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Graphics & Vision

Graph Theory using Python

Modern Deep Learning Architectures

Highlights

Study in Computational Visualization

Advancing Image Classification Performance

Discovering Thoughts, Inventing Future

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Constructing Classic Graphs in Graph Theory using Python and Generative AI: A Case Study in Computational Visualization and Prompt Engineering

By Dr. Shanzhen Gao, Dr. Weizheng Gao, Dr. Julian D. Allagan, Dr. Jianning Su, Dr. Ephrem Eyob & Dr. Hank B. Strevel

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Abstract- This study explores the construction of several classic graphs in graph theory through Python programming, offering a hands-on computational approach to understanding their mathematical properties. The selected graphs-including the Wagner, Desargues, Herschel, Möbius-Kantor, Franklin, truncated icosahedral, and triangular grid graphs-are chosen for their historical significance and structural complexity. Using Python's turtle graphics module, each graph is visualized through trigonometric and geometric logic, illustrating core concepts such as regularity, symmetry, Hamiltonicity, and planarity. In addition to manual code development, the study integrates generative AI, specifically ChatGPT, to reproduce graph constructions via prompt engineering.

Keywords: graph theory, python programming, graph visualization, classic graphs, generative AI, prompt engineering.

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Constructing Classic Graphs in Graph Theory using Python and Generative AI: A Case Study in Computational Visualization and Prompt Engineering

Dr. Shanzhen Gao [α], Dr. Weizheng Gao [σ], Dr. Julian D. Allagan [ρ], Dr. Jianning Su [ω], Dr. Ephrem Eyob [¥] & Dr. Hank B. Strevel [§]

Abstract- This study explores the construction of several classic graphs in graph theory through Python programming, offering a hands-on computational approach to understanding their mathematical properties. The selected graphs-including the Wagner, Desargues, Herschel, Möbius-Kantor, Franklin, truncated icosahedral, and triangular grid graphs-are chosen for their historical significance and structural complexity. Using Python's turtle graphics module, each graph is visualized through trigonometric and geometric logic, illustrating core concepts such as regularity, symmetry, Hamiltonicity, and planarity. In addition to manual code development, the study integrates generative AI, specifically ChatGPT, to reproduce graph constructions via prompt engineering. This dual approach showcases the educational potential of AI-assisted programming and reinforces algorithmic thinking. The work aims to bridge the gap between theoretical graph concepts and their algorithmic applications. It provides a replicable methodology that enhances student engagement, supports active learning, and promotes interdisciplinary exploration across mathematics, computer science, and education.

Keywords: graph theory, python programming, graph visualization, classic graphs, generative AI, prompt engineering.

I. Introduction

Graph theory, a foundational discipline within discrete mathematics, explores graphs comprising vertices (or nodes) connected by edges(or links). These abstract constructs are powerful tools for modeling pair wise relationships across various fields, including computer science, biology, physics, chemistry, transportation, and social network analysis. Graphs enable the representation of systems as diverse as internet connectivity, molecular structures, urban transportation networks, and social interactions. The construction and analysis of specific types of graphs provide deeper insights into the properties and behaviors of these complex systems.

This paper presents a computational approach to constructing classic graphs in graph theory using Python programming. The primary objective is to bridge the theoretical framework of graph theory with the practical application of computer programming to foster understanding, visualization, and manipulation of intricate graph structures. With its ease of use, extensive libraries, and built-in graphic capabilities like the turtle module, Python offers a suitable platform for modeling and animating these graphs in an educational and research context.

The study focuses on a collection of well-known graphs that hold historical, mathematical, and practical significance. These include the Wagner graph, Desargues graph, Herschel graph, Möbius–Kantor graph, Franklin graph, truncated icosahedral graph, and triangular grid graph. Each graph selected for this project embodies unique structural and topological properties that make it ideal for exploring advanced concepts such as regularity, symmetry, non-planarity, chromatic characteristics, and Hamiltonicity.

The Wagner graph, a 3-regular graph with 8 vertices and 12 edges, is a key structure in minor theory used in studying apex and toroidal graphs. Its girth of 4, radius and diameter of 2, and chromatic number of 3 exemplify important constraints in planar graph theory and are instrumental in Ramsey's theory.

The Desargues graph, with 20 vertices and 30 edges, is known for its high symmetry and serves as a model in stereochemistry. Its distance-transitive and Hamiltonian nature makes it a powerful object in mathematics and chemistry. This graph also belongs to

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the family of cubic, distance-regular graphs and exhibits elegant structural harmony.

The Herschel graph, though relatively small with 11 vertices and 18 edges, holds significance as the smallest non-Hamiltonian polyhedral graph. It provides a clear example of the limits of Hamiltonian cycles in three-dimensional graph structures and plays a crucial role in understanding planar graph exceptions.

The Möbius–Kantor graph, a cubic bipartite symmetric graph with 16 vertices and 24 edges, offers insights into the behavior of generalized Petersen graphs. It is a helpful substructure within higher-dimensional graphs like the hypercube and plays a key role in studying symmetry and Cayley graphs.

The Franklin graph, famous for its application to topological coloring problems, was used by Philip Franklin to disprove the Heawood conjecture on the Klein bottle. With 12 vertices and 18 edges, it remains an essential case study in topological graph theory and graph coloring.

The truncated icosahedral graph, or the Buckminster Fullerene graph, is derived from an Archimedean solid and features 60 vertices and 90 edges. Its structure models the carbon molecule C_{60} and is widely recognized in chemistry and architecture. As a 3-regular graph, it demonstrates the complexity and symmetry of polyhedral graphs and the feasibility of rendering them computationally.

Finally, the triangular grid graph is a visual model for lattice structures. It represents the layout of triangular tilings and has applications in physics, chemistry, and game theory. These graphs are important in modeling networks with hexagonal or triangular symmetry.

In this research, each graph is constructed algorithmically using Python's turtle module. The process involves deriving polar coordinates for vertex placement, calculating edge connections using trigonometry, and applying stylized rendering for clear visualization. This computational method enables students and researchers to dynamically visualize and interact with graph properties, fostering deeper engagement with abstract concepts.

Additionally, this study incorporates generative artificial intelligence tools, such as ChatGPT, to reproduce and verify Python programs for each graph. Through prompt engineering, the researchers crafted queries that guided the AI in generating accurate code representations of each graph structure. This dual approach-combining manual programming with AI-assisted verification-demonstrates the synergy between human logic and machine learning in computational mathematics.

The integration of Python into graph theory education offers numerous pedagogical advantages. It provides a platform for visual experimentation, encourages algorithmic thinking, and bridges the gap between abstract mathematical definitions and concrete visual outputs. Furthermore, using AI tools introduces learners to emerging technologies in computational science, enhancing their digital literacy and programming fluency.

This paper aims to serve as both a research contribution and a teaching resource. Illustrating how classic graphs can be constructed through code provides a replicable methodology for instructors and students to explore graph theory in an interactive, project-based environment. Including code, figures, and AI-generated examples supports active learning and promotes inquiry-based exploration.

In the following sections, the mathematical characteristics of each selected graph are discussed in detail, followed by their respective Python implementations. Through this work, the authors aim to deepen understanding, inspire further research, and promote computational literacy in graph theory.

II. Methodologies

This study adopts a computational and algorithmic methodology to construct and analyze classic graphs in graph theory using Python programming. The primary goal is to bridge mathematical abstraction with visual comprehension by implementing graph structures through code. Python's flexibility, particularly its turtle graphics module, is the foundation for this approach, enabling accurate and dynamic graph rendering based on geometric and trigonometric calculations.

The methodology follows a systematic, replicable process applied across all selected graphs. Each begins with a thorough mathematical analysis-defining vertex counts, edge arrangements, degrees, symmetries, and other graph invariants. Next, the design transitions to coordinate planning, typically utilizing polar geometry to determine optimal vertex placement around circular or polygonal paths. Edges are drawn between these vertices by calculating precise movements and rotations within the turtle environment.

Each Python program is customized to the individual graph's structure. This includes 3-regular graphs like the Wagner and Franklin graphs, symmetric bipartite graphs like the Möbius–Kantor graph, and complex polyhedral graphs like the truncated icosahedral graph. The visualizations often employ color-coded vertices, labeled nodes, and edge stylizations to reflect graph attributes like chromatic number, connectivity, and planarity for enhanced educational value and clarity.

In addition to constructing the graphs manually through code, this study integrates generative AI tools, specifically ChatGPT, by using prompt engineering to generate alternative Python implementations. This dual strategy-manual coding followed by AI-assisted

reproduction-enables cross-verification of graphical outputs and exposes learners to collaborative AI programming practices.

Overall, this methodology emphasizes reproducibility, educational accessibility, and computational precision. It supports the theoretical exploration of graph properties and enables hands-on learning and experimentation. By merging algorithmic thinking with visual modeling, this framework equips students and researchers with a powerful toolkit for advancing their understanding of graph theory through Python.

III. Wagner Graph

In the mathematical field of graph theory, the Wagner graph is a 3-regular graph with 8 vertices and 12 edges (Bondy & Murty, 2007). It is the 8-vertex Möbius ladder graph. It is nonplanar but has a crossing number of one, making it an apex graph. It can be embedded without crossings on a torus or projective plane and is also a toroidal graph. It has girth 4, diameter 2, radius 2, chromatic number 3, chromatic index 3, and is both 3-vertex-connected and 3-edge-connected. It is a vertex-transitive graph but is not edge-transitive. Its whole automorphism group is isomorphic to the dihedral group D_8 of order 16, the group of an octagon symmetries, including rotations and reflections ("Wagner Graph," 2024).

The Wagner graph is triangle-free and has independence number three, providing one half of the proof that the Ramsey number R(3,4) (the least number n such that any n-vertex graph contains either a triangle or a four-vertex independent set) is 9 (Soifer, 2008).

Wagner graph has 392 spanning trees; it and the complete bipartite graph $K_{3,3}$ have the most spanning trees among all cubic graphs with the same number of vertices (Jakobson & Rivin, 1999).

The Wagner graph is also one of four minimal forbidden minors for the graphs of tree width at most three (the other three being the complete graph K_5, the graph of the regular octahedron, and the graph of the pentagonal prism) and one of four minimal forbidden minors for the graphs of branch width at most three (the other three being K_5, the graph of the octahedron, and the cube graph) ("Wagner Graph," 2024; Bodlaender, 1998; Bodlaender & Thilikos, 1999).

Wagner's famous conjecture asserts that for any infinite set of graphs, one of its members is isomorphic to a minor of another (all graphs in this paper are finite) (Wagner, 1970). The project proving Wagner's conjecture was started by Robertson and Seymour, later joined by Thomas, and completed in 2004, which led to entirely new concepts and a new way of looking at graph theory (Lovász, 2006).

Python Program for Wagner Graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
for k in range(8):
    t.penup()
    x1 = 300*math.cos(math.pi*((45*k)%360)/180)
    y1 = 300*math.sin(math.pi*((45*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 300*math.cos\
(math.pi*((45*k+45)%360)/180)
    y2 = 300*math.sin(math.pi*((45*k+45)%360)/180)
    t.goto(x2,y2)
radius = 300
for k in range(8):
    t.penup()
    t.goto(0,0)
    t.setheading(45*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
radius = 300
for k in range(4):
    t.penup()
    x1 = radius*math.cos(math.pi*((45*k)%360)/180)
    y1 = radius*math.sin(math.pi*((45*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = radius*math.cos\
(math.pi*((45*k+180)%360)/180)
    y2 = radius*math.sin\
(math.pi*((45*k+180)%360)/180)
    t.goto(x2, y2)
t.hideturtle()
```

Using the previous algorithm, we generate the Wagner graph as shown in Figure 1.

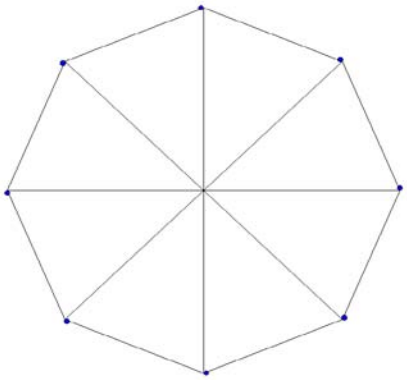

Figure 1: Wagner Graph

Using ChatGPT to Reproduce the Above Graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 1(a).

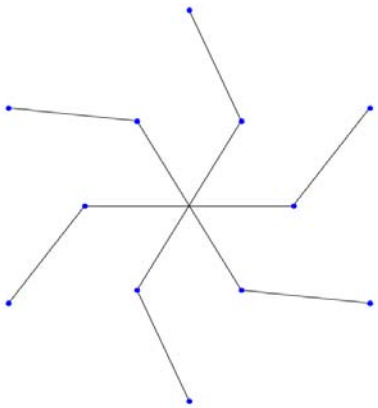

Figure 1(a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 1(b).

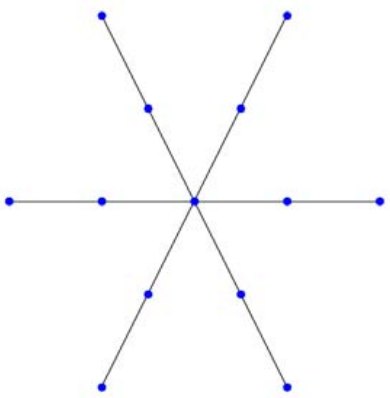

Figure 1(b)

IV. Desargues Graph

The Desargues graph is a distance-transitive, cubic graph with 20 vertices and 30 edges. It is named after Girard Desargues, arises from several different combinatorial constructions, has a high level of symmetry, is the only known non-planar cubic partial cube, and has been applied in chemical databases. It is a symmetric graph with symmetries that take any vertex to any other vertex and any edge to any other edge. Its symmetry group has order 240, and is isomorphic to the product of a symmetric group on 5 points with a group of order 2 ("Desargues Graph," 2024).

In chemistry, the Desargues graph is known as the Desargues–Levi graph; it is used to organize systems of stereoisomers of 5-ligand compounds. In this application, the thirty edges of the graph correspond to pseudorotations of the ligands ("Desargues Graph," 2024; Balaban, Fărcaşiu, & Bănică, 1966; Mislow, 1970).

It has chromatic number 2, chromatic index 3, radius 5, diameter 5, and girth 6. It is also a 3-vertex-connected and a 3-edge-connected Hamiltonian graph. It has a book thickness of 3 and a queue number of 2 ("Desargues Graph," 2024).

All the cubic distance-regular graphs are known (Brouwer, Cohen, & Neumaier, 1989). The Desargues graph is one of the 13 such graphs ("Desargues Graph," 2024).

Python Program for Creating Desargues Graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
t.penup()
t.goto(0,-300)
t.pendown()
t.circle(300)
radius = 300
for k in range(10):
    t.penup()
    t.goto(0,0)
    t.setheading(36*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
radius = 150
for k in range(10):
    t.penup()
    t.goto(0,0)
```

```
    t.setheading(36*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("red")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
for k in range(10):
    t.penup()
    x1 = 300*math.cos(math.pi*((36*k)%360)/180)
    y1 = 300*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 150*math.cos(math.pi*((36*k)%360)/180)
    y2 = 150*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x2,y2)
for k in range(10):
    t.penup()
    x1 = 150*math.cos(math.pi*((36*k)%360)/180)
    y1 = 150*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 150*math.cos\
(math.pi*((36*k+108)%360)/180)
    y2 = 150*math.sin\
(math.pi*((36*k+108)%360)/180)
    t.goto(x2,y2)
t.hideturtle()
```

Using the previous algorithm, we generate the Desargues graph shown in Figure 2.

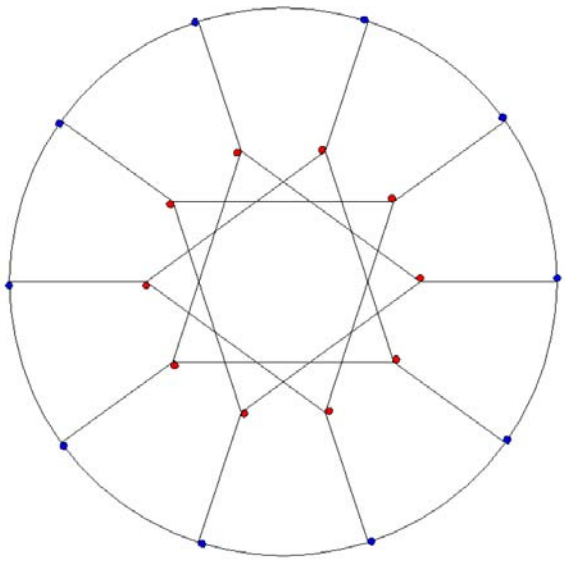

Figure 2: Desargues Graph

Using ChatGPT to Reproduce the Above Graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 2 (a).

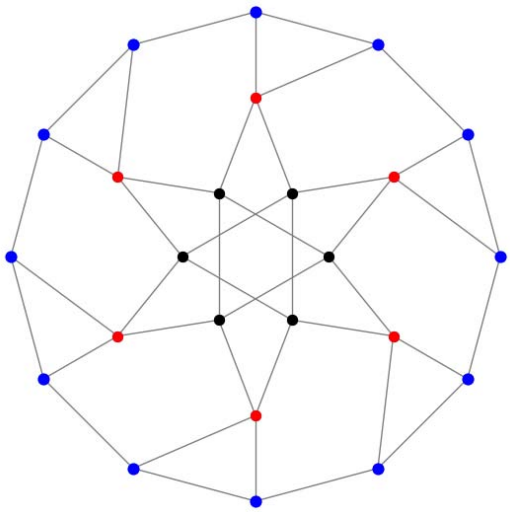

Figure 2 (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 2 (b).

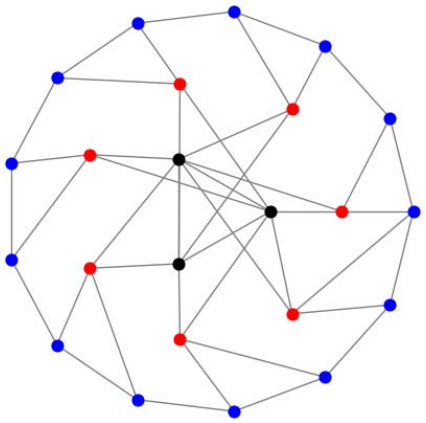

Figure 2 (b)

V. Herschel Graph

The Herschel graph is a bipartite undirected graph with 11 vertices and 18 edges. It is a polyhedral graph (the graph of a convex polyhedron). It is the smallest polyhedral graph that does not have a Hamiltonian cycle, a cycle passing through all its vertices. It is named after British astronomer Alexander Stewart Herschel, because Herschel studied Hamiltonian cycles in polyhedral graphs (but not of this graph) (Wikipedia contributors, 2023).

