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Mathematical Concepts in Graphic Design

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Abstract:- Graphic design involves the creation of visual content to effectively convey information to an audience. Concurrently, mathematics encompasses the study of numbers, shapes, and patterns, serving as the fundamental basis for various fields, including design. Despite the apparent disparity between these two disciplines, they are intertwined in multiple ways, giving rise to a potent amalgamation. This review paper aims to delve into the correlation between graphic design and various mathematical concepts and theories.

Keywords:- *Math, Geometry , Graphic Design, Golden Ratio.*

I. INTRODUCTION

Have you ever considered math while looking at a logo, animation, graphic art, or design? Graphic art is the application of arts and math to create visual content to communicate messages using images, color, and typography.

Graphic design has deep historical roots, tracing back to the print industry of the 1920s and even further to ancient visual communication forms such as Egyptian hieroglyphs and 17,000-year-old cave paintings[1].

The principles of math form the basis of every visual medium, encompassing everything from traditional art to contemporary graphic and web design. Math permeates in tiny details, as well as the majority of compositions. Interactive software is vital to graphic design, but its effective use is only possible when you understand that graphic design is deeply rooted in mathematical theories. As a graphic designer, one needs to have a firm grasp of not only pixels and vectors but also color theory, tonality, Symmetry, Balance, Flow, Repetition, Typography, and Patterns.

II. ELEMENTS OF GRAPHIC DESIGN

➢ *There are Three Major Categories of These Elements:*

- **Basic Elements -** The fundamental components of composition encompass abstract concepts and lack tangible existence. In graphic design, a dot is a visual representation of an abstract concept also known as 'point'. In graphic design, a line is a point in motion whose thickness or thinness creates a visual impact. A line creates a 2D Plane and an infinite expression of a 3D space creating shapes. A shape when filled with color, texture or gradation becomes 'meaningful' giving it a form or illusion of three dimensions.
- **Relational Elements -** This group of elements governs the placement and interrelationship of the basic elements such as dot, line and form in a visual composition to enhance the visual impact of the composition.
- **Intentional Elements -** A design has to serve a purpose and graphics have a powerful effect on the people they are meant for. For instance, an ad in a magazine has greater impact if it has aligned images or graphics . This impact is possible because of using intentional elements in the right way. There are three types of intentional elements: Aesthetic, Content, and Function.

All the above are based on basic Mathematical functionalities as discussed below.

III. MATHEMATICAL CONCEPTS IN GRAPHIC DESIGN

The convergence of logic and aesthetics, organization and cadence, symmetry and unpredictability can be a compelling testament to the symbiotic relationship between Mathematics and Graphic Art. Math is a fundamental building block of graphic design. Understanding its principles can elevate your designs to the next level. Image editing involves mathematical operations such as transformations (scaling, rotating, translating), color adjustments, and blending modes, all of which are based on mathematical formulas and algorithms.

The language of design is **geometry**. Geometric shapes, from basic dots and lines to circles or squares or more intricate like polygons and curves, are significant in design. The field of computer graphics heavily relies on geometry as its fundamental underpinning, offering the mathematical framework necessary for the representation and manipulation of geometric forms in a digital context.

Linear algebra plays a crucial role in computer graphics, particularly in the representation and manipulation of vectors and matrices.

Calculus is employed in computer graphics to model and simulate the behavior of light and materials in a virtual environment.

Coordinate geometry plays a basic role in computer graphics and animation.

[1] https://ntop.in/graphics

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A. Pixels:

Pixels are fundamentally a function of coordinate geometry & all Digital images are formed with rows each assigned a specific color. When we look at an image on a screen, we see a mosaic of these colored pixels. The clarity and detail of an image, known as its resolution, are measured in pixels per inch. Every pixel on a screen is defined by its horizontal (X-axis) and vertical positions (Y-axis) and based on **coordinate geometry.** The color of each dot is usually shown digitally, such as RGB (Red, Green, Blu Digital images are formed with tiny squares called pixels, with each assigned a specific color. [2]

