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1. Graph

1. Dijkstra

```
typedef pair<ll, int> p;
const ll INF = 1e12;
auto dijkstra = [&](int start, vector<p> e[]) -> vector<ll>{
  vector<ll> v(N + 1);
  for (auto &i : v)i = INF;
  priority_queue<p, vector<p>, greater<p>> pq;
  v[start] = 0; pq.push({ 0, start });
  while (!pq.empty()) {
    ll cost, des, next, there;
    tie(cost, des) = pq.top(); pq.pop();
    for (auto k : e[des]) {
      tie(next, there) = k; next += cost;
      if (v[there] > next) {
        v[there] = next;
        pq.push({ next,there });
      }
    }
  }
  return v;
};
```

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
  ll 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], res;
  queue<int> q;
  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 ll 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

```
vector<int> v[MAXN];
```

```
int nbook[MAXN];
bool vish[MAXN];
int human[MAXN];
int n, m;
int a, b;
bool dfs(int h) {
    vish[h] = true;
    for (int a : v[h]) {
        if (nbook[a] == 0 || !vish[nbook[a]] && dfs(nbook[a])) {
            nbook[a] = h;
            human[h] = a;
            return true;
        }
    }
    return false;
}
int main() {
    ios::sync_with_stdio();
    cin.tie(0); cout.tie(0);
    cin >> n >> m;
    for (int i = 1; i <= m; i++) {
        cin >> a >> b;
        v[a].push_back(b);
    }
    int ans = 0;
    for (int i = 1; i <= n; i++) {
        if (human[i] == 0) {
            fill(vish, vish + 1 + n, false);
            ans += dfs(i);
        }
    }
    cout << ans;
}
```

8. Lowest Common Ancestor

```
int t, n, p1, p2, root;
int p[20][10001], depth[10001], visit[10001], ind[10001];
vector<vector<int>> v;
void dfs(int cur) {
    visit[cur] = true;
    for (auto i : v[cur]) {
        if (!visit[i]) {
            depth[i] = depth[cur] + 1;
            p[0][i] = cur;
            dfs(i);
        }
    }
}
int lca(int x, int y) {
    if (depth[x] > depth[y])swap(x, y);
    for (int i = 19; i >= 0; i--) {
        int dif = depth[y] - depth[x];
        if (dif >= (1 << i))y = p[i][y];
    }
    if (x == y)return x;
    for (int i = 19; i >= 0; i--) {
        if (p[i][x] != p[i][y]) {
            x = p[i][x];
            y = p[i][y];
        }
    }
    return p[0][x];
}
int main() {
    cin >> n;
    v.resize(n + 1);
    for (int i = 0; i < n - 1; i++) {
        cin >> p1 >> p2;
        v[p1].push_back(p2);
        ind[p2]++;
    }
    for (int i = 1; i <= n; i++) {
        if (!ind[i]) {
            root = i;
            break;
        }
    }
    dfs(root);
    for (int i = 1; i < 20; i++)
        for (int j = 1; j <= n; j++)
```

```
      p[i][j] = p[i - 1][p[i - 1][j]];
  cin >> p1 >> p2;
  cout << lca(p1, p2) << '\n';
```

2. Data Structure

1. Segment Tree

```
struct SegTree {
  ll sz, st, dep;
  vector<ll> pw2, v;
  SegTree(ll size) {
    ll k = 1;
    for (int i = 0; i < 30; i++)pw2.push_back(k), k <<= 1;
    sz = size; v.resize(sz * 4, 0); dep = 1;
    while(1) {
      if (sz <= pw2[dep - 1])break;
      dep++;
    }
    st = pw2[dep - 1] - 1;
  }
  void init(ll val) {
    for (int i = 1; i < 4 * sz; i++)v[i] = val;
  }
  ll val(ll ind) {
      return v[st + ind];
  }
  void update(ll ind, ll val) {
    v[st + ind] = val; ind = (ind + 1) / 2;
        for (int i = dep - 1; i >= 1; i--) {
      ll cur = pw2[i - 1] - 1 + ind;
      v[cur] = v[cur * 2] + v[cur * 2 + 1];
      ind = (ind + 1) / 2;
    }
  }
     ll query(ll start, ll end) {
    ll ret = 0;
    start += st; end += st;
    while (start <= end) {
      if (start % 2 == 1)ret += v[start];
      if (end % 2 == 0)ret += v[end];
      start = (start + 1) / 2;
      end = (end - 1) / 2;
    }
      return ret;
  }
};
```

