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Contents

1. Graph

1. Dijkstra

```
typedef pair<long long, int> p;
const long long INF = 10000000000000;
int V, E, K;
long long v[20001];
vector<p> e[20001];
void init() {
  for (int i = 1; i <= V; i++) {
    v[i] = INF;
  }
}
void dijkstra(int start) {
  init();
  priority_queue<p, vector<p>, greater<p>> pq;
  v[start] = 0;
  pq.push({ 0, start });
  while (!pq.empty()) {
    long long cost = pq.top().first;
    int des = pq.top().second;
    pq.pop();
    if (v[des] < cost) continue;
    for (int i = 0; i < e[des].size(); i++) {
      int there = e[des][i].second;
      long long next = cost + e[des][i].first;
      if (v[there] > next) {
        v[there] = next;
        pq.push({ next,there });
      }
    }
  }
}
int main() {
  cin >> V >> E >> K;
  for (int i = 1; i <= E; i++) {
    long long in1, in2, in3;
    cin >> in1 >> in2 >> in3;
    e[in1].push_back({ in3, in2 });
  }
  dijkstra(K);
  for (int i = 1; i <= V; i++) {
    if (v[i] == INF) cout << "INF\n";
    else cout << v[i] << '\n';
  }
}
```

2. Floyd-Warshall

```
const int INF = 1000000000;
int N, M, dist[101][101];
int main() {
  cin >> N >> M;
  for (int i = 1; i <= N; i++) {
    for (int j = 1; j <= N; j++) {
      dist[i][j] = i == j ? 0 : INF;
    }
  }
  for (int i = 1; i <= M; i++) {
    int in1, in2, in3;
    cin >> in1 >> in2 >> in3;
    dist[in1][in2] = min(dist[in1][in2], in3);
  }
  for (int k = 1; k <= N; k++) {
    for (int i = 1; i <= N; i++) {
      for (int j = 1; j <= N; j++) {
        dist[i][j] = min(dist[i][j], dist[i][k] + dist[k][j]);
      }
    }
  }
  for (int i = 1; i <= N; i++) {
    for (int j = 1; j <= N; j++) {
      cout << dist[i][j] << ' ';
    }
    cout << '\n';
  }
}
```

3. Minimum Spanning Tree

```
typedef tuple<int, int, int> t;
```

```
int uf[10001];
int N, M, in1, in2, in3;
priority_queue<t, vector<t>, greater<t>> pq;
int find(int a) {
  if (uf[a] == a) return a;
  return uf[a] = find(uf[a]);
}
void merge(int a, int b) {
  a = find(a);
  b = find(b);
  if (a != b) uf[b] = a;
}
int main() {
  cin >> N >> M;
  for (int i = 0; i < M; i++) {
    cin >> in1 >> in2 >> in3;
    pq.push({ in3,in1,in2 }); //Distance, Start, End
  }
  for (int i = 1; i <= N; i++) uf[i] = i; //Union-Find Initialization
  long long cnt = 0, ans = 0;
  while (!pq.empty()) {
    if (cnt == N - 1) break; //N - 1 connections are enough for a spanning tree
    tie(cost, st, se) = pq.top();
    pq.pop();
    if (find(st) == find(se)) continue;
    merge(st, se);
    cnt++; ans += cost;
  }
  cout << ans;
}
```

4. Topological Sort

```
int main() {
  int N, M;
  int indegree[32001] = { 0 };
  vector<int> edge[32001];
  queue<int> q;
  vector<int> res;
  cin >> N >> M;
  for (int i = 1; i <= M; i++) {
    int in1, in2;
    cin >> in1 >> in2;
    indegree[in2]++;
    edge[in1].push_back(in2);
  }
  for (int i = 1; i <= N; i++) {
    if (indegree[i] == 0)q.push(i);
  }
  for (int i = 1; i <= N; i++) {
    if (q.empty()) {
      cout << "Cannot Sort";
      return 0;
    }
    int cur = q.front();
    q.pop();
    res.push_back(cur);
    for (int next : edge[cur]) {
      if (--indegree[next] == 0)q.push(next);
    }
  }
  for (int i = 0; i < res.size(); i++) {
    cout << res[i] << ' ';
  }
}
```