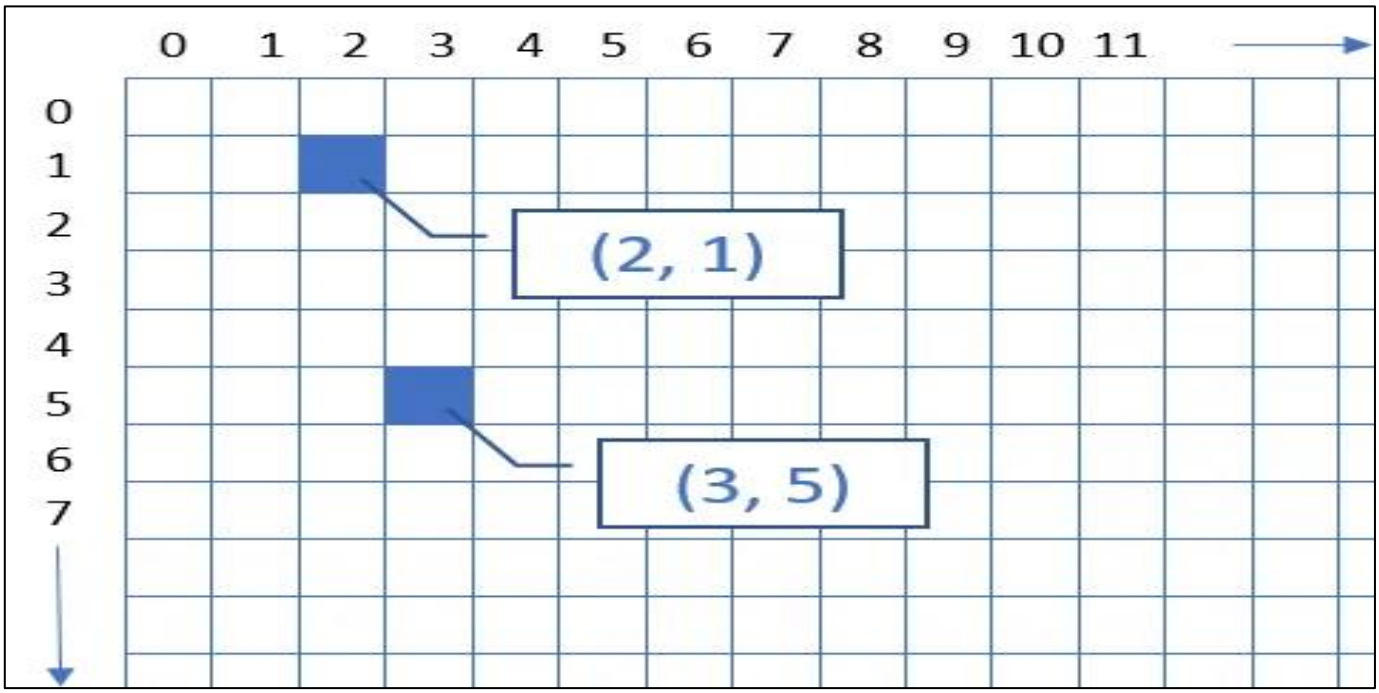

Fig 1: Codeguppy/Pixels-and-Coordinates

Shows: Pixels need 2 numbers as coordinates: one for horizontal and one for the vertical

When we look at an image on a screen, we see a mosaic of these colored pixels.

Adobe Photoshop is an example of Pixel-Based Mathematics' wherein mathematical algorithms, coordinate geometry and matrix multiplication are applied to perform operations such as scaling, rotation, skewing, and perspective changes.

Many Photoshop filters and effects use complex mathematical formulas. For example, Gaussian blur applies a mathematical function to create a smooth blur effect.[3]

B. Vectors:

Vectors are rooted in linear algebra and geometry. Unlike pixels, vector graphics rely not on a grid of squares but on paths. These paths are made up of points, lines, curves, and shapes, mathematically described in their position, length, and direction. [4] Vectors can be depicted graphically in two or three dimensions. The magnitude of the vector is shown as the length of a line segment.