2. Fenwick Tree with Lazy Propagation

```
struct lazy {
  struct fenwick {
    ll sz;
    ll *arr;
    fenwick(int size) {
      sz = size + 1;
      arr = new ll[sz];
      fill(arr, arr + sz, 0);
    }
    void update(int i, ll x) {
      while (i <= sz) {
        arr[i] += x;
        i += i & -i;
      }
    }
    ll sum(int i) const {
      ll x = 0;
      while (i) {
        x += arr[i];
        i -= i & -i;
      }
      return x;
    }
  };
  fenwick *suma, *sumb;
  lazy(int size) {
    suma = new fenwick(size);
    sumb = new fenwick(size);
  }
  void add(int L, int R, ll val) {
    suma->update(L, val);
    suma->update(R + 1, -val);
    sumb->update(L, (1LL - L)*val);
    sumb->update(R + 1, 1LL * R*val);
  }
  ll query(int L, int R) {
    ll ans = 0;
    ans += suma->sum(R)*R + sumb->sum(R);
    ans -= suma->sum(L - 1)*(L - 1) + sumb->sum(L - 1);
    return ans;
  }
};
```

3. Segment Tree with Lazy Propagation

```
void propagate(ll lo, ll hi, ll node) {
  if (!lazy[node])return;
  else {
    if (lo != hi) {
      lazy[node * 2] += lazy[node];
      lazy[node * 2 + 1] += lazy[node];
    }
  }
  seg[node] += lazy[node] * (hi - lo + 1);
  lazy[node] = 0;
}
ll update(ll lo, ll hi, ll val, ll node, ll x, ll y) {
  propagate(x, y, node);
  if (hi < x || y < lo)return seg[node];
  if (lo <= x && y <= hi) {
    lazy[node] += val;
    propagate(x, y, node);
    return seg[node];
  }
  ll mid = (x + y) >> 1;
  return seg[node] = update(lo, hi, val, node * 2, x, mid) + update(lo, hi, val, node * 2 + 1, mid + 1, y);
}
ll query(ll lo, ll hi, ll node, ll x, ll y) {
  propagate(x, y, node);
  if (hi < x || y < lo)return 0;
  if (lo <= x && y <= hi)return seg[node];
  ll mid = (x + y) >> 1;
  return query(lo, hi, node * 2, x, mid) + query(lo, hi, node * 2 + 1, mid + 1, y);
}
```

4. Merge Sort Tree

```
struct MergeSortTree {
  ll sz, st, dep;
  vector<vector<ll>> v; vector<ll> pw2;
  MergeSortTree(ll size) {
    ll k = 1;
    for (int i = 0; i < 30; i++)pw2.push_back(k), k <<= 1;
    sz = size; v.resize(sz * 4); dep = 1;
    while (1) {
      if (sz <= pw2[dep - 1])break;
      dep++;
    }
    st = pw2[dep - 1] - 1;
  }
  void make(vector<ll> in) {
    for (int i = 0; i < sz; i++) {
      v[st + i].push_back(in[i]);
    }
    int ind = st, cnt = sz;
    while (ind > 0) {
      ind = (ind + 1) / 2; cnt = (cnt + 1) / 2;
      for (int i = 0; i < cnt; i++) {
        v[ind + i].resize(v[(ind + i) * 2].size() + v[(ind + i) * 2 + 1].size());
        merge(v[(ind + i) * 2].begin(), v[(ind + i) * 2].end(),
        v[(ind + i) * 2 + 1].begin(), v[(ind + i) * 2 + 1].end(),
        v[ind + i].begin()
        );
      }
      if (ind == 1)break;
    }
  }
  ll query(ll start, ll end, ll val) {
    ll ret = 0;
    start += st; end += st;
    while (start <= end) {
      if (start % 2 == 1) {
        auto k = upper_bound(v[start].begin(), v[start].end(), val) - v[start].begin();
        ret += v[start].size() - k;
      }
      if (end % 2 == 0) {
        auto k = upper_bound(v[end].begin(), v[end].end(), val) - v[end].begin();
        ret += v[end].size() - k;
      }
      start = (start + 1) / 2;
      end = (end - 1) / 2;
    }
    return ret;
  }
};
```

