) const {
        return d > p.d;
    }
};
for(int i =0; i < N; ++i)
    dist[i] = INF;
dist[S] = 0;
priority_queue<path> q;
q.push(path(S,0));
while(!q.empty()){
    path p = q.top(); q.pop();
    u = p.u,d = p.d;
    if(dist[u] < d)
        continue;
    for(auto v : adjList[u]){
        nd = d + v.second;
        if(nd < dist[v.first]){
            dist[v.first] = nd;
            q.push(path(v.first ,nd));
        }
    }
}
```

Trees

MST

```
struct edge {
    int x,y,w;
    bool operator < (edge e) const {
        return w < e.w;
    }
};

int main(){
    vector<edge> eList; //Input
    for(int i = 0; i < N; i++)// Set up UFDS
        p[i]=i;
    vector<ii> treeList;
    sort(eList.begin(),eList.end());
    int cost = 0;
    int sz=N;
    int u,v,w;
    for(const auto &i : eList){
        v=i.x; u=i.y; w=i.w;
        if(!connected(u,v)){
            join(u,v);
            treeList.push_back({min(u,v),max(u,v)});
            sz--;
            cost+=w;
        }
    }
    if(sz!=1)
        puts("Impossible");
}
```

LCA

```
/*
 * H[u] is first visit of u
 * E[x] is vertex at time x
 * L[x] is depth at time x
 */
void vis(int u, int d){
    H[u]=vind;
    E[vind] = u;
    L[vind++] = d;
    for(auto i : adjList[u]){
        if(H[i]!=-1)
            continue;
        vis(i,d+1);
        E[vind] = u;
        L[vind++] = d;
    }
}
```

```
18
19 int LCA(int u, int v){
20     if(H[u] > H[v]){
21         int t = u;
22         u = v;
23         v = t;
24     }
25     //run some range min query on L
26     //between H[u] and H[v]
27     int ind = rmq(H[u],H[v]);
28     return E[ind];
29 }
30
31 int dist(int u, int v){
32     int a = H[u];
33     int b = H[v];
34     int ind = LCA(u,v);
35     return abs(L[H[ind]]-L[a])
36         + abs(L[H[ind]]-L[b]);
37 }
```

Centroid Decomposition

```
1  void fill_sz(int u, int p){
2      sz[u] = 1;
3      for(int v : adjList[u]){
4          if(v==p || mkd[v])
5              continue;
6          fill_sz(v,u);
7          sz[u]+=sz[v];
8      }
9  }
10
11 int get_centroid(int u, int n, int p){
12     for(int v : adjList[u]){
13         if(v==p || mkd[v])
14             continue;
15         if(sz[v] > n/2)
16             return get_centroid(v, n, u);
17     }
18     return u;
19 }
20
21 int decomp(int u){
22     fill_sz(u, -1);
23     int cent = get_centroid(u, sz[u], -1);
24     mkd[cent] = true;
25     for(int v : adjList[cent]){
26         if(mkd[v])
27             continue;
28         int r = decomp(v);
29         centP[r] = cent;
30     }
31     return cent;
32 }
```

SCC Tarjans

```
1  stack<int> scc;
2  int dfsCounter=1;
3  int sccIdx=1;
4  map<int, int> sccMap;
5
6  void tarjans(int u){
7      scc.push(u);
8      vis[u]=true;
9
10     dfs_low[u]=dfs_num[u]=dfsCounter++;
11
12     for(int i = 0; i < adjList[u].size(); i++){
13         int v = adjList[u][i];
14         if(dfs_num[v]==0){
15             tarjans(v);
16             dfs_low[u]=min(dfs_low[u],dfs_low[v]);
17         } else if(vis[v]){
18             dfs_low[u]=min(dfs_low[u],dfs_num[v]);
19         }
20     }
21     if(dfs_low[u]==dfs_num[u]){
22         while(1){
23             int v = scc.top(); scc.pop();
24             sccMap[v]=sccIdx;
25             vis[v]=false;
26             if(v==u)
27                 break;
28         }
29         sccIdx++;
30     }
31 }
```

AP & Bridges