5. Strongly Connected Components

```
const int MAX = 10001;
int V, E;
vector<int> edge[MAX];
int sccCnt; //How many SCCs?
vector<vector<int>> SCC; //Stores Vertices of each SCCs
int dfscnt, dfsn[MAX], sccInd[MAX];
bool finished[MAX];
stack<int> s;
int makeSCC(int cur) { //return index cur's SCC number
  dfsn[cur] = ++dfscnt;
  s.push(cur);
  int res = dfsn[cur];
  for (int next : edge[cur]) {
    if (dfsn[next] == 0)res = min(res, makeSCC(next));
```

```
    else if (finished[next] == 0) res = min(res, dfsn[next]);
  }
  if (res == dfsn[cur]) {
    vector<int> curSCC;
    while (1) {
      int t = s.top();
      s.pop();
      curSCC.push_back(t);
      finished[t] = 1;
      sccInd[t] = sccCnt;
      if (t == cur) break;
    }
    //sort(curSCC.begin(), curSCC.end());
    SCC.push_back(curSCC);
    sccCnt++;
  }
  return res;
}
int main() {
  cin >> V >> E;
  for (int i = 0; i < E; i++) {
    int in1, in2;
    cin >> in1 >> in2;
    edge[in1].push_back(in2);
  }
  for (int i = 1; i <= V; i++) if (dfsn[i] == 0) makeSCC(i);
  //sort(SCC.begin(), SCC.end());
  //cout << sccCnt << '\n';
  for (auto& curSCC : SCC) {
    for (int cur : curSCC) {
      cout << cur << ' ';
    }
    cout << '\n';
  }
}
```

6. Maximum Flow

```
const int MAX = 800;
const long long INF = 2100000000;
int c[MAX][MAX], f[MAX][MAX], visited[MAX];
vector<int> edge[MAX];
/*
S에서 T로 가는 증가 경로 구하기(에드몬드 카프)
S : 시작점, T : 도착점
c[a][b] : a에서 b로 흐를 수 있는 최대 양 (Capacity)
f[a][b] : a에서 b로 흐른 실제 양 (Flow)
조건
용량 제한 : f[a][b] <= c[a][b]
유량의 대칭성 : f[a][b] == -f[b][a]
나오는 유량의 합 == 들어오는 유량의 합
*/
int maxFlow(int S, int T);
int bfs(int S, int T);
int maxFlow(int S, int T) {
  int result = 0;
  while (1) {
    int flow = bfs(S, T);
    if (!flow)break;
    result += flow;
  }
  return result;
}
int bfs(int S, int T) {
  memset(visited, -1, sizeof(visited));
  queue<int> q;
  q.push(S);
  while (!q.empty()) {
    int cur = q.front();
    q.pop();
    for (int next : edge[cur]) { //방문했는지, 용량이 남아 있는지 체크
      if (c[cur][next] - f[cur][next] <= 0)continue;
      if (visited[next] != -1)continue;
      q.push(next);
      visited[next] = cur; //cur->next 경로 기억
      if (next == T)break; //도착했을 경우 종료
    }
  }
  if (visited[T] == -1)return 0;
  int flow = INF;
  for (int i = T; i != S; i = visited[i]) { //최소 유량 탐색
```

```
    flow = min(flow, c[visited[i]][i] - f[visited[i]][i]);
  }
  for (int i = T; i != S; i = visited[i]) { //최소 유량 추가
    f[visited[i]][i] += flow;
    f[i][visited[i]] -= flow;
  }
  return flow;
}
int main() {
  int N; cin >> N;
  for (int i = 0; i < N; i++) {
    int in1, in2, in3;
    cin >> in1 >> in2 >> in3;
    c[in1][in2] += in3;
    c[in2][in1] += in3;
    edge[in1].push_back(in2);
    edge[in2].push_back(in1);
  }
  int S, T; cin >> S >> T;
  cout << maxFlow(S, T);
}
```

7. Bipartite Matching

```
const int MAX = 1001;
int N, M, A[MAX], B[MAX]; //A[i], B[i] : 각 정점이 매칭된 반대편 정점 인덱스
vector<int> edge[MAX];
bool visited[MAX];
//A그룹의 정점 a를 매칭시키는 데 성공하면 1 반환
//반대편이 매칭되지 않았으면 매칭시키고,
//이미 매칭되어 있다면 원래 매칭된 정점을 다른 정점과 매칭시킨다.
bool dfs(int a) {
  visited[a] = 1;
  for (int b : edge[a]) {
    if (B[b] == -1 || !visited[B[b]] && dfs(B[b])) {
      A[a] = b;
      B[b] = a;
      return 1;
    }
  }
  return 0;
}
int main() {
  cin >> N >> M;
  for (int i = 1; i <= N; i++) {
    int cnt;
    cin >> cnt;
    while (cnt--) {
      int in;
      cin >> in;
      edge[i].push_back(in);
    }
  }
  int match = 0;
  fill(A + 1, A + MAX - 1, -1);
  fill(B + 1, B + MAX - 1, -1);
  for (int i = 1; i <= N; i++) {
    if (A[i] == -1) {
      fill(visited + 1, visited + MAX - 1, 0);
      if (dfs(i))match++;
    }
  }
  cout << match;
}
```

