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Research Article

A Note on the Adversary Degree Associated Reconstruction Number of Graphs

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A vertex-deleted subgraph of a graph G is called *a card* of G. A card of G with which the degree of the deleted vertex is also given is called *a degree associated card* (or dacard) of G. The *degree associated reconstruction number drn* (G) of a graph G is the size of the smallest collection of dacards of G that uniquely determines G. The *adversary degree associated reconstruction number of a graph* G, *adrn*(G), is the minimum number k such that every collection of k dacards of G that uniquely determines G. In this paper, we show that *adrn* of wheels and complete bipartite graphs on at least 4 vertices is 2 or 3.

1. Introduction

All graphs considered are simple, finite, and undirected. We will mostly follow the standard graph theoretic terminology of [1]. A *vertex-deleted subgraph* or *card* $G - v$ of a graph G is the unlabeled graph obtained from G by deleting the vertex v and all edges incident with v. The ordered pair $(d(v), G - v)$ is called a *degree associated card* or *dacard* of the graph G where $d(v)$ is the degree of v in G. The *deck (dadeck)* of a graph G is its collection of cards (dacards). *Ulam's Conjecture* [2], also called *Reconstruction Conjecture* (RC), asserts that every graph on at least three vertices is determined uniquely (up to isomorphism) by its deck. Graphs that obey RC are called *reconstructible*.

For a reconstructible graph G, Harary and Plantholt [3] have defined the *reconstruction number rn*(G) to be the size of the smallest subcollection of the deck of G which is not contained in the deck of any other graph H; $H \ncong G$. Myrvold [4] referred to this number as *ally-reconstruction number* of G. Myrvold [5] also studied *adversary reconstruction number* of G which is the smallest k such that no subcollection of the deck of G of size k is contained in the deck of any other graph H; $H \ncong G$.

An extension of RC to digraphs, the *Digraph Reconstruction Conjecture,* was disproved when Stockmeyer exhibited [6] several infinite families of counter-examples. In view of this, Ramachandran [7] studied the degree (degree triple) associated reconstruction of graphs (digraphs). For a vertex v of a digraph, the ordered triple (r, s, t) is called the *degree triple* of v where r, s, and t are, respectively, the number of unpaired outarcs, unpaired inarcs, and symmetric pairs of arcs incident with v. A graph (digraph) is called degree associated reconstructible if it can be determined uniquely from its dadeck. For a degree associated reconstructible graph (digraph) G, the *degree (degree triple) associated reconstruction number*, *drn*(G), of G is the size of the smallest subcollection of the dadeck of G which is not contained in the dadeck of any other graph (digraph) H; $H \ncong G$. Barrus and West [8] have shown that $drn(G) = 2$ for all caterpillars except stars and one 6-vertex example, and that $drn(G) \geq 3$ for all vertex-transitive graphs G (not complete or edgeless).

The following weakening of the reconstruction problem has also been considered by Harary and Plantholt [3]. A graph G, in a given class of graphs $\mathscr{C}$, is called class-reconstructible if whenever $H \in \mathscr{C}$ has the same deck as G, then $G \cong H$. If a graph is degree associated reconstructible then it is class-reconstructible, and vice-versa, where the class is the class of graphs with a given number m of edges.

In this paper, we study the parameter *adversary degree associated reconstruction number adrn(G)* of a graph G. For a reconstructible graph G from its dadeck, $adrn(G)$ is the minimum number k such that every collection of k dacards of G is not contained in the dadeck of any other graph H; $H \not\cong G$. From their definitions, it is clear that $drn(G) \le adrn(G)$ for any graph G; the equality holds for vertex-transitive graphs (where all the dacards are necessarily identical). In this paper, we show that $adrn$ is 2 or 3 for wheels and complete bipartite graphs on at least 4 vertices.

2. *adrn* of Standard Graphs

Since $drn(G)$ and $adrn(G)$ are exactly equal for any vertex-transitive graph G, the next theorem follows from [7].

