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# Science Within the Art – Aesthetics Based on the Fractal and Holographic Structure of Nature

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## ABSTRACT

This chapter discusses how both art and science proceed from an appreciation for and application of the natural proportions and forms associated with nature. Brief descriptions of the Golden Ratio, fractals, and the holographic metaphor are presented with illustrative examples from geometry, nature, science, and art. This material is followed by an outline of a personal theory of aesthetics based on emulation of natural form, and concepts from Thomas Aquinas and James Joyce. Application of the aesthetics will be illustrated with art from a series of collage entitled, *The Elements in Golden Ratio*. A discussion of the four classical elements (earth, air, fire, and water) and application of the Golden Ratio forms used in the art underscores how the emulation of form in nature is central to the author's artistic process. The author, an artist and scientist, concludes with personal observations on the commonalities between art and science.

**Keywords:** Art, aesthetics, science, form, structure of nature, composition, creativity, Golden Ratio, geometry, Golden Rectangle, regular pentagon, Golden Triangle, phi, Fibonacci numbers, fractal, fractal dimension, fractal noise, self similarity, hologram, holographic metaphor, holographic correspondence, classical elements, collage of backgrounds, proportional polygons, resonance, integritas, consonantia, claritas, proper art

## INTRODUCTION

Science and art are creative vocations, and form and structure are important aspects of both. Form will be defined here as the organizing structure, geometry, and causality we observe in nature. The scientist may use mathematical equations to describe the behavior or structure of a system where mathematics is used to emulate or model the form observed in nature, and the success of a scientific theory is judged according to the elegance and simplicity of its mathematical equations, the falsifiability or refutability of the hypothesis, and how closely the theory actually emulates nature. Form to an artist refers to the geometric arrangement of elements (color, line, shape) in a work of art that defines composition, and I would suggest that the composition of a successful work of art should emulate the forms and structures that appear in nature (Boles & Newman, 1987; Ghyka, 1946).

Science and mathematics have revealed that nature is sublimely organized from the subatomic to the cosmic scale (Mandelbrot, 1977; Ball, 1999; Gazalé, 1999). Many of the structural forms in nature embody the Golden Ratio, a universal constant that has been known and used by artisans, architects, and artists since antiquity (Livio, 2002; Herz-Fischler, 1987; Cook, 1979). The development of fractal mathematics and computer graphics has revealed that nature also creates forms that have a fractal structure (Mandelbrot, 1977). If we observe nature at different size scales, we often see similar fractal structural forms repeated: windblown clouds, wood grain, and sand may all exhibit herringbone patterns, and protein molecules on cellular membranes show structural branching similar to trees (Bak, 1996; Doczi, 1981). Wilbur (1982, 1992) and others have also observed that subtle structures in nature might be organized in a holographic manner, where the structural form of the part suggests the structural form of the whole. For example, the model of the atom (electrons orbiting a nucleus) is repeated at the solar system as well as the galactic scale. Metabolic and excretory functions within the cell are repeated at the organismic and societal levels.

This chapter will discuss how both art and science may benefit from an appreciation for and application of the natural proportions and forms associated with the structure of nature. Brief descriptions of the Golden Ratio, fractals, and the holographic metaphor will be presented along with examples of each from nature, science, and art. I will then outline my theory of aesthetics based on the structure of nature and illustrate the application of the theory using images from my collage series, *The Elements in Golden Ratio* (Craft, 2010a). A discussion of the Golden Ratio forms used in my art work and the classical elements (earth, air, fire, and water) will underscore how the emulation of form in nature is central to my art process. As an artist who is also a scientist, I will conclude with some personal observations of the commonalities between art and science and how an appreciation of natural form can enhance the practice of both.

## THE STRUCTURE AND FORMS OF NATURE

Some of the important structures and forms of nature that both artists and scientists see, hear, feel, and touch may be summarized by reference to the Golden Ratio, fractals, and the holographic metaphor. Form in nature is a profound and humbling subject that has been studied by many great minds since antiquity. As a student of the subject, I recommend Theodore Andrea Cook's 1914 book, *The Curves of Life* (Cook, 1979) and D'Arcy Wentworth Thompson's 1917 book, *On Growth and Form* (Thompson, 1961), as excellent introductory sources and reference material. I hope reading this chapter might encourage the reader to begin or expand upon their personal study of nature's forms by considering the work by scholars, scientists, and artists who made the observation and elucidation of nature's forms their life's work.

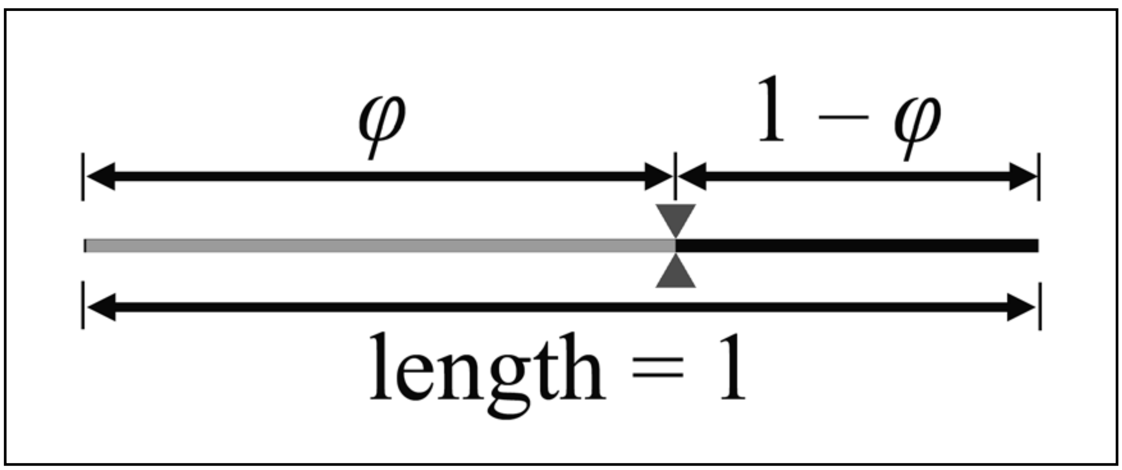
## The Golden Ratio

Many forms in nature feature a very special mathematical constant: the Golden Ratio, or Golden Section (section referring to a cut or division). The Golden Ratio is an irrational number equal to 0.618034... (where the dots indicate that the decimals continue infinitely with no repeated number patterns), and is usually represented by the Greek letter *phi*, $\varphi$, after the sculptor Phidias, one of the architects of the Parthenon. I will begin by showing the algebraic derivation of $\varphi$, discuss some unusual mathematical properties of $\varphi$, describe Fibonacci and Lucas numbers, discuss examples of $\varphi$ in simple polygons studied by the classical Greeks, and then provide examples how $\varphi$ appears in nature and art.

> *Geometry has two great treasures: one is the theorem of Pythagoras; the other, the division of a line into extreme and mean ratio. The first we may compare to a measure of gold; the second we may name a precious jewel. – Johannes Kepler (1571 – 1630)* (Huntley, 1970, p. 23)

**The Extreme and Mean Ratio—** The Golden Section was defined by Euclid as the division of a line segment into "extreme and mean ratio" in Book VI of his *Elements* (Herz-Fischler, 1987). To understand what this means, and to help set up an algebraic equation to solve for $\varphi$, a diagram may be constructed as seen in Figure 1.

Figure 1. Diagram of a line segment of length = 1 (middle gray and black line segment) illustrating how the Golden Section may be calculated by setting up ratios that correspond to the extreme and mean ratios as defined by Euclid. © 2010, Doug Craft. Used with permission.




Another way to state the extreme and mean ratio problem is, how do you section a line segment so that the ratio of the smaller to the larger sub segment is the same as the ratio of the larger sub segment to the whole segment? By assigning 1 as the length of the whole segment, $\varphi$ as the length of the larger sub segment, and $(1 - \varphi)$ as the length of the smaller sub segment (Figure 1), we can set up the following ratios that must be true if $\varphi$ is the Golden Section:

$$\frac{(1 - \varphi)}{\varphi} = \frac{\varphi}{1}$$

If you recall high school algebra, we can simplify this expression of the ratios by multiplying the extremes (the upper left term, $(1 - \varphi)$, and the lower right term, 1), and the 'in between' means (the lower left term, $\varphi$, and the upper right term, $\varphi$) to get:

$$\varphi^2 = 1 - \varphi$$

This expression may be rearranged to obtain the 2nd degree polynomial equation we can use to solve for $\varphi$:

$$\varphi^2 + \varphi - 1 = 0$$

Solving this polynomial using the quadratic formula gives us two solutions, notable for the appearance of the irrational number square root of 5 ($\sqrt{5}$):

$$(-1 - \sqrt{5})/2 \ \text{ and } \ (-1 + \sqrt{5})/2$$

The first solution is –1.6180339..., which we ignore because it is a negative number with an absolute value greater than the length of our line segment. The other solution is the irrational number 0.6180339... I prefer this value for $\varphi$ following Runion (1990), because I like to think of the Golden Ratio as a fractional portion of the whole associated with the number 1. It should be noted that some authors define $\varphi$ as 1.618..., with its reciprocal = 0.618... (Walser, 2001; Huntley, 1970). Here I will refer to the Golden Ratio as $\varphi$ (the lesser) and its reciprocal, $1/\varphi$ as the capital letter *Phi,* $\Phi$ (the greater).