[2]https://pittsburghkids.org/events/tag/math/list/?tribe-bar-date=2022-12-01

[3]https://www.zekagraphic.com/pixels-and-vectors-of-digital-graphics/

[4]https://www.zekagraphic.com/pixels-and-vectors-of-digital-graphics/

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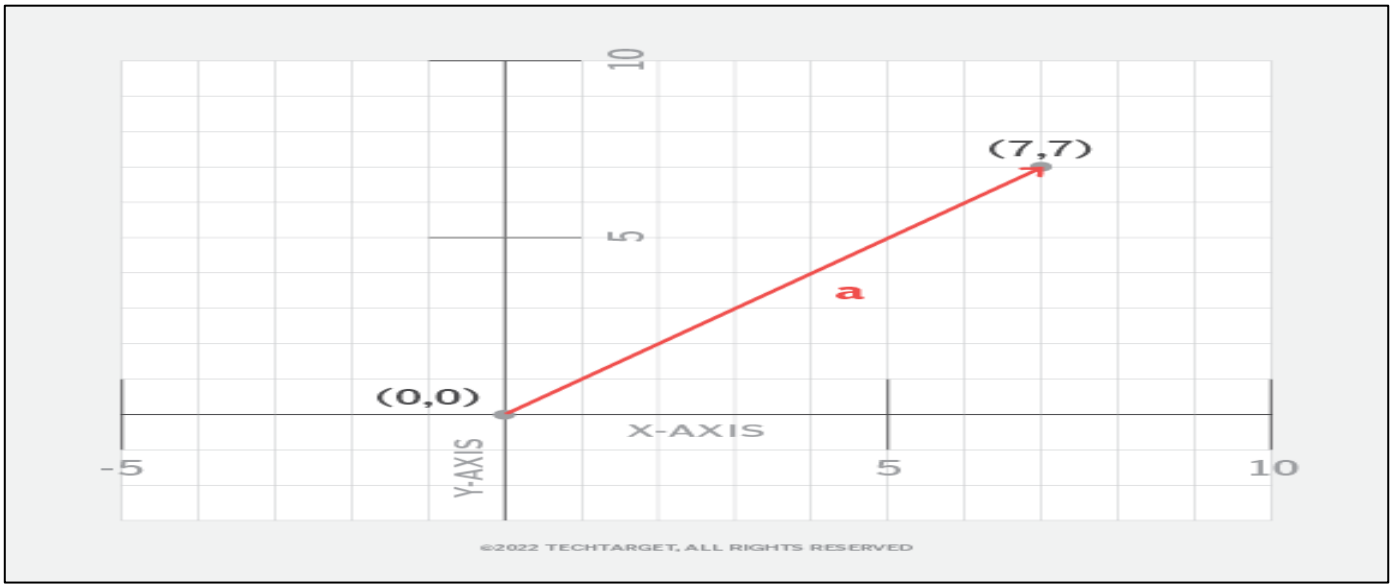

Fig 2: Graphically Depicts a Vector
Pic Courtesy -[5]

The direction of the vector is shown by the orientation of the line segment and by an arrowhead at one end. Vector graphics, with their unique ability to be scaled to any size without losing quality, open a world of creative. Vector graphics are usually made in Adobe Illustrator. Unlike pixel-based images, which can lose their sharpness when resized, vector graphics remain clear and detailed.

C. 3D Objects and Polygons Triangles-

Are the fundamental shape in 3D modeling, unlike squares or, due to their precise definition and versatility triangles can seamlessly fit together without gaps, making them ideal for describing surfaces.

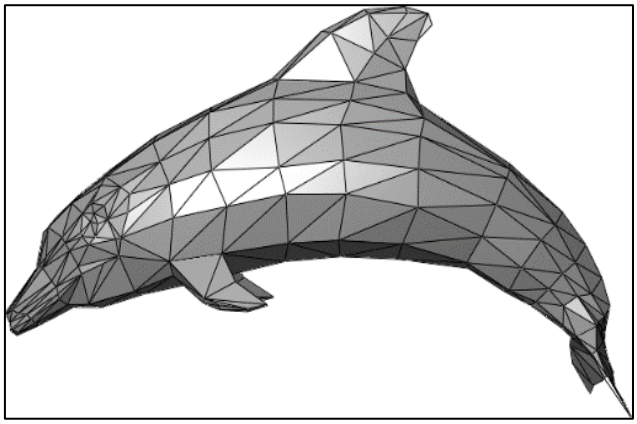

Fig 3: How Triangles form 3D Objects

The sequence of these points determines the orientation of the triangle, distinguishing the "out" and "in" sides, commonly known as the normal vector of the surface. 3D models are built by connecting lines between points to create shapes, with each point containing its unique color information.

D. Bezier Curves

Have you ever wondered how computer software creates those smooth and precise shapes in designs and animations? Well, it's all thanks to something called the Bezier curve. This mathematical function helps software produce different shapes and letters, making it useful in fields like art, design, engineering, and even robotics.