Theorem 1. *(i)* $adrn(K_n) = 1$.

(ii) $adrn(K_{n,n}) = 3$ *for* $n > 1$.

(iii) $adrn(C_n) = 3$ *for* $n \ge 4$, *where* C_n *is a cycle on* n *vertices.*

It is clear, from the definition of $adrn$, that $adrn(K_n) = adrn(\overline{K_n}) = 1$. In fact, it is true that the $adrn$ of the complement of a graph is equal to the $adrn$ of the graph.

Lemma 2. *For any graph* G, $adrn(\overline{G}) = adrn(G) \ge drn(G)$.

Proof. The latter inequality follows immediately from the definitions of drn and $adrn$. To prove the first equality, let G be a graph of order n; let $adrn(G) = s$. Then, there exists a graph $H\,(\not\cong G)$ such that G and H have $s-1$ dacards in common. If (d_i, G_i) is a dacard of G, then $(n-1-d_i, \overline{G_i})$ is a dacard of $\overline{G}$ and vice-versa. The graph $\overline{H}\,(\not\cong \overline{G})$ has therefore $s-1$ dacards in common with those of $\overline{G}$. Consequently, we have $adrn(\overline{G}) \ge s$.

On the other hand, if $adrn(\overline{G}) > s$, then there exists a graph $T\,(\not\cong \overline{G})$ such that T has s dacards of $\overline{G}$. It follows that the graph $\overline{T}\,(\not\cong G)$ has s dacards of G. Therefore, $adrn(G) > s$, giving a contradiction. Hence, $adrn(\overline{G}) = s = adrn(G)$. □

An *extension* of a dacard $(d(v), G-v)$ of G is a graph obtained from the dacard by adding a new vertex x and joining it with $d(v)$ vertices of the dacard, and it is denoted by $H(d(v), G-v)$ (or simply by H). Throughout this paper, H and x are used in the sense of this definition.

For a graph G, to prove $adrn(G) = k$, we proceed as follows.

(i) First, find the dadeck of G.

(ii) Determine next all possible extensions of every dacard of G.

(iii) Finally, show that every extension other than G has at most $k-1$ dacards in common with those of G, and that at least one extension has precisely $k-1$ dacards in common with those of G.

A vertex of degree m is called an *m-vertex*. We call a neighbour of degree r of a vertex v by an *r-neighbour* of v. The *union* $G \cup H$ of graphs G and H is the graph with vertex set $V(G) \cup V(H)$ and edge set $E(G) \cup E(H)$. The join $G + H$ of disjoint graphs G and H is the graph obtained from $G \cup H$ by joining each vertex of G to each vertex of H.

Remark 3. Note that if a dacard of a graph G is vertex-transitive and the degree associated with the dacard is one or else the degree associated with the dacard equals the number of vertices in the dacard, then the dacard has a unique extension (up to isomorphism), and, hence, $drn(G) = 1$.

Since the wheel W_n on n (≥ 4) vertices has an $(n-1)$-vertex, the dacard (obtained by deleting the $(n-1)$-vertex of W_n) has a unique extension, and so $drn(W_n) = 1$ by Remark 3. We now show that $adrn(W_n) = 3$ for $n > 4$.

Theorem 4. *If* W_n *is a wheel on* $n\,(\ge 4)$ *vertices, then*

$$adrn(W_n) = \begin{cases} 1, & if\ n = 4, \\ 3, & otherwise. \end{cases} \tag{1}$$

Proof. The dadeck of $W_n = K_1 + C_{n-1}$ consists of one copy of the dacard $(n-1, C_{n-1})$ and $n-1$ copies of the dacard $(3, K_1 + P_{n-2})$, where v is a vertex of C_{n-1}. Let $H(3, K_1 + P_{n-2})$ be an extension of the dacard $(3, K_1 + P_{n-2})$. We consider four cases depending on the value of n.