8. Lowest Common Ancestor

```
const int MAX = 100000;
const int MAXDEP = 18;//more than log(2, 100000)
int N, M;
int par[MAX][MAXDEP];//par[i][k] : i의 2^k번째 부모
int dep[MAX];
vector<int> edge[MAX];
void makeTree(int cur) {
  for (int next : edge[cur]) {
    if (dep[next] == -1) {
      par[next][0] = cur;
      dep[next] = dep[cur] + 1;
      makeTree(next);
    }
  }
}
```

```
int getLCA(int in1, int in2) {
  in1--; in2--;
  if (dep[in1] < dep[in2])swap(in1, in2);
  int dif = dep[in1] - dep[in2];
  for (int j = 0; dif; j++) {
    if (dif % 2)in1 = par[in1][j];
    dif /= 2;
  }
  if (in1 != in2) {
    for (int j = MAXDEP - 1; j >= 0; j--) {
      if (par[in1][j] != -1 && par[in1][j] != par[in2][j]) {
        in1 = par[in1][j];
        in2 = par[in2][j];
      }
    }
    in1 = par[in1][0];
  }
  return in1 + 1;
}
int main() {
  cin >> N;
  for (int i = 0; i < N - 1; i++) {
    int in1, in2;
    cin >> in1 >> in2;
    in1--; in2--;
    edge[in1].push_back(in2);
    edge[in2].push_back(in1);
  }
  memset(par, -1, sizeof(par));
  fill(dep, dep + N, -1);
  dep[0] = 0;
  makeTree(0);
  for (int j = 0; j < MAXDEP - 1; j++) {
    for (int i = 1; i < N; i++) {
      if (par[i][j] != -1) {
        par[i][j + 1] = par[par[i][j]][j];
      }
    }
  }
  cin >> M;
  for (int i = 0; i < M; i++) {
    int in1, in2;
    cin >> in1 >> in2;
    cout << getLCA(in1, in2) << '\n';
  }
}
```

2. Data Structure

1. Segment Tree

```
const long long MAX_SIZE = 1000001;
long long tree[MAX_SIZE * 4];
long long N, M, depth, st;
void update(long long ind, long long val) {
  tree[st + ind] = val;
  ind = (ind + 1) / 2;
  for (int i = depth - 1; i >= 1; i--) {
    int cur = pow(2, i - 1) - 1 + ind;
    tree[cur] = tree[cur * 2] + tree[cur * 2 + 1];
    ind = (ind + 1) / 2;
  }
}
long long query(long long start, long long end) {
  long long ret = 0;
  start += st; end += st;
  while (start <= end) {
    if (start % 2 == 1) ret += tree[start];
    if (end % 2 == 0) ret += tree[end];
    start = (start + 1) / 2;
    end = (end - 1) / 2;
  }
  return ret;
}
int main() {
  cin >> N;
  depth = 1;
  while (1) {
    if (N <= (long long)pow(2, depth - 1))break;
    depth++;
```

```
  }
  st = (long long)pow(2, depth - 1) - 1;
  for (int i = 1; i <= N; i++) {
    cin >> tree[i + st];
  }
  for (int i = depth - 1; i >= 1; i--) {
    for (int j = 0; j < pow(2, i - 1); j++) {
      long long ind = pow(2, i - 1) + j;
      tree[ind] = tree[ind * 2] + tree[ind * 2 + 1];
    }
  }
  cin >> M;
  for (int t = 0; t < M; t++) {
    int in1, in2, in3;
    cin >> in1 >> in2 >> in3;
    if (in1 == 1) {//set in2-nd index to in3
      update(in2, in3);
    }
    else if (in1 == 2) {//perform query for in2 ~ in3
      cout << query(in2, in3) << '\n';
    }
  }
}
```

2. Segment Tree with Lazy Propagation

3. String

1. KMP

```
string src, tar;
vector<int> fail, KMP;
void getFail(string t) {
  fail.resize(t.length());
  int j = 0;
  for (int i = 1; i < t.length(); ++i) {
    while (j > 0 && t[i] != t[j]) j = fail[j - 1];
    if (t[i] == t[j]) fail[i] = ++j;
  }
}
void getKMP(string s, string t) {
  int sLen = s.length(), tLen = t.length(), j = 0;
  for (int i = 0; i < sLen; ++i) {
    while (j > 0 && s[i] != t[j]) j = fail[j - 1];
    if (s[i] == t[j]) {
      if (j == tLen - 1) {
        KMP.push_back(i - tLen + 1 + 1);
        j = fail[j];
      }
      else j++;
    }
  }
}
int main() {
  getline(cin, src); getline(cin, tar);
  getFail(tar);
  getKMP(src, tar);
  cout << KMP.size() << "\n";
  for (int i : KMP) {
    cout << i << " ";
  }
}
```