When creating 2D or 3D objects, one needs to use a combination of straight lines and curves. Drawing a curve on paper is straightforward, but it's not as simple when using a computer.

With one simple mathematical function, Pierre Bézier revolutionized digital design took the world by storm. A Bézier curve creates a smooth and curved line by using just a few points. It's like connecting the dots, but the middle dots helps decide how the line curves using the “binomial polynomial” for both x and y outputs. Polynomials will be represented as the formula below:

$$f(x) = a \cdot x^3 + b \cdot x^2 + c \cdot x + d$$ [6]

Pic Source – Github.
Showing how a Polynomial Looks like

[5] https://www.techtarget.com/whatis/definition/vector

[6] https://www.linearity.io/blog/bezier-curves/

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Polynomials with x3 as the highest order term are "cubic" polynomials, and if it's x2, we have a "square" polynomial. If it's x, we call it a line. Bézier curves are polynomials of t, as opposed to x, and the value for t is fixed between 0 and 1. Coefficients a, b, etc., then take the "binomial" form like so:

$$linear = (1-t) + t$$

$$square = (1-t)^2 + 2 \cdot (1-t) \cdot t + t^2$$

$$cubic = (1-t)^3 + 3 \cdot (1-t)^2 \cdot t + 3 \cdot (1-t) \cdot t^2 + t^3$$

Pic Source – Github.
Curves ar Polynomial of t

Bézier curves are really interesting because we can look at them in two different ways. The first way involves a lot of math, like understanding derivatives and functions. We unpack the curve to see how it's made using polynomial functions. The second way is to see the curve in terms of connections between points. This means that the curve can only go as far as the points that were used to create it.

E. Golden Ratio and Fibonacci Sequence

Golden Mean or Divine Proportion with its roots in the Fibonacci sequence is used in various fields, viz; design projects, paintings, illustrations, photography, music, and other compositions that thrive on balance. It's represented as **Greek letter ϕ (Phi) or τ and equals 1.618** and is used to create a visual appeal and increase the effectiveness of a Graphic design. It's also connected to the Fibonacci sequence, which starts with 0 and 1, and each subsequent number is the sum of the two preceding ones. When you use these numbers to create rectangles, you end up with shapes that have the Golden Ratio. The extremely famous logo for Apple Inc., is based on the Golden Ratio. This ratio gives the logo a balanced and pleasing look, which is why it's so well-known and recognizable.

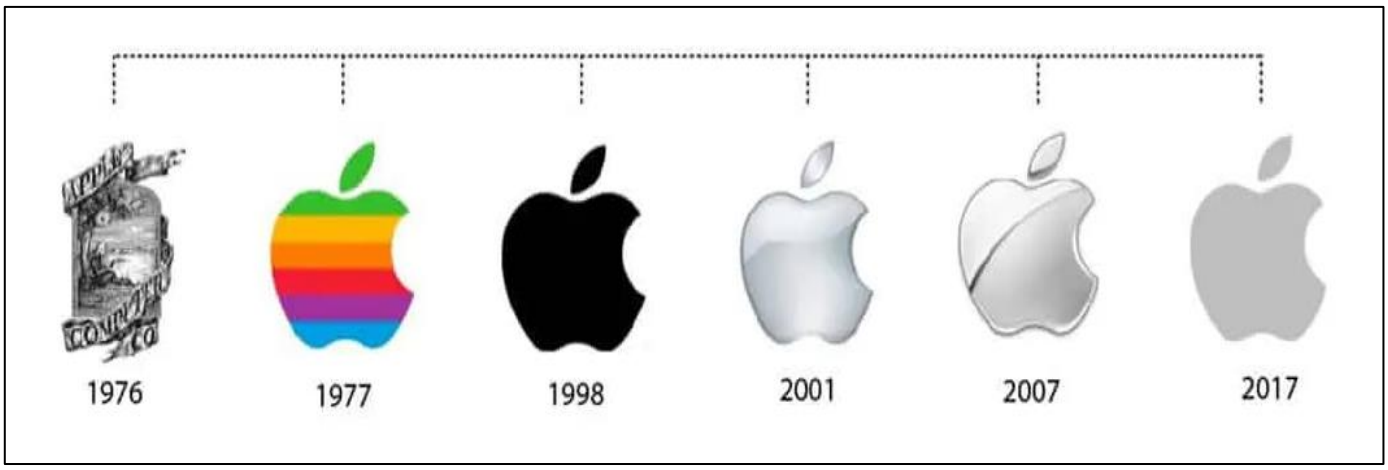

Fig 4: The Apple Logo based on Golden Ratio Over the Years

In mathematics, Golden Ratio is derived using a geometric method. It starts with a line segment (ab) and divides it into two unequal parts such that the ratio of a to b is equivalent to the ratio of b to a+b. This can be expressed using the following mathematical equation: a/b = b/(a+b)

