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Average Degree-Distance and Gutman Indices of Mycielskian Graph and its Complement

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ABSTRACT

For a graph G = (V, E), the Mycielskian of G is the graph μ(G)(or simply μ) [6] is defined as the graph having vertex set V ∪ X ∪{x} and edge set E ∪{vixj : vivj ∈ E} ∪ {xixj : 1 ≤ j ≤ n}, where V = {v1, v2, · · · , vn} and X = {x1, x2, · · · , xn}. In this paper, we define a new distance based parameters viz., average degree-distance index DDa(G) and average Gutman index GIa(G) of molecular graph G and calculated DDa(G) and GIa(G) of Mycielskian graph and its compliment.

1 Introduction

All graphs ~~c~~onsidered in this paper are finite, connected without loops or multiple edges. Let $G = (V, E)$ be graph of order n and size m. If $u, v \in V(G)$ are said to be adjacent if $e = uv \in E(G)$. The degree of a vertex $v \in V(G)$ is the number of edges incident to v in G. It is denote by $degG(v)$. Let G denote the complement of a graph G, where the order and size of G are n and m respectively. For $u, v \in V(G)$, the distance $d(u, v)$ is the length of the shortest path connectinsg the vertices u, v. If u and v belongs to different different components then the $d(u, v) = \infty$. The average distance of $u, v \in V(G)$ is defined as ^{1} $n(n(1))$ $d(u, v)$. For undefined terminology in this paper we refer the interested reader to [5].

Graph theory has become one of the emerging field of Mathematics, due to its ap-plications in different areas such as computer science, physics, chemistry, etc. On of the interesting application is in the field of Mathematical chemistry, in particular chemical graph theory. Due to the applications of topological indices in QSPR studies, this area

of research got immediate attention from the chemists as well as mathematician around the world.

The topological index is basically, some positive integer associated with the molecular graph. There are three types of topological indices viz.,

- Degree based topological indices
- Distance Based Topological Indices
- Matrix Based Based Topological Indices∑

In the year 1947, H. Wiener [8] has introduced the first topological index, unknowingly he used graph theory to predict the boiling point of certain paraffin alkanes.

$$W(G) = \sum_{\{u,v\}\subseteq V(G)} d(u,v)$$

Later, the Gutam [4] conceived the Zagreb indices.

$$\begin{aligned} M_1(G) &= \sum_{u\in V(G)} d_G(u)^2 \\ M_2(G) &= \sum_{uv\in E(G)} d_G(u)\, d_G(v) \end{aligned}$$

These parameters are the most studied topological indices in the field of Mathematical Chemistry. After, that many parameters have been put forward by the various researchers such as terminal Wiener index T$W(G)$ [3], degree-distance index $DD(G)$ [1], Gutman index $GI(G)$ [2], Ashwini index [7] etc., and now there are more than 1000 parameters have been introduced so far.

$$TW(G) = \sum_{\{u,v \subseteq V_T(G)\}} d(u, v \setminus G) = \sum_{1 \le i < j \le k} d(u, v \setminus G)$$

$$DD(G) = \sum_{\{u,v\} \subseteq V(G)} d_G(u,v)[deg_G(u) + deg_G(v)].$$

$$GI(G) = \sum_{\{u,v\} \subseteq V(G)} d_G(u,v)[deg_G(u) deg_G(v)].$$

$$\mathcal{A}(T) = \sum_{1 \le i < j \le n} d_T(v_i, v_j)[deg_T(N(u_i)) + deg_T(N(v_j))].$$

Where $N(v) = \{u \in V(G) \colon uv \in E(G)\}$.

In this connection, we are defining a new distance based topological index namely, the average degree-distance index of molecular graph as follows:

$$DD^a(G) = \frac{1}{n(n-1)} \sum_{\{u,v\} \subseteq V(G)} d(u,v)[deg(u) + deg(v)]$$

2 Mycielskian Graph

For a graph $G = (V, E)$, the Mycielskian of G is the graph $\mu(G)$ (or simply μ) [6] is defined as the graph having vertex set $V \cup X \cup \{x\}$ and edge set $E \cup \{v_i x_j : v_i v_j \in E\} \cup \{x_i x_j : 1 \le j \le n\}$, where $V = \{v_1, v_2, \cdots, v_n\}$ and $X = \{x_1, x_2, \cdots, x_n\}$.