**Odd Mathematical Properties of $\varphi$ and $\Phi$—** There are some peculiar mathematical properties associated with $\varphi$ and $\Phi$, and I will only present a few of the examples that have been described. It is one of the few numbers whose reciprocal can be calculated by adding or subtracting 1 to or from itself:

$$1/\varphi = \varphi + 1 \ \text{ and } \ 1/\Phi = \Phi - 1$$

Other interesting properties are associated with the integer exponent powers of $\Phi$. Table 1 shows that successive powers of $\Phi$ (denoted by the exponent $n$) are calculated by *adding* the previous 2 powers, and that powers of $\varphi$ are calculated by *subtracting* the previous two powers as the following formulas suggest:

$$\Phi^n = \Phi^{(n-2)} + \Phi^{(n-1)}$$
$$\varphi^n = \varphi^{(n-2)} - \varphi^{(n-1)}$$

**Fibonacci and Lucas Numbers—** The Golden Ratio may also be derived using Fibonacci and Lucas numbers. Leonardo Pisano (Leonardo of Pisa, called Fibonacci, c. 1170 – 1250), wrote the *Liber Abaci* in 1202*,* a revolutionary book that introduced the Hindu-Arabic decimal number system and several other mathematical topics to European culture (Hoggett, Jr., 1969; Livio, 2002). *Liber Abaci* included topics on geometry, algebra, and a discussion of a special additive number series we now call the Fibonacci series. This series was illustrated by Leonardo's observation of the way numbers of rabbits increased from a single mating pair. From this example he defined the generalized series where starting with 1 and 1 (or 0 and 1 as used in the Table 1 formulas), successive numbers are determined by adding the previous two numbers, $F_n = F_{(n-2)} + F_{(n-1)}$, to produce the series:

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, ...

Table 1. Properties associated with powers of Φ (upper portion of table), and φ (lower portion of table). Powers of Φ and φ may be calculated based on addition or subtraction of lower powers, or by use of Fibonacci number formulas.

| $\Phi = 1.61803398...$ | | | | | |
|---|---|---|---|---|---|
| ***Exponent*** | ***Calculated Value*** | ***Additive Exponent Formula*** | ***Additive Exponent Value*** | ***Fibonacci Formula*** $\Phi^n = F_{n-1} + (F_n \times \Phi)$ | ***Fibonacci Formula Value*** |
| $\Phi^0$ | 1 | $\Phi^{-2} + \Phi^{-1}$ | 1 | | |
| $\Phi^1$ | 1.61803... | $\Phi^{-1} + \Phi^0$ | 1.61803... | 0 + 1Φ | 1.61803... |
| $\Phi^2$ | 2.61803... | $\Phi^0 + \Phi^1$ | 2.61803... | 1 + 1Φ | 2.61803... |
| $\Phi^3$ | 4.23606... | $\Phi^1 + \Phi^2$ | 4.23606... | 1 + 2Φ | 4.23606... |
| $\Phi^4$ | 6.85410... | $\Phi^2 + \Phi^3$ | 6.85410... | 2 + 3Φ | 6.85410... |
| $\Phi^5$ | 11.0901... | $\Phi^3 + \Phi^4$ | 11.0901... | 3 + 5Φ | 11.0901... |
| $\varphi = 0.61803398...$ | | | | | |
| ***Exponent*** | ***Calculated Value*** | ***Subtractive Exponent Formula*** | ***Subtractive Exponent Value*** | ***Fibonacci Formula*** $\varphi^n = 1 \div (F_n + (F_{n+1} \times \varphi^{-1}))$ | ***Fibonacci Formula Value*** |
| $\varphi^0$ | 1 | $\varphi^{-2} - \varphi^{-1}$ | 1 | | |
| $\varphi^1$ | 0.618033... | $\varphi^{-1} - \varphi^0$ | 0.618033... | $1/(0 + 1\varphi^{-1})$ | 0.618033... |
| $\varphi^2$ | 0.381966... | $\varphi^0 - \varphi^1$ | 0.381966... | $1/(1 + 1\varphi^{-1})$ | 0.381966... |
| $\varphi^3$ | 0.236067... | $\varphi^1 - \varphi^2$ | 0.236067... | $1/(1 + 2\varphi^{-1})$ | 0.236067... |
| $\varphi^4$ | 0.145898... | $\varphi^2 - \varphi^3$ | 0.145898... | $1/(2 + 3\varphi^{-1})$ | 0.145898... |
| $\varphi^5$ | 0.0901699... | $\varphi^3 - \varphi^4$ | 0.0901699... | $1/(3 + 5\varphi^{-1})$ | 0.0901699... |

Dividing adjacent numbers in the Fibonacci series can calculate an approximation of the Golden Ratio. With greater Fibonacci numbers, the ratios of adjacent numbers (for example 21 ÷ 34 = 0.6176... and 89 ÷ 144 = 0.6180...) begin to converge on the irrational value of *φ*. After the 17th Fibonacci number, *φ* is approximated to 6 decimal places (1,597 ÷ 2,584 = 0.618034). Higher Fibonacci number ratios yield changes in estimates of *φ* only in the 7th decimal place and beyond. Curiously, each successive paired ratio alternates between values that are slightly greater than *φ* and slightly less than *φ*, for example: 5 ÷ 8 = 0.625 (> *φ*), 8 ÷ 13 = 0.6153...(< *φ*), and 13 ÷ 21 = 0.6190... (> *φ*).

Table 1 shows that the powers of Φ and *φ* can also be expressed using formulas based on the Fibonacci series. The general formulas for calculating powers greater than 1 of Φ and *φ* are as follows: where $F_n$ represents the Fibonacci number with sequence number, $n$, and I define $F_1 = 0$ in the Fibonacci series,

$$\Phi^n = F_{n-1} + (F_n \times \Phi)$$
$$\varphi^n = 1 \div (F_n + (F_{n+1} \times \varphi^{-1}))$$

Another additive number series that is observed in nature, but less frequently, is the *Lucas Series*. This series also calculates successive numbers in the series by adding the previous 2 numbers, but begins with 2 and 1:

2, 1, 3, 4, 7, 11, 18, 29, 47, 76, 123, 199, 322, 521, 843, ...

The ratios of adjacent Lucas numbers also converge on $\varphi$, but not as quickly as the Fibonacci series. In fact, ratios of adjacent numbers in *all* similar additive number sequences exhibit the property of convergence to $\varphi$ (Livio, 2002; Olsen, 2006).

Fibonacci numbers appear frequently in living and growing things and are the way that nature embodies and approximates $\varphi$. This occurs because as things grow, they usually grow on top of a previous structure, so that the new growth is "added to" the existing structure (e.g., new chambers in mollusk shells or new offspring added to the existing population). Doczi (1981) documents many examples of how Fibonacci and Lucas numbers appear in vegetative life.

Many plants exhibit Fibonacci numbers in phyllotaxis (from the Greek *phullon*, leaf + *taxis*, arrangement). In the early 19th Century Karl Friedric Schimper observed Fibonacci numbers and common divergence angles in phyllotaxis, and the Bravais brothers noted an optimum divergence angle for some plant species of 137.5°. Curiously, this angle is equal to $360°/\Phi^2$ (Livio, 2002). Adjacent bones in your fingers and the positions of many features on the human body are also approximately scaled according to $\varphi$ as Fibonacci number ratios. Fibonacci numbers are also observed in plant and crystal branching, and in spiral structures like the arrangement of rows of bracts on pinecones, petals on an artichoke, and scales on a pineapple (Doczi, 1981; Ghyka, 1946; Thompson, 1961; Cook, 1979).

**The Golden Rectangle—** The Golden Rectangle (GR) is a rectangle whose height = 1 and length = $1 + \varphi$ (aspect ratio = 1 : 1.618...) and is one of the basic Golden polygons. It is featured in the composition of many art works and is often used by architects and designers of industrial goods (Elam, 2001; Droste, 1998). It is also a polygon commonly associated with animal and plant life forms (Doczi, 1981).

An interesting property of the Golden Rectangle (GR) may be seen in Figure 2 where a GR is subdivided into smaller $\varphi$-proportional squares and GRs. The square was called a *gnomon* by Thompson (1961), defined as a polygon that sections a larger polygon to produce another smaller proportional polygon. The square gnomon on the left sections the long side at 1 and leaves a $\varphi$-proportioned smaller vertical $GR_1$ that is also rotated 90°, sometimes called the reciprocal of the original $GR_0$. The GR is the only rectangle with the square as its gnomon (Ghyka, 1946; Runion, 1990; Hambidge, 1967).

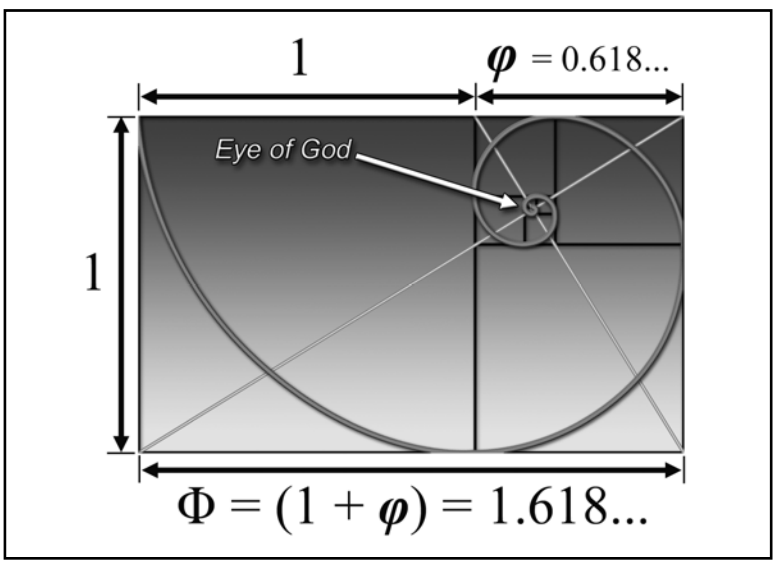



Figure 2. A GR subdivided by $\varphi$-proportioned squares suggests a logarithmic spiral that converges on the Eye of God. The Eye of God is also defined by the intersection of the diagonal of the initial $GR_0$ and the diagonal of the first subordinate $GR_1$ (diagonals are light gray). © 2010, Doug Craft. Used with permission.