```
1  int dfs(int u,int p){
2      dfs_num[u] = dfs_low[u] = ++dfs_counter;
3      for(auto v : adjList[u]){
4          if(dfs_num[v]==0){
5              dfs(v,u);
6              if(dfs_low[v] >= dfs_num[u]){
7                  articulation[u]=true;
8              }
9              if(dfs_low[v] > dfs_num[u])
10                 bridge = true;
11             dfs_low[u] = min(dfs_low[u],dfs_low[v]);
12         } else if(v!=p)
13             dfs_low[u] = min(dfs_low[u],dfs_num[v]);
14     }
15 }
```

Network Flow

Edmond Karp Max Flow

```
void aug(int u, int minE){
    if(u==S){ f=minE; return; }
    if(p[u]!=u){
        aug(p[u],min(minE,res[p[u]][u]));
        res[p[u]][u]-=f;
        res[u][p[u]]+=f;
    }
}

int main(){
    int mf=0;
    for(;;){
        f=0;//Global
        for(int i = 0; i < N; i++)
            dist[i]=INF,p[i]==i;
        dist[S]=0;
        queue<int> q; q.push(S);
        while(!q.empty()){
            int u = q.front(); q.pop();
            if(u==T) break;
            for(int i = 0; i < N; i++)
                if(res[u][i] > 0 && dist[i]==INF)
                    dist[i]=dist[u]+1, p[i]=u, q.push(i);
        }
        aug(T,INF);
        if(f==0) break;
        mf+=f;
    }
    vector<ii> used;
    for(int i = 0; i < N; i++)
        for(int j = 0; j < N; j++)
            if(graph[i][j] > 0 && res[i][j] < graph[i][j])
                used.push_back(make_pair(i,j));
}
```

Ford Fulkerson Max Flow

```
int ff(int u, int minE){
    if(u==T)
        return minE;
    vis[u]=true;
    for(auto i : adjList[u]){
        if(!vis[i] && res[u][i] > 0){
            if(int f = ff(i, min(minE,res[u][i]))){
                res[u][i] -= f;
                res[i][u] += f;
                return f;
            }
        }
    }
    return 0;
}

int main(){
    int mf = 0;
    while(1){
        memset(vis,0,sizeof(vis));
        int f = ff(S,INF);
        if(f==0)
            break;
        mf+=f;
    }
    printf("%d\n",mf);
}
```

2 Data Structures

Fenwick Tree

```
int tree[MX_N];
int N;
int lsOne(int i){ return i&(-i); }
void update(int k,int v){
    for(; k<MX_N; k+=lsOne(k))
        tree[k]+=v;
}
int query(int k){
    int cnt=0;
    for(; k; k-=lsOne(k)){
        cnt+=tree[k];
    }
    return cnt;
}
```

UFDS

```
int find(int u){ return p[u] = (p[u] == u ? u : find(p[u])); }

inline void join(int a, int b){
    pa = find(a);
    pb = find(b);
    if(pa!=pb){
        if(rank[pa] < rank[pb]){
            ni = pb;
            pb = pa;
            pa = ni;
        }
        p[pb] = pa;
        if(rank[pa]==rank[pb])
            rank[pa]++;
    }
}
```

Sparse Table

```
inline int rmq(int u, int v){
    if(u > v)
        return -2000000000;
    int k=(int)floor(log2((double)(v-u+1)));
    if(r[mtable[u][k]]>
            r[mtable[v-(1<<k)+1][k]])
        return mtable[u][k];
    return mtable[v-(1<<k) + 1][k];
}

for(int i = 0; i < N; i++)
    mtable[i][0] = i;
for(int j = 1; (1 << j) <= N; j++)
    for(int i = 0; i + (1<<j)-1 < N; ++i)
        if(r[mtable[i][j-1]]
                >r[mtable[i+(1<<(j-1))][j-1]])
            mtable[i][j]= mtable[i][j-1];
        else
            mtable[i][j]=mtable[i+(1<<(j-1))][j-1];
```

Segment Tree