Case 1. $n = 4$. Now, all the four dacards are isomorphic and they are $(3, C_3)$. Since it has a unique extension, it follows that $adrn(W_4) = 1$.

Case 2. $n = 5$. In the dacard $(3, K_1 + P_3)$, there are two 2-vertices and two 3-vertices. If we join the newly added vertex x to the two 2-vertices and a 3-vertex, then the extension H is isomorphic to W_n. Therefore, we join the newly added vertex x to a 2-vertex and the two 3-vertices. The extension H so has one 2-vertex, two 3-vertices, and two 4-vertices (Figure 1). The dacard of the extension H corresponding to each of the two 3-vertices is $(3, K_1 + P_3)$. The extension H has thus only two dacards in common to those of W_n, and, hence, $adrn(W_5) = 3$.

Case 3. $n = 6$. In the dacard $(3, K_1 + P_4)$, there are exactly two 2-vertices, one 4-vertex, and two 3-vertices.

Case 3.1. Join x to none of the two 2-vertices.

The extension H has one vertex of degree 3, two vertices of degree 2, two vertices of degree 4, and one vertex of degree 5 (Figure 2). The dacard corresponding to the 3-vertex of the extension H is clearly in common with that of W_n. The dacard of H obtained by deleting the 5-vertex has endvertices, and, hence, it is not a dacard of W_n. The extension H has thus only one dacard in common with that of W_n.

Case 3.2. Join x to one 2-vertex and two 3-vertices.

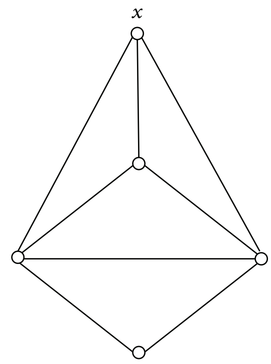

Figure 1: The extension H in Case 2.

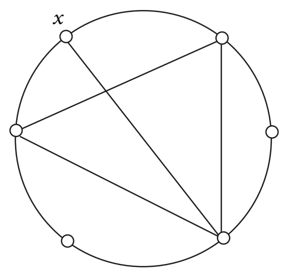

Figure 2: The extension H in Case 3.1.

The extension H has two vertices of degree 3, one vertex of degree 2, and three vertices of degree 4. The dacard corresponding to each of the two 3-vertices is a dacard of W_n. The extension H has thus only two dacards in common with those of W_n.

Case 3.3. Join x to one 2-vertex (say y), one 3-vertex (say z), and the unique 4-vertex.

Case 3.3.1. Vertices y and z are nonadjacent.

In H, y is a 3-vertex and z is a 4-vertex. The dacards of H corresponding to x and the 3-vertex other than y are dacards of W_n. The dacard corresponding to y of H is not a dacard of W_n, since the subgraph of H obtained by deleting y has three 2-vertices. The dacard corresponding to the 5-vertex of H is not a dacard of W_n. The extension H has thus only two dacards in common with those of W_n.

Case 3.3.2. Vertices y and z are adjacent.

The dacards corresponding to the 3-vertices x and y in H are dacards of W_n. The dacard corresponding to the other 3-vertex is not a dacard of W_n, since the 3-vertex is adjacent to a 2-vertex in H. Also in H, the 5-vertex is adjacent to a 2-vertex, and so the dacard corresponding to the 5-vertex is not a dacard of W_n. The extension H has thus only two dacards in common with those of W_n.

Case 3.4. Join x to two 2-vertices and a 3-vertex or 4-vertex (say y).

If y is the 4-vertex, then H is isomorphic to W_n. Otherwise, H has four 3-vertices and two 4-vertices. The dacards of H corresponding to x and the 3-vertex z not adjacent to y are dacards of W_n. But the dacard obtained from H by deleting a 3-vertex other than x and z has no 4-vertex, and so it is not a dacard of W_n. Thus, H has only two dacards in common with those of W_n.