5. Segment Tree(OpeningSound)

```
ll mseg(int left, int right, int node) {
  if (left == right) {
    return seg[node] = arr[left];
  }
  int mid = (left + right) / 2;
  return seg[node] = (mseg(left, mid, node * 2) % MOD) * (mseg(mid + 1, right, node * 2 + 1)) % MOD;
}
ll update(int left, int right, int node, int change, int diff) {
  if (!(left <= change && right >= change))
    return seg[node];
  if (left == right)
    return   seg[node] = arr[left];
  int mid = (left + right) / 2;
  return seg[node] = (update(left, mid, node * 2, change, diff) % MOD) * (update(mid + 1, right, node * 2 + 1, change, diff) % MOD) % MOD;
}
ll gop(int left, int right, int node, int first, int end) {
  if (first <= left && right <= end)
    return seg[node];
  if (first > right || left > end)
    return 1;
  int mid = (left + right) / 2;
  return (gop(left, mid, node * 2, first, end) % MOD) * (gop(mid+1,right, node * 2+1, first, end) % MOD) % MOD;
}

int main() {
  ios::sync_with_stdio(0);
  cin.tie(0), cout.tie(0);
  cin >> N >> M>> K;
  for (int i = 1; i <= N; i++) {
    cin >> arr[i];
  }
  mseg(1, N, 1);
  for (int i = 1; i <= M+K; i++) {
    int a, b, c;
    cin >> a >> b >> c;
    if (a == 1) {
      arr[b] = c;
      update(1, N, 1, b, c);
    }
    else {
      cout << gop(1,N,1,b, c)<<'\n';
    }
  }
}
```

5. Segment Tree with Lazy Propagation(OpeningSound)

```
void lazyche(int leng, int node) {
  if (lazy[node]) {
    seg[node] += leng * lazy[node];
    if (leng != 1) {
      lazy[node * 2] += lazy[node];
      lazy[node * 2+1] += lazy[node];
    }
    lazy[node] = 0;
  }
}

ll mseg(int left, int right, int node) {
  if (left == right)
    return seg[node] = arr[left];
  int mid = (left + right) / 2;
  return seg[node] = mseg(left, mid, node * 2) + mseg(mid + 1, right, node * 2 + 1);
}

void update(int left, int right, int node, int start, int end, int diff) {
  int leng = right - left + 1;
  lazyche(leng, node);
  if (start <= left && right <= end){
    seg[node] += leng * diff;
    if (leng != 1) {
      lazy[node * 2] += diff;
      lazy[node * 2 + 1] += diff;
    }
    return;
  }
  if (start > right || end < left)
    return;
  int mid = (left + right) / 2;
  update(left, mid, node * 2, start, end, diff);
  update(mid+1, right, node * 2+1, start, end, diff);
  seg[node] = seg[node * 2] + seg[node * 2 + 1];
}

ll sseg(int left, int right, int node, int start, int end) {
  int leng = right - left + 1;
  lazyche(leng, node);
  if (start <= left && right <= end)
    return seg[node];
  if (start > right || end < left)
    return 0;
  int mid = (left + right) / 2;
  return sseg(left, mid, node * 2, start, end) + sseg(mid + 1, right, node * 2+1, start, end);
}
int main() {
  ios::sync_with_stdio(0);
  cin.tie(0); cout.tie(0);
  cin >> N >> Q1 >> Q2;
  for (int i = 1; i <= N; i++)
    cin >> arr[i];
  mseg(1, N, 1);
  int Q12 = Q1 + Q2;
  for (int i = 1; i <= Q12; i++) {
    int a, b, c, d;
    cin >> a;
    if (a == 1) {
      cin >> b >> c;
      cout << sseg(1, N, 1, b, c) << '\n';
    }
    else {
      cin >> b >> c >> d;
      update(1, N, 1, b, c, d);
    }
  }
}
```

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;
ll mod(ll n) { if (n >= 0) return n % MOD; return ((-n / MOD + 1) * MOD + n) % MOD; }
int L;
string src;
int rabinKarp(int len) {
  ll 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 << suffixArray[i] << " "; cout << "\n";
  cout << "LA: "; for (int i = 0; i < s.length(); ++i) cout << 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

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

2. Sieve of Eratosthenes

```
const ll MAX = 100001;
bool isprime[MAX];
void sieve(){
  fill(isprime, isprime + MAX, 1);
  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 ll MOD = 1000000007;
const ll MAX_NUM = 4000001;
ll f[MAX_NUM];
ll mypow(ll base, ll exp, ll MOD) {
  ll 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;
  }
}
ll nCr(int n, int r) {
  return (f[n] * mypow((f[r] * f[n - r]) % MOD, MOD - 2, MOD)) % MOD;
}
int main() {
  ll n, r;
  nCrInit();
  cin >> n >> r;
  cout << nCr(n, r) << "\n";
}
```

4. Matrix Exponential

```
ll a[3][3], a2[3][3], ans[3][3], temp[3][3], N;
void mult(ll a[3][3], ll 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