In a Golden Ratio Rectangle, if you cut off a square with its side length equal to the shortest side of the rectangle, the remaining part of the rectangle will have the same proportions as the original one, no matter how many times you cut it. If you continue cutting the Golden Ratio rectangle to get squares out, you'll end up with smaller squares each time, forming the base for the Golden Ratio spiral. Drawing an arch in each square will create the Golden Spiral. You can also draw circles inside the squares, and all of them will have a balanced relationship with each other, following the 1:1.618 ratio.[7]

[7] https://www.creatopy.com/blog/golden-ratio-in-graphic-design/amp/

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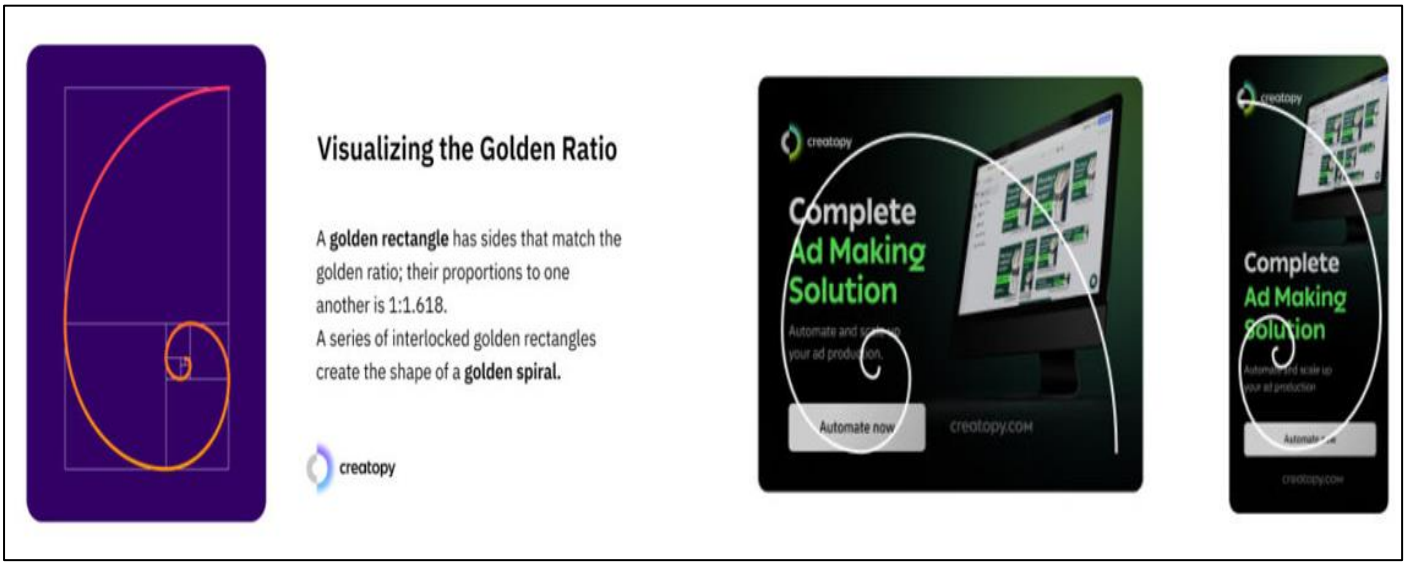

Fig 5: Courtesy – Creatopy
Title - Golden Square & Spiral

A Golden Spiral can also be created by a Golden Triangle; which is an isosceles triangle, by continuously cutting the golden triangle into smaller triangles.

The Golden Ratio is applied extensively in graphic design to enhance visual appeal and effectiveness:

- **Layout and Composition:** Incorporating the Golden Ratio can streamline elements' layout, spacing, and placement while creating a visual interface. Typically, an important message will be placed in the center of the spiral, or, using the golden rectangle as a guide, a two-column layout is preferred while positioning strategic information.