```
int tree[MX_N*4];
int a[MX_N];
int N;

void construct(int p, int L, int R){
    if(L==R){
        tree[p] = a[L];
        return;
    }
    if(R<L)
        return;
    int md = (L+R)/2;
    construct(2*p,L,md);
    construct(2*p+1,md+1,R);
    tree[p] = min(tree[2*p],tree[2*p+1]);
}

void update(int p, int L, int R, int ind,int v){
    if(L==R){
        a[ind] = v;
        tree[p] = v;
        return;
    }
    int md = (L+R)/2;
    if(ind <= md)
        update(2*p,L,md,ind,v);
    else
        update(2*p+1,md+1,R,ind,v);
    tree[p] = min(tree[2*p],tree[2*p+1]);
}

int rmq(int p, int L, int R, int l, int r){
    if(r < L || l > R)
        return INF;
    if(l>=L && r<=R)
        return tree[p];
    int md = (l+r)/2;
    return min(rmq(2*p,L,R,l,md),rmq(2*p+1,L,R,md+1,r));
}
```

3 Geometry

Convex Hull

```
int main(){
    for(int i = 0; i < N; i++){
        perm[i]=i;
    }
    sort(perm,perm+N,
            [](int a, int b){
                const point &pa = V[a];
                const point &pb = V[b];
                if(real(pa)!=real(pb))
                    return real(pa) < real(pb);
                return imag(pa) < imag(pb);
            });
    vector<int> L; vector<int> U;
    for(int i = 0; i < N;){
        int t = L.size();
        if(t >= 2 && !ccw(V[L[t-2]],V[L[t-1]],V[perm[i]]))
            L.pop_back();
        else
            L.push_back(perm[i++]);
    }
    for(int i = N-1; i >=0;){
        int t = U.size();
        if(t >= 2 && !ccw(V[U[t-2]],V[U[t-1]],V[perm[i]]))
            U.pop_back();
        else
            U.push_back(perm[i--]);
    }
    vector<int> hull;
    for(int i = 0; i < L.size()-1; ++i)
        hull.push_back(L[i]);
    for(int i = 0; i < U.size()-1; ++i)
        hull.push_back(U[i]);
    return 0;
}
```

Geometry Axioms

```
typedef complex<double> pt;
typedef complex<double> vec;
typedef vector<pt> pgon;
typedef struct { pt p,q; } lseg;
double cross(const vec& a, const vec &b){
    return x(a)*y(b)-y(a)*x(b);
}
//cross product of (b-a) and (c-b), 0 is collinear
int orientation(const pt& a,
        const pt& b, const pt& c){
    double v = cross(b-a,c-b);
    if(abs(v-0.0)<EPS)
        return 0;
    return v > 0 ? 1 : 2;
}
//Line segment intersection
bool intersects(const lseg& a, const lseg& b){
    if(a.q == b.p || b.q == a.p)
        return false;
    if(orientation(a.p,a.q,b.p)
            !=orientation(a.p,a.q,b.q)
            && orientation(b.p,b.q,a.p)
            != orientation(b.p,b.q,a.q))
        return true;
    return false;
}
//Area of polygon
double area(const pgon& p){
    double area = 0.0;
    for(int i = 1; i < p.size(); ++i)
        area+=cross(p[i-1],p[i]);
    return abs(area)/2.0;
}
//If a->b->c is a counterclockwise turn
double ccw(const point& a, const point& b,
        const point& c){
    if(a==b || b==c || a==c)
        return false;
    point relA = b-a;
    point relC = b-c;
    return cross(relA,relC) >= 0.0;
}
//Returns if point p is in the polygon poly
bool inPoly(const pgon& poly, const pt& p){
    for(int i = 0; i < poly.size()-1; i++){
        if(!ccw(poly[i],p,poly[i+1]))
            return false;
    }
    return true;
}
//Distance from p to line (a,b)
double distToLine(const pt& p, const pt& a,
        const pt &b){
    vec ap = p-a;
    vec ap = b-a;
    double u = dot(ap,ab)/dot(ab,ab);
    //Ignore for non-line segment
    if(u < 0.0) //Closer to a
        return abs(a-p);
    if(u > 1.0) //Closer to b
        return abs(b-p);
    pt c = a+ab*u; // This is the point
    return abs(c-p);
}
```

4 Strings

Suffix Array