Herschel graph has three vertices of degree four and eight vertices of degree three. Each two distinct degree-four vertices share two degree-three neighbors, forming a four-vertex cycle with these shared neighbors. Three of these cycles pass through six of the eight degree-three vertices. Two more degree-three vertices do not participate in these four-vertex cycles; instead, each is adjacent to three of the six vertices (Wikipedia contributors, 2023; Lawson-Perfect, 2013).

Herschel's graph also provides an example of a polyhedral graph for which the medial graph has no Hamiltonian decomposition into two edge-disjoint Hamiltonian cycles. The medial graph of the Herschel graph is a 4-regular graph with 18 vertices, one for each edge of the Herschel graph; two vertices are adjacent in the medial graph whenever the corresponding edges of the Herschel graph are consecutive on one of its faces (Wikipedia contributors, 2023; (Bondy & Häggkvist, 1981).

Python Program for Creating Herschel Graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
t.penup()
t.goto(0,0)
t.pendown()
t.fillcolor("blue")
t.begin_fill()
t.circle(4)
t.end_fill()
t.penup()
t.goto(0,-300)
t.pendown()
t.circle(300)
radius = 300
for k in range(4):
    t.penup()
    t.goto(0,0)
    t.setheading(90*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
radius = 150
for k in range(6):
    t.penup()
    t.goto(0,0)
    t.setheading(60*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("red")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
for k in range(1,3,1):
    t.penup()
    x1 = 150*math.cos(math.pi*((60*k)%360)/180)
    y1 = 150*math.sin(math.pi*((60*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    t.goto(0,0)
for k in range(4,6,1):
    t.penup()
    x1 = 150*math.cos(math.pi*((60*k)%360)/180)
    y1 = 150*math.sin(math.pi*((60*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    t.goto(0,0)
t.penup()
x1 = 300*math.cos(math.pi*((90*0)%360)/180)
y1 = 300*math.sin(math.pi*((90*0)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*0)%360)/180)
y2 = 150*math.sin(math.pi*((60*0)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 300*math.cos(math.pi*((90*1)%360)/180)
y1 = 300*math.sin(math.pi*((90*1)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*1)%360)/180)
y2 = 150*math.sin(math.pi*((60*1)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 300*math.cos(math.pi*((90*1)%360)/180)
y1 = 300*math.sin(math.pi*((90*1)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*2)%360)/180)
y2 = 150*math.sin(math.pi*((60*2)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 300*math.cos(math.pi*((90*2)%360)/180)
y1 = 300*math.sin(math.pi*((90*2)%360)/180)
t.goto(x1,y1)
t.pendown()
```

```
x2 = 150*math.cos(math.pi*((60*3)%360)/180)
y2 = 150*math.sin(math.pi*((60*3)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 300*math.cos(math.pi*((90*3)%360)/180)
y1 = 300*math.sin(math.pi*((90*3)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*4)%360)/180)
y2 = 150*math.sin(math.pi*((60*4)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 300*math.cos(math.pi*((90*3)%360)/180)
y1 = 300*math.sin(math.pi*((90*3)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*5)%360)/180)
y2 = 150*math.sin(math.pi*((60*5)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 150*math.cos(math.pi*((60*0)%360)/180)
y1 = 150*math.sin(math.pi*((60*0)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*1)%360)/180)
y2 = 150*math.sin(math.pi*((60*1)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 150*math.cos(math.pi*((60*0)%360)/180)
y1 = 150*math.sin(math.pi*((60*0)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*5)%360)/180)
y2 = 150*math.sin(math.pi*((60*5)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 150*math.cos(math.pi*((60*3)%360)/180)
y1 = 150*math.sin(math.pi*((60*3)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*2)%360)/180)
y2 = 150*math.sin(math.pi*((60*2)%360)/180)
t.goto(x2,y2)
t.penup()
x1 = 150*math.cos(math.pi*((60*3)%360)/180)
y1 = 150*math.sin(math.pi*((60*3)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((60*4)%360)/180)
y2 = 150*math.sin(math.pi*((60*4)%360)/180)
t.goto(x2,y2)
t.hideturtle()
```

We generate the Herschel graph shown in Figure 3 using the previous algorithm.

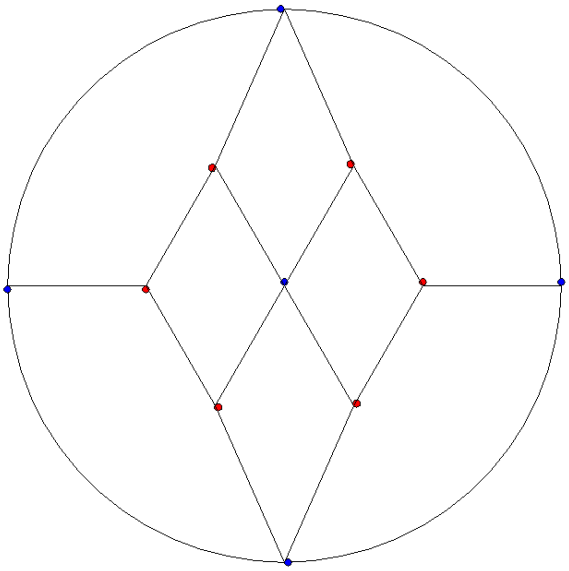

Figure 3: Herschel Graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 3 (a).

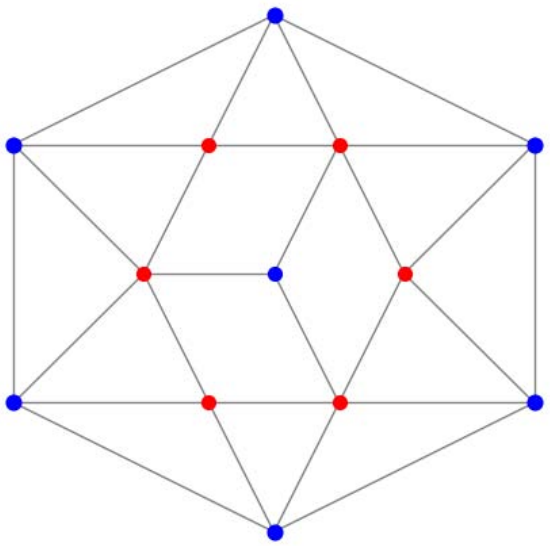

Figure 3 (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 3 (b).

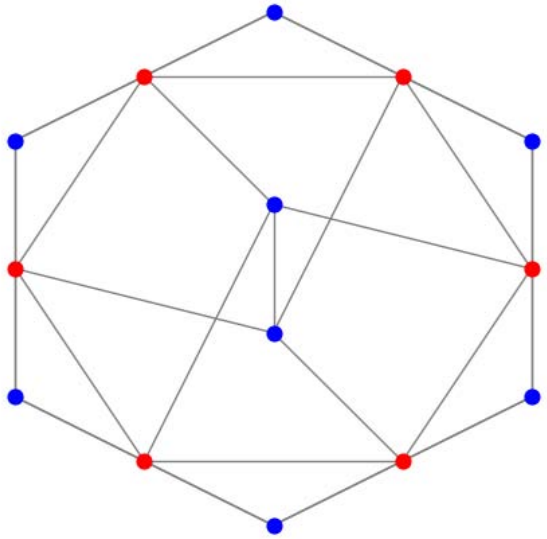

Figure 3 (b)

VI. Möbius–Kantor Graph

The Möbius–Kantor graph is a symmetric bipartite cubic graph with 16 vertices and 24 edges named after August Ferdinand Möbius and Seligmann Kantor. It can be defined as the generalized Petersen graph G(8,3): that is, it is formed by the vertices of an octagon, connected to the vertices of an eight-point star in which each point of the star is connected to the points three steps away from it (Wikipedia contributors, 2024).

Möbius–Kantor graph is a subgraph of the four-dimensional hypercube graph, formed by removing eight edges from the hypercube. Since the hypercube is a unit distance graph, the Möbius–Kantor graph can also be drawn in the plane with all edges unit length, although such a drawing will necessarily have some pairs of crossing edges. The Möbius–Kantor graph also often occurs as an induced subgraph of the Hoffman–Singleton graph. Each of these instances is, in fact, an eigenvector of the Hoffman-Singleton graph, with an associated eigenvalue of -3. Each vertex not in the induced Möbius–Kantor graph is adjacent to exactly four vertices in the Möbius–Kantor graph, two each in half of a bipartition of the Möbius–Kantor graph. The Möbius–Kantor graph cannot be embedded without crossings in the plane; it has crossing number 4, and is the smallest cubic graph with that crossing number (Wikipedia contributors, 2024; Coxeter, 1950).

The automorphism group of the Möbius–Kantor graph is a group of order 96. It acts transitively on the graph's vertices, edges, and arcs. Therefore, the Möbius–Kantor graph is a symmetric graph. It has automorphisms that take any vertex to any other vertex and any edge to any other edge. According to the Foster census, the Möbius–Kantor graph is the unique cubic symmetric graph with 16 vertices, and the smallest cubic symmetric graph is not also distance-transitive. The Möbius–Kantor graph is also a Cayley graph (Wikipedia contributors, 2024).

Python Program for Creating Möbius–Kantor Graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
t.penup()
t.goto(0,-300)
t.pendown()
t.circle(300)
radius = 300
for k in range(8):
    t.penup()
    t.goto(0,0)
    t.setheading(45*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
radius = 150
for k in range(8):
    t.penup()
    t.goto(0,0)
    t.setheading(45*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("red")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
for k in range(8):
    t.penup()
    x1 = 150*math.cos(math.pi*((45*k)%360)/180)
    y1 = 150*math.sin(math.pi*((45*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 300*math.cos\
(math.pi*((45*k+45)%360)/180)
    y2 = 300*math.sin\
(math.pi*((45*k+45)%360)/180)
    t.goto(x2,y2)
for k in range(4):
    t.penup()
    x1 = 150*math.cos(math.pi*((45*k)%360)/180)
    y1 = 150*math.sin(math.pi*((45*k)%360)/180)
    t.goto(x1,y1)
```

```
    t.pendown()
    x2 = 150*math.cos\
(math.pi*((45*k+135)%360)/180)
    y2 = 150*math.sin\
(math.pi*((45*k+135)%360)/180)
    t.goto(x2,y2)
for k in range(4):
    t.penup()
    x1 = 150*math.cos(math.pi*((45*k)%360)/180)
    y1 = 150*math.sin(math.pi*((45*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 150*math.cos\
(math.pi*((45*k+225)%360)/180)
    y2 = 150*math.sin\
(math.pi*((45*k+225)%360)/180)
    t.goto(x2,y2)
t.penup()
x1 = 150*math.cos(math.pi*((45*4)%360)/180)
y1 = 150*math.sin(math.pi*((45*4)%360)/180)
t.goto(x1,y1)
t.pendown()
x2 = 150*math.cos(math.pi*((45*7)%360)/180)
y2 = 150*math.sin(math.pi*((45*7)%360)/180)
t.goto(x2,y2)
t.hideturtle()
```

Using the previous algorithm, we generate Möbius the Möbius-Kantor graph as shown in Figure 4.

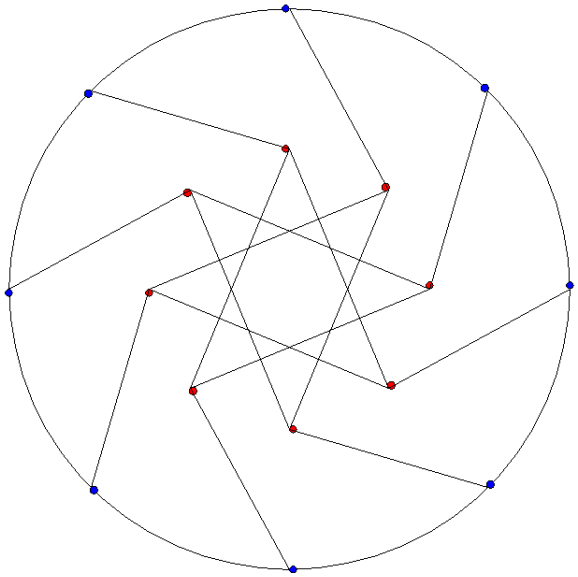

Figure 4: Möbius–Kantor graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 4 (a).

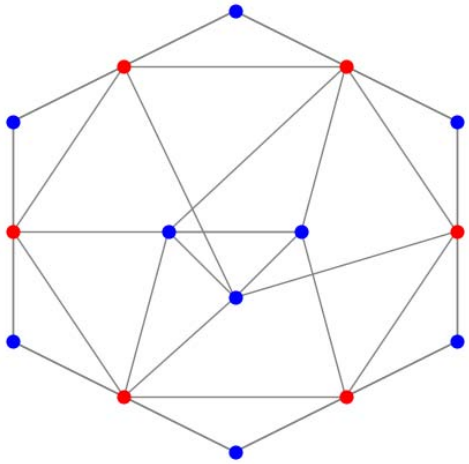

Figure 4 (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 4 (b).

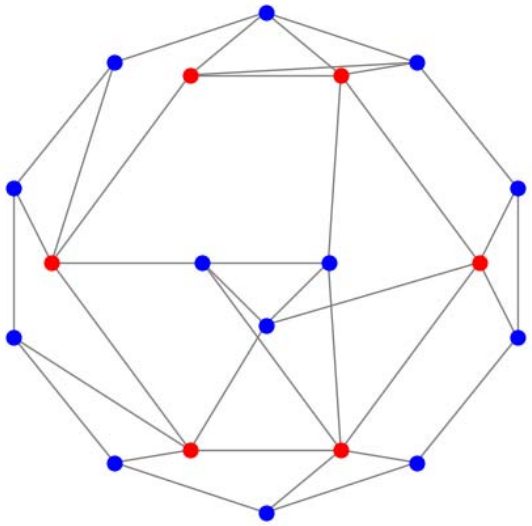

Figure 4 (b)

VII. Franklin Graph

The Franklin graph is a 3-regular graph with 12 vertices and 18 edges. Franklin graph is named after Philip Franklin, who disproved the Heawood conjecture on the number of colors needed when a two-dimensional surface is partitioned into cells by a graph embedding (Wikipedia contributors, 2022; Franklin, 1934).

The Heawood conjecture implied that the maximum chromatic number of a map on the Klein bottle should be seven, but Franklin proved that in this case six colors always suffice. (The Klein bottle is the only surface for which the Heawood conjecture fails.)

The Franklin graph can be embedded in the Klein bottle so that it forms a map requiring six colors, showing that six colors are sometimes necessary in this case. Franklin graph is Hamiltonian and has chromatic number 2, chromatic index 3, radius 3, diameter 3 and girth 4. It is also a 3-vertex-connected and 3-edge-connected perfect graph (Wikipedia contributors, 2022).