This proportional sectioning by the square gnomons can be continued producing smaller and smaller squares and GRs that converge on a point mathematician Clifford A. Pickover called the *Eye of God* (Livio, 2002). The Eye of God is explicitly defined by the intersection of the diagonal of $GR_0$ and the diagonal of the reciprocal $GR_1$ created by sectioning with the 1 x 1 square. The intersection of these diagonals also forms a right (90°) angle. Figure 2 suggests that the 'coiling' square gnomons implied by the proportional subdivision of the GR approximates a logarithmic spiral that converges on the Eye of God. Thus the GR implies a nonlinear curved spiral often associated with living growth (Gazalé, 1999; Hambidge, 1967; Dozci, 1981; Cook, 1979).

**Symmetry of the Golden Rectangle and the √5—** There are further curious properties of GRs that may be observed by investigating the polygons implied within a GR by the diagonals arising from the proportional sectioning seen in Figure 2. This use of proportional subdivisions with squares and GR diagonals was called harmonic analysis by Ghyka (1946). We should not be surprised that the √5 that appeared in the quadratic formula solutions for $\varphi$ would also appear in the internal geometry implied by the diagonals in a GR.

The division of the GR using proportional squares can proceed in 4 different directions (left up, left down, and right up, right down) and thus shows a 4-fold symmetry that implies 4 possible Eyes of God within the GR. Figure 3 shows how the harmonic analysis of a GR proceeds using diagonals and squares revealing the geometric presence of the √5. The smaller 5 stepwise GRs (Figures 3*a* – 3*e,* top) show intersecting diagonals for $GR_0$ (3*a*), the division of $GR_0$ into 2 smaller reciprocal GRs with overlapping squares (3*b*), and the addition of diagonals for the 2 reciprocal GRs (3*c*). The 4 Eyes of God can be seen in Figure 3*d* at the intersections of the diagonals of $GR_0$ and the diagonals of the 2 subordinate GRs. Horizontal and vertical lines that intersect the 4 Eyes of God are seen in Figure 3*e*, and these lines produce some interesting rectangles within $GR_0$ seen in the larger GR Figures 3*f* and 3*g*.

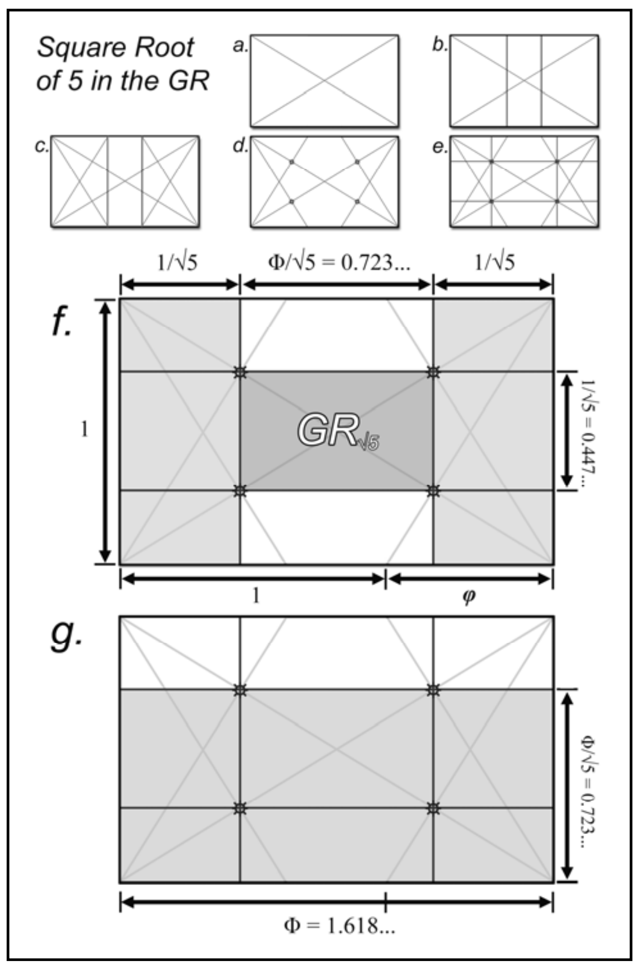



Figure 3. Intersecting diagonals reveal the 4-fold symmetry of the GR (smaller GRs a through e, at top) and the presence of 4 Eyes of God (☼) that form the vertices of the central $GR_{\sqrt{5}}$ (darker gray rectangle in f.). The central $GR_{\sqrt{5}}$ (in f.) sections $GR_0$ to form 2 vertical lighter gray rectangles with aspect ratio of 1: √5. A larger √5 rectangle is also seen in the lower GR (g.). © 2010, Doug Craft. Used with permission.

The upper larger GR in Figure 3*f* shows a shaded central inner $GR_{\sqrt{5}}$ with vertices at the Eyes of God, and both horizontal and vertical sides in √5 ratio (1 : 2.236...) to the *sides* of the original $GR_0$. To either side of the central $GR_{\sqrt{5}}$ are two lighter gray vertical rectangles with aspect ratio of 1 : √5. These are called √5 rectangles and two additional larger √5 rectangles implied by horizontal lines intersecting the Eyes of God may be seen in Figure 3*g* (only the lower √5 rectangle is shaded gray). The √5 rectangle can be thought of as overlapping GRs that share a central square.

**The Regular Pentagon and the Golden Triangle—** Another important Golden polygon considered sacred by the Pythagoreans is the regular, or equilateral pentagon, and the regular pentangle that is formed by the intersection of the diagonals within the pentagon. These polygons are simply full of the Golden Ratio (Lawlor, 1982; Olsen, 2006). The Pythagoreans noted the Golden Section in the regular pentagram but did not mathematically explore the irrational mysteries of $\varphi$ because it could not be expressed as a simple ratio of sacred whole numbers (Lawlor, 1982).

Harmonic analysis of this polygon gives us another Golden Polygon, the acute Golden Triangle (GT) and its gnomon the obtuse GT. Note that a multiplicity of acute GTs (a larger one is shaded in Figure 4), an isosceles triangle with base:side length ratio of 1 : Φ, base angles of 72°, and an acute angle of 36°, are created by the diagonals within the regular pentagon. The pentagon diagonals create 5 large acute GTs with base = Φ and sides = $\Phi^2$, 10 acute GTs with base = 1 and sides = Φ that overlap the base sides of the larger GTs, and 5 acute GTs associated with the points of the pentagram with base = $\varphi$ and sides = 1.

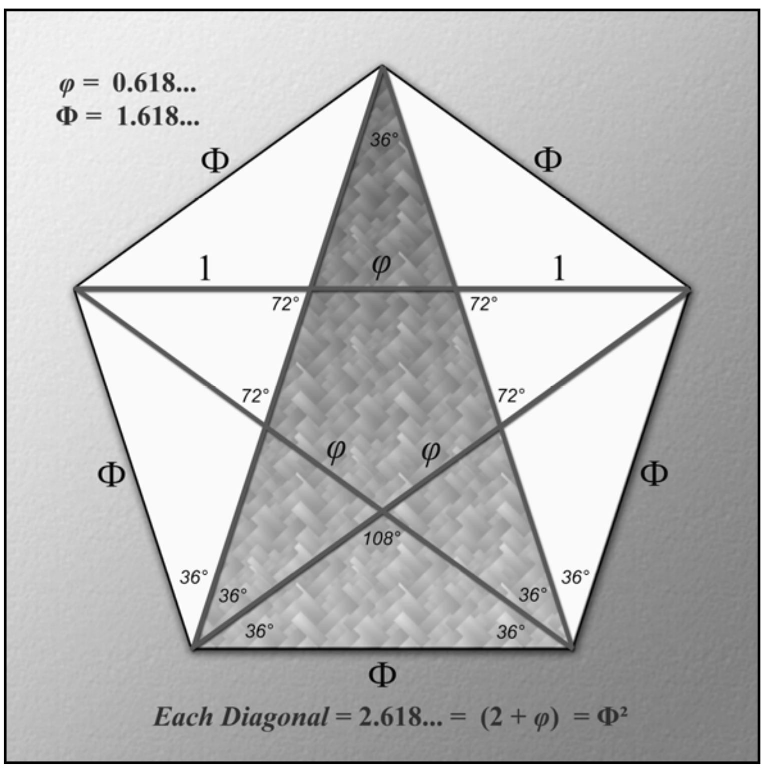



Figure 4. Diagram of the regular pentagon and its diagonals show the Golden Triangle (shaded). This polygon contains many φ-based ratios and was a favorite of the Pythagoreans. © 2010, Doug Craft. Used with permission.

The acute GT can also be proportionally divided like the GR, and this gnomonic division may also be seen within the intersecting diagonals of Figure 4. The gnomon here is the obtuse GT, an isosceles triangle with base:side length ratio of Φ : 1, base angles = 36° and obtuse angle = 108°. This division of the acute GT also produces a rotation of the smaller acute GTs and can be used to approximate the logarithmic spiral.

Both $\Phi$ and $\varphi$ can be used to express the segment lengths *and* the trigonometric functions associated with the angles that appear in the regular pentagon and the diagonal pentagram seen in Figure 4. Table 2 summarizes trigonometric functions for some of the Golden Pentagon angles $\theta$ (Olsen, 2006) expressed as functions of $\varphi$ and $\Phi$.

Table 2. Trigonometric functions for angles present in the regular pentagon and its diagonals expressed as a function of $\Phi$ and $\varphi$ (after Olsen, 2006).

| ***Angle θ*** | ***sin θ*** | ***cos θ*** |
|---|---|---|
| 18° | $\frac{\sqrt{1-\varphi}}{2}$ | $\frac{\sqrt{2+\Phi}}{2}$ |
| 36° | $\frac{\sqrt{2-\varphi}}{2}$ | $\frac{\sqrt{1+\Phi}}{2}$ |
| 54° | $\frac{\sqrt{1+\Phi}}{2}$ | $\frac{\sqrt{2-\varphi}}{2}$ |
| 72° | $\frac{\sqrt{2+\Phi}}{2}$ | $\frac{\sqrt{1-\varphi}}{2}$ |

**The Golden Ratio in Nature—** Besides appearing often in animals and plants, $\varphi$ and its Fibonacci number approximations also appear in many unexpected places elsewhere in nature. Martineau (2001) provides many examples of Fibonacci and $\Phi$ relationships between the orbits and timing of planetary conjunctions and the synodic cycles of the planets with the sun in our solar system. Interestingly, the motions of Venus (orbital period = 224.7 earth days) as seen in the sky from earth, trace out a perfect pentagon around the sun over an 8-year synodic cycle. During this same synodic cycle, Venus has made 13 orbits (8 and 13 are Fibonacci numbers). Similar $\Phi$ and Fibonacci ratios may be observed between the synodic patterns between the Earth, Jupiter, and Saturn.