2. Rabin-Karp

```
const int MOD = 1000000007;
inline long long mod(long long n) { if (n >= 0) return n % MOD; return ((-n / MOD + 1) *
MOD + n) % MOD; }
int L;
string src;
int rabinKarp(int len) {
  long long H = 0, power = 1;
  unordered_map<int, vector<int>> hashTable;
  for (int i = 0; i <= src.length() - len; ++i) {
    if (i == 0) {
      for (int j = 0; j < len; ++j) {
        H = mod(H + 1LL * src[len - 1 - j] * power);
        if (j < len - 1) power = mod(power * 127);
      }
    }
    else {
```

```
      H = mod(127 * (H - 1LL * src[i - 1] * power) + src[i + len - 1]);
    }
    if (hashTable[H].size() == 0) hashTable[H].push_back(i);
    else {
      for (int pos : hashTable[H]) {
        for (int p = 0; p < len; ++p) {
          if (src[pos + p] != src[i + p]) break;
          if (p == len - 1) return true;
        }
      }
      hashTable[H].push_back(i);
    }
  }
  return false;
}
```

3. Trie

```
struct Trie;
typedef pair<char, Trie*> pct;
struct Trie {
  vector<pct> child;
  bool isRet;
  Trie() {
    isRet = false;
  }
  ~Trie() {
    for (pct c : child) delete c.second;
  }
  void insert(const char* key) {
    int k = *key;
    if (k == '\0') {
      isRet = true;
      return;
    }
    for (pct c : child) {
      if (c.first == k) {
        c.second->insert(key + 1);
        return;
      }
    }
    child.push_back(pct(*key, new Trie));
    child.back().second->insert(key + 1);
  }
  bool demoFunc(const char* key) {
    int k = *key;
    if (isRet && k == '\0') return true;
    for (pct c : child) {
      if (c.first == k) return c.second->demoFunc(key + 1);
    }
    return false;
  }
};
int main() {
  Trie* root = new Trie;
  int n; cin >> n;
  for (int i = 0; i < n; ++i) {
    string input; cin >> input;
    root->insert(input.c_str());
  }
  int m; cin >> m;
  for (int i = 0; i < m; ++i) {
    string input; cin >> input;
    cout << (root->demoFunc(input.c_str()) ? "YES" : "NO") << "\n";
  }
  delete root;
}
```

4. Aho-Corasick

```
struct Trie {
  unordered_map<char, Trie*> child;
  Trie* fail;
  bool isRet = false;
  void push(string& s) {
    Trie* cur = this;
    for (char const& c : s) {
      if (cur->child.find(c) == cur->child.end())
        cur->child[c] = new Trie;
      cur = cur->child[c];
      cur->fail = this;
    }
```

```
    cur->isRet = true;
  }
  void build() {
    queue<Trie*> Q;
    for (auto const& p : child)
      if (p.second) Q.push(p.second);
    while (!Q.empty()) {
      Trie* cur = Q.front(); Q.pop();
      for (auto const& c : cur->child) {
        Trie* p = cur->fail;
        while (p != this && p->child.find(c.first) == p->child.end()) p = p->fail;
        p = p->child[c.first];
        if (!p) p = this;
        c.second->fail = p;
        if (p->isRet) c.second->isRet = true;
        Q.push(c.second);
      }
    }
  }
  bool ask(string& s) {
    Trie* p = this;
    for (char& c : s) {
      while (p != this && p->child.find(c) == p->child.end()) p = p->fail;
      p = p->child[c];
      if (!p) p = this;
      if (p->isRet) return 1;
    }
    return 0;
  }
};
int main() {
  Trie* root = new Trie;
  int N, Q;
  string input;
  cin >> N; while (N--) {
    cin >> input; root->push(input);
  }
  root->build();
  cin >> Q; while (Q--) {
    cin >> input; cout << (root->ask(input) ? "YES" : "NO") << "\n";
  }
}
```