Python Program for Creating Franklin Graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
t.pensize(1)
for k in range(12):
    t.penup()
    x1 = 300*math.cos(math.pi*((30*k)%360)/180)
    y1 = 300*math.sin(math.pi*((30*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 300*math.cos\
(math.pi*((30*k+30)%360)/180)
    y2 = 300*math.sin\
(math.pi*((30*k+30)%360)/180)
    t.goto(x2,y2)
radius = 300
for k in range(12):
    t.penup()
    t.goto(0,0)
    t.setheading(30*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
radius = 300
for k in range(0,12,2):
    t.penup()
    x1 = radius*math.cos(math.pi*((30*k)%360)/180)
    y1 = radius*math.sin(math.pi*((30*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = radius*math.cos\
(math.pi*((30*k+150)%360)/180)
    y2 = radius*math.sin\
(math.pi*((30*k+150)%360)/180)
    t.goto(x2,y2)
t.hideturtle()
```

Using the previous algorithm we generate the Franklin graph as shown in Figure 5.

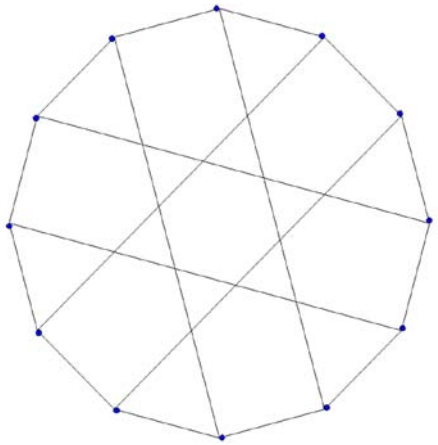

Figure 5: Franklin graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 5 (a).

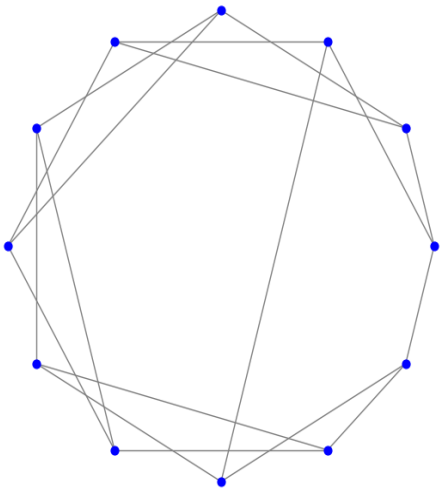

Figure 5 (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 5 (b).

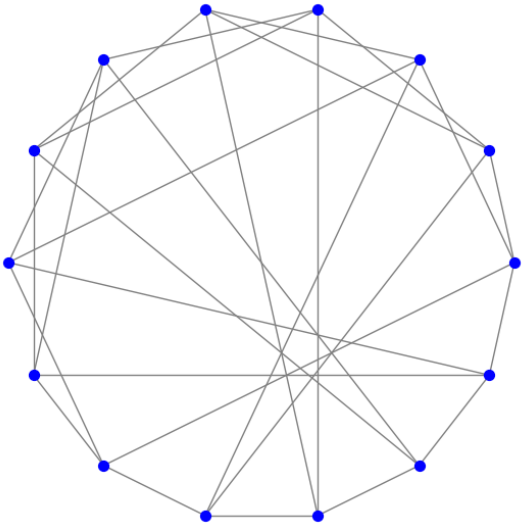

Figure 5 (b)

VIII. Truncated Icosahedral Graph

In geometry, the truncated icosahedron is a polyhedron that can be constructed by truncating all of the regular icosahedron's vertices. Intuitively, it may be regarded as footballs (or soccer balls) that are typically patterned with white hexagons and black pentagons. It can be found in the application of geodesic dome structures such as those whose architecture Buckminster Fuller pioneered are often based on this structure. It is an example of an Archimedean solid, as well as a Goldberg polyhedron (Weisstein, 2025).

According to Steinitz's theorem, the skeleton of a truncated icosahedron, like that of any convex polyhedron, can be represented as a polyhedral graph, meaning a planar graph (one that can be drawn without crossing edges) and 3-vertex-connected graph (remaining connected whenever two of its vertices are removed). The graph is known as *truncated icosahedral graph,* with 60 vertices and 90 edges. It is an Archimedean graph because it resembles one of the Archimedean solids. It is a cubic graph, meaning that each vertex is incident to exactly three edges. It is sometimes known as the Buckminster Fullerene graph (Weisstein, 2025; Wikipedia contributors, 2024).

Python Program for Creating truncated icosahedral graph

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
#20-gons
for k in range(20):
    t.penup()
    t.goto(0,0)
    t.setheading(18*k)
    t.forward(300)
    t.pendown()
    t.fillcolor("black")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
    t.penup()
    x1 = 300*math.cos(math.pi*((18*k)%360)/180)
    y1 = 300*math.sin(math.pi*((18*k)%360)/180)
    t.goto(x1,y1)
    t.setposition(x1, y1)
    t.pendown()
    letter = str(k+1)
    t.color('black')
    t.write(letter, align="right", font=("Verdana", 13, "normal"))
    t.color('black')
    x2 = 300*math.cos\
(math.pi*((18*k+18)%360)/180)
    y2 = 300*math.sin(math.pi*((18*k+18)%360)/180)
    t.goto(x2,y2)
#20 red vertices
for k in range(20):
    t.penup()
    t.goto(0,0)
    t.setheading(18*k)
    t.forward(240)
    t.pendown()
    t.fillcolor("red")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
    x1 = 240*math.cos(math.pi*((18*k)%360)/180)
    y1 = 240*math.sin(math.pi*((18*k)%360)/180)
    t.goto(x1,y1)
    t.setposition(x1, y1)
    t.pendown()
    letter = str(20+k+1)
    t.color('red')
    t.write(letter, align="right", font=("Verdana", 13, "normal"))
    t.color('black')
#10 blue vertices
radius = 180
for k in range(10):
    t.penup()
    t.goto(0,0)
    t.setheading(36*k)
    t.forward(radius)
    t.pendown()
```

```
    t.fillcolor("blue")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
    x1 = 180*math.cos(math.pi*((36*k)%360)/180)
    y1 = 180*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.setposition(x1, y1)
    t.pendown()
    letter = str(40+k+1)
    t.color('blue')
    t.write(letter, align="right", font=("Verdana", 13,
"normal"))
    t.color('black')
# 10 green vertices
radius = 120
for k in range(10):
    t.penup()
    t.goto(0,0)
    t.setheading(36*k)
    t.forward(radius)
    t.pendown()
    t.fillcolor("green")
    t.begin_fill()
    t.circle(4)
    t.end_fill()
    x1 = 120*math.cos(math.pi*((36*k)%360)/180)
    y1 = 120*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.setposition(x1, y1)
    t.pendown()
    letter = str(50+k+1)
    t.color('green')
    t.write(letter, align="right", font=("Verdana", 13,
"normal"))
    t.color('black')
#edges between black and red vertices
for k in range(0,19,2):
    t.penup()
    x1 = 300*math.cos(math.pi*((18*k)%360)/180)
    y1 = 300*math.sin(math.pi*((18*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    t.color('red')
    x2 = 240*math.cos(math.pi*((18*k+18)%360)/180)
    y2 = 240*math.sin(math.pi*((18*k+18)%360)/180)
    t.goto(x2,y2)
    t.color('black')
for k in range(0,19,2):
    t.penup()
    x1 = 240*math.cos(math.pi*((18*k)%360)/180)
    y1 = 240*math.sin(math.pi*((18*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    t.color('green')
    x2 = 300*math.cos\
(math.pi*((18*k+18)%360)/180)
    y2 = 300*math.sin(math.pi*((18*k+18)%360)/180)
    t.goto(x2,y2)
    t.color('black')
# edges between red vertices
for k in range(1,20,2):
    t.penup()
    x1 = 240*math.cos(math.pi*((18*k)%360)/180)
    y1 = 240*math.sin(math.pi*((18*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 240*math.cos\
(math.pi*((18*k+18)%360)/180)
    y2 = 240*math.sin(math.pi*((18*k+18)%360)/180)
    t.goto(x2,y2)
#edges between red and blue vertices
for k in range(10):
    t.penup()
    x1 = 180*math.cos(math.pi*((36*k)%360)/180)
    y1 = 180*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 240*math.cos(math.pi*((2*18*k)%360)/180)
    y2 = 240*math.sin(math.pi*((2*18*k)%360)/180)
    t.goto(x2,y2)
for k in range(10):
    t.penup()
    x1 = 180*math.cos(math.pi*((36*k)%360)/180)
    y1 = 180*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 240*math.cos\
(math.pi*((2*18*k+54)%360)/180)
    y2 = 240*math.sin(math.pi*((2*18*k+54)%360)/180)
    t.goto(x2,y2)
# edges between blue and green vertices
for k in range(10):
    t.penup()
    x1 = 180*math.cos(math.pi*((36*k)%360)/180)
    y1 = 180*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
```

```
    x2 = 120*math.cos(math.pi*((36*k)%360)/180)
    y2 = 120*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x2,y2)
# edges between green and green vertices
for k in range(0,10,2):
    t.penup()
    x1 = 120*math.cos(math.pi*((36*k)%360)/180)
    y1 = 120*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 120*math.cos\
(math.pi*((36*k+72)%360)/180)
    y2 = 120*math.sin(math.pi*((36*k+72)%360)/180)
    t.goto(x2,y2)
for k in range(1,10,2):
    t.penup()
    x1 = 120*math.cos(math.pi*((36*k)%360)/180)
    y1 = 120*math.sin(math.pi*((36*k)%360)/180)
    t.goto(x1,y1)
    t.pendown()
    x2 = 120*math.cos\
(math.pi*((36*k+72)%360)/180)
    y2 = 120*math.sin(math.pi*((36*k+72)%360)/180)
    t.goto(x2,y2)
t.hideturtle()
```

Using the previous algorithm we generate the truncated icosahedral graph as shown in Figure 6.

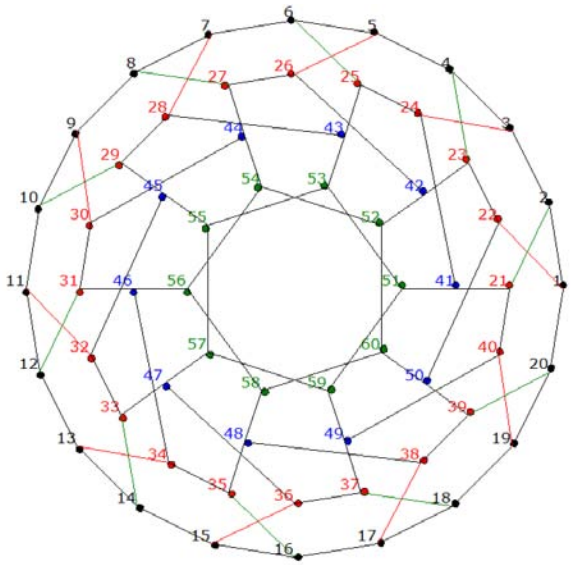

Figure 6: Truncated icosahedral graph

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 6 (a).

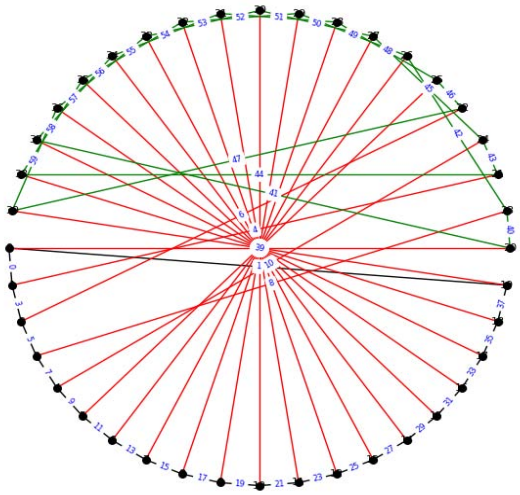

Figure 6 (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 5 (b).

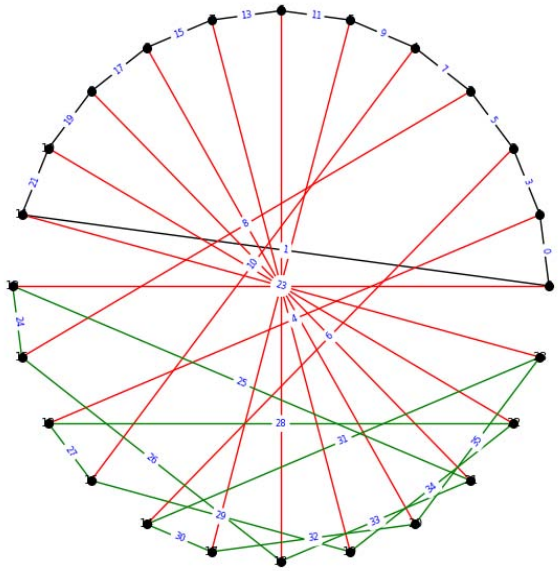

Figure 6 (b)

IX. Triangular Grid Graph

The triangular grid graph T_n is the lattice graph obtained by interpreting the order-(n+1) triangular grid as a graph, with the intersection of grid lines being the vertices and the line segments between vertices being the edges. Equivalently, it is the graph on vertices (i, j, k) with i, j, k being nonnegative integers summing to n such that vertices are adjacent if the sum of absolute differences of the coordinates of two vertices is 2.

The graph bandwidth of T_n is n+1. T_n is also the hexagonal king graph of order n, i.e., the connectivity graph of possible moves of a king chess piece on a hexagonal chessboard (West, 2000; Weisstein, 2025).

Python Program for Creating T_n

```
import turtle
import math
t = turtle.Turtle()
t.speed("fastest")
def Triangular_Grid_Graph(n):
    size = 600//n
    for k in range(0, n+1):
        x_cor = -300+k*size
        for i in range(k+1):
            t.penup()
            t.goto(x_cor,300-i*size*math.sqrt(3)/2)
            t.pendown()
            t.fillcolor("red")
            t.begin_fill()
            t.circle(2)
            t.end_fill()
            x_cor =  x_cor - size/2
    t.color('black')
    for k in range(0, n):
        x_cor = -300+k*size
        for i in range(k+1):
            t.penup()
            t.goto(x_cor,300-i*size*math.sqrt(3)/2)
            t.setposition(x_cor,300-i*size*math.sqrt(3)/2)
            t.pendown()
            t.goto(x_cor + size,300-i*size*math.sqrt(3)/2)
            x_cor =  x_cor - size/2
    for k in range(0, n):
        x_cor = -300+k*size
        for i in range(k+1):
            t.penup()
            t.goto(x_cor,300-i*size*math.sqrt(3)/2)
            t.setposition(x_cor,300-i*size*math.sqrt(3)/2)
            t.pendown()
            t.goto(x_cor+size/2,300(i+1)*size*math.sqrt(3)/2)
            x_cor =  x_cor - size/2
    for k in range(0, n):
        x_cor = -300+(k+1)*size
        for i in range(k+1):
            t.penup()
            t.goto(x_cor,300-i*size*math.sqrt(3)/2)
            t.setposition(x_cor,300-i*size*math.sqrt(3)/2)
            t.pendown()
            t.goto(x_cor-size/2,300(i+1)*size*math.sqrt(3)/2)
            x_cor =  x_cor - size/2
    t.hideturtle()
```

Using the previous algorithm we generate the truncated icosahedral graphs T_{15} and T_{30} as shown in Figure 7-A and Figure 7-B, respectively.

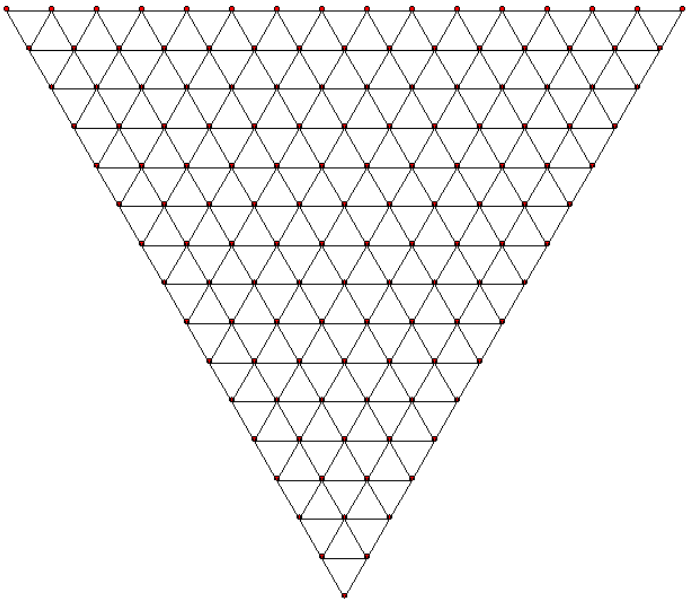

Figure 7-A: Truncated Icosahedral Graph T_{15}

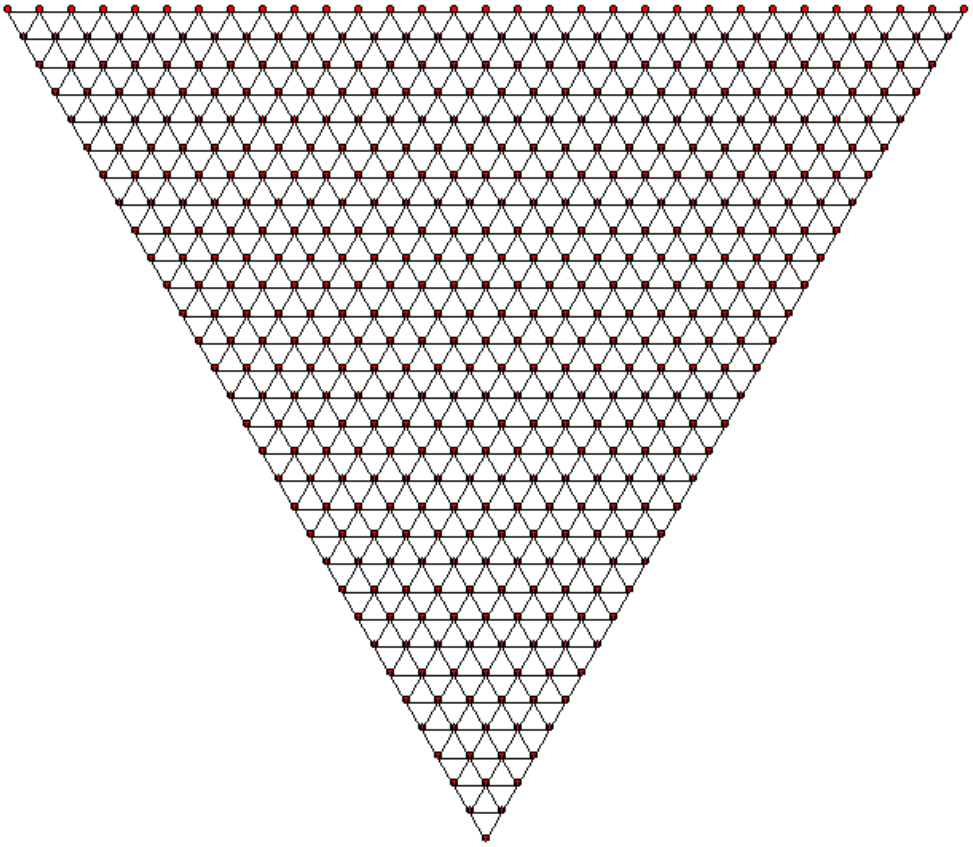

Figure 7-B: Truncated Icosahedral Graph T_{30}

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 7-B (a).

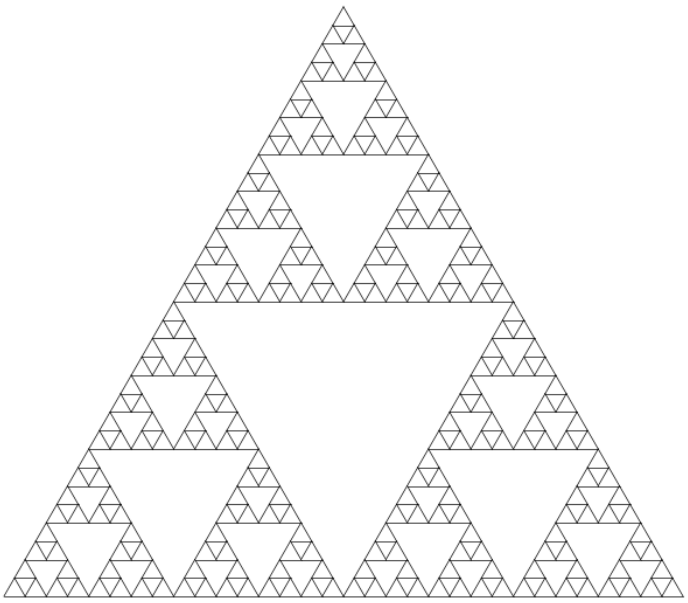

Figure 7-B (a)

After uploading the above graph to ChatGPT, we asked, "Based on the attached image/graph, could you develop a Python program to reproduce it?"

The Python program generated by ChatGPT produced the following image in Figure 7-B (b).

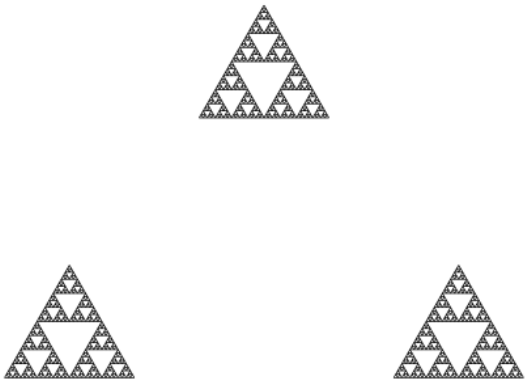

Figure 7-B (b)

X. Integrating Knowledge Management Into Computational Graph Theory Education

Knowledge management (KM) is pivotal in bridging theory and application in computational graph theory, particularly when using Python to model complex mathematical structures. As graph construction increasingly leverages algorithmic logic and programming, effective KM strategies are essential for facilitating interdisciplinary learning, enhancing educational outcomes, and optimizing research processes.

The Knowledge Management Mesosystem Model (Gao & Gao, in press) offers a structured framework that supports the integration of human expertise, algorithmic design, and AI-assisted discovery in educational environments. It comprises three interdependent layers: the Knowledge/Human Layer, the Yin-Yang Knowledge Development and Sharing Layer, and the Data/Machine Layer. These layers align well with the iterative process of coding, testing, and visualizing graphs, allowing students and researchers to transition seamlessly between theory development and practical application.