Topologists have long studied symmetry and plane filling with polygons (tiling), and Islamic artists are well known for their complex tiling using Golden geometric forms (Critchlow, 1999). The regular pentagon cannot be tiled to perfectly fill the space on a plane, so it was assumed for many years that this was a property of all polygons with 5-fold symmetry. However, in 1974, astrophysicist Roger Penrose discovered a plane-filling tiling of polygons that was based on the acute and obtuse GTs and thus contained many $\Phi$ traits. These polygons, called *kites* and *darts*, have 5-fold symmetry and can be combined to fill a plane using *non-periodic* tiling. This is a more complex plane filling, called long-range order, compared to the regular repeatability of periodic tiling with squares or hexagons (Gardner, 1989).

Material scientists working with aluminum alloys in the 1980s unexpectedly found that the alloy crystals showed long-range order and 5-fold symmetry, which they called quasi-crystals. During the 1990s, Steinhardt and Jeong applied a physical model of quasi-crystals that used a form of Penrose tiling with decagons embodying $\Phi$ and found that this mode of crystal packing provided greater stability (lower energy and higher density). The Steinhardt-Jeong model was later confirmed for some alloys using X-ray and electron diffraction (Livio, 2002).

At the small extreme of the size scale, El Naschie (1994) suggested that the subatomic particles arising out of the quantum vacuum field could be modeled using a geometry based on a fractal Cantor set with Φ scaling. While this theory has not been embraced by most physicists, the ubiquity of Φ in nature suggests that Φ may be lurking somewhere in the geometry and organization of the ultra-small quantum universe, as well as other natural processes not yet investigated by science.

**The Golden Ratio in Art—** Because of its observed universality in nature, the Golden Ratio has been long recognized by shamans, priests, and philosophers, and used as a formal element by architects, artists and designers at least since Egyptian civilization and perhaps earlier (Livio, 2002; Gazalé, 1999; Boles & Newman, 1987). Lawlor (1982) noted pentagonal symmetries based on Φ, the √2, and √5 in the Egyptian *Osirion* temple, and the Great Pyramid's sides are composed of a diagonally bisected GR rearranged to form a isosceles triangle. Classical Greek architecture, visual art, and household goods commonly used Golden Ratio forms like the GR (aspect ratio 1: 1.618...) and the √5 rectangle (aspect ratio 1: 2.236...) (Ghyka, 1946; Doczi, 1981; Elam, 2001). The layout of Beijing's Forbidden City uses three adjacent GRs and each of these spaces were further divided into squares and other GRs (Olsen, 2006).

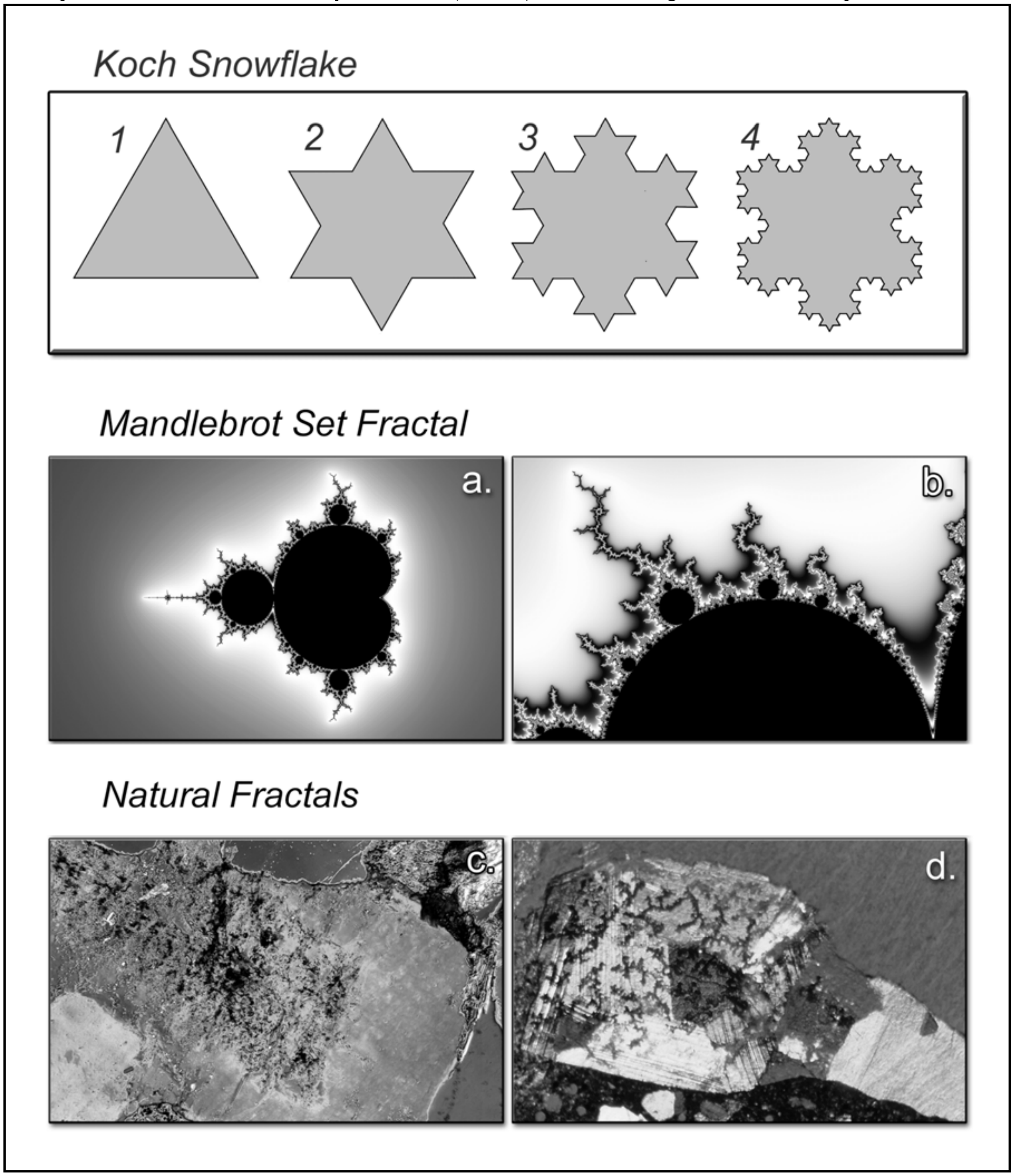
During the Renaissance, the influence of the Golden Ratio on artists began in earnest after the monk Luca Pacioli published his influential book in 1509 about the Golden Ratio, *Divina Proportione*. This book was illustrated by Leonardo Da Vinci, and led to the widespread study of proportions by artists and architects based on Pythagorean musical harmonies and the Golden Ratio. The Golden Rectangle and other proportional rectangles were widely utilized as formal elements by artists during the Renaissance and more recently by Seurat (Smith, 1997), Le Corbusier, and others (Ghyka, 1946; Elam, 2001). The underlying aesthetic implied by these artists is that beauty in art depends on emulation and congruence with natural laws of form as suggested by the Golden Ratio.

## Fractals

The term fractal was coined by Benoit Mandelbrot and refers to a geometric figure that is composed of repeating identical or quasi-identical geometric units that look the same (that is, they are self similar) no matter how much the figure is enlarged or reduced. A mathematical fractal is created when an equation or geometric transformation undergoes iteration to smaller scales – a form of mathematical feedback called recursion (Barnsley & Rising, 1993).

**Self Similarity—** Self similarity is a basic property of fractals that may be visualized in Figure 5. At the top of Figure 5 are the first three recursive geometric iterations of a simple fractal, the Koch Snowflake, that is constructed from an equilateral triangle (the self similar unit). Each iteration involves adding a new equilateral triangle in the middle third of each side and removing the base of the new triangle. Each iteration increases the complexity and length of the perimeter of the Koch Snowflake. In the middle of Figure 5 (a and b) are two views of the mathematically generated Mandelbrot set fractal which features quasi-self similarity. I generated these images using the Ultra Fractal program, version 5 (Slijkerman, 2010). At the bottom of Figure 5 are two microphotos of rock thin sections I shot using a polarizing microscope (c and d) that show examples of natural fractal structures. Interestingly, the image in Figure 5c is reminiscent of images of the earth taken from orbiting satellites.

Figure 5. Examples of fractals. At the top are the first 4 iterations of the Koch Snowflake, a simple fractal created using recursion of a simple geometric rule. Below are two views of the quasi-self similar Mandelbrot set fractal (a and b) showing the entire set (a) and a zoomed image (b). At the bottom are microphotos of rock thin sections by the author (c and d). © 2010, Doug Craft. Used with permission.




**Fractal Dimension—** An additional characteristic of fractals is a property called fractal dimension (Lauwerier, 1991; Mandelbrot, 1977), denoted as *D*. While Euclid tells us that a point has zero dimension, a line has one dimension, a plane has two dimensions, and that we live in a three-dimensional world, dimension for fractals is not a simple concept. From a topological perspective, '2-dimensional' fractals (that can rendered on a sheet of paper) occupy an intermediate dimension between a line (one dimension) and a plane (two dimensions), and hence have a non integer or fractional dimension, *D*, between 1 and 2. In Figure 5, the Koch Snowflake has *D* = 1.26 (Mandelbrot, 1977) and the Mandelbrot set fractal (images a and b) has *D* = 1.64 (Elenbogen & Kaeding, 1989). Coastlines and river networks show a fractal dimension *D* = 1.2 which is similar to the Koch Snowflake (Mandelbrot, 1977). Three-dimensional fractals, such as broccoli florets or a cauliflower, have a fractal dimension between 2 and 3. This in-between dimensionality is one of the characteristics that differentiate fractal geometry from traditional plane and solid geometry.

