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ON LUCAS CORDIAL LABELING OF SOME SNAKE GRAPHS

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ABSTRACT. An injective function $f : V(G) \to \{L_1, L_2, \ldots, L_n\}$, where L_j is the jth Lucas number $(j = 1, 2, \ldots, n)$ is said to be Lucas cordial labeling if the induced function $f^* : E(G) \to \{0, 1\}$ defined by $f^*(uv) = (f(u) + f(v)) \pmod 2$ satisfies the condition $|e_f(0) - e_f(1)| \leq 1$, where $e_f(0)$ is the number of edges labeled with 0 and $e_f(1)$ is the number of edges labeled with 1. A graph which admits Lucas cordial labeling is called Lucas cordial graph.

1. INTRODUCTION

In the early ages, on the banks of the Pregel River (now called Pregolya River), there was a significant town and center of trading due to its strategic location in the old city of Konigsberg (now Kaliningrad in Russia), Prussia, where ships filled the Pregel, which made the town a hub for merchants. As the economy continues to grow, people of the city build seven bridges across the river. In the latter part, they created a game in which the main goal is to draw up a way to traverse around the town, crossing each of the seven bridges only once. This game leads to the birth of the Konigsberg Bridge Problem. Further, a Swiss mathematician, Leonhard Euler, acquired a solution to the prominent Konigsberg Problem which led to Graph Theory [3].

Graph Theory is the study of relationships, providing a helpful tool to quantify and simplify the moving parts of a dynamic system. It allows researchers to take a set of nodes and connections to abstract anything from city layouts to computer data and analyze optimal routes. The theory is also intimately related to many branches of mathematics, including group theory, matrix theory, numerical analysis, probability, topology, and combinatorics. The fact is that graph theory serves as a mathematical model for any system involving a binary relation. Partly because of their diagrammatic representation, graphs have an intuitive and aesthetic appeal. Moreover, it has become a well-developed tool for research extension in various specialized fields, including Graph Labeling.

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Graph labeling is an assignment of integers to the vertices or edges, or both, subject to certain conditions. It was first introduced in the mid-1960s [1] and used in many applications like social network analysis, chemoinformatics, computer vision, biological applications, biomedical research, etc. There are many types of graph labeling, including cordial labeling.

The concept of cordial labeling of a graph was introduced by Cahit in 1987 and Golomb defined the idea of numbering in a graph. A graph is called cordial if it is possible to label its vertices with 0's and 1's so that when the edges are labeled with the difference of the labels at their endpoints, the number of vertices (edges) labeled with ones and zeros differ at most by one. Cordial labeling has a lot of classifications or variants being studied by researchers and continues to be discovered. See [2, 4, 7, 8] for some of the list of cordial labeling and its variants.

Throughout this paper, the researcher explores a new concept or variant of cordial labeling, Lucas Cordial Labeling, by utilizing the idea of Lucas Divisor Cordial labeling [5] and On Fibonacci Cordial Labeling [6]. The researcher also wants to examine some Snake Graphs that admit Lucas cordial labeling, called Lucas cordial graphs.

2. PRELIMINARIES

Definition 2.1 [5] The Lucas sequence of number can be defined as the linear recurrence relation satisfying the following condition:

$$L_1 = 1,\ L_2 = 3, \qquad \text{and} \qquad L_n = L_{(n-1)} + L_{(n-2)},\ n \geq 3.$$

This generates a sequence of integers in the following order: 1,3,4,7,11,18,....

Definition 2.2 An injective function $f : V(G) \to \{L_1, L_2, \ldots, L_n\}$, where L_j is the jth Lucas number $(j = 1, 2, \ldots, n)$ is said to be Lucas cordial labeling if the induced function $f^* : E(G) \to \{0, 1\}$ defined by $f^*(uv) = (f(u) + f(v)) \pmod 2$ satisfies the condition $|e_f(0) - e_f(1)| \leq 1$. A graph which admits Lucas cordial labeling is called Lucas cordial graph.

3. LUCAS CORDIAL GRAPHS

This section presents the results of Lucas cordial labeling of the quadrilateral snake graph Q_n, cycle quadrilateral snake graph CQ_n, alternate triangular snake graph $A(T_n)$ and double alternate quadrilateral snake graph $DA(QS_n)$.

Theorem 3.1 The Lucas Sequence of the form L_{3n} is even for all $n \in \mathbb{N}$.