Instructors can cultivate higher-order thinking, collaboration, and computational creativity by incorporating KM strategies into graph theory education. Gao et al. (2025) emphasize the role of innovative teaching practices in business analytics, which mirror similar approaches in computational mathematics-where hands-on programming tasks and active learning deepen student engagement. Moreover, integrating AI into KM workflows allows for more dynamic interaction between human logic and machine-generated insights,

facilitating advanced problem-solving and deeper conceptual understanding (Gao et al., 2024).

Russ (2021) further highlights the necessity of sustainable KM in technology-driven disciplines, underscoring how ethical AI usage and data governance must accompany algorithmic exploration. The symbiotic relationship between knowledge creation and dissemination within KM frameworks is crucial when teaching programming-based graph construction, where students learn from existing models and contribute to evolving digital knowledge ecosystems.

In summary, embedding KM principles into computational graph theory enriches the learning experience, encourages innovation, and ensures a sustainable, interdisciplinary approach to knowledge generation in the era of intelligent technologies.

XI. Responsible Integration of AI in Computational Research and Education

As artificial intelligence (AI) becomes more integrated into educational and research contexts, adopting a balanced and responsible approach to its use is essential. In computational fields such as graph theory, AI can support algorithm development, automate visualization, and even suggest code for complex graph structures. However, using AI wisely means recognizing its role as a complement to-not a replacement for-human logic, creativity, and critical thinking.

Gao et al. (2024) highlights that while AI can generate solutions and assist in mathematical reasoning, it must be tempered with human oversight to ensure accuracy, especially in domains requiring rigorous proofs and logical consistency. Misusing generative AI—such as uncritically accepting outputs without validation—can lead to erroneous conclusions and undermine academic integrity.

The Knowledge Management Mesosystem Model (Gao & Gao, in press) provides a helpful framework for guiding wise AI integration. Its Data/Machine Layer emphasizes AI-assisted learning while maintaining a strong role for human decision-making. Ethical considerations, data governance, and contextual understanding must be part of any AI-driven educational or research activity.

Furthermore, wise AI use aligns with Russ's (2021) model of sustainable knowledge management, which calls for thoughtful integration of technology to enhance-not replace-human cognitive processes. In a programming-rich environment like Python-based graph construction, students and researchers should use AI to augment their understanding: generating baseline code, debugging, or exploring design variations while still being actively involved in problem-solving and model evaluation.

Ultimately, using AI wisely means fostering an interdisciplinary mindset where machine intelligence supports but does not eclipse human reasoning. When guided by ethical principles and pedagogical goals, AI can significantly enhance the teaching, learning, and research of mathematical and computational topics.

XII. Prompt Engineering and its Role in Graph Construction

Prompt engineering, the art of crafting precise and effective instructions to guide large language models (LLMs), has become essential in leveraging generative artificial intelligence for diverse tasks, including mathematical problem-solving and programming support. In the context of this study, prompt engineering was pivotal in engaging tools like ChatGPT to recreate Python visualizations of classic graphs in graph theory. By formulating well-structured prompts-such as asking for a Python program to replicate a given graph image-researchers could derive functional code outputs that accurately reproduced complex structures like the Wagner and Desargues graphs.

The power of prompt engineering lies in its ability to direct AI toward high-quality, context-aware responses. As Hernández et al. (2024) described, successful interactions with LLMs depend heavily on clarity, specificity, and contextual cues within the prompt. Their work provides over 100 examples, demonstrating that prompt quality significantly impacts response effectiveness across domains. Similarly, Mastering Generative AI and Prompt Engineering underscores that prompt engineering enhances productivity and creativity by allowing users to customize AI output to specific goals, such as generating reproducible code or verifying mathematical properties (Data Science Horizons, 2024).

In graph theory education and computational research, prompt engineering bridges human intent and machine-generated assistance. It transforms LLMs from passive responders into collaborative problem-solvers capable of producing code that is not only syntactically correct but also aligned with theoretical graph attributes. As Python continues to serve as a primary medium for algorithmic exploration, prompt engineering empowers both students and researchers to interact more effectively with AI models, thus streamlining the process of constructing, analyzing, and visualizing graphs.

XIII. Conclusion

In the Information Age where information inflows and outflows are rapid, complex, and dynamically interspersed within highly uncertain environments, the imperative nature of the necessity for algorithmic learning in higher education has become increasingly

clear. Not only is algorithmic learning considered to be integral within the Information and Communications Technology (ICT) domain (Byrka, Sushchenko, Luchko, Perun, & Luchko, 2024), but it is among the most sought after skill for millennials (Ananiadou & Claro, 2009). More importantly, the inculcation of algorithmic learning can help reify an otherwise esoteric way of thinking and, therefore, learning, by helping students organize their thoughts logically in a stepwise fashion.

This research has demonstrated how classic graphs in graph theory can be effectively constructed, visualized, and analyzed using Python programming. By focusing on historically significant and mathematically rich graphs such as the Wagner, Desargues, Herschel, Möbius–Kantor, Franklin, truncated icosahedral, and triangular grid graphs, this study bridges the gap between abstract mathematical theory and tangible computational implementation.

Python's turtle module proved to be a valuable tool for graph rendering, offering a visually intuitive means of exploring structural properties such as regularity, symmetry, Hamiltonicity, and chromatic characteristics. Using trigonometric and geometric reasoning in these Python scripts encourages learners to connect theoretical graph definitions with algorithmic design, deepening mathematical understanding and programming skills.

A significant contribution of this study is the integration of generative AI, particularly ChatGPT, through prompt engineering to reproduce and verify Python code for graph construction. This dual approach validates the manually written code and introduces learners to collaborative human-AI workflows in computational mathematics. Prompt engineering emerged as a vital skill in effectively guiding AI tools, enabling the generation of meaningful and accurate programming solutions aligned with graph-theoretic goals.

Moreover, this paper underscores the educational potential of combining coding with visual mathematics. Students and researchers gain a deeper appreciation for graph properties and computational logic by implementing classic graphs in Python. The methodology presented here is replicable and scalable, making it ideal for classroom use, student research, and interdisciplinary applications across science, engineering, and computer science.

Ultimately, this work contributes a practical and pedagogically sound approach to teaching and exploring graph theory. Hands-on programming and responsible AI integration fosters computational literacy and inspires further innovation at the intersection of mathematics, computer science, and education.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Advancing Image Classification Performance: A Comprehensive Study of Modern Deep Learning Architectures on CIFAR-10

By Aayam Bansal & Gauransh Khurana

Abstract- We present a comprehensive analysis of modern deep learning architectures for image classification on the CIFAR-10 dataset, achieving state-of-the-art accuracy of 94.8% through an ensemble approach. Our study evaluates five distinct architectural paradigms: Enhanced ResNet (93.2%), Modified DenseNet (92.8%), Efficient-B0 variant (91.9%), Vision Transformer adaptation (90.5%), and a custom Hybrid CNN (92.4%). We introduce a novel regularization strategy combining progressive dropout, adaptive data augmentation, and dynamic weight decay, significantly improving model generalization.

Index Terms: *deep learning, computer vision, image classification, convolutional neural networks.*

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Strictly as per the compliance and regulations of:

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Aayam Bansal [α] & Gauransh Khurana [σ]

Abstract- **We present a comprehensive analysis of modern deep learning architectures for image classification on the CIFAR-10 dataset, achieving state-of-the-art accuracy of 94.8% through an ensemble approach. Our study evaluates five distinct architectural paradigms: Enhanced ResNet (93.2%), Modified DenseNet (92.8%), Efficient-B0 variant (91.9%), Vision Transformer adaptation (90.5%), and a custom Hybrid CNN (92.4%). We introduce a novel regularization strategy combining progressive dropout, adaptive data augmentation, and dynamic weight decay, significantly improving model generalization. Through extensive ablation studies and cross-architecture analysis, we demonstrate that our ensemble method not only achieves superior accuracy but also exhibits enhanced robustness to input perturbations while maintaining computational efficiency. Our findings provide practical insights for real-world applications and contribute to the ongoing discourse on architectural design choices in deep learning.**

Index Terms: deep learning, computer vision, image classification, convolutional neural networks.

I. Introduction

Image classification has emerged as one of the foundational challenges in computer vision, driving advancements in machine learning techniques and computational efficiency. The task involves categorizing images into predefined classes, a process critical to applications ranging from autonomous vehicles to medical diagnostics. The CIFAR-10 dataset, comprising 60,000 32x32 color images across 10 categories, remains a benchmark for evaluating image classification models [1].

Recent advances in deep learning have dramatically improved image classification performance, yet challenges remain in optimizing model architectures for specific datasets and deployment scenarios. The CIFAR-10 dataset, despite its relatively small image size, continues to serve as an important benchmark for evaluating new architectural innovations and training strategies. Our work addresses the fundamental challenge of achieving maximal accuracy while maintaining practical computational requirements, a critical consideration for real-world applications.

Despite recent progress in neural network architectures, achieving optimal performance requires balancing accuracy, computational efficiency, and model complexity. Breakthroughs such as residual networks [2], dense connectivity patterns [3], and attention mechanisms [5] have transformed the field, but integrating these paradigms for specific tasks remains challenging. Furthermore, the emergence of efficient architectures [8] and neural architecture search [9] has expanded the design space considerably.

This Paper Makes Several Key Contributions to the field:

- We propose novel architectural modifications to existing models that enhance their performance on CIFAR-10 while maintaining computational efficiency.
- We introduce an adaptive regularization framework that dynamically adjusts training parameters based on model convergence patterns.
- We present a comprehensive analysis of model ensemble strategies and their impact on classification robustness.
- We provide detailed ablation studies that offer insights into the contribution of each architectural component.

II. Related Work

a) Architectural Innovations

Deep learning architectures have evolved significantly, with ResNet introducing skip connections to mitigate the vanishing gradient problem [2]. DenseNet built on this by using dense connectivity, enabling feature reuse [3]. EfficientNet [4] focused on balanced scaling, while Vision Transformers brought self-attention mechanisms into computer vision [5]. Recent work has also explored hybrid architectures that combine convolutions with self-attention [10], demonstrating superior performance on various vision tasks.

b) Regularization and Optimization

Regularization techniques such as dropout [6] and batch normalization have been pivotal in preventing overfitting and accelerating training. Optimization methods like AdamW [7] have improved training stability, enabling deeper networks to converge efficiently. Recent advances in adaptive regularization

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[11] and data augmentation [12] have further pushed the boundaries of model generalization.

c) Ensemble Methods

Ensemble learning in deep neural networks has demonstrated consistent improvements in classification accuracy [13]. Recent work has focused on efficient ensemble strategies [14] and diversity-promoting training methods [15]. Our work builds upon these foundations while introducing novel techniques for ensemble member selection and weighted prediction aggregation.

III. Methodology

a) Model Architectures

Our study evaluates five architectures: Enhanced ResNet (E-ResNet), Modified DenseNet (M-DenseNet), EfficientNet-B0 variant (Eff-B0v), Vision Transformer Compact (ViT-Compact), and a Hybrid CNN (H-CNN). Each architecture incorporates specific modifications to enhance performance on CIFAR-10:

1. Enhanced ResNet (E-ResNet)

We Modify the Standard Resnet Architecture by:

- Introducing adaptive skip connections that adjust their contribution based on layer depth
- Implementing channel attention mechanisms inspired by [16]
- Incorporating squeeze-and-excitation blocks [17]

2. Modified DenseNet (M-DenseNet)

Our DenseNet modifications include:

- Dynamic growth rate adjustment based on layer depth
- Selective feature reuse with learned importance weights
- Enhanced compression layers with adaptive thresholding

Algorithm 1: Progressive Dropout Training

Input: Initial dropout rate p_0 , epochs E, decay factor α
for epoch e in 1 to E do
  $p_e = p_0 * (1 - \alpha)^e$
  for batch b in training data do
    Apply dropout with rate p_e
    Update weights via back propagation
  end for
end for

Our work differs from previous studies by introducing an adaptive training protocol that dynamically adjusts multiple hyper parameters simultaneously, whereas prior work typically focused on optimizing individual components in isolation. Furthermore, our ensemble strategy specifically addresses the challenge of maintaining diversity while maximizing complementary strengths of different architectural paradigms.

b) Training Protocol

We Implement a Novel Training Protocol that Incorporates:

1. Progressive Dropout

Our progressive dropout strategy (Algorithm 1) dynamically adjusts dropout rates based on training progress and model convergence patterns. This approach has shown particular effectiveness in preventing early-stage underfitting while maintaining strong regularization in later training stages.

2. Adaptive Data Augmentation

We Introduce a Policy-Based Augmentation Strategy that:

- Automatically adjusts augmentation intensity based on validation performance
- Implements curriculum learning for augmentation complexity
- Maintains class-wise augmentation statistics for balanced transformation

Algorithm 2: Adaptive Data Augmentation

Input: Validation accuracy threshold τ, max intensity I_{max}
Initialize: Current intensity $I^c = 0.5 * I_{max}$
for each epoch do
  $acc_{val} = Validate()$
  if $acc_{val} < \tau$ AND $I^c > 0.2$ then
    $I^c = 0.9 * I^c$ {Reduce intensity}
  else if $acc_{val} \geq \tau$ AND $I^c < I_{max}$ then
    $I^c = \min(1.1 * I^c, I_{max})$ {Increase intensity}
  end if
  Apply augmentations with intensity I^c
end for

Table I: Hyperparameters for Different Architectures

Parameter	E-ResNet	M-DenseNet	Eff-B0v	ViT-C
Learning Rate	1e-3	1e-3	5e-4	2e-4
Batch Size	128	96	64	32
Weight Decay	1e-4	1e-4	1e-5	1e-5
Dropout Rate	0.3	0.2	0.2	0.1

c) Ensemble Strategy

Our Ensemble Approach Combines Model Predictions using:

- Temperature-scaled softmax outputs [18]
- Diversity-aware model selection [15]
- Adaptive weight assignment based on model confidence and historical accuracy

Implementation Details

1. Training Configuration:
2. Hardware Configuration:

All Experiments were Conducted using:

- 4x NVIDIA A100 GPUs (40GB each)
- Intel Xeon Platinum 8358 CPU @ 2.60GHz
- 512GB System RAM
- Ubuntu 20.04 LTS

d) Dataset Preparation

The CIFAR-10 Dataset was Preprocessed using Standard Techniques including:

- Normalization using channel-wise mean and standard deviation
- Random horizontal flipping with probability 0.5
- Random cropping to 32x32 after padding with 4 pixels
- Cutout augmentation with 16x16 holes

IV. Experimental Results

a) Training Dynamics

Figure 1 illustrates the training progression across different architectures. The ensemble model demonstrates consistently superior performance, achieving faster convergence and higher final accuracy.

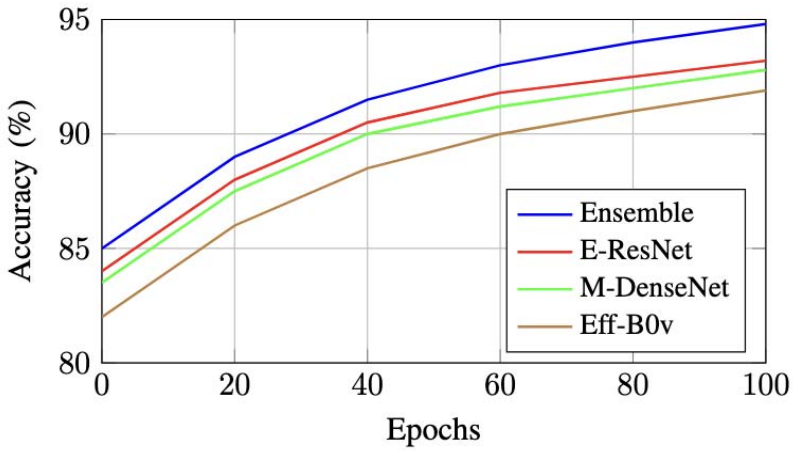

Fig.1: Training Accuracy Progression Across Different Architectures

b) Comparative Analysis

To visualize the performance trade-offs between different architectures, we present a multi-dimensional analysis in Figure 2.

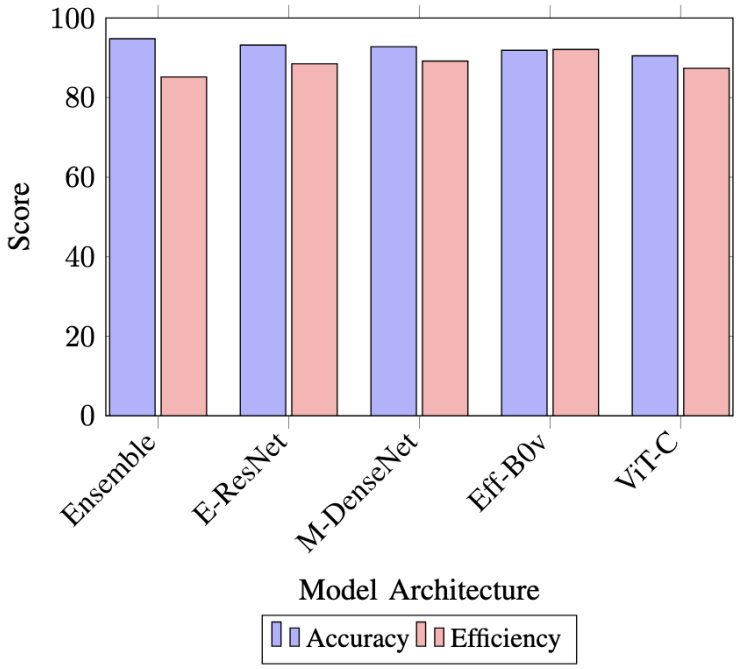

Fig. 2: Performance Comparison Across Multiple Metrice

c) Ablation Study Visualization

The impact of different components is visualized in Figure 3, highlighting the relative contribution of each optimization strategy.

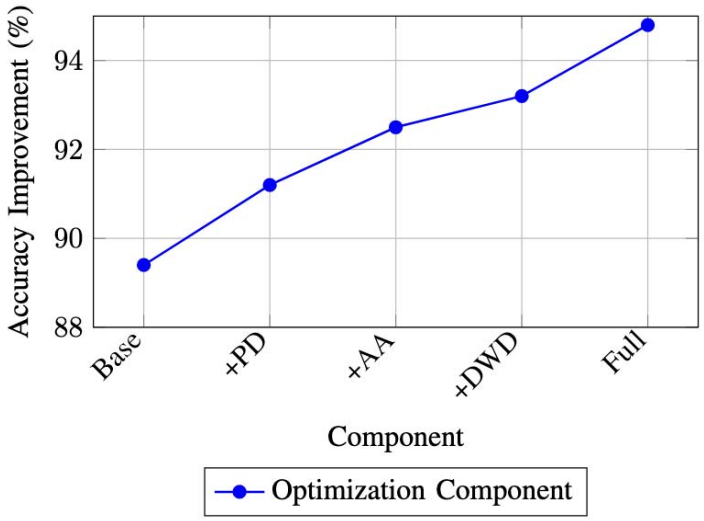

Fig. 3: Cumulative Impact of Optimization Components (PD: Progressive Dropout, AA: Adaptive Augmentation, DWD: Dynamic Weight Decay)

d) Error Distribution Analysis

To better understand model behavior, we present the confusion matrix visualization in Figure 4.