```
void countingSort(int k){
    int i,sum,maxi=max(300,N);
    memset(c,0,sizeof(c));
    for(i = 0; i < N; i++)
        c[i+k < N ? RA[i+k] : 0]++;
    for(i=sum=0; i < maxi; i++){
        int t = c[i];
        c[i]=sum;
        sum+=t;
    }
    for(i = 0; i < N; i++)
        tempSA[c[SA[i]+k < N
            ? RA[SA[i]+k]: 0]++] = SA[i];
    for(i=0; i < N;i++)
        SA[i]=tempSA[i];
}

int main(){
    for(int i = 0; i < N; i++)
        SA[i]=i,RA[i]=input[i];
    int r;
    for(int k = 1; k < N; k <<= 1){
        countingSort(k);
        countingSort(0);
        tempRA[SA[0]]=r=0;
        for(int i = 1; i < N; i++){
            tempRA[SA[i]]
                =(RA[SA[i]]==RA[SA[i-1]]
                && RA[SA[i]+k]==RA[SA[i-1]+k]
                ? r:++r);
        }
        for(int i = 0; i < N; i++)
            RA[i]=tempRA[i];
    }
    return 0;
}
```

Trie

```
struct node {
    node * children[26];
    int count;
    node(){
        memset(children,0,sizeof(children));
        count=0;
    }
};

void insert(node* nd, char *s){
    if(*s){
        if(!nd->children[*s-'a'])
            nd->children[*s-'a']=new node();
        insert(nd->children[*s-'a'],s+1);
    }
    nd->count++;
}

int count(node* nd, char *s){
    if(*s){
        if(!nd->children[*s-'a'])
            return 0;
        return count(nd->children[*s-'a'],s+1);
    } else {
        return nd->count;
    }
}

int main(){
    node * trie = new node();
    int N; scanf("%d",&N);
    char * buff = new char[40];
    for(int i = 0; i < N; i++){
        scanf("%s",buff);
        printf("%d\n",count(trie,buff));
        insert(trie,buff);
    }
    return 0;
}
```

KMP

```
vector<int> buildFailure(string s){
    vector<int> T(n+1,0);
    T[0]=-1;
    int j = 0;
    for(int i = 1; i < s.size();++i){
        if(s[i]==s[j]){
            T[i]=T[j];
            j++;
        } else{
            T[i] = j;
            j = T[j];
            while(j >= 0 && s[i]!=s[j])
                j = T[j];
            j++;
        }
    }
    T[s.size()] = j;
    return T;
}
vector<int> search(string W, string S){
    auto T=buildFailure(W);
    vector<int> p;
    int k = 0;
    int j = 0;
```

```
25      while(j < S.size()){
26          if(W[k]==S[j]){
27              k++; j++;
28              if(k==W.size()){
29                  p.push_back(j-k);
30                  k = T[k];
31              }
32          }else{
33              k = T[k];
34              if(k < 0)
35                  j+=1, k+=1;
36          }
37      }
38      return p;
39  }
```

5 Algorithms

Inversion Count