Proof. To show that for $n \in \mathbb{N}$, the Lucas number L_{3n} is an even number, we can use the recurrence relation for Lucas numbers in Definition 2.1 for $n \geq 3$ as

$$L_n = L_{n-1} + L_{n-2}.$$

We know that $L_1 = 1$ and $L_2 = 3$, which are both odd numbers. Observe that,

$$\begin{aligned} L_3 &= L_2 + L_1 = 3 + 1 = 4, \\ L_4 &= L_3 + L_2 = 4 + 3 = 7, \\ L_5 &= L_4 + L_3 = 7 + 4 = 11, \\ L_6 &= L_5 + L_4 = 11 + 7 = 18. \end{aligned}$$

Notice that the sum of two even or odd numbers is always even, and the sum of an odd and an even number is always an odd number.

Suppose that L_{3k} is true for some $k \in \mathbb{N}$. We need to show that the claim holds up to $L_{3(k+1)} = L_{3k+3}$. Now,

$$\begin{aligned} L_{3(k+1)} = L_{3k+3} &= L_{3k+2} + L_{3k+1} \\ &= L_{3k+1} + L_{3k} + L_{3k+1} \\ &= 2L_{3k+1} + L_{3k}. \end{aligned}$$

Since L_{3k} is even by the inductive hypothesis and $2L_{3k+1}$ is even, L_{3k+3} is also even. Therefore, by Principle of Mathematical Induction, the Lucas sequence of the form L_{3n} is even for all $n \in \mathbb{N}$. □

Theorem 3.2 The Lucas Sequence of the form L_{3n+1} or L_{3n+2} is odd for all $n \in \mathbb{N}$.

Proof. Suppose the Lucas sequence of the form L_{3n+1} or L_{3n+2} is even. By Theorem 3.1, the Lucas sequence L_{3n} is even for all $n \in \mathbb{N}$. Observe that, $3n+1 \neq 3n$ and $3n+2 \neq 3n$. Thus, L_{3n+1} and L_{3n+2} are not even. A contradiction to our assumption. Hence, the Lucas sequence of the form L_{3n+1} or L_{3n+2} is odd for all $n \in \mathbb{N}$. □

Theorem 3.3 The Quadrilateral Snake Graph Q_n admits Lucas Cordial Labeling for all $n \geq 2$.

Proof. Suppose the vertex set and edge set of graph Q_n are as follows.

$$V(Q_n) = \{v_i | 1 \leq i \leq n\} \cup \{u_i, w_i | 1 \leq i \leq n-1\} \qquad \text{and}$$

$$E(Q_n) = \{v_i v_{i+1} | 1 \leq i \leq n-1\} \cup \{u_i w_i, v_i u_i, v_{i+1} w_i | 1 \leq i \leq n-1\}.$$

The order and the size of Quadrilateral Snake Graph Q_n are $|V(Q_n)| = 3n-2$ and $|E(Q_n)| = 4n-4$, respectively. Let $f : V(Q_n) \to \{L_1, L_2, L_3, \ldots, L_{3n-2}\}$ be the function defined by:

$$\begin{aligned} f(u_i) &= L_{3i-1}, \qquad 1 \leq i \leq n-1 \\ f(w_i) &= L_{3i}, \qquad 1 \leq i \leq n-1 \\ f(v_i) &= L_{3i-2}, \qquad 1 \leq i \leq n \end{aligned}$$

Hence, the induced edge labels where $1 \leq i \leq n-1$ are

$$\begin{aligned} f^*(v_i v_{i+1}) &= 0, \\ f^*(v_i u_i) &= 0, \\ f^*(u_i w_i) &= 1, \\ f^*(v_{i+1} w_i) &= 1. \end{aligned}$$

Observe that $e_f(0) = n-1+n-1 = 2n-2$ and $e_f(1) = n-1+n-1 = 2n-2$. Thus, $|e_f(0) - e_f(1)| = |(2n-2) - (2n-2)| = |0| = 0 \leq 1$. Therefore, the Quadrilateral Snake Graph Q_n is a Lucas Cordial Graph for all $n \geq 2$. □

Theorem 3.4 The Cycle Quadrilateral Snake Graph CQ_n admits Lucas Cordial Labeling for all $n \geq 3$.