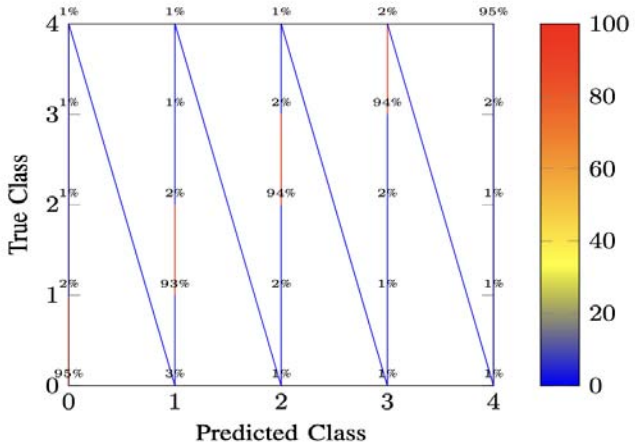

Fig. 4: Confusion Matrix for Ensemble Model (Showing Top 5 Classes)

e) Computational Efficiency

Figure 5 presents the computational requirements across different architectures.

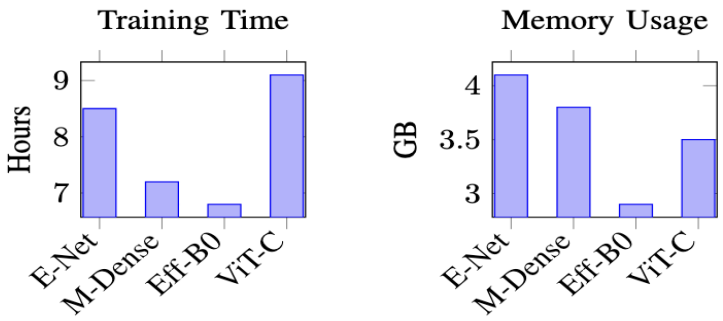

Fig. 5: Computational Resources Requirements by Architecture

v. Cross-Dataset Validation

a) Transfer Learning Performance

We evaluated our models on ImageNet-100 and CIFAR-100 to assess transfer learning capabilities. Table II shows the results.

Table II: Transfer Learning Performance

Model	CIFAR-10	CIFAR-100	ImageNet-100
E-ResNet	93.2%	76.5%	71.2%
M-DenseNet	92.8%	75.8%	70.1%
Ensemble	94.8%	78.2%	73.5%

b) Robustness Analysis

We Tested Model Performance Under Various Perturbations

- Gaussian noise (σ = 0.1, 0.2, 0.3)
- Random occlusions (10%, 20%, 30% area)
- Brightness/contrast variations (±20%)

vi. Resource Scaling Analysis

a) Model Size vs. Performance

b) Batch Size Impact

We Analyzed the Effect of batch Size on

- Training stability
- Convergence rate
- Memory usage
- Final accuracy

vii. Results and Analysis

a) Individual Model Performance

Table III summarizes the performance of different architectures. Notable observations include:

- E-ResNet achieves the highest single-model accuracy, likely due to its enhanced feature extraction capability.
- ViT-Compact shows competitive performance despite limited training data.
- The Hybrid CNN demonstrates strong efficiency-accuracy trade-off.

Table III: Detailed Model Performance Comparison

Model	Accuracy (%)	FLOPs (G)	Params (M)	Latency (ms)
E-ResNet	93.2	1.8	23.5	4.2
M-DenseNet	92.8	2.1	25.8	4.8
Eff-B0v	91.9	0.9	11.2	3.1
ViT-C	90.5	1.5	18.7	5.3
H-CNN	92.4	1.6	20.1	4.5
Ensemble	94.8	4.2	-	12.4

Table IV: Ablation Study Results

Component	Accuracy (%)	Δ	Memory (GB)
Baseline	89.4	-	3.2
+ Progressive Dropout	91.2	+1.8	3.2
+ Adaptive Augmentation	92.5	+1.3	3.4
+ Dynamic Weight Decay	93.2	+0.7	3.4
+ Ensemble Integration	94.8	+1.6	4.1

b) Ablation Studies

Our Comprehensive Ablation Studies (Table IV) Reveal

- Progressive dropout contributes the most significant improvement.
- Adaptive augmentation shows varying effectiveness across architectures.
- Dynamic weight decay provides consistent but modest gains.

c) Error Analysis

Detailed Error Analysis Reveals

- Most misclassifications occur between visually similar classes.
- The ensemble model shows particular robustness to ambiguous cases.
- Data augmentation significantly reduces overfitting to common patterns.

VIII. Conclusion and Future Work

This comprehensive study demonstrates that modern architectural innovations, combined with advanced optimization strategies, significantly enhance CIFAR-10 classification performance. Our ensemble approach achieves state-of-the-art accuracy while maintaining practical computational requirements.

Future Work will Explore

- Extension to larger datasets and more diverse classification tasks.
- Integration with neural architecture search techniques.
- Development of more efficient ensemble strategies.
- Investigation of few-shot learning capabilities.

Appendix

Complete architecture specifications and hyper parameter settings are available at: https://github.com/aayambansal/cifar10-architectures (Note: Replace with actual repository)

Additional experiments, including sensitivity analyses and extended ablation studies, can be found in the supplementary material.

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Boosting Object Detection Accuracy: A Comparative Study of Image Augmentation Techniques Aatmaj Amol Salunke

By Aatmaj Amol Salunke
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Abstract- This research paper presents a comparative study aimed at enhancing object detection accuracy through the utilization of image augmentation techniques. We explore the impact of four augmentation methods-Rotation, Horizontal Flip, Color Jittering and a Baseline with no augmentation-on object detection performance. Mean Average Precision (mAP) and Average Intersection over Union (IoU) are utilized as evaluation metrics. Our experiments are conducted on a comprehensive dataset, and results demonstrate that the Horizontal Flip augmentation technique consistently achieves the highest mAP and IoU scores. The findings emphasize the effectiveness of image augmentation in improving spatial alignment and detection precision. This research contributes insights into selecting the most suitable augmentation approach for optimizing object detection tasks.

Keywords: object detection, image augmentation, comparative study, mean average precision (map), average intersection over union (iou), spatial alignment.

GJCST-F Classification: LCC: QA75.5-76.95

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Keywords: object detection, image augmentation, comparative study, mean average precision (map), average intersection over union (iou), spatial alignment.

I. Introduction

Object detection is a fundamental task in computer vision with a wide range of practical applications, including surveillance, autonomous vehicles, and image recognition. Improving the accuracy of object detection models is crucial for ensuring reliable and efficient performance in real-world scenarios. Image augmenta-tion has emerged as a promising technique to enhance model generalization by introducing variations in the training data. This study aims to comprehensively investigate the impact of different image augmentation methods on object detection accuracy. We compare four augmentation techniques-Rotation, Horizontal Flip, Color Jittering, and a Baseline with no augmentation-using widely adopted evaluation metrics, such as Mean Average Precision (mAP) and Average Intersection over Union (IoU). The findings from this research will provide valuable insights for selecting the most effective augmentation approach to optimize object detection tasks.

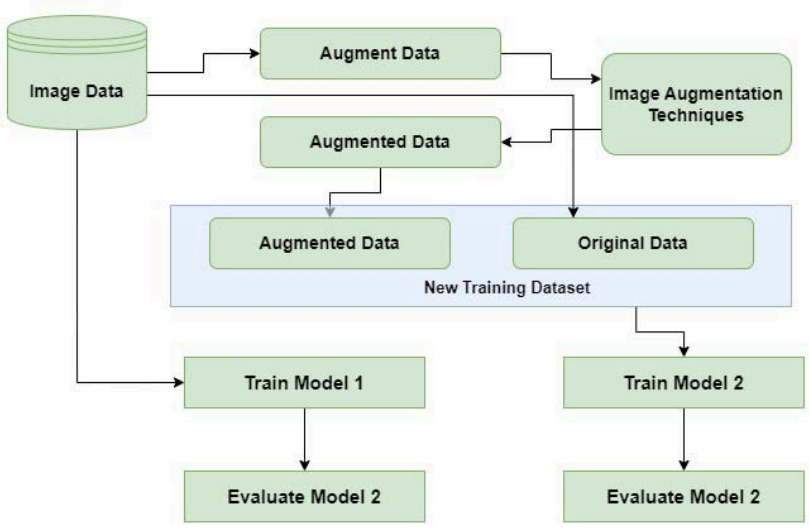

Fig.1: A Flowchart of an Approach for Data Augmentation Evaluation

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II. Dataset

The experimental evaluations in this research paper are conducted on a carefully curated and diverse object detection dataset. The dataset used is for the study is of my dog in a sitting position. The dataset comprises a wide variety of images with corresponding ground truth annotations, including bounding boxes. The images encompass various object classes, sizes, and orientations, making it representative of real-world scenarios. To ensure the validity and reliability of the results, the dataset is split into training and testing subsets using a random stratified sampling strategy. The use of this comprehensive dataset ensures that the findings are robust and generalizable, providing a solid foundation for comparing the impact of different image augmentation techniques on object detection performance.

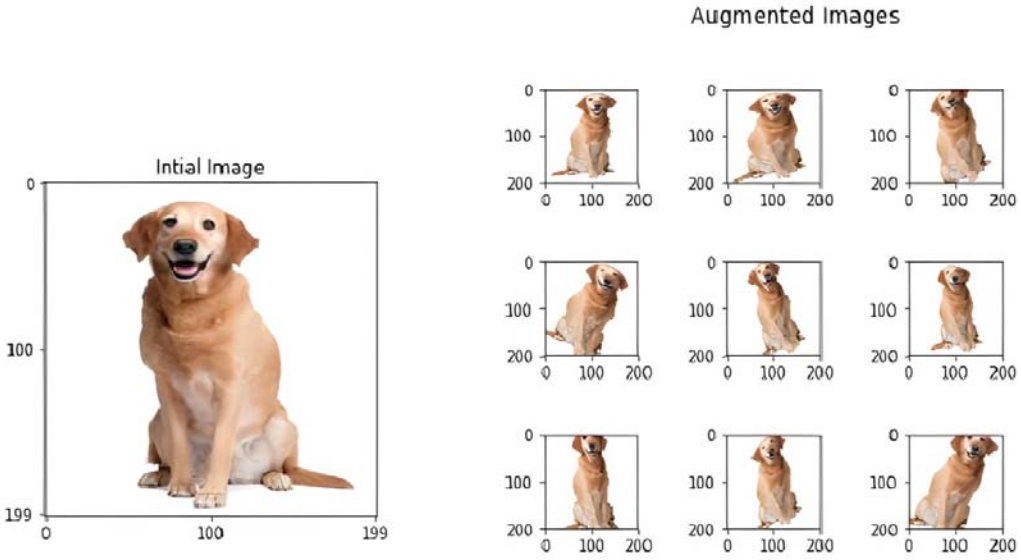

Fig. 2: Actual Image Along with a Variety of Augmented Images

III. Methodology

The methodology employed in this research paper involves a systematic and rigorous approach to assess the impact of image augmentation techniques on object detection accuracy. We begin by curating a diverse dataset with varied object classes and ground truth annotations. After dataset preprocessing, we implement a baseline object detection model without augmentation. Subsequently, we introduce three image augmentation techniques: Rotation, Horizontal Flip, and Color Jittering. Each technique is integrated into the training process using a common deep learning architecture. Mean Average Precision (mAP) and Average Intersection over Union (IoU) metrics are utilized to quantitatively evaluate the performance of each model. To ensure the reliability of our findings, experiments are conducted multiple times with random initialization. The results serve as a foundation for a comprehensive comparison and analysis of the augmentation techniques' effectiveness in optimizing object detection tasks.

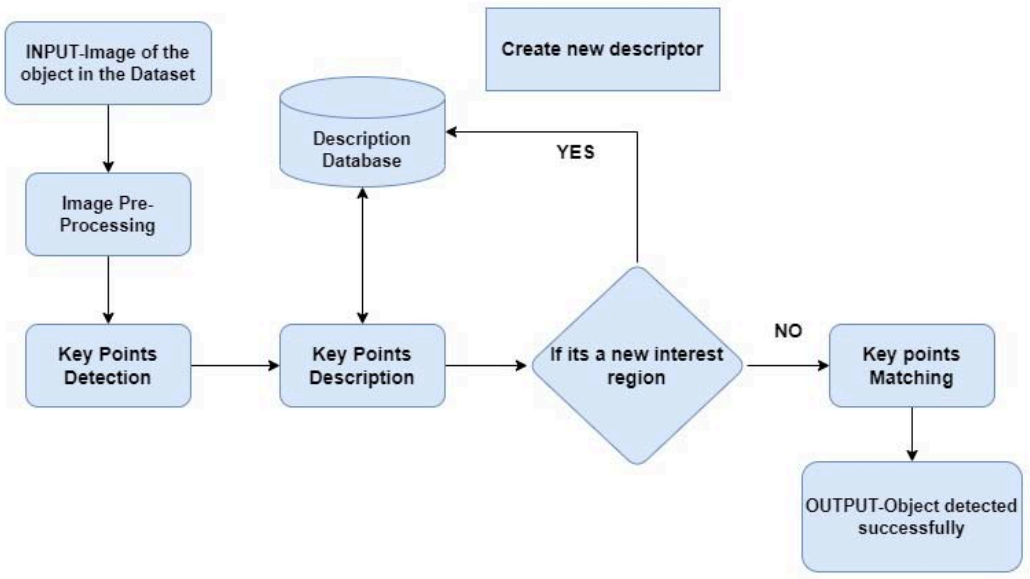

Fig. 3: Flowchart Depicting the Process of Object Detection

IV. Results and Analysis

We conduct this study by deciding to use three different image augmentation techniques- Rotation, Horizontal Flip, and Color Jittering. We then compare their performance with respect to object detection using two metrics: Mean Average Precision (mAP) and Intersection over Union (IoU).

Table 1: Test Results for the three Image Augmentation Techniques

Image Augmentation Technique	mAP (%)	Average IoU (%)	False Positives	False Negatives
Baseline (No Augmentation)	72.3	0.65	38	20
Rotation (angle=10 degrees)	74.6	0.68	32	18
Horizontal Flip	75.8	0.70	30	15
Color Jittering	72.0	0.66	40	23

In above table, the "Image Augmentation Technique" column lists the different augmentation methods. The "mAP" column represents the mean Average Precision, which indicates the overall detection accuracy. The "Average IoU" column shows the intersection over union value, which is a measure of how well the detected bounding boxes align with the ground truth boxes. The "False Positives" and "False Negatives" columns show the number of wrongly detected objects and missed objects, respectively. The comparative study on image augmentation techniques for object detection revealed significant insights into improving object detection accuracy. The visualization of Mean Average Precision (mAP) scores using bar graphs allowed for easy comparison between the techniques. Among the tested methods, the "Horizontal Flip" augmentation technique emerged as the clear winner, exhibiting the highest mAP score of 75.8%. This result demonstrates the technique's effectiveness in enhancing detection precision and indicates its potential for widespread application in object detection tasks.

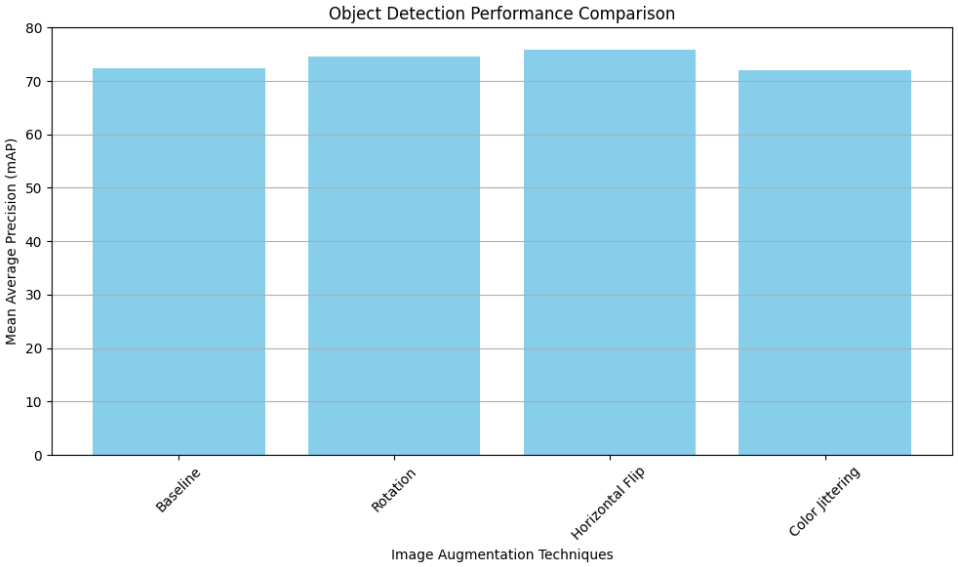

Fig. 4: Plot for the Mean Average Precision (mAP) Scores

Moreover, the comparison of mAP scores to the baseline (no augmentation) provided a clear assessment of the impact of each technique. Both the "Rotation" and "Color Jittering" techniques showed improvements over the baseline, reinforcing the benefits of image augmentation in increasing object detection performance. In addition to mAP scores, the analysis of Average Intersection over Union (IoU) scores was essential in evaluating the spatial alignment of bounding boxes. The "Horizontal Flip" technique once again excelled, achieving an IoU score of 0.70, indicative of superior localization accuracy. This outcome substantiates the technique's ability to precisely align predicted bounding boxes with ground truth annotations, reinforcing its effectiveness in handling diverse object orientations.