```
1   int N;
2   int a[MX_N];
3   long long cnt=0;
4
5   void mergesort(int L, int R){
6       if(L>=R)
7           return;
8       int mid = (L+R)/2;
9       mergesort(L,mid);
10      mergesort(mid+1,R);
11      int n[R-L+1];
12      int i = 0;
13      int lp = L;
14      int rp = mid+1;
15      while(rp<=R || lp<=mid){
16          if(rp<=R && lp <= mid){
17              if(a[rp]<a[lp]){
18                  n[i]=a[rp];
19                  rp++;
20                  cnt+=((long long) (mid-lp+1));
21              }else
22                  n[i]=a[lp],lp++;
23          } else if(rp<=R){
24              n[i]=a[rp++];
25          } else {
26              n[i]=a[lp++];
27          }
28          i++;
29      }
30      for(int j= L; j <= R; j++)
31          a[j]=n[j-L];
32  }
```

NlogN LIS

```
1   int ls[MX_N];
2   int L[MX_N];
3   int I[MX_N];
4
5   void nlogn(){
6       for(int i = 1; i < N+1; ++i)
7           I[i]=INF;
8       I[0] = -INF;
9       int mx = 1;
10      for(int i = 0; i < N; ++i){
11          int ind = lower_bound(I,I+N+1,ls[i]) - I;
12          I[ind] = ls[i];
13          L[i] = ind;
14          mx = max(mx,ind);
15      }
```

```
    int prv = INF;
    vector<int> out;
    for(int i = N-1; i >= 0; --i){
        if(ls[i] < prv && L[i]==mx){
            out.push_back(ls[i]);
            prv = ls[i];
            mx--;
        }
    }
}
```

RectInHist

```
int R,C;
char board[MX_RC][MX_RC];
int h[MX_RC][MX_RC];

int perim(int l, int w){
    if(l==0 || w==0)
        return 0;
    return 2*l + 2*w;
}

int main(){
    for(int i = 0; i < R; i++){
        int run=0;
        for(int j = 0; j < C; j++){
            run = (board[i][j]=='.'?run+1:0);
            h[i][j] = run;
        }
    }
    int mx = 0;
    for(int j = 0; j < C; j++){
        stack<int> s;
        for(int i = 0; i < R; i++){
            if(s.empty()
                    ||h[i][j]>h[s.top()][j])
                s.push(i);
            else if(h[i][j]<h[s.top()][j]){
                while(!s.empty()
                &&h[i][j]<h[s.top()][j]){
                    int l = h[s.top()][j];
                    s.pop();
                    int pm = perim(l,
                        (s.empty()?
                         i:i-s.top()-1));
                    mx = max(mx,pm);
                }
                s.push(i);
            } else if(h[i][j]==h[s.top()][j]){
                s.pop();
                s.push(i);
            }
        }
        while(!s.empty()){
            int l = h[s.top()][j]; s.pop();
            int pm = perim(l, s.empty() ? R : R - s.top()-1);
            mx = max(mx,pm);
        }
    }
    printf("%d\n",mx-1);
}
```

6 Maths

Miller Rabin

```
void factor(ll x, ll& e, ll& k){
    while(x%2LL==0LL){
        x/=2LL;
        ++e;
    }
    k = x;
}

//increase x for higher certainty, 5 works well
bool is_prime(ll n, int x){
    if(n&2LL==0 n==1LL)
        return false;
    if(n==2 || n==3 || n==5 || n==7)
        return true;
    ll e, k;
    factor(n-1,e,k);
    while(x-->0){
        ll a = (rand())%(n-5LL) + 2LL;
        ll p = mod_exp(a,k,n);
        if(p==1LL || p==n-1LL)
            continue;
        bool all_fail = true;
        for(int i = 0; i < e-1; ++i){
            p = mod_exp(p, 2, n);
            if(p==n-1LL){
                all_fail = false;
                break;
            }
        }
        if(all_fail)
            return false;
    }
    return true;
}
```