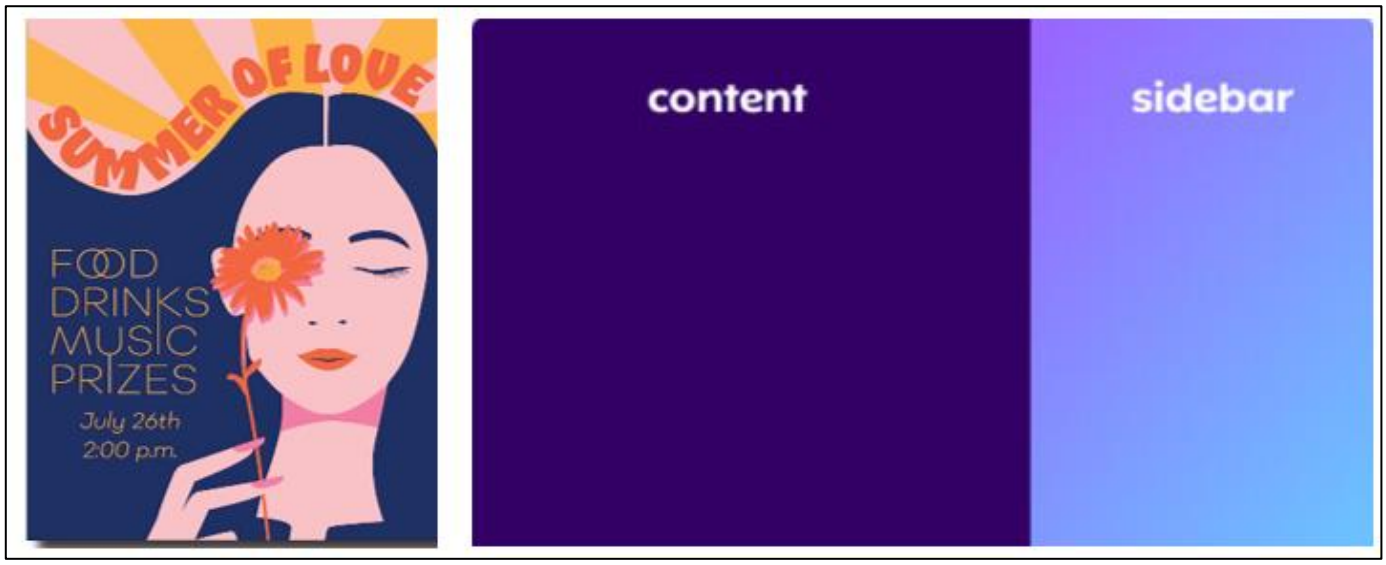

Fig 6: Golden Spiral & Golden Rectangle in Graphic Design

- **Composing, Cropping & Resizing Images:** The rule of thirds or the phi grid is deployed while composing or editing an image. The picture is divided into three unequal sections with a ratio of 1:1.618, closely approximating the dimensions of 35mm film and digital cameras, this method allows for precise placement of image details during photography without the need for subsequent resizing. The ratio follows a 1:0.618:1 distribution.When you're cropping photos a designer can ensure that the picture still looks good after its size is adjusted by positioning the Golden Spiral in the middle or over the main focus of the picture.
- **Typography:** Golden Ratio also facilitates the determination of appropriate font sizes for various layouts of websites, advertisements, landing pages, blog posts, print campaigns etc. Let's say your body copy is 12px. And you multiply that by 1.618, you'll get 19.416, (app 20), to make it visually appealing the header text size should be 19px or 20px.Conversly if your header text is 25px, you can divide it by 1.618 to find the body text (15 or 16 px).