5. Suffix Array and Longest Common Prefix Array

```
const char baseChar = '`'; // @ for uppercase ` for lowercase
const int baseSize = 27; // 27 : 59
vector<int> suffixArray, LCPArray;
void getLCP(vector<int>& sa, vector<int>& lcpa, string& s) {
  int i, j, k, u = 0, m = baseSize, sLen = s.length();
  sa.resize(sLen, 0); lcpa.resize(sLen, 0);
  vector<int> cnt(max(sLen, m), 0), x(sLen, 0), y(sLen, 0);
  for (i = 0; i < sLen; ++i) cnt[x[i] = s[i] - baseChar]++;
  for (i = 0; i < m; ++i) cnt[i] += (i == 0 ? 0 : cnt[i - 1]);
  for (i = sLen - 1; i >= 0; --i) sa[--cnt[x[i]]] = i;
  for (int len = 1, p = 1; p < sLen; len <<= 1, m = p + 1) {
    for (i = sLen - len - 1, p = 0; ++i < sLen;) y[p++] = i;
    for (i = 0; i < sLen; ++i) if (sa[i] >= len) y[p++] = sa[i] - len;
    for (i = 0; i < m; ++i) cnt[i] = 0;
    for (i = 0; i < sLen; ++i) cnt[x[y[i]]]++;
    for (i = 0; i < m; ++i) cnt[i] += (i == 0 ? 0 : cnt[i - 1]);
    for (i = sLen - 1; i >= 0; --i) sa[--cnt[x[y[i]]]] = y[i];
    swap(x, y); p = 1; x[sa[0]] = 1;
    for (i = 0; i < sLen - 1; ++i) x[sa[i + 1]] = sa[i] + len < sLen&& sa[i + 1] + len < sLen &&
y[sa[i]] == y[sa[i + 1]] && y[sa[i] + len] == y[sa[i + 1] + len] ? p : ++p;
  }
  vector<int> rank(sLen, 0);
  for (i = 0; i < sLen; i++) rank[sa[i]] = i;
  for (i = 0; i < sLen; ++i) if (k = rank[i]) {
    j = sa[k - 1];
    while (i + u < sLen && j + u < sLen && s[i + u] == s[j + u]) u++;
    lcpa[k] = u;
    u = u ? u - 1 : 0;
  }
}
int main() {
  string s; cin >> s;
  getLCP(suffixArray, LCPArray, s);
  cout << "SA: "; for (int i = 0; i < s.length(); ++i) cout << setw(2) << suffixArray[i] << " "; cout
<< "\n";
  cout << "LA: "; for (int i = 0; i < s.length(); ++i) cout << setw(2) << LCPArray[i] << " "; cout
```

```
<< "\n";
}
```

6. Manacher

```
vector<int> manacher(string& src) {
  int srcLen = src.size(); src.resize(srcLen * 2 + 1, '#');
  for (int i = srcLen - 1; i >= 0; --i) src[i * 2 + 1] = src[i], src[i] = '#';
  int c = 0, r = 0, len = src.size();
  vector<int> ret(len, 0);
  for (int i = 0; i < len; ++i) {
    int sym = 2 * c - i;
    if (i < r) ret[i] = min(r - i, ret[sym]);
    while (i - ret[i] > 0 && i + ret[i] - 1 < len && src[i - ret[i] - 1] == src[i + ret[i] + 1])
ret[i]++;
    if (ret[i] + i > r) r = ret[i] + i, c = i;
  }
  return ret;
}
int main() {
  string src; cin >> src;
  vector<int> pal = manacher(src);
  for (int i : pal) cout << i << ' ';
}
```

7. Z

```
vector<int> Z;
void getZ(string& src) {
  int l = 0, r = 0, len = src.length();
  Z.resize(len);
  for (int i = 1; i < len; i++) {
    Z[i] = max(0, min(Z[i - l], r - i));
    while (src[i + Z[i]] && src[Z[i]] == src[i + Z[i]]) Z[i]++;
    if (i + Z[i] > r) l = i, r = i + Z[i];
  }
  Z[0] = len; // Z[0] = 0;
}
int main() {
  string src; cin >> src;
  getZ(src);
  for (auto i : Z) cout << i << " ";
}
```

4. Math

1. Greatest Common Divisor, Least Common Multiple

```
long long gcd(long long a, long long b) { for (; b; a %= b, swap(a, b)); return a; }
long long lcm(long long a, long long b) { return a * b / gcd(a, b); }
```

2. Sieve of Eratosthenes

```
const long long MAX = 100001;
bool isprime[MAX];
void sieve(){
  memset(isprime, 1, sizeof(isprime));
  isprime[1] = 0;
  for (int i = 2; i*i <= MAX; i++) {
    if (isprime[i]) {
      for (int j = i*i; j <= MAX; j += i) {
        isprime[j] = 0;
      }
    }
  }
}
```

3. Binomial Coefficient

```
const long long MOD = 1000000007;
const long long MAX_NUM = 4000001;
long long f[MAX_NUM];
long long mypow(long long base, long long exp, long long MOD) {
  long long ans = 1;
  while (exp > 0) {
    if (exp % 2 != 0) {
      ans *= base;
      ans %= MOD;
    }
    base *= base;
    base %= MOD;
    exp /= 2;
  }
  return ans;
}
void nCrInit() {
  f[0] = 1; f[1] = 1;
```

```
  for (int i = 2; i <= MAX_NUM - 1; i++) {
    f[i] = f[i - 1] * i;
    f[i] %= MOD;
  }
}
long long nCr(int n, int r) {
  return (f[n] * mypow((f[r] * f[n - r]) % MOD, MOD - 2, MOD)) % MOD;
}
int main() {
  long long n, r;
  nCrInit();
  cin >> n >> r;
  cout << nCr(n, r) << "\n";
}
```