**Fractal Noise—** Another more subtle way that fractal structures appear in nature is through random processes such as noise in signals, and what we commonly call noise. Audible noise is a complex sound composed of many frequencies that is not perceived as a discrete pitch or note as in music. For example, white noise is sound that contains a random distribution or spectrum of all audible frequencies and amplitudes. No single pitch (frequency) or loudness level (amplitude) appears more often than any other. Natural noises, on the other hand, feature a frequency distribution (or spectrum) with a bias that favors certain pitches and loudness levels (Bak et. al., 1987).

The bias observed in natural noise is called 1/*f* or fractal noise, and sometimes also called pink noise. The reason why natural noise and noise in signals measured over time from complex natural and man-made systems show 1/*f* spectra remains a mystery of physics (Bak, 1996). Yet 1/*f* noise is observed in all electronics devices and circuits (from ceramic capacitors and vacuum tubes to large scale integrated circuits), the movements of automobiles in traffic, and changes in the annual Nile River flood stages (Voss, 1988; Mandelbrot, 1998). Voss and Clark (1975) observed 1/*f* noise in music and speech, noting that most people do not hear tones generated randomly as 'musical.' Widely different types of traditional and classical music from many cultures and historical eras show a similar 1/*f* fractal noise structure.

**Fractals in Nature—** Almost everywhere the scientist or artist looks in nature, fractal forms dominate. Mandelbrot was interested in the self similarity of fractals because this iterative geometry seemed to emulate the complex forms he observed in nature, and the mathematics of fractal recursion is the basis of many computerized special effects that mimic natural landscapes now used in cinema (Voss, 1988). Many of the simple and complex structural features in nature are fractal, or approximately fractal: crystals, glycoproteins on cell surfaces, artichokes, wetting and drying cracks in soil and rock, rock formations, coastlines, clouds, landscapes, and the melodic and time domain structure of music and language (Peitgen & Saupe, 1988; Briggs, 1992).

Nature is complex and random processes are often adjacent to and influencing other processes, introducing a blurring or approximation of the fractal forms that is called statistical self similarity (Mandelbrot, 1977). An example of a random process common in nature is the dissipative influence of entropy which constantly wears and erodes emergent natural structures at all size scales in the universe. This may be seen in the complex abstract shapes of coastlines and rocks, and in the Figure 5 microphotos (bottom images 5c and 5d). Note the dark fractal crack features on the surface of the rock crystal in Figure 5d. These cracks approximate the Julia set dendrite fractal, a fractal closely related to the Mandelbrot set.

**Abstract Art and Fractals—** Figurative and representational art depict objects and living things, and therefore naturally embody the fractal elements of landscapes and living things. However, the subtle fractal structure in nature also gives us an insight into abstract art and the widely held idea that abstraction is somehow *not* related to nature or representation.

Before the industrial revolution, art served as the medium for accurately rendering representational images of reality such as portraits, great events, landscapes, and still lifes. The development of photography through the 19th Century, however, provided a new technological means to render and document life, and this trend gradually allowed painters and sculptors to explore the creation of non-representational or abstract art. With photography providing liberation from the task of representation, many Modernist artists sought to create a 'pure art' free of visual representation that suggested a rejection of the imitation of nature (Klee, 1966). A progression of decreasing figurative content and increasing abstraction in art can be seen from early 20th Century Post Impressionism to Cubism, to Dada and Surrealism, culminating in the mid 20th Century 'pure' abstract images of Jackson Pollock, Franz Kline, Helen Frankenthaler, Robert Motherwell, and Mark Rothko.

The discovery and study of fractals, however, have cast a new light on abstraction in art. Jackson Pollock's famous drip paintings, which have been variously described as chaotic, random, and not art, were analyzed by Taylor and others for fractal properties (Taylor et al., 1999; Taylor, 2002). Taylor mathematically analyzed several of Pollock's drip paintings and found that these art works embodied fractal dimension and had an inherent structure associated with nature. Apparently, despite a non-intentional or random drip painting technique, the patterns created though Pollock's improvisational method embodied a fractal structure. It should not be surprising that humans, being creatures of nature with brains evolved to recognize natural fractal patterns, would also possess an innate ability to create fractal patterns.

I have noted while taking microphotographs that many microscopic images of rock thin sections and chemical crystals have a notable abstract quality, and the same kind of abstract/fractal quality can be seen in satellite images from space, and also at the macro- and landscape-size scales. Note again how the microphoto of a rock thin section in figure 5c resembles Landsat photos from space of coastlines and mountain ranges. The implication is that what is thought of as being "abstract" may really be representational of the deeper and subtle fractal structure of nature, and that perhaps the distinction between representation of nature and abstraction is sometimes a false dichotomy.

## The Holographic Metaphor

The holographic metaphor suggests that nature is organized similarly to the way a laser hologram behaves, where the full dimensional structure and form of an object is encoded throughout the hologram's complex interference pattern at the very small scale: that the whole is embodied in the part. By analogy, we could surmise that nature is structured holographically such that small forms and systems in the universe emulate the structural form of the whole. This is similar to the concept of self similarity in fractals, but is not applied with the same kind of mathematical rigor.

The idea that the part embodies the whole and the whole is present within the part is not new. It has been associated with many different philosophical and mystical religious traditions (Suzuki, 1973; Campbell, 1991a). Carl Jung's concept of the collective unconscious is a psychoanalytic version of the idea.

**The Laser Hologram—** The term "holographic" refers to the photographic laser hologram. To create a hologram, a laser beam, a focused and coherent light of a single wavelength, is split using a partially transparent mirror. The reflected beam is directed to illuminate an object and the laser light that bounces off the object is recombined with the original non-reflected beam. This recombination creates a complex *interference pattern* that is then captured on a photographic plate. When the photographic plate is developed, the original object is not visible and we instead see the interference pattern: a complex matrix of finely detailed whorls and apparent smudges that were created when laser light waves bouncing off the object at many different angles (and with varying reflectances) interacted with the non-reflected laser light waves (Kock, 1981).

An analogy for the way the holographic interference pattern appears could be the collection of waves generated on a pond when different sized raindrops hit the surface during a shower. As the circular water waves propagate outward from each drop's impact, the waves collide with each other, sometimes in a constructive (additive) way creating larger waves, and sometimes in a destructive (subtractive) way creating smaller waves or even flat surfaces. The rippled surface of a pond during rain represents a complex interference pattern, and a photograph of such a pond from above approximates the way a hologram plate might look.

The strangeness of holography begins when the laser light is beamed back through the interference pattern on the photographic plate. Diffraction of the laser light by the interference pattern re-creates a projected image of the original object that appears some distance beyond the plate, not as a flat 2-dimensional object like a photograph, but as a complete 3-dimensional representation. You can walk around the projected hologram and the details of the object are visible much like the original object would have been seen. So, the interference pattern on the flat photographic plate contains *all* the information (shape as viewed from different angles, reflectance properties, dimensionality) associated with the object originally under laser illumination.

**From Optical Phenomenon to Metaphor—** The hologram becomes the basis for a metaphor of universal structure because of a unique property of the hologram interference pattern. If the photographic plate is cut into four equal sections and the laser is again beamed though any one of the plate quarters, the original object once again appears, complete, in the projected hologram. The sectioning process could be repeated into 16th- or 64th-sized sections of the plate and the result would be the same. In actual practice, the resolution of the projected hologram will become fuzzier as the sections become smaller and smaller, but even the smaller sections of the hologram still contain most of the information (shape, texture, etc.) needed to recognize the object.
This suggests that the dimensional and reflectance information about the complete object is imbedded throughout the interference pattern *practically down to the atomic scale*! Each minute part contains the information about the whole. This is the basis for the analogy with the structure of the universe, wherein, for example the structure of the galaxy is implied in the atom.

**Metaphor vs. Theory—** The idea of the universe as a giant hologram (or holographic system) is a powerful integrative concept that helps us understand nature and form. It remains a metaphor because it is not yet a fully falsifiable or predictive hypothesis in the scientific sense. However, since the development of holography in 1947 by physicist Dennis Gabor (who later won the 1971 Nobel Prize for the discovery) there has been notable scientific interest in the subject (Talbot, 1991; Wilbur, 1982). Three scientists who have proposed holographic models are the neuroscientist Karl Pribram (b. 1919), physicist David Bohm (1917 – 1992), and biologist Rupert Sheldrake (b. 1942).

Karl Pribram observed hologram-like behavior during his studies of memory and cognition. Pribram observed that memories were not localized in specific small regions of the brain, then called *engrams*, but were instead distributed over the 3-dimensional peripheral structure of the brain. He suggested that information was being encoded throughout the brain in a quantum-scale hologram. Pribram called this model *holonomic brain theory*, and speculated that our sensory organs and their associated brain structures were actually manifesting what we see, feel, and hear as reality by creating a three-dimensional representation from an external universal hologram (Pribram, 1991).

Observing that many subatomic particles have very short life spans, manifesting measureable properties and then disappearing back into the quantum vacuum field, David Bohm suggested that this field, which he called the *implicate order*, was a dynamic hologram he called the *holomovement* (Bohm, 1995; Wilbur, 1982). All matter and phenomena we observe in our 3-dimensional reality, which he called the *explicate order*, arise from the fluctuating energy field of the universal and nonlocal implicate order holomovement. Bohm suggested that the holomovement is the fundamental ground of matter and causality, rather than the collection of subatomic particles, atoms, and molecules that are proposed to make up what we perceive as solid matter and dimensionality. He also noted that the idea is philosophical, but is certainly a reasonable deduction based on the nonlocal behavior of nature observed at the quantum level (Wilbur, 1985).