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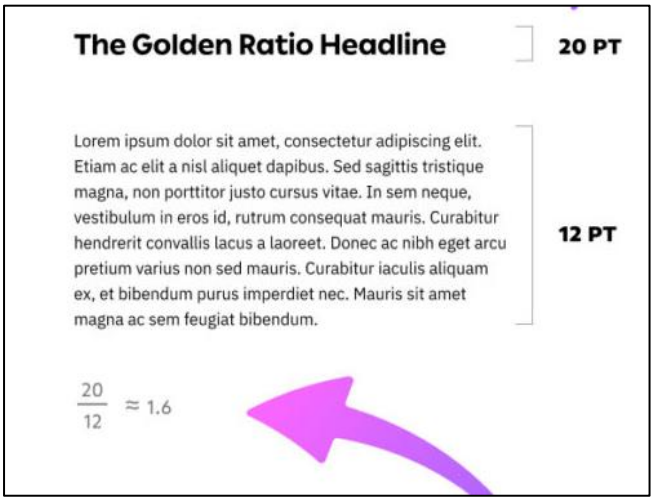

Fig 7: The Header & Body Text Golden Ratio

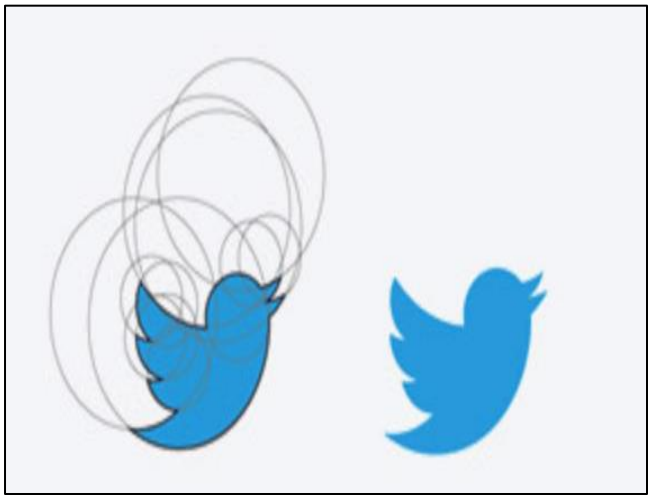
Fig 8: Twitter Logo Designed using Fibonacci Sequence

- **Logo Design:** A well-designed logo becomes a brand's identity so people can understand your core message at almost a glance, and often, Golden Ratios are the prime basis of such logos. Let's study the case of the Twitter bird logo, wherein a circular grid was designed using the Fibonacci sequence by a series of circles that maintain a perfect ratio to each other. These circles were then strategically positioned to form a grid and give it the shape of a bird.

Because of the scientific, even universal nature of the Golden Ratio, designers often use it whether they know it or not. However, it's always good to check to see if your designs sit within the magic of 1.618 so you can take them to the next level of awesomeness!

- **Color Theory** - forms the foundation of design, leveraging the emotional impact of different hues and shades. The mathematical principles are based on the color wheel, wherein analogous colors within 30 to 60 degrees of each other are used harmoniously. The Golden Ratio determines the emphasis each color should receive in the design.