4. Matrix Exponential

```
long long a[3][3], a2[3][3], ans[3][3], temp[3][3], N;
void mult(long long a[3][3], long long b[3][3]) {
  for (int i = 0; i < 3; i++) {
    for (int j = 0; j < 3; j++) {
      for (int k = 0; k < 3; k++) {
        temp[i][j] += a[i][k] * b[k][j];
        temp[i][j] %= 1000000007;
      }
    }
  }
  for (int i = 0; i < 3; i++) {
    for (int j = 0; j < 3; j++) {
      a[i][j] = temp[i][j];
      temp[i][j] = 0;
    }
  }
}
int main() {
  cin >> N; N--;
  /*
  행렬 설명
  a : 가운데 거듭제곱되는 행렬
    초기화는 점화식으로 유도된 행렬로 한다.
  a2 : 거듭제곱된 결과가 저장되는 행렬
    초기화는 영행렬로 한다.
  temp : mult함수에서 사용되는 임시 행렬
  ans : 답이 저장되어 있는 행렬.
    초기화를 할 때는 ans[0][i]의 꼴로 베이스 값을 저장해놓는다.
  mult(ans, a2)를 하면 ans[0][i]에 원하는 값이 들어간다.
  */
  for (int i = 0; i < 3; i++) {
    for (int j = 0; j < 3; j++) {
      a[i][j] = 1;
      if (i == j)a2[i][i] = 1;
    }
  }
  a[0][0] = a[1][1] = 0;
  ans[0][0] = ans[0][1] = ans[0][2] = 1;
  while (N > 0) {
    if (N % 2 == 1) {
      mult(a2, a);
    }
    mult(a, a);
    N /= 2;
  }
  mult(ans, a2);
  cout << (ans[0][0] + ans[0][1] + ans[0][2]) % 1000000007;
}
```

5. Fast Fourier Transform

```
const long double pi = acos(-1);
typedef complex<double> base;
void fft(vector <base> &a, bool invert) {
  int n = a.size();
  for (int i = 1, j = 0; i<n; i++) {
    int bit = n >> 1;
    for (; j >= bit; bit >>= 1) j -= bit;
    j += bit;
    if (i < j) swap(a[i], a[j]);
  }
  for (int len = 2; len <= n; len <<= 1) {
    double ang = 2 * pi / len * (invert ? -1 : 1);
    base wlen(cos(ang), sin(ang));
    for (int i = 0; i<n; i += len) {
```

```
        base w(1);
        for (int j = 0; j<len / 2; j++) {
          base u = a[i + j], v = a[i + j + len / 2] * w;
          a[i + j] = u + v;
          a[i + j + len / 2] = u - v;
          w *= wlen;
        }
      }
    }
    if (invert)
      for (int i = 0; i<n; i++) a[i] /= n;
}
void mul(const vector<int> &a, const vector<int> &b, vector<int> &res) {
    vector<base> fa(a.begin(), a.end()), fb(b.begin(), b.end());
    int n = 1;
    while (n < max(a.size(), b.size())) n <<= 1;
    n <<= 1;
    fa.resize(n); fb.resize(n);
    fft(fa, false); fft(fb, false);
    for (int i = 0; i < n; i++) fa[i] *= fb[i];
    fft(fa, true);
    res.resize(n);
    for (int i = 0; i < n; i++) res[i] = int(fa[i].real() + 0.5);
}
int main() {
    int N, M;
    vector<int> v1, v2, res;
    cin >> N >> M;
    for (int i = 0; i < N; i++) {
      int in; cin >> in;
      v1.push_back(in);
    }
    for (int i = 0; i < M; i++) {
      int in; cin >> in;
      v2.push_back(in);
    }
    mul(v1, v2, res);
    for (int i = 0; i < N + M - 1; i++) {
      cout << res[i] << ' ';
    }
}
```

5. Geometry

1. CCW

```
//determines direction of 3 points
long long ccw(const point& A, const point& B, const point& C) {
    long long t = 1LL * (B.x - A.x)*(C.y - A.y) - 1LL * (B.y - A.y)*(C.x - A.x);
    if (t > 0) return 1; //Counter-Clockwise
    if (t == 0) return 0; //Line
    return -1; //Clockwise
}
```

2. Convex Hull

```
const int MAX = 100000;
struct point {
    int x, y;//실제 위치
    int p, q;//기준점으로부터 상대 위치
    point() : point(0, 0, 1, 0) {}
    point(int x1, int y1) :point(x1, y1, 1, 0) {}
    point(int x1, int y1, int p1, int q1) :x(x1), y(y1), p(p1), q(q1) {}
    bool operator<(const point& O) {
      if (1LL * q*O.p != 1LL * p*O.q)return 1LL * q*O.p < 1LL * p*O.q;
      if (y != O.y)return y < O.y;
      return x < O.x;
    }
};
point p[MAX];
int main() {
    int N;
    cin >> N;
    for (int i = 0; i < N; i++) {
      int in1, in2;
      cin >> in1 >> in2;
      p[i] = point(in1, in2);
    }
    sort(p, p + N);
    for (int i = 1; i < N; i++) {
      p[i].p = p[i].x - p[0].x;
      p[i].q = p[i].y - p[0].y;
```

```
  }
  sort(p + 1, p + N);//반시계 방향 정렬
  stack<int> cvh;
  cvh.push(0); cvh.push(1);
  int next = 2;
  while (next < N) {
    while (cvh.size() >= 2) {
      int fst, scd;
      fst = cvh.top();
      cvh.pop();
      scd = cvh.top();
      if (ccw(p[scd], p[fst], p[next]) > 0) {
        cvh.push(fst);
        break;
      }
    }
    cvh.push(next++);
  }
  cout << cvh.size();
}
```