Biologist Rupert Sheldrake has also proposed the holographic metaphor in a tangential manner. Sheldrake posits nonlocal organizing fields that govern forms and behaviors in nature called *morphic fields*. Nonlocality suggests that the fields communicate instantaneously across distances and likely operate at the quantum scale. These hierarchically nested fields are an underlying causal structure associated with organisms, postulated to coordinate the shape and behavior of the individual, the group, and the species (Sheldrake, 1981). For example, there is a morphic field associated with an individual bird, a related field associated with the local flock, and another field for the entire species. Information between these nested fields is exchanged and communicated by what Sheldrake calls *morphic resonance*, thus implying a wave structure to the fields.

Sheldrake suggested that morphic fields are formed and reinforced by repetition that he calls habits of nature (Sheldrake, 1988). According to his theory, the difficulty in crystallizing newly synthesized organic compounds arises because of the variety of possible stable crystal forms with similar stable (degenerate) energy states. Sheldrake notes that after initial crystallization, other chemists find that the compound crystallizes much more quickly and adopts a single stable form. Plant hybrids also go though an exploratory phase where different leaf shapes and phyllotaxis initially appear, but within several generations, the hybrid adopts a leaf pattern that becomes dominant (Sheldrake, 1988). To date, the hypothesis of morphic fields has been tested experimentally with ambiguous results.

**Nested Structures—** The holographic metaphor suggests that structural organizing forms and processes of the universe repeat themselves in a nested hierarchical pattern. Structures at higher (or more complex) levels contain structural elements and patterns associated with simpler systems. These more complex structures are themselves part of larger scale structures. Ken Wilbur calls these nested and similar organizational structures *holons* (Wilbur, 1982, 1992) after Sheldrake (1981). Examples of nested holons are:

cell → organism → family → tribe → society
quantum particles → atom → matter → solar system → galaxy → meta galaxy

The solar system shows structural similarities to the atom, which is also suggested in the galactic organizing structure. An organism repeats the functions of individual cells (metabolism, catabolism, reproduction), which are also repeated at the social level of organization.

Cohan and Cole (2002) suggested that hurricane Hugo in 1989 caused increased marriages, divorces, and childbirths in disaster areas in South Carolina compared to areas not affected by the hurricane. While these decisions may be a collective result of people individually reassessing their life plans in light of a tragedy, perhaps there is also a morphic field that is also causing the country or region to respond to disaster much like an organism responding to an injury or a cell to an invading virus. Similarly, one might think of empires re-enacting feeding by "devouring" and "absorbing" other nations and cultures. The intermarriage following conquest might be considered a form of genetic assimilation, or "digestion." These examples are suggestive of the nested holons associated with the holographic metaphor.

**Other Holographic Correspondences—** I think that the holographic metaphor can also be observed when similar mathematical equations or organizing principals can be applied to different phenomena at different size scales. I call this a holographic correspondence. For example, diffusion equations may be applied to model chemical transport processes that occur at cell membranes, the mixing and dilution of pollutants in a body of water, or the dissemination of ideas in a population (Banks, 2010). The quantum field equations of high energy physics (the Standard Model) can also be applied to condensed matter physics (solids and liquids) (Marder, 2010). Periodic behavior observed with the atomic elements (as seen in the Periodic Table of the Elements) can also be seen among subatomic particles like quarks, leptons, and bosons (Gell-Mann & Ne'eman, 2000). Logistic equations (growth curves) can be used to describe the growth of individuals, populations of individuals, and processes such as the expansion of technology and resource depletion (Modis, 1992).

Consider the vibration of strings and musical intervals, which were studied by the Pythagoreans, and the correspondence with electrons in an atom. A vibrating string will have a fundamental pitch associated with the entire string moving back and forth in one motion. But the string will also vibrate in a more complex manner, with waves and nodes associated with integer fraction divisions of the string length (one-half, one-third, one-fourth, etc.). These integer division vibrational modes create higher harmonic frequencies that are not as loud as the fundamental pitch, but contribute to how the string sounds – the timbre. The electrons in an atom also have a "harmonic" structure with discrete levels associated with the energies of the electrons in orbitals surrounding the nucleus, usually electromagnetic energies in the visible and ultraviolet frequencies that determine the physical and chemical properties of the atom. Erwin Schrödinger used the analogy of a vibrating string to help develop the wave equation for describing the electron in the hydrogen atom. This is the basis for the theory of quantum mechanics, that the electron behaves in some ways like a vibrating string on a guitar.

**Theory as Metaphor—** The holographic theories advanced by Pribram, Bohm, and Sheldrake are not yet widely accepted by neuroscientists, physicists, or biologists as the current scientific paradigm. After all, many physicists note that quantum mechanics and general relativity do a good job of predicting the results of experiments and observed data. Yet, the active search for a unified field theory able to join these separate views of reality suggests that scientists are also seeking a new level of causation and its underlying mathematics that will imply universality and wholeness. Perhaps unification in physics will be found in the mathematics of a model that refers to the holographic metaphor. My fantasy is that the new unified field theory will include the Golden Ratio and some kind of fractal scaling.

## AESTHETICS BASED ON THE STRUCTURE OF NATURE

Aesthetics may be defined as the philosophy of art creation and art appreciation. To an artist, aesthetics is usually a set of principles that defines what art is (or should be), the purpose of art, the definition of and attributes associated with form, beauty, creativity and inspiration, and the role the of the artist in society. Theories of art are not subject to validation or falsification in the manner associated with scientific theories, yet philosophy applies its own criteria of logic, elegance, and internal consistency. A theory of aesthetics is important because it establishes standards and goals for artists, guidelines for assessing art work by the viewing public, and provides for a deeper appreciation of the mystery associated with human creativity. Edward Tufte also suggests that scientists could benefit from aesthetics through the application of form, composition, and elegance when they create data visualizations (Tufte, 1983, 1990, 1997).

## My Personal Aesthetics

My personal aesthetic theory, which I have developed using the ideas of many others, includes the following elements and goals:

1. The higher purpose of art is spiritual and belongs to the domain of consciousness and the universal mystery of life. With proper intention, the creation of art can function as a spiritual practice.

2. The higher calling of the artist is to create *proper art*, as defined by James Joyce in *A Portrait of the Artist as a Young Man* (Joyce, 2010). By creating proper art, an artist serves culture by revealing beauty and harmony through his or her art.

3. Form and composition are the fundamental elements of a work of art, and form in art should emulate the forms, proportions, and structures we observe in nature. Because of resonance or harmony, a work of art with properly executed form is able to embody and transmit aesthetic ideas to the viewer.

4. The creation of proper art is enhanced if the skilled and experienced artist works in a non-personal or meditative state of mind and allows for improvisation.

**The Spiritual in Art—** Science may account for many examples of causality (the 'how') and deepen our appreciation of nature's forms, but only human consciousness can contemplate the meaning (the 'why') of the universe we experience. I define as spiritual those issues associated with consciousness, meaning, mystery, and creativity. I also refer to spiritual as being contemplative rather than religious, and this is what I mean by the term "the spiritual in art."

An artist or scientist who has experienced the sensation of inspiration – the 'eureka moment' – during his or her work likely suspects that creativity is often inexplicable and not a product of intellectual reason or planning. In fact, creative insight often happens in spite of the intellect and at times when the mind is unoccupied with the problem at hand. The origin of creativity is unknown, hence mysterious, and thus I would consider it a part of the spiritual domain.

There is another context where a creative vocation may be associated with the spiritual, and that is when a person intentionally uses the activity as a personal *spiritual practice*. A spiritual practice can be defined as a set of activities a person follows regularly to develop wisdom or relationship with the divine, such as a yoga discipline. The Hindus developed a variety of yoga practices to account for the different spiritual inclinations of people. Bakhti Yoga is a devotional approach that relies on chanting the name of an avatar (an incarnation of God) such as Krishna. Raja Yoga is a practice based on meditation and experiencing *samadhi*, the enlightenment experience associated with the union of the personal soul (*Atman*) and the universal soul (*Brahman*). Karma Yoga is the intentional use of work or the unselfish performance of duty as a spiritual practice (Vivekananda, 1953).

The idea that art could be considered a spiritual activity was discussed by Wassily Kandinsky (1866 – 1944) and other Bauhaus artists such as Johannes Itten (1888 –1967) and Paul Klee (1879 – 1940) who were influenced by theosophy and Buddhism (Droste, 1998). In his 1911 essay, *Concerning the Spiritual in Art*, Kandinsky suggested that the artist must allow *inner necessity* to define the visual content and form of works of art (Kandinsky, 1977). I interpret inner necessity similarly to Zeno of Citium's (c. 333 BC – 264 BC) concept of the logos (λόγος), as an active animating force of reason or divine consciousness in the universe (Pearsons, 2010).

The model of creation espoused by these artists is not a personal act grounded in the ego or intellect, but rather an intuitive, nonpersonal, and even mystical process whereby a universal consciousness is allowed to animate the work of art. Itten further suggested that a calm and meditative state of mind was needed before inner necessity could manifest a suitable form through art, and he had his classes at the Bauhaus perform meditation exercises before working on art projects (Itten, 1975, 1997; Droste, 1998).

This nonpersonal model of art creation bears some similarity to the traditional practice of shamanism, though to a much lesser degree. The shaman receives knowledge and insight during trance states entered via prolonged privation, chanting, dancing, or ingesting psychoactive plants. While the artist does not need to enter the profound trance state of the shaman, both the artist and shaman are revealing new knowledge to their culture, and are thus performing similar duties (Campbell, 1991a).

**The Creation of Proper Art—** James Joyce formulated an aesthetic theory via his protagonist Stephen Dedalus in *A Portrait of the Artist as a Young Man*, that I have incorporated into my philosophy of art. For his aesthetics, Joyce drew upon Aristotle (384 – 322 BC) from his *Poetics* and *Rhetoric* (Rhys Roberts & Bywater, 1984), and Thomas Aquinas' (1225 – 1274) *Commentary on the Divine Names* (Campbell. 1991a; Eco & Bredin, 1988).