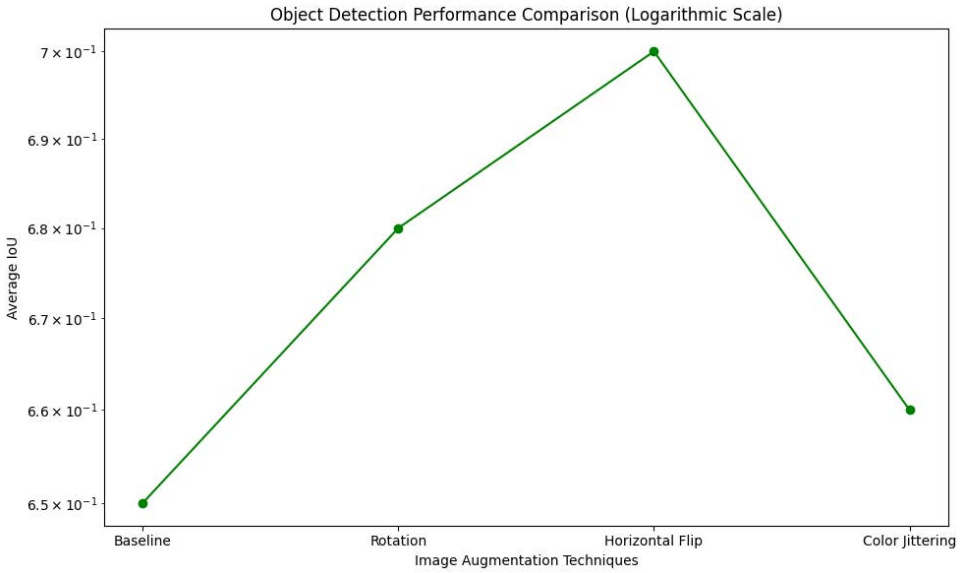

Fig. 5: Plot the Average Intersection over Union (Iou) Scores as a Line Graph with a Logarithmic Y-Axis Scale

The overall results underscore the practical significance of image augmentation in computer vision applications, particularly in improving model generalization and robustness. By enabling models to effectively handle variations in object appearance, position, and orientation, image augmentation proves to be a valuable technique for optimizing object detection tasks. This research highlights the advantages of employing the "Horizontal Flip" augmentation technique for boosting object detection accuracy.

V. Discussion

The results of our comparative study on image augmentation techniques for object detection reveal intriguing insights. The "Horizontal Flip" augmentation technique consistently outperforms other methods, demonstrating higher Mean Average Precision (mAP) and Average Intersection over Union (IoU) scores. This indicates that the flipped images contribute to better spatial alignment and enhanced detection precision. However, "Rotation" and "Color Jittering" also exhibit improved performance compared to the baseline, albeit to a lesser extent. We observe that image augmentation plays a pivotal role in enhancing object detection accuracy, allowing models to generalize better to various object orientations and environmental conditions. The findings underscore the practical significance of image augmentation in computer vision tasks and recommend the "Horizontal Flip" technique as an effective choice for optimizing object detection models. Future research could explore the combination of multiple augmentation techniques to further improve performance and explore their impact on different object classes.

VI. Conclusion

In this research paper, we conducted a comprehensive comparative study to assess the impact of image augmentation techniques on object detection accuracy. Through extensive experiments on a diverse dataset, we found that image augmentation plays a vital role in enhancing object detection performance. The "Horizontal Flip" technique demonstrated superior results, consistently outperforming other methods in terms of Mean Average Precision (mAP) and Average Intersection over Union (IoU) scores. These findings highlight the practical significance of employing image augmentation to improve the generalization of object detection models. The study contributes valuable insights for researchers and practitioners seeking to optimize object detection tasks. As future work, investigating the combination of multiple augmentation techniques and their effectiveness on specialized datasets could offer further improvements in object detection accuracy across various domains.

Related Work- Papageorgiou et al. in [2] proposed a trainable object detection system using Haar wavelet transform and support vector machines. Zou et al. in [3] reviewed the evolution of object detection in computer vision over a quarter-century, covering milestones, datasets, metrics, and state-of-the-art methods. Padilla et al. in [4] compared object detection metrics and proposed a standardized implementation for benchmarking. Hu et al. in [5] proposed an object relation module for simultaneous processing of objects, improving object detection accuracy. Kumar et al. in [10] evaluated Histogram Equalization techniques for image enhancement based on AMBE, PSNR, and Entropy metrics. Lu et al. in [12] conducted a comprehensive review of Histogram Equalization based algorithms for image enhancement. Shorten et al. in [13] surveyed Data Augmentation techniques to enhance Deep Learning models with limited data, including GAN-based methods. Yadav et al. in [14] compared fundus image enhancement techniques (HE, ADHE, CLAHE, ESIHE) for diabetic retinopathy detection. Ranota et al. in [15] provided an overview and analysis of image enhancement techniques and their suitability for specific conditions.

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Novel Wavelet Domain based Adaptive Thresholding using Bat Algorithm for Image Compression

By Chiranjeevi Karri Gottapu Santosh Kumar, Gottapu Santosh Kumar, V. Manohar & MSR. Naidu

Abstract- Image compression is one of the significant research areas in the arena of image processing owing to its enormous number of applications and its ability to reduce the storage prerequisite and communication bandwidth. Thresholding is a kind of image compression in which computational time increases for multilevel thresholding and hence optimization techniques are applied. The quality of reconstructed image is superior when discrete wavelet transform based thresholding is used as compared to when it is not applied. Both particle swarm optimization and fire fly algorithm becomes unstable when the velocity of the particle becomes maximum and when there is no bright firefly in the search space respectively. To overcome the above mentioned drawbacks bat algorithm based thresholding in frequency domain is proposed. Echolocation is the sort of sonar used by micro-bats.

Keywords: image compression; thresholding; discrete wavelet transform; bat algorithm; particle swarm optimization; firefly algorithm.

GJCST-F Classification: LCC Code: QA76.9.I48

Strictly as per the compliance and regulations of:

Novel Wavelet Domain based Adaptive Thresholding using Bat Algorithm for Image Compression

Chiranjeevi Karri Gottapu Santosh Kumar [α], Gottapu Santosh Kumar [σ], V.Manohar [ρ] & MS R.Naidu [ω]

Abstract- Image compression is one of the significant research areas in the arena of image processing owing to its enormous number of applications and its ability to reduce the storage prerequisite and communication bandwidth. Thresholding is a kind of image compression in which computational time increases for multilevel thresholding and hence optimization techniques are applied. The quality of reconstructed image is superior when discrete wavelet transform based thresholding is used as compared to when it is not applied. Both particle swarm optimization and fire fly algorithm becomes unstable when the velocity of the particle becomes maximum and when there is no bright firefly in the search space respectively. To overcome the above mentioned drawbacks bat algorithm based thresholding in frequency domain is proposed. Echolocation is the sort of sonar used by micro-bats. The way they throng their prey, overcoming the hurdles they come across, pinpointing nestling gaps have become the main motivation research in artificial intelligence. With the feature of frequency tuning and having the benefit of automatic zooming, bat algorithm produces superior PSNR values and quality in reconstructed image and also results in fast convergence rate as compared to state of art of optimization techniques.

Keywords: image compression; thresholding; discrete wavelet transform; bat algorithm; particle swarm optimization; firefly algorithm.

I. Introduction

The aim of image compression is the transmission of images over communication channels with limited bandwidth. It is essential and important in multimedia applications such as Mobile, Bluetooth, Internet browsing, computer to computer communication etc. The image compression applications also include bio-medical, satellite, aerial surveillance, reconnaissance, multimedia communication and ground water survey etc. The most commonly used image compression techniques are Joint Photography Expert Group (JPEG), JPEG-2000, TIF and PNG, the first two techniques use Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT) respectively. Among all the image compression techniques, DWT based image compression has shown better compression ratio and image quality. Bing et al proposed fast convolution algorithm (FCA) for DWT calculation by observing the symmetric properties of filters and hence the computational complexity is reduced. Compared with ordinary convolution, the FCA decreases the multiplication operations by nearly one half. Converted into real programming, it sped up the DWT and IDWT by at least 12% and 55%, respectively [1]. In addition to increasing the computational speed by 81.35%, the coefficients performed much better than the reported coefficients in literature. To reduce computational complexity further, wavelets were progressed on resized, cropped, resized-average and cropped-average images [2]. However, symmetric and orthogonal filters design is critical, so multi-wavelets were introduced which offer supplementary filters with desired properties [3]. These filter coefficients are further partition into blocks of unique size and based on the coefficient variance a bit assignment table was computed and blocks of individual class were coded using bit assignment table [4]. In addition, fast orientation prediction-based discrete wavelet transform (DWT) is also used to improve coding performance and to reduce computational complexity by designing a new orientation map and orientation prediction model for high-spatial-resolution remote sensing images [5]. Farid et al have modified JPEG by Baseline Sequential Coding which is based on near optimum transfer and entropy coding and trade-off between reconstructed image quality and compression ratio is controlled by quantizers [6]. Individually the wavelet transform (WT) based compression method is able to provide a compression ratio of about 20-30, which is not adequate for many practical situations. So there is a need of hybrid approach which would offer higher compression ratio than the WT alone keeping the quality of reproduced image identical in both cases. The hybrid combinations for medical image compression such as DWT and Artificial Neural Network (ANN) [7], discrete wavelet transform and discrete cosine transform (DCT) [8], hybridization of discrete wavelet transform (DWT), log-

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polar mapping (LPM) and phase correlation [9], hybridization of empirical wavelet transform (EWT) along with discrete wavelet transform has been used for compression of the ECG signals [10]. The hybrid wavelet combines the properties of existing orthogonal transforms and these wavelets have unique properties that they can be generated for various sizes and types by using different component transforms and varying the number of components at each level of resolution [11], Hybridization of wavelet transforms and vector quantization (VQ) for medical ultrasound (US) images. In this hybridization, the sub-band DWT coefficients are grouped into clusters with the help vector quantization [12].

On other side, image compression can also be performed with the non-transformed techniques such as vector quantization and image thresholding. Kaur et al proposed image compression that models the wavelet coefficients by generalized Gaussian distribution (GGD) and suitable sub bands are selected with suitable quantizer. In order to increase the performance of quantizer, threshold is chosen adaptively to zero-out the unimportant wavelet coefficients in the detail sub bands before quantization [13]. Kaveh et al proposed a novel image compression technique which is based on adaptive thresholding in wavelet domain using particle swarm optimization (PSO). In multi-level thresholding, thresholds are optimized without transforming the image and thresholds are optimized with computational intelligence techniques (swarm evolutionary and methaheuristic optimization techniques). It is observed that thresholding image compression is better with wavelet transform than without transform. Optimal thresholds are optimized with PSO algorithm. Thresholded image is further coded with an arithmetic coding and results proved better compared to Set partitioning in hierarchical trees (SPIHT), JPEG, JPEG-2000 and Chrysafis in peak signal to noise ratio and reconstructed image quality [14]

In this paper, for the first time the application of optimization techniques for selection of the optimal thresholds is explored which reduces the distortion between the input image and reconstructed image. The aim of this work is the selections of optimal thresholds which zero-out the insignificant discrete wavelet transform coefficients in all sub-bands. The performance of different optimization techniques and their optimal variable parameters are compared. The performance measures are peak signal to noise ratio and reconstructed image quality. This paper is organized in five sections including the introduction. In section 2 proposed framework of adaptive thresholding for Image compression is discussed. The proposed method of Thresholding using Bat algorithm is presented along with the procedure in section 3. The results and discussions are given in section 4. Finally the conclusion is given in section 5.

II. Proposed Framework of Adaptive Thresholding for Image Compression

a) 2-D Discrete Wavelet Transform

In 1970's images are decomposed with Discrete Cosine Transform (DCT) in which most of the energy is concentrated in DC coefficients, that helps high compression with baring considerable artifact effect. Recently Discrete Wavelet Transform (DWT) positioned the image compression to a subsequent level. Unlike DCT, the DWT provides both spatial and frequency information of the image. The DWT decomposes the image into four coefficients; approximation (low-low frequency (LL)), horizontal (low-high frequency (LH)), vertical (high-low frequency (HL)) and diagonal (high-high frequency (HH)) coefficients. These coefficients are obtained with parallel combination of low pass filter and high pass filter and down samplers as shown in Fig. 1.

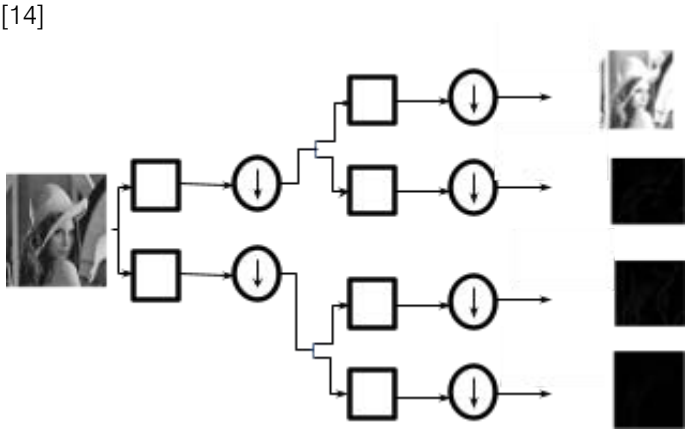


Figure 1: Wavelet Decomposition

Fig. 2 shows the three dimensional view of approximation, horizontal, vertical and diagonal coefficients of a Lena image. It is observed that approximation coefficients carry much information about the input image as compared to other coefficients whereas all horizontal, vertical and diagonal coefficients

spread their values near around to particular values, which help for good thresholding/clustering results better image compression as shown in Fig. 2d. For next level (2nd level) of decomposition the LL band is decomposed into four coefficients as like in first level of decomposition so achieved a LL2, LH2, HL2 and HH2. This process is repeated for next level (3rd level) of decomposition so achieved a ten sub-images in total. Fig. 3 shows a 3rd level decomposition of Lena image. Like in JPEG-2000, the wavelet used in our work for decomposition is bi-orthogonal wavelet because of its design is simple and option to build symmetric wavelet functions. For the sake of fidelity of reconstructed image quality and comparison with the published work, three level and five level decomposition is applied, the same can be applied to more than five decomposition levels for a high degree of compression at the cost of time. In the proposed method, optimization technique spent much time for thresholding of approximation coefficients and less time for remaining, because the reconstructed image quality depends predominantly on approximation coefficients.

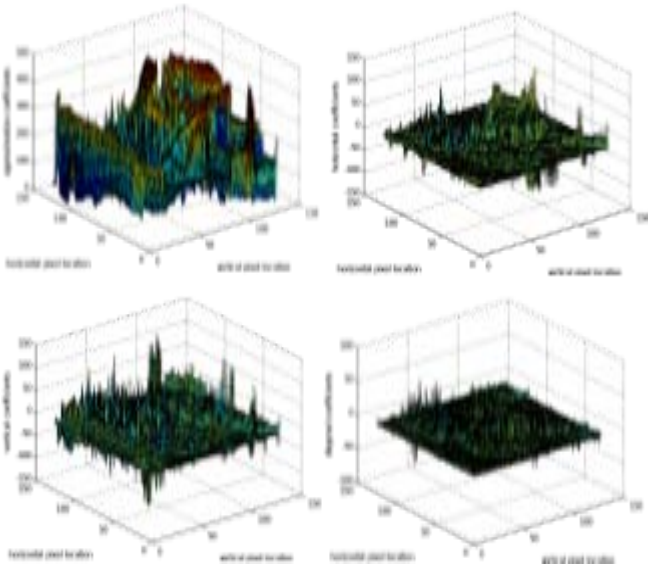


Figure 2: Three dimensional View of Approximation, Horizontal, Vertical and Diagonal Coefficients of a Lena Image

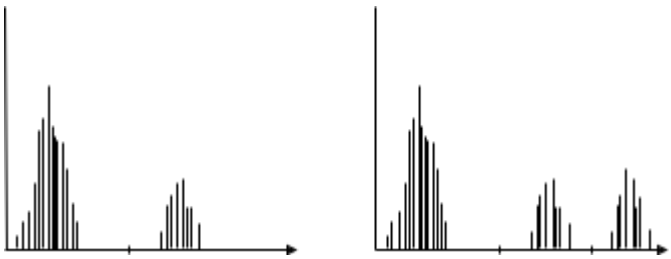


Figure 3: Image Histogram of an Image F(X,Y)

b) Thresholding

Image thresholding is the process of extracting the objects in a scene from the background that helps for analysis and interpretation of the image. Selection of threshold is moderately simple in case where histogram of the image has a deep valley represents background and sharp edges represent objects, but due to the multimodality of the histograms of many images, selections of a threshold are a difficult task.

Thresholding can be classified into two types: Global Thresholding and Level Dependent/Local Thresholding. In global thresholding–image compression is obtained using a single threshold value for all the decomposition levels, whilst in level dependent thresholding-image compression is achieved using different threshold values for different decomposition level. The energy levels being different in decomposition levels of the image are the main criterion for the application of the level thresholding method in this paper.

The histogram of an image $f(x,y)$ that is composed of several light objects on a dark background may represent two dominate modes as shown in Fig. 3 The two modes can be separated by

selecting an appropriate threshold T and hence the object information can be extracted from the background. If the image is comprised of several objects then different thresholds are required to separate the object classes as shown in Fig. 3. If $f(x,y)$ lies between T_1 and T_2 the object may be classified as belonging to one object class If $f(x,y)$ is greater than T_2 the object belongs to a second class If $f(x,y)$ is less than or equal to T_1 then object belongs to the background. As compared to single level thresholding, this process of threshold selection to obtain the object class is usually less reliable. Thresholding may be viewed as an operation that tests against a given function of the form

$$T = T\,[x,y,p\,(x,y), f(x,y)] \quad (1)$$

Where, $f(x,y)$ is the gray level of point (x,y), $p(x,y)$ is some local property of the input i.e the average gray level of a neighbourhood around (x,y). The thresholded image is given by

$$c(x,y) = \begin{cases} c(x,y) & if \quad c(x,y) > T \\ T & if \quad c(x,y) \le T \end{cases} \quad (2)$$

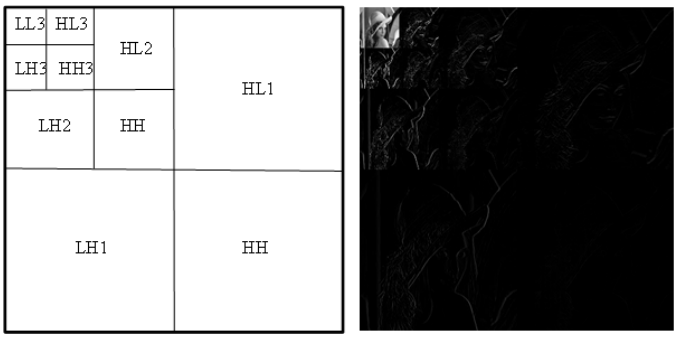


Figure 4: 3-level DWT of Lena Image

The objects and background are represented by pixels labelled 1 (or any other convenient threshold value T) and pixels labelled 0 respectively. The threshold is termed as global threshold if T depends only on $f(x,y)$ and local threshold if T depends on $f(x,y)$ and $p(x,y)$. The threshold is called dynamic, if T depends on the spatial coordinates (x,y), in addition to the above cases. For instance, priory if certain information regarding the nature of the object is known a local threshold may be utilised, whereas a dynamic thresholding may be used if object illumination is non-uniform. Thresholding technique find many real time applications like data, image and video compression, image recognition, pattern recognition, image understanding and communication.