3. Line Intersection

```
struct point {
  int x, y;
  point(int x, int y) {
    this->x = x;
    this->y = y;
  }
  bool operator< (point a) {
    if (a.x != this->x) {
      return a.x < this->x;
    }
    else {
      return a.y < this->y;
    }
  }
  bool operator<= (point a) {
    if (a.x == this->x && a.y == this->y) return 1;
    if (a.x != this->x) {
      return a.x < this->x;
    }
    else {
      return a.y < this->y;
    }
  }
};
bool isIntersect(pair<point, point> line1, pair<point, point> line2) {
  point p1 = line1.first;
  point p2 = line1.second;
  point p3 = line2.first;
  point p4 = line2.second;
  int l1 = ccw(p1, p2, p3) * ccw(p1, p2, p4);
  int l2 = ccw(p3, p4, p1) * ccw(p3, p4, p2);
  if (l1 == 0 && l2 == 0) {
    if (p2 < p1) swap(p1, p2);
    if (p4 < p3) swap(p3, p4);
    return (p3 <= p2 && p1 <= p4);
  }
  return (l1 <= 0 && l2 <= 0);
}
```

6. Others

1. Big Integer in Java

```
import java.math.*;
public class Main {
  public static void main(String[] args) {
    BigInteger a, b, c;
    a = new BigInteger("65535");
    b = new BigInteger("FFFF", 16); // 매개변수로 문자열, 2, 8, 16진수 입력
    c = BigInteger.valueOf(65535); // BigInteger의 valueOf 메서드를 사용
    a.add(b); // return (a + b)
    a.subtract(b); // return (a - b)
    a.multiply(b); // return (a * b)
    a.divide(b); // return (a / b), 몫만 반환
    a.remainder(b); // return (a % b)
    a.abs(); // return abs(a)
    a.pow(123); // return a^123, exponential should be an integer
    a.compareTo(b);
```

```
    // a > b 일때 1
    // a == b 일때 0
    // a < b 일때 -1
    a.equals(b); // return (a == b)
    a.min(b); // return min(a, b)
    a.max(b); // return max(a, b)
    a.gcd(b); // return gcd(a, b)
    a.toString();
    // a를 String 타입으로 변환
    // 보통 그냥 a를 출력하려 하면 해당 메서드로 변환하여 출력
    // 매개변수로 int값을 넣으면, 해당 진법으로 변환하여 출력
    BigInteger one = BigInteger.ONE;
    // BigInteger에서  상수 1. 상수는 0, 1, 2, 10 4개 있음.
  }
}
```

2. Big Decimal in Java

```
import java.math.*;
public class Main {
  public static void main(String[] args) {
    BigDecimal a = new BigDecimal("0.12345"),
        b = new BigDecimal("1.2345e-1"),
        c = new BigDecimal(0.12345),
        d = new BigDecimal(12345),
        e = BigDecimal.valueOf(0.12345),
        f = BigDecimal.valueOf(12345);
    // 문자열, double, long값 혹은 valueOf 메서드로도 생성이 가능
    a.add(b); // return (a + b)
    a.subtract(b); // return (a - b)
    a.multiply(b); // return (a * b)
    a.divide(b); // return (a / b)
    a.remainder(b); // return (a % b)
    a.divide(b, BigDecimal.ROUND_CEILING); // ceil
    a.divide(b, BigDecimal.ROUND_FLOOR); // floor
    a.divide(b, BigDecimal.ROUND_UP); // positive : ceil, negative : floor
    a.divide(b, BigDecimal.ROUND_DOWN); // positive : floor, negative : ceil
    a.divide(b, BigDecimal.ROUND_HALF_UP); // round
    // divide 연산 후 무한소수일때 올림 지정 안하면 예외발생
    a.setScale(6); // set precision
    a.setScale(3, BigDecimal.ROUND_HALF_UP); // set precision and half-up round
    a.abs(); // return abs(a)
    a.pow(123); // return a^123, exponential should be an integer
    a.compareTo(b);
    // a > b 일때 1
    // a == b 일때 0
    // a < b 일때 -1
    a.equals(b); // return (a == b)
    a.min(b); // return min(a, b)
    a.max(b); // return max(a, b)
    a.toString();
    // a를 문자열로 변환, 보통 그냥 a를 출력 시 이 과정을 거쳐 출력됨
    // 필요에 따라(길이가 길어질 경우) 1.0e-n 형식으로 변환되어 출력
    a.toPlainString();
    // 1.0e-n 형식이 아닌 원래 형태 그대로 문자열로 변환.
    a.toBigInteger();
    // BigInteger 형식으로 변환
    BigDecimal one = BigDecimal.ONE;
    // 0, 1, 10 등 자주쓰는 상수값
  }
}
```