A graph G and and its Mycielskian graph $\mu(G)$ are depicted in Figure 1 and 2.

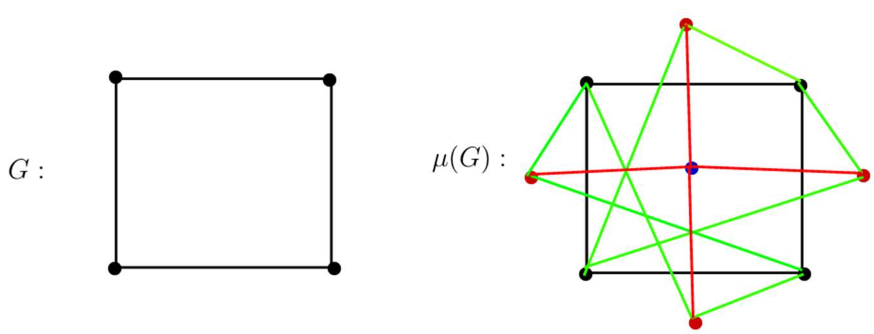

Fig. 1. A Graph G and its Mycielskian graph μ(G)

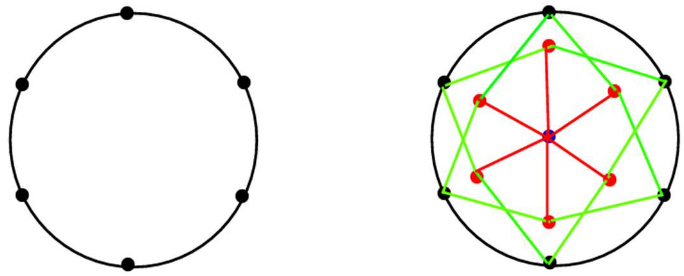

Fig. 2. A graph G and its Mycielskian graph $\mu(G)$

By the construction of Mycielskian graph $\mu(G)$ we can see that the vertex set of $\mu(G)$ contains $2n + 1$ vertices. The vertices indicating black color are the original vertices of G and the vertices indicating by red color and blue color are the newly formed vertices in $\mu(G)$. Similarly, the edges indicating black color are the original edges of G and the edges indicating green and blue colors are the newly formed edges in $\mu(G)$.

3 Results

Theorem 1. *Let $G = (V, E)$ be a graph with $|V| = n$ and $|E| = m$. If μ is mycilskian graph of G. Then the average degree-distance index of μ is given by*

$$DD^a(\mu(G)) \;=\; \frac{1}{n(n-1)}[4m(n+4) - M_1(G)] + \frac{3(n+1)}{(n-1)} + 2[2(\frac{m}{n}+1) + DD^a(G)]$$

Proof. Let J be a graph of order n and size m. The mycilskian graph $\mu(J)$ of J is of order $(2n + 1)$ and size $(2m + n)$. Now we have the following observations regarding the distance between the pair of vertices in $\mu(J)$:

- Suppose $u = x$ and $v = x_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x$ and $v = v_i$ then $d_\mu(u, v) = 2$
- Suppose $u = x_i$ and $v = x_j$ then $d_\mu(u, v) = 2$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) \leq 3$ then $d_\mu(u, v) = d_t(v_i, v_j)$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) \geq 4$ then $d_\mu(u, v) = 4$

- Suppose $u = v_i$, $v = x_j$ and $i = j$ then $d_\mu(u, v) = 2$
- Suppose $u = x_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \leq 2$ then $d_\mu(u, v) = d_t(v_i, v_j)$
- Suppose $u = v_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \geq 3$ then $d_\mu(u, v) = 3$ With these information, we proceed for the following cases:

Case 1. If $u = x$ and $v \in X$ then

$$\begin{aligned}\sum_{i=1}^{n} d_\mu^a(x, x_i)[deg_\mu(x) + deg_\mu(x_i)] &= \frac{1}{n(n-1)}[n(n+1) + 2m] \\ &= \frac{(n+1)}{(n-1)} + \frac{2m}{n(n-1)}\end{aligned}$$

Case 2. If $u = x$ and $v \in V$ then

$$\begin{aligned}\sum_{i=1}^{n} d_\mu^a(x, v_i)[deg_\mu(x) + deg_\mu(v_i)] &= \frac{1}{n(n-1)}[2(n^2 + 4m)] \\ &= \frac{(2n)}{(n-1)} + \frac{8m}{n(n-1)}\end{aligned}$$

Case 3. If {u,v} ⊆ X then

$$\begin{aligned}\sum_{\{x_i, x_j\} \subseteq X} d_\mu^a(x_i, x_j)[deg_\mu(x_i) + deg_\mu(x_j)] &= \frac{1}{n(n-1)}[2n^2 - 2n + 4(n-1)m] \\ &= 2(\frac{(2m)}{(n)} + 1)\end{aligned}$$

Case 4. If {u,v} ⊆ V then

$$\sum_{\{v_i, v_j\} \subseteq V} d_\mu^a(v_i, v_j)[deg_\mu(v_i) + deg_\mu(v_j)] = 2DD^a(G)$$

Case 5. If u = vi and v = xi, 1 ≤ i ≤ n then

$$\sum_{i=1}^{n} d_\mu^a(v_i,x_i)[deg_\mu(v_i)+deg_\mu(x_i)] = \frac{1}{n(n-1)}[2n+12m]$$
$$= \frac{(2)}{(n-1)}+\frac{12m}{n(n-1)}$$

Case 6. If u = v_i and v = x_j, i $\neq$ j then,

$$\sum_{\{v_i,x_j\}\subseteq V(\mu(G))} d_\mu^a(v_i,x_j)[deg_\mu(v_i)+deg_\mu(x_j)] = \frac{1}{n(n-1)}[2n(n-1)+2m(2n-3)-M_1(G)]$$
$$= 2+\frac{(2m(2n-3))}{n(n-1)}-\frac{M_1(G)}{n(n-1)}$$

By combining the cases (1) to (6), we get the required result

Theorem 2. Let G = (V,E) be a graph with |V| = n and |E| = m. If μ is mycilskian graph of G and $\overline{\mu}$ is the compliment of the mycilskian graph . Then the average degree distance index of is given by

$$DD^a(\overline{\mu}(G)) = 2n+\frac{144m+31n-9}{(n-1)}-\frac{48n^2}{(n-1)}-\frac{2m^2}{n(n-1)}+\frac{16mn-36m-28M_1(G)}{n(n-1)}$$

Proof. Let G be a graph of order n and size m. The mycilskian graph $\mu(G)$ of G is of order $(2n+1)$ and size $(2m+n)$. Now we have the following observations regarding the distance between the pair of vertices in $\overline{\mu}(G)$:

- Suppose $u = x$ and $v = x_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x$ and $v = v_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x_i$, $v = x_j$ and $d_t(v_i, v_j) > 1$ then $d_\mu(u, v) = 1$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) = 1$ then $d_\mu(u, v) = 2$
- Suppose $u = v_i$, $v = x_j$ and $i = j$ then $d_\mu(u, v) = 1$
- Suppose $u = x_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \geq 1$ then $d_\mu(u, v) = 1$
- Suppose $u = v_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) = 1$ then $d_\mu(u, v) = 2$

With these information, we proceed for the following cases:

Case 1. If $u = x$ and $v \in X$ then

$$\begin{aligned}\sum_{i=1}^{n} d_{\overline{\mu}}^{a}(x, x_i)[deg_{\overline{\mu}}(x) + deg_{\overline{\mu}}(x_i)] &= \frac{1}{n(n-1)}[6n^2 - 2n - 4m] \\ &= \frac{(2(3n-1))}{(n(n-1))} - \frac{4m}{n(n-1)}\end{aligned}$$