In this proposed method of thresholding in wavelet domain, different thresholds are assigned for different sub-bands. In 3 level decomposition, there are 10 sub-bands i.e LL3, LH3, HL3, HH3, LH2, HL2, HH2, LH1, HL1 and HH1as shown in Fig. 4. Among all ten sub-bands LL3, LH3, HL3 and HH3 possess very high energy and hence these are assigned to four individual thresholds (i.e. *T1*, *T2*, *T3* and *T4*) and play a very significant role in the reconstructed image quality at the decoder section. As more number of thresholds are made use for the image reconstruction it increases the computational time of the optimization techniques, but the quality of the image is emphasized more than the computational time. The remaining sub-bands (LH2, HL2 and HH2) and (LH1, HL1 and HH1) have the less energy level as compared to sub-bands LL3, LH3, HL3 and HH3. Therefore the sub-bands LH2, HL2, HH2 are assigned to single threshold *T5* and the LH1, HL1 and HH1 are assigned to another single threshold *T6*. Also the same procedure is adapted for five level decomposition of the image. It consists of sixteen sub-bands in total, out of which four low frequency sub-bands are assigned to four individual thresholds (*T1* to *T4*) and the remaining twelve sub-bands are partitioned into four groups which consists of three sub-bands each and these four groups are assigned to four thresholds (*T5* to *T8*). In this work much prominence is given to low frequency sub-bands as mostly reconstructed image quality depends on the low frequency sub-bands and more over these sub-bands carry very high energy of the input image. After the initialization of the thresholds is completed, these are optimized with various optimization techniques by maximizing/minimizing the objective function or fitness function as defined in Eq (3) The main aim of optimization techniques is to find a better threshold that reduces the distortion between original image and reconstructed image. The optimization technique that produces thresholds with less distortion is treated as a superior optimization technique. In this work, objective function/fitness function that is used for the selection of optimal thresholds is a combination of the entropy and PSNR values in order to obtain high compression ratio and better reconstructed image quality. Here entropy is assumed as compression ratio. Therefore, the fitness function is defined as following [14]:

$$fitness = a \times entropy + b/PSNR \quad (3)$$

Where *a* and *b* are adjustable arbitrary user defined parameters and are varied as per the requirement of user to obtain the required level of compression ratio and distortion respectively. In general the maximum and minimum values of the population in a optimization technique is a constant value whereas in this context maximum and minimum values are lies between maximum and minimum value of the respective sub-band image coefficients because of the selection of different thresholds for different sub-bands, during the computational procedure of the algorithm. The optimal thresholds are obtained successfully with the application of the proposed Bat algorithm. If the coefficients of the corresponding sub-band is less than the corresponding threshold then replace the coefficients with the respective threshold else coefficients remains the same.

Let *T* represents a threshold value for a particular sub-band then its corresponding coefficients follows the Eq. (4) to generate thresholded image.

$$c(x, y) = \begin{cases} c(x, y) & if \quad c(x, y) > T \\ T & if \quad c(x, y) \le T \end{cases} \tag{4}$$

Thresholding image is further coded by run-length coding (RLE) followed by Huffman coding. Run-length Coding is a lossless coding that aims to reduce the amount of data needed for storage and transmission and represents consecutive runs of the same value in the data as the value, followed by the count or vice versa. RLE reduces the thresholded image to just two pixel values when all the pixel values in the thresholded image are unique and if the pixel values of threshold image are not unique then it doubles the size of the original image. Therefore, RLE is applied only in cases where the expect runs of the same value are of importance.

Huffman coding is a losses variable length coding which is best fit for compressing the outcome of RLE. As the RLE produces repetitive outcomes, the probability of a repeated outcome is defined as the desired outcome, which can be obtained by integrating RLE and Huffman coding techniques. Repeated outcomes are represented by fewer bits and higher bits are used to represent infrequent outcomes. The performance of Huffman coding purely depends on the effective development of Huffman tree with minimum weighted path length. The time complexity of Huffman coding is $O(N \log_2 N)$.

III. Thresholding Using Bat Algorithm

PSO generates efficient thresholds but undergoes instability in convergence when practical velocity is high [15]. Firefly algorithm (FA) was developed to generate near global thresholds but it experience a problem when no such significant brighter fireflies in the search space [15]. So a Bat algorithm (BA) is developed that gives a global threshold with minimum number of iterations. It is a nature inspired Metaheuristic algorithm developed by YANG in 2010 [16]. Bat algorithm works with the three assumptions: 1. All bats use echolocation to sense distance, and they also 'know' the difference between food/prey and background barriers in some magical way; 2. Bats fly randomly with velocity v_i at position x_i with a fixed frequency *Qmin*, varying wavelength and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r € [0, 1], depending on the proximity of their target; 3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}. Intensification (local search/local optimum) of the algorithm is attaining with pulse rate and diversification (global search/local optimum) is attaining with loudness parameter. Here thresholds are assumed as Bats. The detailed Bat algorithm is as follows:

Step 1: (Initialize the bat & parameters): Initialize the number of thresholds (*n*) and randomly select the threshold values i.e., X_i, (i = 1, 2, 3, -----, n), loudness (*A*), velocity (*V*), pulse rate (*R*), minimum frequency (*Qmin*) and maximum frequency (*Qmax*).

Step 2: (Find the best threshold): Calculate the fitness of all thresholds using Eq. (3), and the best fitness threshold is the Xbest.

Step 3: (Automatic zooming of threshold towards *Xbest*): Each threshold is zoomed as per Eq. (7) by adjusting frequency in Eq. (5) and velocities in Eq. (6).

Frequency update:

$$Q_i\,(t+1) = Qmax(t) + (Qmin(t) - Qmax(t))*\beta \tag{5}$$

Where β is random number [0 to 1]

Velocity update:

$$v_i\,(t+1) = v_i\,(t) + (X_i - Xbest) * Q_i\,(t+1) \tag{6}$$

$$X_i\,(t+1) = X_i\,(t) + v_i\,(t+1) \tag{7}$$

Step 4: (Selection of step size of random walks): If generated random number is greater than pulse rate '*R*' then move the threshold around the selected best threshold based on Eq. (8).

$$X_i\,(t+1) = Xbest\,(t) + w * R_i \tag{8}$$

Where R_i = random numbers, w = step size for random walk

Step 5: (Generate a new threshold): Generate a random number, if it is less than loudness and new threshold

fitness is better than the old threshold, accept the new threshold.

Step 6: Rank the bats and find the current best *Xbest*.

Step 7: Repeat step (2) to (6) until maximum iterations.

IV. Results and Discussions

The proposed method of image compression in discrete wavelet domain using bat algorithm based optimal thresholding has been executed in MATLAB environment with a laptop of HP Probook 4430s, Intel core i5 processor, 2GB random access memory (RAM). The performance of the algorithm is tested for the readily available standard images obtained from the link www.imageprocessingplace.com. Six popular images which are extensively used for compression test images like Barbara, Cameraman, Gold Hill, Jet Plane, Lena, and Peppers are selected to test the performance of the proposed algorithm. The experimental results of published methods for the above said images are available in the literature. For the simulation of PSO algorithm, the Trelea type-2 PSO toolbox is used. The same parameters as in paper [14] are selected for PSO as well as to QPSO such as number of particles, maximum number of epochs, distortion and compression ratio parameter (a, b). Similarly for firefly algorithm a particular value to tuning parameters is selected where its performance is better in compression ratio and reconstructed image quality. The parameter values are finalized after the implementation of firefly algorithm to the problem stated. The parameters which are set for tuning of firefly algorithm are alpha (α) = 0.01, beta minimum (β_0) = 1, gamma (γ) = 1. The maxima of maximum of average PSNR obtained from the repeated experimental results for loudness and pulse rate with respect to PSNR as shown in Fig. 5, is chosen as the Bat algorithm parameter value for simulating the Lena image. From experimental shown in Fig. 5, it can be observed that Loudness = 0.3 and Pulse rate = 0.1, and the same parameters values are used for later experiments. The remaining parameters: frequency Qmin = 0.3, Qmax = 0.9 and step-size of random walks = 0.36 is selected randomly.

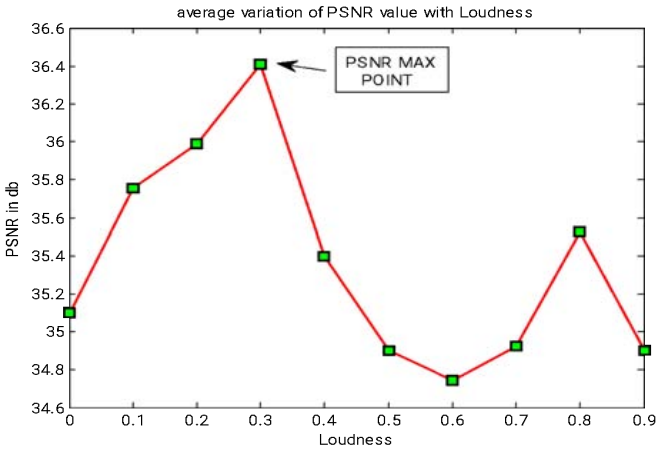
The performance measuring parameter for evaluation of effectiveness and efficiency of the proposed method is Peak Signal to Noise Ratio (PSNR) and objective function/fitness function. The equation for fitness function is as given in Eq (3) and PSNR value of original signal $f(X,Y)$ and reconstructed image $g(X,Y)$ is calculated using Eq (9)

$$PSNR = 10 \times 10 \log\left(\frac{255^2}{MSE}\right)(\text{dB}) \quad (9)$$

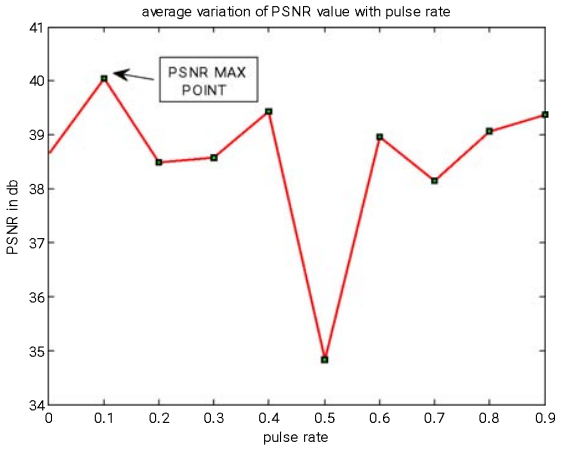
Where Mean Square Error (MSE) is given as-

$$MSE = \frac{1}{M \times N}\sum_{X}^{M}\sum_{Y}^{N}\{f(X,Y) - g(X,Y)\}^2 \quad (10)$$

Where M x N is size of image, X and Y represents the pixel value of original and reconstructed/decompressed images. In our experiment we have taken N=M a square image. $f(X,Y)$ is an original image and g(X,Y) reconstructed image of size 512 by 512. The performance of the proposed method of image compression in frequency domain for the six images is compared with the other techniques such as PSO, QPSO and FA.



(a)



(b)

Figure 5: Average PSNR of Lena Image being Performed 5 times for Selection of Parameter (A) Loudness (B) Pulse Rate

Table 1-6 shows PSNR of the proposed method and other methods for six tested images. From tables it is observed that the PSNR achieved with the proposed method is better than the PSO, QPSO and FA. As five level and three level decomposition are used so for the sake of comparison [14], a three level and five level decomposition with appropriate (a, b) parameters is also chosen. Parameters (a, b) are adjusted according to the user requirements to maintain trade-off between compression ratio and reconstructed image quality as both objectives cannot be achieved at the same time. Table 1-6 shows the (a, b) values to achieve corresponding bits per pixels for six images. The major drawback with the PSO and firefly is that large number of tuning parameters and improper parameter tuning causes performance degradation of the PSO and FA, whereas in bat algorithm only two tuning parameters are enough, so effect of tuning parameters on BA is much smaller compared to PSO and FA. The bat algorithm optimization process combines the advantages of simulated annealing and particle swarm optimization process and with the concept of frequency tuning, the PSNR values which indicates the quality of the image is superior to PSO and FA as well as harmony search. With suitable simplifications PSO and harmony search becomes the special cases of Bat algorithm. In addition the bat algorithm possesses the benefit of automatic zooming that is accompanied by the automatic switch from explorative moves to local intensive exploitation, which results in fast convergence rate as compared to other techniques

Table 1: PSNR Comparison for Barbara Image at Different Bit Per Pixel (BPP)

BPP	a,b	a,b	PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(11,1)	(11,1)	25.60	25.72	25.63	25.82	25.71	25.92	26.05	26.32
0.250	(10,1)	(9,1)	28.32	28.42	28.39	28.47	28.43	28.64	28.83	28.93
0.500	(8,1)	(8,2)	32.15	32.34	32.55	32.71	32.78	32.98	32.96	33.23
1.000	(4,1)	(4,1)	37.10	37.12	37.15	37.31	37.39	37.64	37.52	37.83
1.250	(2,1)	(2,1)	39.98	40.04	40.08	40.24	40.34	40.53	40.44	40.87

Table 2: PSNR Comparison for Gold Hill Image at Different Bit Per Pixel (BPP)

BPP	(a, b)		PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(7,1)	(4,1)	29.12	29.19	29.28	29.42	29.41	29.62	29.44	29.67
0.250	(5,1)	(3,2)	31.28	31.43	31.39	31.51	31.58	31.64	31.61	31.77
0.500	(3,1)	(2,3)	33.81	33.93	33.92	34.13	33.99	34.41	34.05	34.51
1.000	(2,2)	(1,5)	37.27	37.40	37.31	37.58	37.55	37.75	37.65	37.90
1.250	(1,5)	(1,7)	41.75	41.90	41.82	41.95	41.96	42.11	42.01	42.32

Table 3: PSNR Comparison for Lena Image at Different Bit Per Pixel (BPP)

BPP	(a, b)		PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(15,1)	(15,1)	30.82	30.98	30.91	31.08	31.11	31.15	31.23	31.43
0.250	(11,1)	(10,1)	35.17	35.26	35.21	35.32	35.34	35.46	35.45	35.68

0.500	(7,1)	(7,1)	37.91	38.23	37.98	38.28	38.18	38.55	38.35	38.70
1.000	(4,1)	(4,2)	40.94	41.42	40.97	41.53	41.27	41.67	41.33	41.71
1.250	(2,1)	(2,3)	42.15	42.31	42.19	42.37	42.30	42.46	42.47	42.62

Table 4: PSNR Comparison for Cameraman Image at Different Bit Per Pixel (BPP)

BPP	(a, b)		PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(18,1)	(16,1)	26.17	26.53	26.21	26.60	26.37	26.71	26.43	26.74
0.250	(12,1)	(11,1)	30.05	30.10	30.09	30.15	30.17	30.41	30.27	30.56
0.500	(10,1)	(10,2)	33.46	33.52	33.51	33.63	33.55	33.69	33.58	33.73
1.000	(3,1)	(3,2)	38.02	38.13	38.09	38.19	38.21	38.37	38.33	38.39
1.250	(1,1)	(1,1)	40.11	40.23	40.13	40.28	40.33	40.32	40.43	40.51

Table 5: PSNR Comparison for Jetplan Image at Different Bit Per Pixel (BPP)

BPP	(a,b)		PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(12,1)	(12,1)	27.98	28.23	27.98	28.28	28.04	28.33	28.11	28.39
0.250	(10,1)	(10,1)	31.38	31.65	31.41	31.69	31.51	31.72	31.57	31.80
0.500	(8,1)	(7,1)	34.12	34.32	34.18	34.32	34.25	34.45	34.37	34.53
1.000	(3,1)	(3,1)	38.89	38.97	38.92	39.05	38.99	39.25	39.15	39.44
1.250	(1,1)	(1,1)	41.16	41.24	41.18	41.30	41.25	41.41	41.46	41.63

Table 6: PSNR Comparison for Pepper Image at Different Bit Per Pixel (BPP)

BPP	(a,b)		PSO		QPSO		FA		BA	
	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level	3-level	5-level
0.125	(10,1)	(9,1)	34.81	34.98	34.82	35.01	34.89	35.16	34.90	35.21
0.250	(5,1)	(4,1)	37.58	37.82	37.63	37.89	37.69	37.98	37.73	38.18
0.500	(1,1)	(1,1)	39.75	39.92	39.84	40.12	39.92	40.27	40.12	40.44
1.000	(3,1)	(1,4)	42.92	43.21	42.98	43.33	43.04	43.46	43.26	43.61
1.250	(1,5)	(1,5)	43.10	43.42	43.19	43.43	43.29	43.52	43.38	43.74

V. Conclusions

This paper presents a novel approach to obtain image compression in discrete wavelet domain by optimizing threshold values using bat algorithm for the first time. The coefficients obtained by applying discrete wavelet transform for the image to be compressed are classified into different groups by making use of the optimal thresholds, these optimal thresholds are obtained using bat algorithm, keeping a balance between the quality of the reconstructed image and compression ratio. The proposed technique is simple and adaptive in nature as individual thresholds are assigned to high energy sub-bands individually and for rest of the sub-bands a common threshold are assigned. The successful thresholded image is further coded with Runlenght coding followed by Hauffman coding. It is observed that for multilevel thresholding bat algorithm produces superior PSNR values, good quality of the reconstructed image with less convergence time as compared to PSO and firefly as the later techniques are unstable if the particle velocity is maximum and no brighter firefly in the search space respectively. The algorithm convergence time is further improved by the fine adjustment of the pulse emission and loudness parameters and time delay between pulse emission and the echo.

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Implementation of Developed Signature Character for an Eco-Friendly Infantswear Collection

By Ragamalya M

Abstract- The aim of this study is to create and incorporate signature character for a mass market organic apparel brand in the collection of Spring summer 2021 for the age group of 0-2 years and to implement this character in all other trims, packages, name tags and carton boxes, promotion posters, flyers / banners or other products used for the brand. This study focusses mainly on sustainable fashion and the need of comfort for infants' wear. Detailed research was executed to know the preference of the parents towards the new character developed and their application onto various mediums. Samples were developed for eccentric silhouettes and new designs as per the theme chosen and designs are shown in the methodology.

Keywords: signature character, design, infants, organic, sustainability, comfort.

GJCST-F Classification: LCC Code: TT492-TT499

Strictly as per the compliance and regulations of:

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Keywords: signature character, design, infants, organic, sustainability, comfort.

I. Introduction

Manufacturing of infants' wear clothing requires various specially treated materials like anti-microbial finish, ergonomically fit for wear and tear since children's skin is more delicate and often prone to rashes. Most of the children are playful and thus the garments should be durable to all their activities. Development of signature cartoon character calls in for various attributes which could be applied in all forms of apparel items right from garments to packaging. Fabric choices, dyes, trims and packages to meet the sustainable goals and the application of signature character is the main focus of the journal. Organic cotton and azo free dyes are being implemented to every style of the collection. Preferences of parents are taken into consideration in the further development process.