3. Bit Operations

```
k & (1 << N) // return N-th bit of k
k | (1 << N) // make N-th bit of k to 1
k & ~(1 << N) // make N-th bit of k to 0
k & ~k // return least index of bit which has value 1
```

4. Coordinate Compression

```
long long getind(long long in){
  return lower_bound(a.begin(), a.end(), in) - a.begin();
}
sort(a.begin(), a.end());
a.erase(unique(a.begin(), a.end()), a.end());
```

5. Knuth Optimization

```
Optimization of O(N^3) DP to O(N^2)
Condition 0 : dp[i][j] is defined under 1 <= i <= j <= n
Condition 1 : dp[i][j] = min(dp[i][k] + dp[k + 1][j]) + cost[i][j]
Condition 2 : under a <= b <= c <= d, cost[a][c] + cost[b][d] <= cost[a][d] + cost[b][c]
Condition 3 : under a <= b <= c <= d, cost[b][c] <= cost[a][d]
Original O(N^3) DP :
for(i = 1; i <= n; i++){
```

```
  for(j = i; j < n; j++){
      for(k = j + 1; k < i; k++){
        dp[i][j] = min(dp[i][j] , dp[i][k] + dp[k + 1][j]);
        }
         dp[i][j] += C[i][j];
  }
}
```

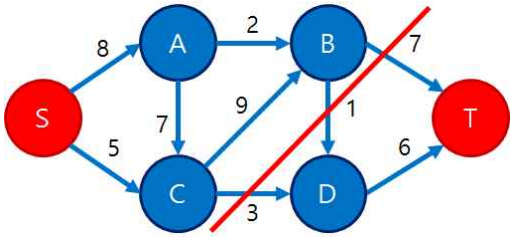
Optimized O(N^2) DP :

```
for(i=1; i<=n; i++){
  for(j=i; j<n; j++){
       dp[i][j] = MAX;
    for(k=A[i][j - 1]; k<=A[i + 1][j]; k++){ //상수 번 반복
      if(dp[i][j] > dp[i][k] + dp[k + 1][j]){
        dp[i][j] = dp[i][k] + dp[k + 1][j];
        A[i][j] = k;
      }
    }
    dp[i][j] += C[i][j];
  } //A[i][j] = minimum k to minimize dp[i][j]
} //A[i][j - 1] <= A[i][j] <= A[i + 1][j]
```

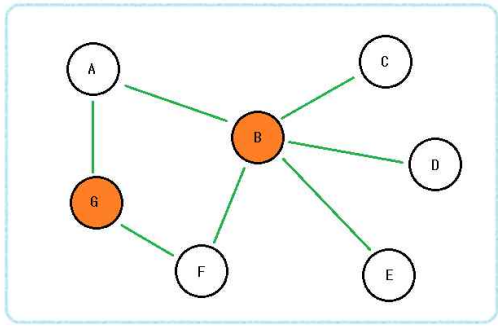
6. Some Prime Numbers

127, 131, 137, 139, 10007, 100003, 998244353, 1000000007, 1000000009

7. Tips



1. Minimum Cut of vertices is same as Maximum Flow of Vertices.



2. Minimum Vertex Cover is same as Maximum Matching.
3. Maximum Independent Set is Number of Vertices - Minimum Vertex Cover.
4. If node C is between node A and node B in a tree,
{LCA(A, C) == C && LCA(A, B) == LCA(C, B)} || {LCA(B, C) == C && LCA(A, B) == LCA(C, A)}
is true.
5. Derangement : dp[i] = (i - 1) * (dp[i - 1] + dp[i - 2]);
6. Erasing particular value in a vector

```
void erase(vector<int> &v, int val){
  for(auto it = v.begin(); it != v.end(); ){
    if(*it == val) it = v.erase(it);
    else it++;
  }
}
```

7. Partition of Number

Let dp[n][k] be the number of cases dividing n to k numbers.

a. dp[n][1] = dp[n][n] = 1
b. dp[n][k] = dp[n - k][1] + dp[n - k][2] + ... + dp[n - k][k]
c. dp[n][k] = dp[n - 1][k - 1] + dp[n - k][k]

8. Fermat's Little Theorem

If p is a prime number and a is not divisible by p, a^(p-1) % p == 1 is true.