Case 4. $n \geq 7$. The dacard $(3, K_1 + P_{n-2})$ has two vertices of degree 2, $n-4$ (≥ 3) vertices of degree 3, and one vertex of degree $n-2$ (≥ 5). If the newly added vertex x is not joined to the $(n-2)$-vertex, then the extension H cannot have more than one dacard in common with that of W_n. If x is joined to the $(n-2)$-vertex and the two 2-vertices, then H is isomorphic to W_n. Therefore, it is enough to consider the case in which x is joined to the $(n-2)$-vertex and not joined to at least one 2-vertex.

Case 4.1. Join x to the $(n-2)$-vertex, one 2-vertex, and one 3-vertex.

The extension H has one 2-vertex, $n-3$ vertices of degree 3, one vertex of degree 4, and one vertex of degree $n-1$. The dacard $(3, K_1 + P_{n-2})$ cannot have a vertex of degree 4. Therefore, only dacards corresponding to the 3-neighbours of the 4-vertex in H can be isomorphic to the dacard $(3, K_1 + P_{n-2})$.

If the 4-vertex is adjacent to the 2-vertex in H, then there are two 3-vertices adjacent to the 4-vertex. The extension H therefore can have at most two dacards in common with those of W_n, and the dacard, corresponding to each of the two 3-vertices adjacent to the 4-vertex, is a dacard of W_n. Otherwise, the 3-neighbour closest to the 2-vertex yields a dacard with a cut vertex, while no dacard of W_n has a cut vertex.

Case 4.2. Join x to the $(n-2)$-vertex and two 3-vertices.

The extension H has two vertices of degree 2, $n-5$ (≥ 2) vertices of degree 3, two vertices of degree 4, and one vertex of degree $n-1$. The dacard $(3, K_1 + P_{n-2})$ cannot have a vertex of degree 4. Therefore, only dacards corresponding to the 3-vertices which are common neighbours of the two 4-vertices can be isomorphic to the dacard $(3, K_1 + P_{n-2})$. In the extension H, there are at most two 3-vertices which are the common neighbours of the two 4-vertices. Thus, the extension H has at most two dacards in common with those of W_n, which completes the proof. □

From Remark 3, it follows that $drn(K_{1,n}) = 1$. But $adrn(K_{1,n})$ can be greater than one for $n \geq 3$ by the next theorem.

Theorem 5. *For $n \geq 1$*

$$adrn(K_{1,n}) = \begin{cases} 1, & if\ n \leq 2, \\ 3, & if\ n = 3, \\ 2, & if\ n > 3. \end{cases} \quad (2)$$

Proof. The dadeck of $K_{1,n}$ consists of one copy of $(n, \overline{K}_n)$ and n copies of $(1, K_{1,n-1})$. The extension $H(n, \overline{K}_n)$ is clearly isomorphic to $K_{1,n}$. Consider the extension $H(1, K_{1,n-1})$. If we join the newly added vertex x to the $(n-1)$-vertex of the dacard $(1, K_{1,n-1})$, then the extension H is isomorphic to $K_{1,n}$. We join therefore the vertex x to any one of the endvertices of the dacard. For $n = 2$, the extension H is isomorphic to $K_{1,n}$, and, hence, $adrn(K_{1,2}) = 1$. For $n = 3$, the extension H is isomorphic to P_4. The dadeck of P_4 consists of 2 copies of $K_{1,2}$ and 2 copies of $K_1 \cup K_2$. The extension H therefore has exactly two dacards in common with those of $K_{1,n}$ and $adrn(K_{1,3}) = 3$. Now, let us assume that $n \geq 4$. Then, in the extension H, there is exactly one 2-vertex which is adjacent to the newly added endvertex and a unique $(n-1)$-vertex. Since there is no 2-vertex in $K_{1,n-1}$ for $n \geq 4$, only the dacard corresponding to the 1-neighbour of the 2-vertex in the extension H can be a dacard of $K_{1,n}$. Hence, $adrn(K_{1,n}) = 2$. □

Ramachandran [7] proved that $drn(K_{m,n}) = 2$ for $2 \leq m < n$. We shall show that $adrn$ of $K_{m,n}$ is not always two.