Joyce builds on Aristotle and Aquinas when he defines *improper art* and *proper art*, suggesting that the goal of true artists should be to create proper art. Improper art is either *pornographic*, an image causing desire in the viewer for a tangible object in the image, or it is *didactic*, causing fear and loathing in the viewer. Accordingly, all advertising imagery would be termed pornographic, and advocacy art, political art, and propaganda would be considered didactic. Improper art provokes in the viewer either a movement desiring or being repelled by the image and is thus termed *kinetic* by Joyce.

Proper art, on the other hand is *static* and should produce what Joyce called "esthetic arrest," an impassive capture or rapture of the viewer's attention. To paraphrase Aquinas, proper art embodies a sublime beauty, "something the mere apprehension of which gives pleasure." (Eco & Bredin, 1988, p. 36). Proper art has no application or purpose other than to act as a transmitter of the aesthetic idea or inner necessity, and thus is associated with the spiritual or transcendent. Because proper art functions as a object of contemplation, rather than a means to excite or create fear, its content is better suited to the domain of mythology, universal and human archetypes, and trancendent truths and beauty.

Joyce further defined proper art by referring to three characteristics of beauty suggested by Aquinas: *integritas* (wholeness), *consonantia* (harmony), and *claritas* (radiance) (Eco & Bredin, 1988; Joyce, 2010). Art having integritas suggests that that the work is complete in and of itself and represents a distinct wholeness. The artist selects the boundaries of the art work and thus frames the work to create a visual field that denotes its separateness and wholeness. Consonantia, which Joyce calls the "rhythm of beauty," refers to the harmonious placement of objects, colors, lines, and space within the art work – a statement of the importance of form and composition in art. Successful inclusion of consonantia in the art work suggests that the art can create radiance and aesthetic arrest in the viewer, and thus function as proper art (Joyce, 2010; Campbell, 1986, 1991a).

**Form in Art and Nature—** Following Joyce and Aquinas, I would suggest that form and composition are *fundamental* to artistic beauty, and I define this sublime beauty as harmony or resonance with the forms, geometry, and structures of nature. This is not beauty as a cultural or personal idea of attractiveness, but rather a correspondence with or emulation of nature. Paul Cezanne (1839 – 1906) noted that, "Art is a harmony parallel to nature," (Campbell, 1991a, p. 250). The Golden Ratio and the natural proportions in nature were significant inspirations to the classical Greeks, the artists of the Renaissance, and Bauhaus artists also made the connection between natural forms, the Golden Ratio, and design aesthetics (Droste, 1998; Elam, 2001). In 1950, Le Corbusier published *Le Modulor*, his theory of design in architecture based on his analysis of the Golden Ratio and proportion in the human body (Le Corbusier, 1996).

**Resonance and Form—** Another reason I assign importance to form in art is related by analogy to one of the ways energy and information are transmitted and exchanged in nature: through the process of *resonance*. The physical universe we can sense and all energy are vibratory and have the wave properties of wavelength and frequency. Einstein showed us that matter and energy are equivalent, so both have wave properties. Light is vibratory electromagnetic energy – sound is vibratory mechanical pressure energy. Solid objects have wave properties because they are composed of atoms that contain particles having wave properties. I would suggest that consciousness and thought are also vibratory and have wave properties.

We do not yet know the nature of thought waves or how they might propagate. Insight, reason, memory, perception, and other conscious mental functions likely have an electromagnetic component associated with neurochemistry and the electrical activity of the neural networks in the brain, but we do not yet understand even the physical mechanisms of thought or consciousness. The suggestion that thought has wave properties is thus based on analogy to nature.

In physics, resonance is the sympathetic vibration of an object exposed to oscillating energy waves. You may have observed resonance in certain objects (a table top for example) when music is loud and when specific pitches sound. The pitch that causes the object to vibrate is called the *resonant frequency*. Everyday objects have an acoustic resonant frequency associated with their shape, size, and physical properties. The energy of sound waves at a particular frequency causes physical vibration in the object that has the same resonant frequency. Microwave ovens cook by causing the chemical bonds in water molecules to vibrate and generate heat as they resonate with the microwaves. To properly broadcast and receive radio signals, antennas have to have lengths that are related to the wavelength of the broadcast signal. FM radio waves are around a meter in length, and so is the wire antenna you connect to a radio receiver.

Following this analogy, if thought, the aesthetic logos, or internal necessity are vibratory and have wave properties, then perhaps the form of the art work assumes an important role. Analogous to a radio antenna having a specific length to receive radio waves of a given wavelength, the form of the artwork needs to have certain geometric properties that enable resonance with the thought waves of internal necessity. If the artist creates a form harmonious with the idea (consonantia), then the art work will resonate with the aesthetic logos, and can potentially *transmit* the idea. A person viewing the artwork in a suitably receptive mind state –

*attuned*, so to speak, to the resonant frequency of the artwork – might then experience the idea through aesthetic arrest. In this model, the form of an art work can function as a transceiver of aesthetic thought. As Plotinus (204 – 270) noted (my emphasis):

> *I think, therefore, that those ancient sages, who sought to secure the presence of divine beings by the creation of shrines and statues, showed insight into the nature of the All; they perceived that, though this Soul is everywhere tractable, its presence will be secured all the more readily when an* ***appropriate receptacle*** *is elaborated, a place especially capable of receiving some portion or phase of it, something* ***reproducing or representing it*** *and serving like a mirror to catch an image of it.* (Plotinus, 1991, p. 264)

**State of Mind, Improvisation, and Inner Necessity—** The final element of my aesthetics involves the state of mind appropriate to the creation of proper art. While I believe that art work should assume a form dictated by internal necessity, the expression of the idea can be limited by the nature and quality of my conscious state (which can impose distortion on the idea being manifested). I agree with Itten that a non-personal and meditative mind state is central to creativity.

At the core of my art making process is the simple fact that the repetitive nature of preparative artistic activities – like stretching canvas, or cutting out collage images – helps enable a meditative, nonpersonal state of mind. Practitioners of Zen call this *Beginner's Mind* (Suzuki, 1973) and a neurophysiologist would say that our brain's electroencephalograph was exhibiting delta waves. Someone exercising might call it an endorphin high. As a working scientist, I found that entering and validating data, and preliminary analysis and graphing of data sets also produced this receptive state of mind. As a musician, I found that practicing scales and arpeggios creates a meditative state. Regardless of how the state is attained, the important point is that you are not thinking, judging, or analyzing. You are in a *receptive* state, ready to allow internal necessity to manifest an integrative idea or artistic form.

This emphasis on the meditative state of mind during the actual execution of the art work does not mean that intellectual or analytical modes of thinking are not a part of the overall activity of the artist. Artists, like scientists, must study and learn fundamental skills and the history of their vocation. They must also develop an understanding of the theories they apply and test. Manual skills and facility with the tools and methods of the creative endeavor must be learned and mastered. During art critique, the form and composition of an art work are often analyzed and discussed in relation to use of line, color, and space. This process is no different in spirit to peer review, where the insights and expertise of colleagues are solicited to improve the work of the scientist.

Assuming the proper state of mind, the last element of my creative process is the practice of improvisation, which I define as spontaneously creating forms while in a nonpersonal or meditative mental state. Musicians are usually more familiar with improvisation, but the process can be applied during any creative activity. However, with improvisation the idea of skill and experience must be noted. The artist's skills in drafting, color, and composition are as essential to the quality or success of an art work as a scientist's mastery of his or her field, mathematics, and experimental method. With slight paraphrasing, Louis Pasteur's comment "In the field of observation, chance favors only the mind which is prepared." (Holmes, 1961, p. 39) also applies to improvisation in the arts.

## AESTHETICS APPLIED – *The Elements in Golden Ratio*

I have always been fascinated by images of nature that embody an abstract and fractal quality, and I often use these sorts of images as backgrounds for my figurative collages. When I started studying the Golden Ratio in the late 1990s, I developed an approach for collage creation that combined abstract and fractal-like images of nature from various size scales using sets of Golden proportional squares, GRs, √5 rectangles and other combinations of Golden polygons. The images were arranged in a manner more associated with flat pattern design, tiling, and quilting rather than my previous figurative collages, so I called this work process the *collage of backgrounds* (Craft, 2010b).

The formal aesthetics behind the collage of backgrounds is based upon the use of polygon forms that feature the Golden Ratio. These forms provide a frame and scaling that inherently embody universal natural proportion and form. The selection of a set of Golden forms for collages is a way of establishing formal boundaries that helps define integritas for the work. The cropping and placement of images within the Golden polygon forms is based upon traditional compositional methods (Arnheim, 1988), the use of centers, grids of thirds, and the dynamic symmetry (Hambidge, 1967) associated with the Golden sub divisions, diagonals, and power points (such as the Eyes of God) implied within the polygons. These additional elements of compositional design help enhance the harmony of form, ideally promoting consonantia.

The use of natural images from many size scales that embody fractal forms is another emulation of natural structure associated with self similarity and the holographic metaphor we see in nature. These formal elements, along with the dimensions and shapes of the collages, should function (according to my theory of aesthetics) as good antennas for inner necessity. Assuming I do my job as an artist working in a nonpersonal meditative state, my work may have claritas and function as proper art.

### The Classical Elements

While involved in the process of digitizing my photographic film and slide stock in 2002, I realized that my image selections had been unconsciously following the themes of the classical elements earth, air, fire, and water. This was the inspiration that led me to create a series of collages using the collage of backgrounds based on the classical elements called *The Elements in Golden Ratio* (the *Elements* series) (Craft 2010a).

I can remember being taught in the 1960s that the ancient concept of the elements was a silly or foolish idea, especially considering that we moderns have the scientific quantum model of the atom and the periodic table of the elements. This unfortunate bias ignores the powerful symbolic meanings associated with metaphor, and assumes the ancients defined science like we do today. The ancient elements were part of creation mythology and ontology and were considered attributes associated with matter, perception, and phenomenal causality. If anything, I think the ancients were more likely describing what science now calls the different states of matter: solid (earth), liquid (water), gas (air), and plasma (fire). So, perhaps our scholarly ancestors were not as ignorant as modern prejudice might suggest.