Proof. Suppose the vertex set and edge set of graph CQ_n are as follows.

$$V(CQ_n) = \{v_i, u_i, w_i | 1 \leq i \leq n\} \qquad \text{and}$$

$$\begin{aligned} E(CQ_n) = &\{v_i v_{i+1}, v_{i+1} w_i | 1 \leq i \leq n-1\} \cup \{v_1 v_n\} \cup \{v_1 w_n\} \\ &\cup \{u_i w_i, v_i u_i | 1 \leq i \leq n\}. \end{aligned}$$

The order and the size of Cycle Quadrilateral Snake Graph CQ_n are $|V(CQ_n)| = 3n$ and $|E(CQ_n)| = 4n$, respectively. Let $f : V(CQ_n) \to \{L_1, L_2, L_3, \ldots, L_{3n}\}$ be the function defined by:

$$\begin{aligned} f(u_i) &= L_{3i-1}, && 1 \leq i \leq n \\ f(w_i) &= L_{3i}, && 1 \leq i \leq n \\ f(v_i) &= L_{3i-2}, && 1 \leq i \leq n \end{aligned}$$

Hence, the induced edge labels are

$$\begin{aligned} f^*(v_i v_{i+1}) &= 0, && 1 \leq i \leq n-1 \\ f^*(v_1 v_n) &= 0 && \\ f^*(v_i u_i) &= 0, && 1 \leq i \leq n \\ f^*(u_i w_i) &= 1, && 1 \leq i \leq n \\ f^*(v_{i+1} w_i) &= 1, && 1 \leq i \leq n-1 \\ f^*(v_1 w_n) &= 1 && \end{aligned}$$

Observe that, $e_f(0) = 1 + (n-1) + n = 2n$ and $e_f(1) = 1 + (n-1) + n = 2n$. Thus, $|e_f(0) - e_f(1)| = |2n - 2n| = |0| = 0 \leq 1$. Therefore, the Cycle Quadrilateral Snake Graph CQ_n is a Lucas Cordial Graph for all $n \geq 3$. □

Theorem 3.5 The Alternate Triangular Snake Graph $A(T_n)$ admits Lucas Cordial Labeling for all $n \geq 2$.

Proof. To prove the theorem, we consider the following cases.
Case 1: n is even, $n \geq 2$.
Suppose the vertex set and edge set of graph $A(T_n)$ for all $n \geq 2$ are as follows.

$$V(A(T_n)) = \{v_i | 1 \leq i \leq n\} \cup \left\{u_i | 1 \leq i \leq \frac{n}{2}\right\} \qquad \text{and}$$

$$E(A(T_n)) = \{v_i v_{i+1} | 1 \leq i \leq n-1\} \cup \left\{v_{2i-1} u_i, v_{2i} u_i | 1 \leq i \leq \frac{n}{2}\right\}.$$

The order and the size of the Alternate Triangular Snake Graph $A(T_n)$ are

$$|V(A(T_n))| = \frac{3n}{2} \qquad \text{and} \qquad |E(A(T_n))| = 2n - 1,$$

respectively. Let $f : V(A(T_n)) \to \left\{L_1, L_2, L_3, \ldots, L_{\frac{3n}{2}}\right\}$ be the function defined by:

$$f(u_i) = L_{3i}, \qquad 1 \leq i \leq \frac{n}{2}$$

$$f(v_i) = \begin{cases} L_{\frac{3i-1}{2}}, & 1 \leq i \leq n-1, \ \ i \text{ is odd} \\ L_{\frac{3i-2}{2}}, & 1 \leq i \leq n, \ \ i \text{ is even} \end{cases}$$

Hence, the induced edge labels are

$$\begin{aligned} f^*(v_i v_{i+1}) &= 0, && 1 \leq i \leq n-1 \\ f^*(v_{2i-1} u_i) &= 1, && 1 \leq i \leq \frac{n}{2} \\ f^*(v_{2i} u_i) &= 1, && 1 \leq i \leq \frac{n}{2} \end{aligned}$$

Observe that $e_f(0) = n-1$ and $e_f(1) = \frac{n}{2}+\frac{n}{2} = n$. Thus, $|e_f(0)-e_f(1)| = |n-1-n| = |-1| = 1 \leq 1$. Therefore, if n is even, $n \geq 2$, the Alternate Triangular Snake Graph $A(T_n)$ is a Lucas Cordial Graph.