Theorem 6. *For $2 \leq m < n$,*

$$adrn(K_{m,n}) = \begin{cases} 3, & if\ m = n-2, \\ 2, & otherwise. \end{cases} \quad (3)$$

Proof. The dadeck of $K_{m,n}$ consists of m copies of $(n, K_{m-1,n})$ and n copies of $(m, K_{m,n-1})$. To get an extension H having at least one dacard in common with that of $K_{m,n}$, augment the dacard $(n, K_{m-1,n})$ or $(m, K_{m,n-1})$ by adding a new vertex x and joining it to precisely n or m vertices, respectively, in the dacard.

Case 1. Augmenting the dacard $(n, K_{m-1,n})$.

Let (A, B) be the bipartition of the dacard $K_{m-1,n}$, where $|A| = m-1$. Then, if we join x to every vertex of B, then $H \cong K_{m,n}$. We join x therefore to at least one vertex of A. If we join x to all the $m-1$ vertices of A, then no vertex other than x can have degree n in H. The extension H therefore has only one dacard isomorphic to $(n, K_{m-1,n})$. In this extension, the vertices have degrees $m-1, m, n$, and $n+1$ only. The degrees of the vertices in the dacard corresponding to an m-vertex of the extension H are $m-1, m, n-1$ and n where $m-1 < m \leq n-1 < n$. The dacard $(m, K_{m,n-1})$ is therefore not a dacard of the extension H. Thus, H has only one dacard in common with that of $K_{m,n}$. If at least one vertex of A is not joined to x, then in H, there are vertices of degrees $m-1, m, n$, and $n+1$. This extension clearly has a dacard $(n, K_{m-1,n})$ (dacard corresponding to the vertex x). The degrees of the vertices in the dacard corresponding to an n-vertex other than x of H are $m-2, m-1, n$, and $n+1$. Therefore, H has only one dacard isomorphic to $(n, K_{m-1,n})$. The degrees of the vertices in the dacard corresponding to an m-vertex of H are $m-1, m, n-1$, and n where $m-1 < m \leq n-1 < n$. Hence, this extension H has only one dacard in common with that of $K_{m,n}$.

Case 2. Augmenting the dacard $(m, K_{m,n-1})$.

Let (A, B) be the bipartition of the dacard $K_{m,n-1}$, where A is the set of m vertices. If we join x to every vertex of A, then the extension H is isomorphic to $K_{m,n}$. We join x therefore to at least one vertex of B.

Case 2.1. Join x to no vertex of A.

If $n = m+1$, then the extension H is isomorphic to $K_{m,n}$. If $n = m+2$, then the extension H has two dacards isomorphic to $(m, K_{m,n-1})$, and, hence, it has only two dacards in common with those of $K_{m,n}$. So, we take that $n > m+2$. Now, the extension H has vertices of degrees $m, m+1$ and $n-1$ only. Clearly, this extension H has a dacard $(m, K_{m,n-1})$ corresponding to the m-vertex x. The removal of any other m-vertex from this extension would give a dacard with vertices of degrees $m, m+1$, and $n-2$ only, and, hence, this dacard would not be isomorphic to $K_{m,n-1}$. Thus, H has only one dacard isomorphic to $(m, K_{m,n-1})$, and this is the only dacard in common with that of $K_{m,n}$.

Case 2.2. Join x to at least one vertex of A.

Case 2.2.1. Join x to exactly one vertex (say y) of A and exactly one vertex (say z) of B.