II. Literature Review

In the world of fashion, every new product or style begins with an idea. Fashion designing involves a set of skills that range from market research and creativity to sketching and fabric selection. The fashion designers guide the process from inception to production. Fashion design requires professionals to constantly be in tune with the marketplace, what's trending currently and what economic indicators may influence buying decisions in the future. Market research includes following competitors as well as consumer demands. During early 20th century clothing worn by infants all shared a common feature leading to lack of sex differentiation. They all wore same type of gown, robe or wrap around tunics with no print and colors in it. In late 18th century the theory of swaddling-immobilizing the babies with linen wrap around has been quite popular. Though they believed that by swaddling, babies limbs could be straightened or they may grow bent. Medical theories in late 18th century suggested that swaddling led to weakening of limbs rather than making them strong. Supporting this they arrived at lightweight and garments and 'Long dress' which consisted of tight fitted bodice and long skirt below their feet. Then when they started walking they shifted to 'short clothes' pertaining to petticoats and back opening bodice. Materials used were white cotton since it was easy to bleach, wash and paired with yoke frock or fitted bodice. In late 19th century considering crawling as important aspect for child's growth people came with the idea of 'one-piece Romper suit' and full bloomer like pants called 'Creeping Aprons'. Fabrics for infant wear apparels include light weight cotton knitted fabrics, giving stain resistant, anti-shrink finishes. Linen fabric though could shrink but gives well breathability properties and does not cause any allergies to babies. Climatic conditions also influence the infants' garment selection process. Hand feel of the fabrics and garments with prints or few embellishments should be made sure that it does not affect or cause injuries to babies in any form. The designs and prints or silhouette used for infants should be gender neutral and the colours to play a major role in the selection of garments. Trims and accessories like sharp buttons or poking draw strings have to avoided which may pose a major threat to infants. Animal and character prints continue to dominate infants wear market. Gender neutral prints like stripes polka, checks, abstract prints, geometric prints are still the choices many parents according to Indian market. Mild florals and other summer prints are selected by fashion conscious parents purchasing according to season. Interactive prints and conversational prints also tops the children's wear market. Millennial parents prefer their children to dress fashionably right from their birth. The most prominent

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Style of garment for infants include onesies/ romper, pajama set and mostly with minimal or small motifs. Few parents find mass market for infants being boring to creative spirited kids and prints being less or least interactive. People show huge affinity towards interactive garment styles with kids being able to interact in order to develop creativity and attraction. With interactive message being words kids can learn how to read and express their personal styles through these garments. This will be significant for babies from 1-2 years and not for new born. Brands contribute to environment by developing sustainable practices in all types of the activities carried out. Most of kids' apparel have incorporated sustainable fashion by using organic cotton, recycled packages, chemical free prints and using no harmful dyes. Sustainability considers 'triple bottom line' which are environmental, social and economic impacts. Dyeing and fabric processing cause more damage to environment thus shift in technology like using low liquor-to-material ratio dyeing, urea and salt-free continuous dyeing. Eco friendly labels to create better awareness differentiation retail marketers from 'go green consumers'. Use of knitted fabrics to larger extent gives the scope for easy breathability for kids since the knitting loops could help in pumping air inside the body removing excess heat from the body during day time and night time. Requirements for infants' wear clothing includes nonflammable, light weight, non-irritable, easy access for changing diapers, organic fabrics. Textiles have gained a huge awareness about anti-microbial finish for enhancing the brand's quality of products. Kids wear market mainly focuses on giving antimicrobial finish to almost all of its products. Unique natural agents like Basil, turmeric, neem, Aloe Vera, orange and pomegranate have microbial properties and thus majorly used for eco-friendly finishing treatments.

III. Methodology

Methodologies used to carry out this study are-

1. *Stratified Sampling:* Here homogenous groups of parents are selected and questionnaire is sent to parents with the kids of 0-2 years. Questions related to sizing and placement of characters were included and their responses were condensed to dual-axis bar chart. Questions regarding package designs, cutout label, types of prints and wash care labels were circulated among parents and their preferences are considered for further design rectifications.
2. *Non Participant Observational Method:* Frequent visits to competitors' brands was made to understand the parents' choices for their infants. Focus group parents tend to show affinity towards organic cotton brands and more of mild character prints in them. Parents were highly aware about the package design and it plays a major role in marketing.
3. *Collection of Primary Data:* Direct interviews with the parents having kids of the age group 0-2 years was carried out to explain about the fabrics, trims and designs to be used and their suggestions were taken into account. Questionnaires was circulated to the same group of parents about their preferences of placement of characters on garments, packages, name labels and types of prints.

IV. Sequence of Character Development

Developing the signature character for the brand and its application in all possible garments and trims is the main aim of the project. Initially the various cartoon characters in the market both domestic and international is studied. Character modifications based on colours or poses or the animation done to them is analyzed which could play a major role in the development of our own character. Next is the technique which was used to achieve or print these characters on to various garments and other related products like size label, packaging, etc. Majority of the characters were done screen printing over the garments or when there were lots of colors used the characters were printed digitally using reactive and discharge dyes. Few of the less complicated characters were achieved through embroidery and various other 3d techniques like glitter, pom pom, lace, puff or high density (HD) prints and stickers were used. Placement of the characters were in the middle or right side of the chest as a small coverage or in the middle of the garment over a big area and as discontinuous placement print. Based on all the gathered rough sketches of characters was made. Desired colour palette as per the requirements and uniqueness was experimented. 2D flat images with various combinations of shades was developed. From these combinations, highlights and shadows were given consideringthe effects to be achieved.

These characters were internally examined by group of management people and upon the common grounds final character was decided and given a name. Characters were placed upon different silhouette like onesies, sleeper, Pajama set, Bib and other trims like price label, polybag etc. Various dimensions of characters were experimented and by changing the positions according to the silhouette. Since its difficult and cost effective to achieve more number of colors in screen printing, digital is most preferred.

V. Data Analysis and Findings

a) Character Developed

b) Application of Characters

As the signature character was developed, basic product categories like onesies, polybag, wash care labels, price and hand tags has witnessed the application of this character and was being printed on various mediums.

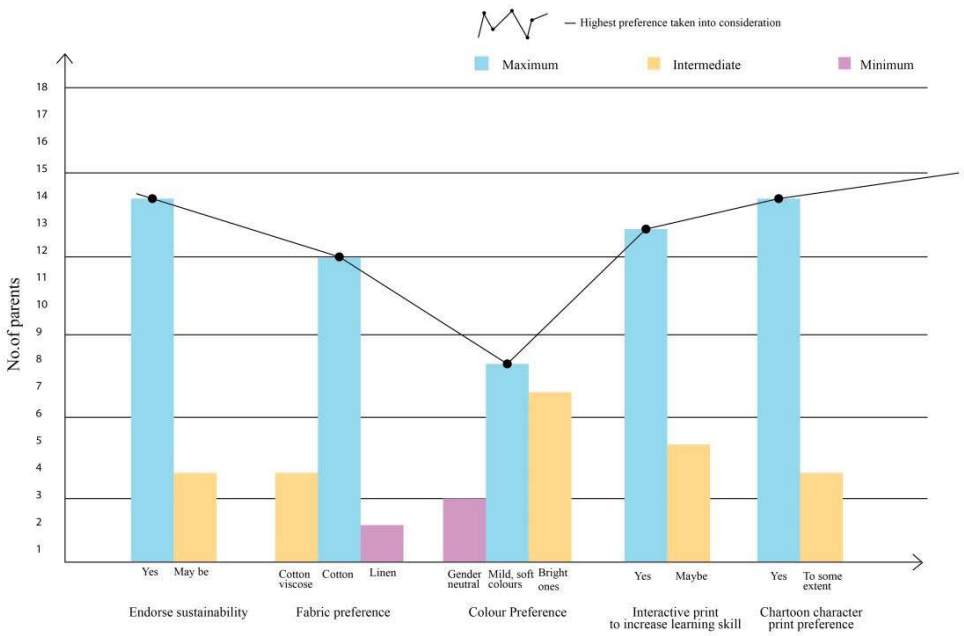
Preference of the parents which was derived from the questionnaire was combined into bar chart and their feedback was noted for further developments.

c) Results of the Questionnaire

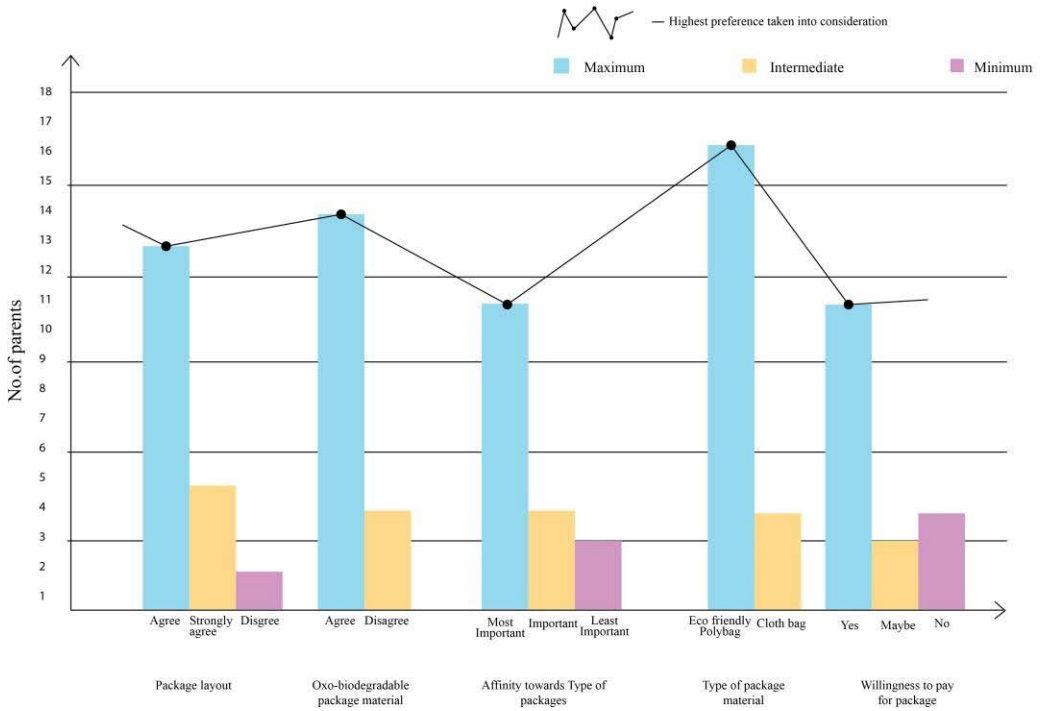
Dual-axis bar chart is used for analysis the questionnaire survey analysis.Three charts are made.

1. Garment Preference -Type of fabric, colours, prints, size of prints.
2. Package Preference -Type of material, type of package, details in package.
3. Label preference –Size of label, placement of labels.

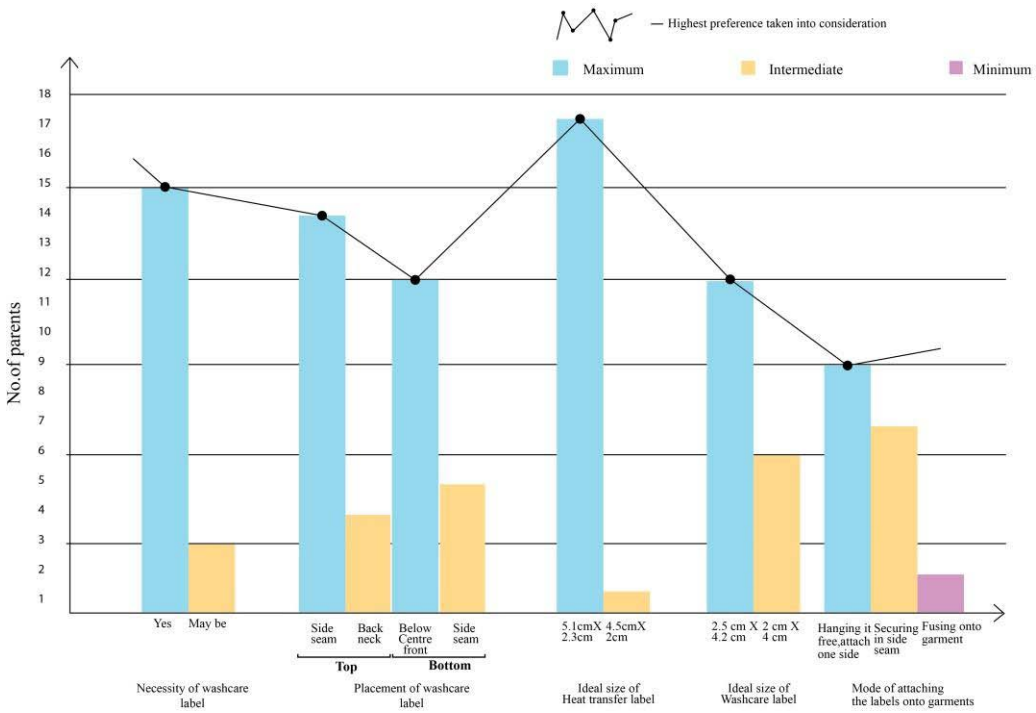
Garment Preference



Package Layout



Care label Preference



Thus it is noticed that most of the parents seemed to like the new cartoon character which was developed and their application on garment as chest print. They mostly preferred Digital printed character on garment, polybag and hand tags. Most of the parents were aware about the Oxo-biodegradable package which was to be used for sustainability and they were willing to pay for it. Organic cotton and cotton viscose blends were their choice of fabric and azo free dyes were used in the process of printing. Also, wash care labels and size label was felt extremely necessary by the parents and the position mentioned by them is either on side seam hanging it free securing one side or fusing it onto garments. Majority of parents are attracted towards sustainable packages and were willing to pay for the same which could help the brand create a unique brand

identity. Irrespective of season the parents seemed to be more affirmative towards mild colours rather than dark ones in their infants clothing.

VI. Cost Sheet for Each Garment

a) Basic Category

Basic collection includes three garments with placement of character and the logo in the graphics which is used as trademark or signature to denote the brand. As the size of the print and design involved is less it is categorized into basic category symbolizing the price point from Rs. 149-199.

S.No.	GARMENT	FABRICS USED	GSM	PRINT	PRICE/PIECE
1.		Organic cotton	Body fabric : 210 Rib : 180	Placement : 4 x 4.9 cm (chest print)	Rs. 149
2.		Organic cotton	Body fabric : 210 Rib : 180	Placement : 10 x 11.5 cm (Mid bodice)	Rs. 180
3.		Organic cotton	Body fabric : 210 Rib : 180 (Contrast colour)	Placement : 9.7 x 8.3 cm (Continous front to back)	Rs. 199

b) Fashion Category

Fashion collection containing all over print according to season's theme with the logo being incorporated into all designs. As the coverage involved is all over the printing cost incurred is comparatively increased and thus the range is from Rs. 269 – 599.

S.No.	GARMENT	FABRICS USED	GSM	PRINT	PRICE/PIECE
1.		Organic cotton	Body fabric : 210 Rib : 180	All over print	Rs. 399
2.		Organic cotton	Body fabric : 210 Rib : 180 (Contrast colour)	All over print	Rs. 399
3.		Organic cotton	Body fabric : 210 Rib : 180 (Contrast colour)	All over print	Rs. 450

S.No.	GARMENT	FABRICS USED	GSM	PRINT	PRICE/PIECE
1.		Organic cotton	Body fabric : 210 Rib : 180	All over print	Rs. 269
2.		Organic cotton	Body fabric : 210	All over print	Rs. 329
3.		Organic cotton	Body fabric : 210 Rib : 180 (Contrast colour)	All over print	Rs. 479

S.No.	GARMENT	FABRICS USED	GSM	PRINT	PRICE/PIECE
1.		Organic cotton	Body fabric : 230	All over print	Rs. 599

c) Cost Comparison for Signature Character

Comparison of Cost for Printing the Signature Character of Size Preferred by Parents is Done.

S.No	Type of Print	Dimensions	Cost Per Piece
1.	Pigment Print	4 cm X 4.9 cm	Screen 2500, Printing-Rs.7
2.	Reactive Print	4 cm X 4.9 cm	Rs.13
3.	Digital Print (Reactive Pigment)	4 cm X 4.9 cm	Rs.7
4.	Embroidery	4 cm X 4.9 cm	Rs.10

According to GSM of 230, 210 and type of print onesies price is compared for printing the signature character.

GSM- 210, onesies garment, Garment price: 147

S.No	Type of Print	Price Per Kg	Print Price Per Garment
1	Pigment Print	Rs. 195	Rs. 32
2	Discharge Print	Rs. 260	Rs.47
3	Reactive Print	Rs. 325	Rs.55

GSM- 230, Onesies garment, Garment price: 169

S.No	Type of Print	Price Per Kg	Print Price Per Garment
1	Pigment Print	Rs. 195	Rs. 48
2	Discharge Print	Rs. 260	Rs.65
3	Reactive Print	Rs. 325	Rs.81

d) Package

Dimension of polybag package: Length -30 cm; Width -25 cm

e) Hand Tag

Labels attached to clothing containing brand name, significant logo, tag line and address. Designed in the form of cut out label to incorporate the signature character of the brand. White hardpaper (recycled paper) is used for the process. Dimension ofthe hand tag is: Length -7 cm; Width -8.25 cm

Front

Back

f) Heat Transfer Label

As per the preference of parent's heat transfer label is attached to back neck and centre back in bottom containing brand name, size and logo with trade mark.

Dimensions of heat transfer label is Length -2.3 cm; Width -5.1 cm.

g) Washcare Label

Type of washes and drying time, type of drying, type of ironing as per organic cotton is specified and is achieved onto cotton fabric using jacquard weaving. Dimensions of wash care label include Length -4.2 cm; Width-2.5 cm.

VII. Conclusion

Therefore, a signature character was developed for a sustainable infants' wear brand through researches of existing characters, initial sketches of various options and thus arriving at a unique one. Their application onto various mediums like packages, garments, hand tags, price labels, social media promotions, etc., was made and their significant preferences from parents were considered onto further developmental process. Samples were developed for each of the applications of which stayed within brand identities. The ultimate goal was to meet sustainability in the application process and the choice of sustainable fabric like organic cotton and azo free dyes was being imperative. Consequently, the comfortability for the babies is achieved through silhouettes used. Further in-depth study could be conducted to develop various design options based on the signature characters and their placements on to the garments. This could also expand the possibilities of the brand to stand out in the competitive market.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for writing a good quality Computer Science Research Paper

Techniques for writing a good quality computer science research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of computer science then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10.Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals Inc. (US)

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals Inc. (US).

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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