```
using ld = double;
using base = complex<ld>;
const ld pi = acos(-1);
void fft(vector<base> &A, bool f) {
  int k = A.size(), i, j, l, t;
  base w, x, y; ld th;
  for (i = 1, j = 0; i < k; i++) {
    for (l = k >> 1; j >= l; l >>= 1) j -= l;
    j += l; if(i < j) swap(A[i], A[j]);
  }
  for (i = 1; i < k; i <<= 1, t--) {
    th = (f ? -pi : pi) / i;
    w = base(cos(th), sin(th));
    for (j = 0; j < k; j += i + i) {
      for (l = 0; l < i; l++) {
        if (l & 2047) x *= w;
        else x = l ? base(cos(th * l), sin(th * l)) : 1;
        y = x * A[l | i | j];
        A[l | i | j] = A[l | j] - y;
        A[l | j] += y;
      }
    }
  }
  if (f) for (i = 0; i < k; i++) {
    A[i] /= k;
  }
}
vector<ll> mult(vector<ll> &X, vector<ll> &Y) { //return vector's size is |X| + |Y| - 1
  ll s, i, j;
  for (s = 1; s < X.size() + Y.size(); s <<= 1);
  vector<base> P(s), Q(s);
  vector<ll> Z(X.size() + Y.size() - 1);
  for (i = 0; i < X.size(); i++)
    P[i] = base(X[i] >> 12, X[i] & 4095);
  for (i = 0; i < Y.size(); i++)
    Q[i] = base(Y[i] >> 12, Y[i] & 4095);
  fft(P, 0); fft(Q, 0);
  for (i = 0; i + i <= s; i++) {
    j = i ? s - i : 0;
    base v1 = P[i] + conj(P[j]), v2 = conj(P[i]) - P[j];
    tie(P[i], Q[i], P[j], Q[j]) = make_tuple(
      v1 * Q[i], conj(v2) * conj(Q[j]),
      conj(v1) * Q[j], -v2 * conj(Q[i]));
  }
  fft(P, 1); fft(Q, 1);
  for(i = 0; i < Z.size(); i++) {
    Z[i] = (((ll)round(P[i].real()) << 23) + ((ll)round(Q[i].real()) >> 1)
      + ((ll)round(P[i].imag() + Q[i].imag()) << 11));
  }
  return Z;
}
```

6. Berlekamp-Massey

```
ll ipow(ll x, ll p) {
  ll ret = 1, piv = x;
  while(p){
    if(p & 1) ret = ret * piv % MOD;
    piv = piv * piv % MOD;
    p >>= 1;
  }
  return ret;
}
vector<ll> berlekamp_massey(vector<ll> x) {
  vector<ll> ls, cur;
  ll lf, ld;
  for(int i = 0; i < x.size(); i++) {
    ll t = 0;
    for(int j = 0; j < cur.size(); j++) {
      t = (t + 1ll * x[i - j - 1] * cur[j]) % MOD;
    }
    if((t - x[i]) % MOD == 0) continue;
    if(cur.empty()) {
      cur.resize(i + 1);
      lf = i;
      ld = (t - x[i]) % MOD;
      continue;
    }
    ll k = -(x[i] - t) * ipow(ld, MOD - 2) % MOD;
    vector<ll> c(i - lf - 1);
    c.push_back(k);
    for(auto &j : ls) c.push_back(-j * k % MOD);
    if(c.size() < cur.size()) c.resize(cur.size());
    for(int j = 0; j < cur.size(); j++) {
      c[j] = (c[j] + cur[j]) % MOD;
    }
    if(i - lf + (ll)ls.size() >= (ll)cur.size()) {
      tie(ls, lf, ld) = make_tuple(cur, i, (t - x[i]) % MOD);
    }
    cur = c;
  }
  for(auto &i : cur) i = (i % MOD + MOD) % MOD;
  return cur;
}
ll get_nth(vector<ll> rec, vector<ll> dp, ll n) {
  ll m = rec.size();
  vector<ll> s(m), t(m);
  s[0] = 1;
  if(m != 1) t[1] = 1;
  else t[0] = rec[0];
  auto mul = [&rec](vector<ll> v, vector<ll> w) {
    int m = v.size();
    vector<ll> t(2 * m);
    for(int j = 0; j < m; j++) {
      for(int k = 0; k < m; k++) {
        t[j + k] += 1ll * v[j] * w[k] % MOD;
        if(t[j + k] >= MOD) t[j + k] -= MOD;
      }
    }
    for(int j = 2 * m - 1; j >= m; j--) {
      for(int k = 1; k <= m; k++) {
        t[j - k] += 1ll * t[j] * rec[k - 1] % MOD;
        if(t[j - k] >= MOD) t[j - k] -= MOD;
      }
    }
    t.resize(m);
    return t;
  };
  while(n) {
    if(n & 1) s = mul(s, t);
    t = mul(t, t);
    n >>= 1;
  }
  ll ret = 0;
  for(int i = 0; i < m; i++) ret += 1ll * s[i] * dp[i] % MOD;
  return ret % MOD;
}
ll guess_nth_term(vector<ll> x, ll n){
  if(n < x.size()) return x[n];
  vector<ll> v = berlekamp_massey(x);
  if(v.empty()) return 0;
  return get_nth(v, x, n);
}
```

7. Extended Euclidean Algorithm