In this case, $m = 2$ and the extension H contains exactly one triangle, say xyz. The dacard of the extension H corresponding to the vertex x is clearly $(m, K_{m,n-1})$. The extension H may have two more dacards (corresponding to the vertices y and z) in common with those of $K_{m,n}$, since no dacard of $K_{m,n}$ contains a triangle. In the extension H, there exists at least one m-vertex in B other than x. Fix one such vertex and let it be u. The m-vertex u in the dacard obtained by deleting the vertex z from H is not adjacent to the $(m-1)$-vertex x. The dacard of H corresponding to the vertex z is therefore not isomorphic to $(n, K_{m-1,n})$ (this verification is needed only for the case when $m+1 = n$). If we remove the vertex y from the extension H, then the $(m-1)$-vertex u in the resulting dacard is not adjacent to the m-vertex z, and, hence, the dacard of H corresponding to the vertex y is not isomorphic to $(m, K_{m,n-1})$. The extension H has thus only one dacard in common with that of $K_{m,n}$.

Case 2.2.2. Join x to exactly one vertex (say y) of A and at least two vertices of B.

The extension H has at least two triangles. Clearly, the dacard of H corresponding to the vertex x is $(m, K_{m,n-1})$. The extension H may have one more dacard (corresponding to the vertex y) in common with that of $K_{m,n}$. In H, there exists at least one $(n-1)$-vertex in A. Fix one such vertex and let it be z. Then, the $(n-1)$-vertex z in the dacard of H obtained by deleting the vertex y is not adjacent to the $(m-1)$-vertex x, where $m \neq n$. The dacard of H (corresponding to the vertex y) is therefore not isomorphic to $(n, K_{m-1,n})$. The extension H has thus only one dacard in common with that of $K_{m,n}$.

Case 2.2.3. Join x to at least two vertices of A and exactly one vertex (say y) of B.

The extension H has at least two triangles. Clearly, the dacard of H corresponding to the vertex x is $(m, K_{m,n-1})$. The extension H may have one more dacard (corresponding to the vertex y) in common with that of $K_{m,n}$. In H, there exists at least one $(n-1)$-vertex of A. Fix one such vertex and let it be z. The $(n-1)$-vertex z in the dacard of H, obtained by deleting the vertex y, is then not adjacent to the $(m-1)$-vertex

Table 1: *drn* and *adrn* of graphs G.

G	m, n	$drn(G)$	$adrn(G)$
K_n		1	1
$K_{n,n}$	$n > 1$	3	3
C_n	$n \geq 4$	3	3
W_n	$n = 4$	1	1
W_n	$n > 4$	1	3
$K_{1,n}$	$n \leq 2$	1	1
$K_{1,n}$	$n = 3$	1	3
$K_{1,n}$	$n > 3$	1	2
$K_{m,n}$	$2 \leq m < n \neq m + 2$	2	2
$K_{m,n}$	$2 \leq m, n = m + 2$	2	3

x, where $m \neq n$. The dacard of H (corresponding to the vertex y) is therefore not isomorphic to $(n, K_{m-1,n})$. The extension H has thus only one dacard in common with that of $K_{m,n}$.

Case 2.2.4. Join x to at least two vertices of A and at least two vertices of B.

Deleting x from H would give a dacard isomorphic to $(m, K_{m,n-1})$. The deletion of any vertex other than x from H will give a dacard containing a triangle. The extension H has thus only one dacard isomorphic to $(m, K_{m,n-1})$, and this is the only dacard in common with that of $K_{m,n}$, which completes the proof of Theorem 6. □

3. Concluding Remarks

It is clear, from their definitions, that $drn(G) \leq \min\{rn(G), adrn(G)\}$. But $rn(G)$ and $adrn(G)$ are not comparable in general. For instance, it is proved [9] that $adrn(P_4) = 3$ and $adrn(P_5) = 4$. Therefore, $adrn(P_4) < rn(P_4) = 4$ and $adrn(P_5) > rn(P_5) = 3$. However, $adrn(K_{1,3}) = rn(K_{1,3}) = 3$.

We summarize our results on the *adrn* and the corresponding results on the *drn* in Table 1.