Case 2: n is odd, $n \geq 3$.
Suppose the vertex set and edge set of graph $A(T_n)$ for all $n \geq 3$ are as follows.

$$V(A(T_n)) = \{v_i|1 \leq i \leq n\} \cup \left\{u_i|1 \leq i \leq \frac{n-1}{2}\right\} \qquad \text{and}$$

$$E(A(T_n)) = \{v_iv_{i+1}|1 \leq i \leq n-1\} \cup \left\{v_{2i-1}u_i, v_{2i}u_i|1 \leq i \leq \frac{n-1}{2}\right\}.$$

The order and the size of the Alternate Triangular Snake Graph $A(T_n)$ are

$$|V(A(T_n))| = \frac{3n-1}{2} \qquad \text{and} \qquad |E(A(T_n))| = 2n-2,$$

respectively. Let $f : V(A(T_n)) \to \left\{L_1, L_2, L_3, \ldots, L_{\frac{3n-1}{2}}\right\}$ be the function defined by:

$$f(u_i) = L_{3i}, \qquad 1 \leq i \leq \frac{n-1}{2}$$

$$f(v_i) = \begin{cases} L_{\frac{3i-1}{2}}, & 1 \leq i \leq n, \ \ i \text{ is odd} \\ L_{\frac{3i-2}{2}}, & 1 \leq i \leq n-1, \ \ i \text{ is even} \end{cases}$$

Hence, the induced edge labels are:

$$f^*(v_iv_{i+1}) = 0, \qquad 1 \leq i \leq n-1$$

$$f^*(v_{2i-1}u_i) = 1, \qquad 1 \leq i \leq \frac{n-1}{2}$$

$$f^*(v_{2i}u_i) = 1, \qquad 1 \leq i \leq \frac{n-1}{2}$$

Observe that $e_f(0) = n-1$ and $e_f(1) = \frac{n-1}{2} + \frac{n-1}{2} = n-1$. Thus, $|e_f(0) - e_f(1)| = |(n-1) - (n-1)| = |0| = 0 \leq 1$. Therefore, if n is odd, $n \geq 3$, the Alternate Triangular Snake Graph $A(T_n)$ is a Lucas Cordial Graph.

Considering the cases above, we could say that the Alternate Triangular Snake Graph $A(T_n)$ is a Lucas Cordial Graph for all $n \geq 2$. □

Theorem 3.6 The Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ admits Lucas Cordial Labeling for all $n \geq 2$.

Proof. To prove the theorem, we consider the following cases.
Case 1: n is even, $n \geq 2$.
Suppose the vertex set and edge set of graph $DA(QS_n)$ for all $n \geq 2$ are as follows.

$$V(DA(QS_n)) = \{v_i|1 \leq i \leq n\} \cup \left\{u_i, x_i, w_i, y_i|1 \leq i \leq \frac{n}{2}\right\} \qquad \text{and}$$

$$E(DA(QS_n)) = \{v_iv_{i+1}|1 \leq i \leq n-1\} \cup \left\{u_ix_i, w_iy_i, v_{2i-1}u_i, v_{2i}x_i, v_{2i-1}w_i, v_{2i}y_i|1 \leq i \leq \frac{n}{2}\right\}.$$

The order and the size of Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ are

$$|V(DA(QS_n))| = 3n \qquad \text{and} \qquad |E(DA(QS_n))| = 4n-1,$$

respectively. Let $f : V(DA(QS_n)) \to \{L_1, L_2, L_3, \dots, L_{3n}\}$ be the function defined by:

$$\begin{aligned} f(v_i) &= L_{3i}, && 1 \le i \le n \\ f(u_i) &= L_{6i-4}, && 1 \le i \le \frac{n}{2} \\ f(x_i) &= L_{6i-5}, && 1 \le i \le \frac{n}{2} \\ f(w_i) &= L_{6i-2}, && 1 \le i \le \frac{n}{2} \\ f(y_i) &= L_{6i-1}, && 1 \le i \le \frac{n}{2} \end{aligned}$$

Hence, the induced edge labels are

$$\begin{aligned} f^*(v_i v_{i+1}) &= 0, && 1 \le i \le n-1 \\ f^*(u_i x_i) &= 0, && 1 \le i \le \frac{n}{2} \\ f^*(w_i y_i) &= 0, && 1 \le i \le \frac{n}{2} \\ f^*(v_{2i-1} u_i) &= 1, && 1 \le i \le \frac{n}{2} \\ f^*(v_{2i} x_i) &= 1, && 1 \le i \le \frac{n}{2} \\ f^*(v_{2i-1} w_i) &= 1, && 1 \le i \le \frac{n}{2} \\ f^*(v_{2i} y_i) &= 1, && 1 \le i \le \frac{n}{2} \end{aligned}$$

Observe that $e_f(0) = n - 1 + \frac{n}{2} + \frac{n}{2} = 2n - 1$ and $e_f(1) = \frac{n}{2} + \frac{n}{2} + \frac{n}{2} + \frac{n}{2} = 2n$. Thus, $|e_f(0) - e_f(1)| = |2n - 1 - 2n| = |-1| = 1 \le 1$. Therefore, if n is even, $n \ge 2$, the Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ is a Lucas Cordial Graph.