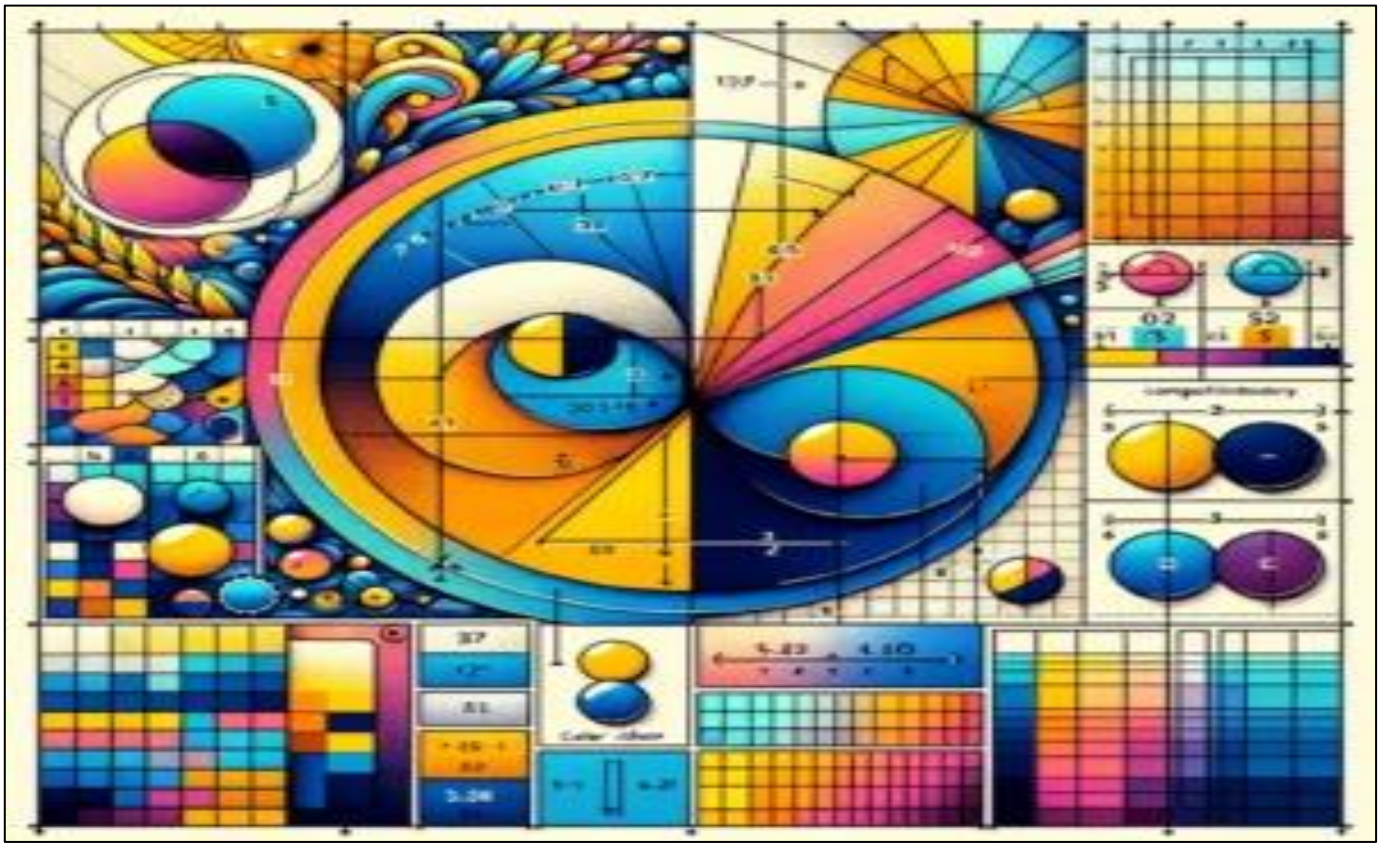
Fig 9: Harmonising Colors by Golden Ratio

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For example, if the primary color could occupy 61.8% of the palette, the secondary color takes up 38.2%, maintaining the Golden Ratio's proportions. Start by identifying the primary color combination that you want to use. This could be a combination of two or three colors that represent your brand or resonate with your website's theme. Once you have your primary colors, you can use the golden ratio to expand your color scheme. To do this, simply multiply or divide the values of your primary colors by the golden ratio (approximately 1.618). This will generate new shades and tones that complement your primary colors while maintaining a sense of proportion and balance.[8] The Golden Ratio also determines the intensity and saturation levels of the colors used by achieving a balanced contrast that highlights the most important elements of the design without overwhelming the viewer.

IV. CONCLUSION

Mathematics underpins geometry, physics, and rendering algorithms that enable the seamless integration of virtual and real environments, providing users with rich and immersive experiences. The foundations of Graphic design and visual computing is clearly based on the mathematical principles of geometry, coordinate geometry, linear algebra, and calculus. In computer graphics, animation or an illusion of motion is achieved by manipulating the position, orientation, and shape of objects over time to create a moving effect. This involves mathematical interpolation, inverse kinematics, and physics-based simulation to generate smooth and realistic animations.

Animators utilize principles from calculus and numerical methods to simulate the dynamics of physical systems, such as rigid bodies, cloth, and fluids, in order to produce lifelike motion and effects.

These basic concepts are the seeds for advanced algorithms and techniques in areas such as image rendering and composition, 2D & 3D graphics, animation, simulation, gaming and virtual reality. As technology progresses, mathematics will continue to play a vital role in driving innovation and expanding the possibilities of visual storytelling and digital artistry in computer graphics.

CONFLICT OF INTEREST

The research paper is for pure academic purposes and has no conflict of interest whatsoever with anyone.

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I would sincerely like to thank my Mother and My teachers at school for helping me understand various Mathematical concepts that are the basis of Graphic Design

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The author is a High School Student of the Pathways World School, Gurugram, India and is looking forward to pursue a career in graphic design and has created many pieces of graphic design and art. He also runs a small business which design graphic art clothes and bean bags.

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