Acknowledgments

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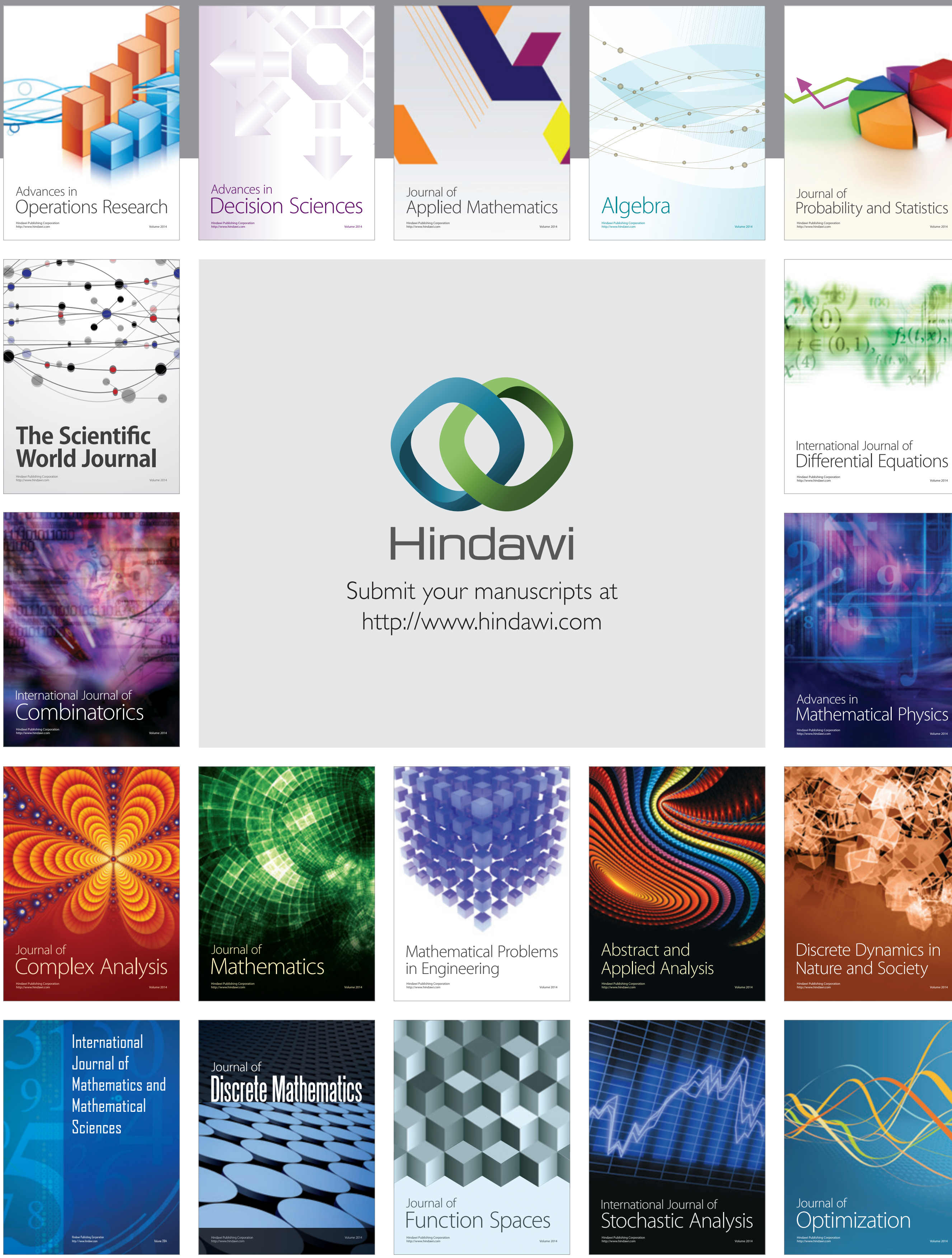
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