Case 2: n is odd, $n \ge 3$.
Suppose the vertex set and edge set of graph $DA(QS_n)$ for all $n \ge 3$ are as follows.

$$V(DA(QS_n)) = \{v_i | 1 \le i \le n\} \cup \left\{u_i, x_i, w_i, y_i | 1 \le i \le \frac{n-1}{2}\right\} \quad \text{and}$$

$$\begin{aligned} E(DA(QS_n)) = &\{v_i v_{i+1} | 1 \le i \le n-1\} \\ &\cup \left\{u_i x_i, w_i y_i, v_{2i-1} u_i, v_{2i} x_i, v_{2i-1} w_i, v_{2i} y_i | 1 \le i \le \frac{n-1}{2}\right\}. \end{aligned}$$

The order and the size of Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ is

$$|V(DA(QS_n))| = 3n - 2 \quad \text{and} \quad |E(DA(QS_n))| = 4n - 4,$$

respectively. Let $f : V(DA(QS_n)) \to \{L_1, L_2, L_3, \ldots, L_{3n-2}\}$ be the function defined by:

$$
\begin{aligned}
f(v_i) &= L_{3i}, && 1 \le i \le n-2\\
f(v_{n-1}) &= L_{3n-2}\\
f(v_n) &= L_{3(n-1)}\\
f(u_i) &= L_{6i-4}, && 1 \le i \le \frac{n-1}{2}\\
f(x_i) &= L_{6i-5}, && 1 \le i \le \frac{n-1}{2}\\
f(w_i) &= L_{6i-2}, && 1 \le i \le \frac{n-1}{2}\\
f(y_i) &= L_{6i-1}, && 1 \le i \le \frac{n-1}{2}
\end{aligned}
$$

Hence, the induced edge labels are

$$
\begin{aligned}
f^*(v_iv_{i+1}) &= 0, && 1 \le i \le n-3\\
f^*(v_iv_{i+1}) &= 1, && n-2 \le i \le n-1\\
f^*(u_ix_i) &= 0, && 1 \le i \le \frac{n-1}{2}\\
f^*(w_iy_i) &= 0, && 1 \le i \le \frac{n-1}{2}\\
f^*(v_{2i-1}u_i) &= 1, && 1 \le i \le \frac{n-1}{2}\\
f^*(v_{2i}x_i) &= 1, && 1 \le i \le \frac{n-3}{2}\\
f^*(v_{n-1}x_{\frac{n-1}{2}}) &= 0\\
f^*(v_{2i-1}w_i) &= 1, && 1 \le i \le \frac{n-1}{2}\\
f^*(v_{2i}y_i) &= 1, && 1 \le i \le \frac{n-3}{2}\\
f^*(v_{n-1}y_{\frac{n-1}{2}}) &= 0
\end{aligned}
$$

Observe that $e_f(0) = n-3+\frac{n-1}{2}+\frac{n-1}{2}+1+1 = 2n-2$ and $e_f(1) = 2+\frac{n-1}{2}+\frac{n-3}{2}+\frac{n-1}{2}+\frac{n-3}{2} = 2n-2$. Thus, $|e_f(0)-e_f(1)| = |(2n-2)-(2n-2)| = |0| = 0 \le 1$. Therefore, if n is odd, $n \ge 3$, the Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ is a Lucas Cordial Graph.

Considering the cases above, we could say that the Double Alternate Quadrilateral Snake Graph $DA(QS_n)$ is a Lucas Cordial Graph for all $n \ge 2$. □

4. CONCLUSION

The study demonstrated the existence of Lucas Cordial Labeling on some snake graphs, namely the Alternate Triangular Snake Graph $A(T_n)$, $n \ge 2$, the Quadrilateral Snake Graph Q_n, $n \ge 2$, the Double Alternate Quadrilateral Snake Graph $DA(QS_n)$, $n \ge 2$, and the Cycle Quadrilateral Snake Graph CQ_n, $n \ge 3$. Through constructive proofs and case analyses, it was shown that for specific values of n, all of these graphs admit Lucas Cordial Labeling. This result adds new mathematical structures to graph labeling by expanding the scope of cordial labeling using Lucas numbers as vertex labels. The results show the flexibility of Lucas Cordial Labeling in snake graphs and provide opportunities for more research in other graph families. Future studies could look into its uses in more general graph classes and its possible significant contribution in real-life applications including coding theory, radar, astronomy, circuit design, communication network addressing, database management, etc.

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