```
tuple<ll, ll, ll> euclid(ll x, ll y) {
  if (x < y) swap(x, y);
  if (y == 0) return { x,1,0 };
  ll g, x1, y1; tie(g, x1, y1) = euclid(y, x%y);
  return { g, y1, x1 - (x / y) * y1 };
}
ll inv = (get<2>(euclid(base, MOD)) + MOD) % MOD;
```

5. Geometry

1. CCW

```
//determines direction of 3 points
ll ccw(const point& A, const point& B, const point& C) {
  ll 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. Decimal in python

```
import decimal; D = decimal.Decimal
# 정밀도 설정
decimal.getcontext().prec = 28000
# Decimal 객제에 인자 넘겨주기
g = D(1/(10**200))
```

2. Fraction in python

```
Import fractions; F = fractions.Fraction
F(f.numerator, f.denominator)
```

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

```
ll getind(ll 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. Longest Increasing Subsequence

```
typedef pair<int, int> p;
vector<int> lis(const vector<int> &v) {
  if (v.empty())return{};
  vector<int> prev(v.size());
  vector<p> res;
  for (int i = 0; i < v.size(); i++) {
    auto it = lower_bound(res.begin(), res.end(), p{ v[i],0 });
    if (it == res.end())res.emplace_back(), it = res.end() - 1;
    *it = { v[i],i };
    prev[i] = it == res.begin() ? 0 : (it - 1)->second;
  }
  int L = res.size(), cur = res.back().second;
  vector<int> ans(L);
  while (L--)ans[L] = cur, cur = prev[cur];
  return ans;
}
```

8. Rope

```
#include <ext/rope>
using namespace __gnu_cxx;
rope<char> rp;
rp.append(str.c_str());
rp.substr(pos, len).c_str()
rp.insert(pos, str);
rp.erase(pos, len);
```

9. PBDS Set

```
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
tree<int,null_type,less<int>,rb_tree_tag,tree_order_statistics_node_update> s;
```

s.order_of_key(k) : number of items in a set that are strictly smaller than k

s.find_by_order(k) : k-th element in a set (counting from zero)

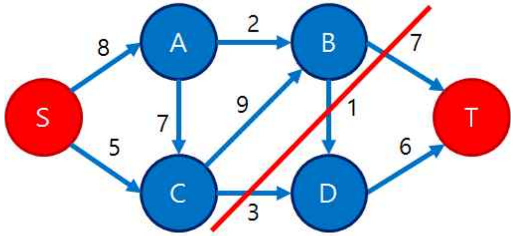
10. Divide and Conquer Optimization

Condition 1 : d[t][i] = min_(k<i)(d[t-1][k]+c[k][i])

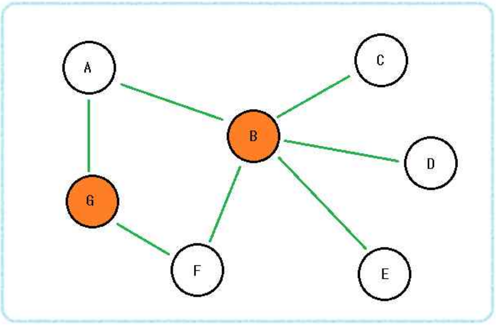
Condition 2 : a[t][j] = d[t][i]를 만족시키는 최소 k라고 할 때 a[t][i] <= a[t][i+1]

```
function<void(ll, ll, ll, ll)> dnc = [&](ll s, ll e, ll l, ll r) -> void {
    if (s > e)return;
    ll m = (s + e) / 2;
    ll k = max(l, m - D);
    for (int i = k; i <= min(m, r); i++) {
      if ((m - k) * T[m] + V[k] < (m - i) * T[m] + V[i])k = i;
    }
    ans = max(ans, (m - k) * T[m] + V[k]);
    dnc(s, m - 1, l , k);
    dnc(m + 1, e, k, r);
  };
```

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.

9. Binary Search

```
while (l <= r) {
    int mid = (l + r) / 2;
    if (!check(mid))
      r = mid - 1;
    else
      l = mid + 1;
  }
```