Case 2. If $u = x$ and $v \in V$ then

$$\begin{aligned}\sum_{i=1}^{n} d_{\overline{\mu}}^{a}(x, v_i)[deg_{\overline{\mu}}(x) + deg_{\overline{\mu}}(v_i)] &= \frac{1}{n(n-1)}[3n^2 - 4m] \\ &= \frac{(3n)}{(n-1)} - \frac{4m}{n(n-1)}\end{aligned}$$

Case 3. If $\{u, v\} \subseteq X$ then

$$\begin{aligned}\sum_{\{x_i,x_j\}\subseteq X} d_{\overline{\mu}}^{a}(x_i, x_j)[deg_{\overline{\mu}}(x_i) + deg_{\overline{\mu}}(x_j)] &= \frac{1}{n(n-1)}[4n^2 - 2n - 2m(m-1)] \\ &= \frac{(2(2n-1))}{(n-1)} - \frac{2m(m-1)}{n(n-1)}\end{aligned}$$

Case 4. If $\{u, v\} \subseteq V$ then

$$\begin{aligned}\sum_{\{v_i,v_j\}\subseteq V} d_{\overline{\mu}}^{a}(v_i, v_j)[deg_{\overline{\mu}}(v_i) + deg_{\overline{\mu}}(v_j)] &= \frac{1}{n(n-1)}[2n^2(n-1) + 4m - 2M_1(G)] \\ &= 2n + \frac{4m}{n(n-1)} - \frac{2M_1(G)}{n(n-1)}\end{aligned}$$

Case 5. If $u = v_i$ and $v = x_i$, $1 \leq i \leq n$ then

$$\begin{aligned}\sum_{i=1}^{n} d_{\overline{\mu}}^{a}(v_i, x_i)[deg_{\overline{\mu}}(v_i) + deg_{\overline{\mu}}(x_i)] &= \frac{1}{n(n-1)}[4n^2 - n - 6m] \\ &= \frac{(4n)}{(n-1)} - \frac{1}{n-1} - \frac{6m}{n(n-1)}\end{aligned}$$

$$\begin{aligned}\sum_{\{v_i,x_j\}\subseteq V(\overline{\mu}(G))} d^a_{\overline{\mu}}(v_i,x_j)[deg_{\overline{\mu}}(v_i)+deg_{\overline{\mu}}(x_j)] &= \frac{1}{n(n-1)}[4m(4n-1)] \\ &- \frac{6}{n(n-1)}[5M_1(G)+8n^3-3n^2] \\ &- \frac{6}{n(n-1)}[24mn+4m+n] \\ &= \frac{4m(4n-1)}{n(n-1)} \\ &- \frac{30M_1(G)}{n(n-1)} - \frac{48n^2}{n-1} \\ &+ \frac{18n}{n-1} + \frac{144m}{n-1} - \frac{24m}{n(n-1)} - \frac{6}{n-1}\end{aligned}$$

By combining the cases (1) to (6), we get the required result.

Theorem 3. *Let $G = (V, E)$ be a graph with $|V| = n$ and $|E| = m$. If μ is mycilskian graph of G. Then the average Gutman index of μ is given by*

$$GI^a(\mu(G)) = \frac{(10m+n)}{(n-1)} + \frac{1}{n(n-1)}[4m^2+8m+3M_2(G)] + 6GI^a + 2DD^a(G)$$

Proof. Let G be a graph of order n and size m. The mycilskian graph $\mu(G)$ of G is of order $(2n+1)$ and size $(2m+n)$. Now we have the following observations regarding the distance between the pair of vertices in $\mu(G)$:

- Suppose $u = x$ and $v = x_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x$ and $v = v_i$ then $d_\mu(u, v) = 2$
- Suppose $u = x_i$ and $v = x_j$ then $d_\mu(u, v) = 2$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) \le 3$ then $d_\mu(u, v) = d_t(v_i, v_j)$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) \ge 4$ then $d_\mu(u, v) = 4$
- Suppose $u = v_i$, $v = x_j$ and $i = j$ then $d_\mu(u, v) = 2$
- Suppose $u = x_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \le 2$ then $d_\mu(u, v) = d_t(v_i, v_j)$
- Suppose $u = v_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \ge 3$ then $d_\mu(u, v) = 3$ With these information, we

proceed for the following cases:

Case 1. If $u = x$ and $v \in X$ then

$$\begin{aligned} \sum_{i=1}^{n} d_{\mu}^{a}(x, x_i)[deg_{\mu}(x) \times deg_{\mu}(x_i)] &= \frac{1}{n(n-1)}[n^2 + 2mn] \\ &= \frac{(n)}{(n-1)} + \frac{2m}{(n-1)} \\ &= \frac{(2m+n)}{(n-1)} \end{aligned}$$

Case 2. If $u = x$ and $v \in V$ then

$$\begin{aligned} \sum_{i=1}^{n} d_{\mu}^{a}(x, v_i)[deg_{\mu}(x) \times deg_{\mu}(v_i)] &= \frac{1}{n(n-1)}[8mn] \\ &= \frac{(8m)}{(n-1)} \end{aligned}$$

Case 3. If $\{u, v\} \subseteq X$ then

$$\begin{aligned} \sum_{\{x_i, x_j\} \subseteq X} d_{\mu}^{a}(x_i, x_j)[deg_{\mu}(x_i) \times deg_{\mu}(x_j)] &= \frac{1}{n(n-1)}[n(n-1) + 4(n-1)m + 4m^2 - M_1(G)] \\ &= 1 + \frac{4m}{n} + \frac{4m^2 - M_1(G)}{n(n-1)} \end{aligned}$$

Case 4. If $\{u, v\} \subseteq V$ then

$$\sum_{\{v_i, v_j\} \subseteq V} d_{\mu}^{a}(v_i, v_j)[deg_{\mu}(v_i) \times deg_{\mu}(v_j)] = 4GI^{a}(G)$$

Case 5. If $u = v_i$ and $v = x_i$, $1 \leq i \leq n$ then

$$\begin{aligned} \sum_{i=1}^{n} d_{\mu}^{a}(v_i, x_i)[deg_{\mu}(v_i) \times deg_{\mu}(x_i)] &= \frac{1}{n(n-1)}[4(2m + M_1(G))] \\ &= \frac{8m + 4M_1(G)}{n(n-1)} \end{aligned}$$

Case 6. If $u = v_i$ and $v = x_j$, $i \neq j$ then

$$\sum_{\{v_i,x_j\}\subseteq V(\mu(G))} d^a_\mu(v_i,x_j)[deg_\mu(v_i)\times deg_\mu(x_j)] \;=\; DD^a(G)+2GI^a(G)$$

By combining the cases (1) to (6), we get the required result.Theorem 4. *Let $G = (V, E)$ be a graph with $|V| = \bar{n}$ and $|E| = m$. If μ is mycilskian graph of G and (μ) is the compliment of the mycilskian graph . Then the average Gutman index of μ is given by*

$$\begin{aligned} GI^a(\overline{\mu}(G)) \;&=\; \frac{1}{n(n-1)}[2m^2+4m-12mn+\frac{3}{2}M_1(G)+4M_2(G)]+\frac{1}{n-1}[4n(2n-1) \\ &+\; 2n^2-8m+4(mn-M_1(G))]+\frac{(2n-1)^2}{2(n-1)}-\frac{2m(2n-1)}{n} \end{aligned}$$

Proof. Let G be a graph of order n and size m. The mycilskian graph $\mu(G)$ of G is of order $(2n + 1)$ and size $(2m + n)$. Now we have the following observations regarding the distance between the pair of vertices in $\mu(G)$:

- Suppose $u = x$ and $v = x_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x$ and $v = v_i$ then $d_\mu(u, v) = 1$
- Suppose $u = x_i$, $v = x_j$ and $d_t(v_i, v_j) > 1$ then $d_\mu(u, v) = 1$
- Suppose $u = v_i$, $v = v_j$ and $d(v_i, v_j) = 1$ then $d_\mu(u, v) = 2$
- Suppose $u = v_i$, $v = x_j$ and $i = j$ then $d_\mu(u, v) = 1$
- Suppose $u = x_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) \geq 1$ then $d_\mu(u, v) = 1$
- Suppose $u = v_i$, $v = x_j$, $i \neq j$ and $d_t(v_i, v_j) = 1$ then $d_\mu(u, v) = 2$ With these information, we proceed for the following cases:

Case 1. If $u = x$ and $v \in X$ then

$$\begin{aligned} \sum_{i=1}^{n} d^a_{\overline{\mu}}(x,x_i)[deg_{\overline{\mu}}(x)\times deg_{\overline{\mu}}(x_i)] \;&=\; \frac{1}{n(n-1)}[2n(2n-1)-2m] \\ &=\; \frac{2[(2n-1)n-2m]}{(n-1)} \end{aligned}$$

Case 2. If $u = x$ and $v \in V$ then

$$\begin{aligned}\sum_{i=1}^{n} d_{\overline{\mu}}^{a}(x, v_i)[deg_{\overline{\mu}}(x) \times deg_{\overline{\mu}}(v_i)] &= \frac{1}{n(n-1)}[2n(n^2-2m)] \\ &= \frac{2(n^2-2m)}{(n-1)}\end{aligned}$$

Case 3. If $\{u, v\} \subseteq X$ then

$$\begin{aligned}\sum_{\{x_i, x_j\} \subseteq X} d_{\overline{\mu}}^{a}(x_i, x_j)[deg_{\overline{\mu}}(x_i) \times deg_{\overline{\mu}}(x_j)] &= \frac{1}{n(n-1)}[n(2n-1)^2 - (2n-1)(n-1) + 2m^2 \\ &- \frac{1}{2}M_1(G)] \\ &= \frac{(2n-1)^2}{2(n-1)} - \frac{2m(2n-1)}{n} \\ &+ \frac{1}{n(n-1)}[2m^2 - \frac{1}{2}M_1(G)]\end{aligned}$$

Case 4. If $\{u, v\} \subseteq V$ then

$$\begin{aligned}\sum_{\{v_i, v_j\} \subseteq V} d_{\overline{\mu}}^{a}(v_i, v_j)[deg_{\overline{\mu}}(v_i) \times deg_{\overline{\mu}}(v_j)] &= \frac{1}{n(n-1)}[4n^2m - 4nM_1(G) + 4M_2(G)] \\ &= \frac{4(mn - M_1(G))}{(n-1)} + \frac{4M_2(G)}{n(n-1)}\end{aligned}$$

Case 5. If $u = v_i$ and $v = x_i$, $1 \leq i \leq n$ then

$$\begin{aligned}\sum_{i=1}^{n} d_{\overline{\mu}}^{a}(v_i, x_i)[deg_{\overline{\mu}}(v_i) \cdot deg_{\overline{\mu}}(x_i)] &= \frac{1}{n(n-1)[2n^2(2n-1) - (6n-2)2m + 2M_1(G)]} \\ &= \frac{2n(2n-1)}{(n-1)} - \frac{(3n-1)4m - 2M_1(G)}{n(n-1)}\end{aligned}$$

Case 6. If $u = v_i$ and $v = x_j$, $i \neq j$ then

$$\begin{aligned}\sum_{\{v_i, x_j\} \subseteq V(\overline{\mu}(G))} d_{\overline{\mu}}^{a}(v_i, x_j)[deg_{\overline{\mu}}(v_i) \cdot deg_{\overline{\mu}}(x_j)] &= \frac{1}{n(n-1)}\Bigg[[2n(2n-1)2m - 2nM_1(G)] \\ &- [2(2n-1)M_1(G) + 4M_2(G)] \\ &+ \sum_{v_i, v_j \subseteq V} 2(2n - 2deg_G(v_i)(2n - 1 - deg_G(v_i))\Bigg]\end{aligned}$$

By combining the cases (1) to (6), we get the required result. □

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