The elements represent an ancient idea that invokes the concept of 4 or 5 essences constituting matter in the physical universe, or as active forces that represent change and transformation. The Babylonian creation myth in the *Enûma Eliš* (c. 1700 – 1100 BC), describes 4 elements: the sea, earth, sky, and wind – likely the earliest written example of the concept (Campbell, 1991b).

Indian civilization developed concepts of the elements based on the Vedas, which originated as oral tradition c. 1500 BC to 1000 BC. Samkhya philosophy elaborated on the concept of the five great elements, *pancha mahabhuta*, in both their subtle and gross appearance as *kshiti* or *bhūmi* (earth), *ap* or *jala* (water), *tejas* or *agni* (fire), *marut* or *pavan* (air or wind), *byom* or *akasha* (aether or void). This scheme accounts for the perception of the world using the 5 senses. Samkhya describes how all phenomena and forms originate as cosmic matter, *prakṛiti*, that first manifests in the 3 *gunas* (*sattva* – serenity and calm, *rajas* – activity and emotion, and *tamas* – darkness or sorrow), which in turn generates the 5 elements (Zimmer, 1946).

The pre-Socratic philosopher Empedocles of Sicily (c. 490 – 430 BC) was the first Greek to write of the division of matter into 4 components that he called 'roots.' Citing Empedocles, Plato (c. 427 – 347 BC) first used the term 'elements' in *Timaeus* for this division of matter into four archetypes (Kalkavage, 2001). Aristotle discussed the elements in his *On Generation and Corruption*, and *Physics*, and suggested a 5$^{th}$ element he called quintessence or aether to denote non-materiality. Aristotle also discussed sense qualities associated with the elements (hot, cold, wet, and dry) (Lloyd, 1968; Waterfield, 2008).

My *Elements* series collages follow the tradition of choosing a metaphorical interpretation of the classical elements as a meditation on nature. This theme has been an inspiration to artists in the past. In 1737, the French baroque composer Jean-Fery Rebel (1666 – 1747) composed a ballet, *Les Elémens*, and Swiss composer Frank Martin (1890 – 1974) wrote a collection of symphonic etudes for orchestra called *The Four Elements* (1964). The French author Georges Bernanos (1888 – 1948) also frequently used the imagery of earth, air, fire and water in his novels (Morris, 1989).

### Creating *The Elements in Golden Ratio*

All collages in the *Elements* series were created digitally using various versions of Adobe Photoshop on a Windows PC. The first step in creating the collages was to select four images from my own or an open source archive: one each of earth (E), air (A), fire (F), and water (W). I used images stored as uncompressed TIF files with dimensions of 3400 x 2100 pixels. These dimensions are based upon Fibonacci number multiples and approximated $\varphi$ to 2 decimal places. An image resolution of 254 dots per inch (dpi, 100 dots per cm) will yield GR prints sized at 34 cm x 21 cm (13.4" x 8.27"). I selected four sets of elemental images that were used to create four sets of 21 collages each. Each set also used several additional images of life or living things (which can be thought of as a fifth element representing the combination and interaction of the other 4 elements) for selected collages in each set. The total for the series was 84 collages plus all the source images.

Figure 6 shows the Golden polygons I used for templates following the work process of the collage of backgrounds. The fundamental basis of this approach is the use of square images and proportional polygons that are in $\varphi$-ratio to each other. In the digital domain, the basic square used in my work is 2100 x 2100 pixels and these squares were compositionally cropped from each of the E-A-F-W source images in each set. Subsequent reductions in dimensions of squares were calculated using the √5-based value for $\varphi$ to produce squares with dimensions 1298 x 1298, 802 x 802, and 496 x 496 pixels. These proportional squares and GRs are combined to create all of the forms seen in the *Elements* collages.

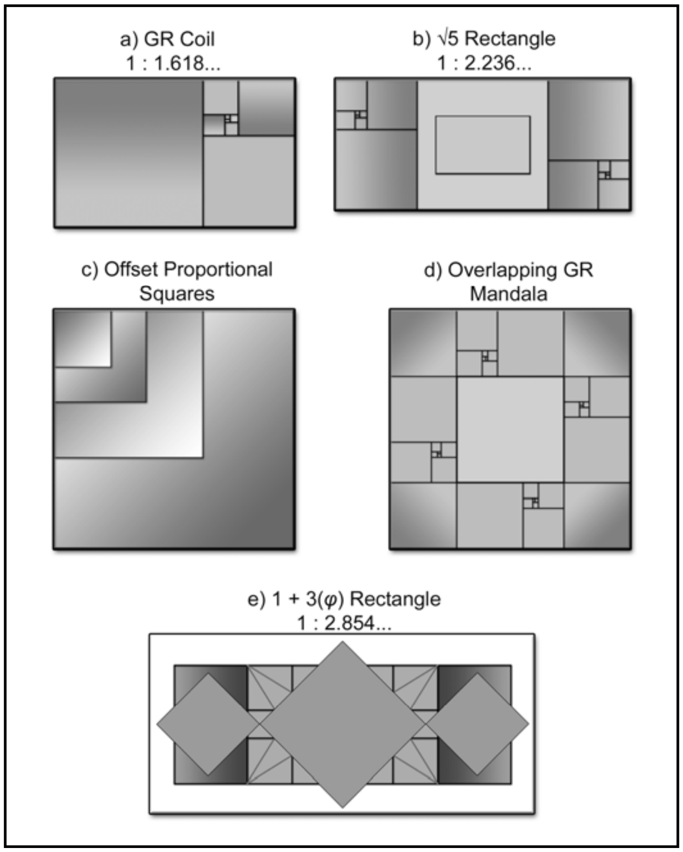


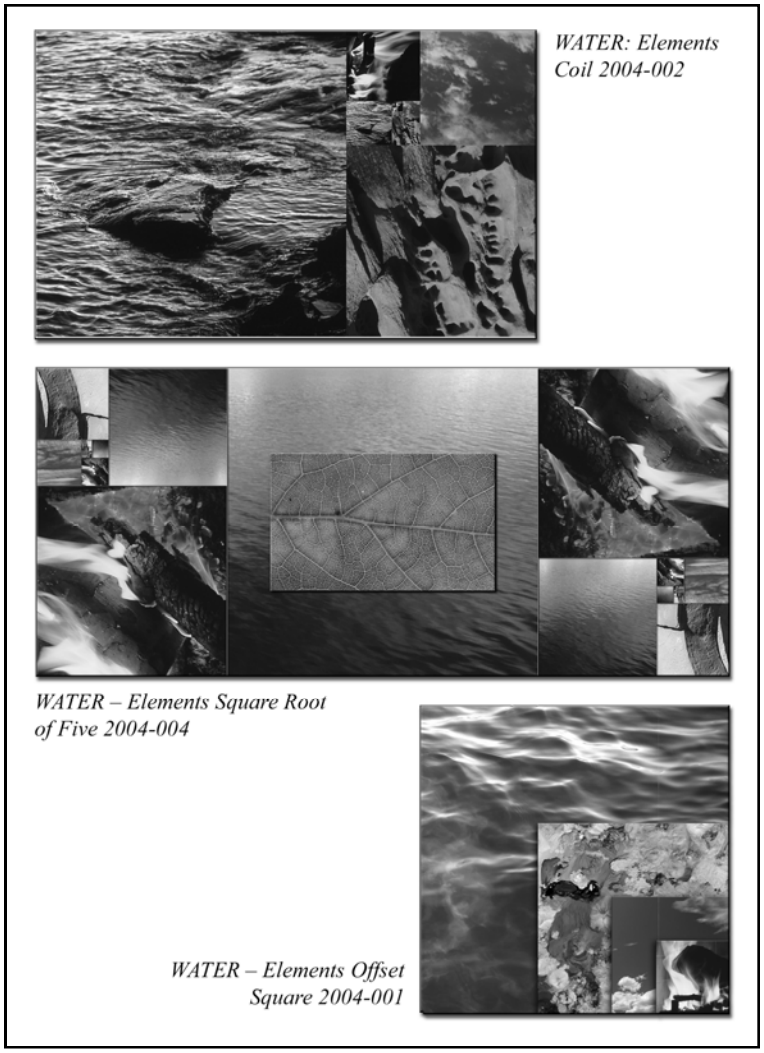

Figure 6. Golden proportional polygons used for the collage of backgrounds and the Elements in Golden Ratio series. © 2010, Doug Craft. Used with permission.

Each set of 21 collages in the *Elements* series included four GR coils (1-each for E-A-F-W), four √5 rectangles (1-each for E-A-F-W), four offset proportional squares (1-each for E-A-F-W), five overlapping GR mandalas (1-each for E-A-F-W plus a 5th combination mandala), and four 1 + 3($\varphi$) rectangles (1-each for E-A-F-W). All collages presented here from the *Elements* series feature the element water in keeping with one of the suggested themes of this book. The collages are reproduced here in black and white, but color versions may viewed at http://www.dougcraftfineart.com/frameElements.htm (Craft, 2010a).

The elements themselves also imply a formal structure. Two sets of opposites are implied in the classical elements: water vs. fire, and earth vs. air. Two sets of elements also have associative relationships: earth with water, and fire with air. These themes provide an additional source for compositional form that refers to the structure of nature. The quaternary nature of the four elements also emulates the four-fold symmetry associated with the Golden Rectangle, thus reinforcing a formal relation between theme, geometry, form and composition.

**Golden Rectangle Coils—** Figure 6a shows the GR Coil created by the subdivision of the GR by short-side squares, seen previously in Figure 2. This form was used to create standalone GR coil collages, which were also used as collage components for other *Elements* series polygon forms. Dimensions of the GR coils are 3400 x 2100 pixels (13.4” x 8.3” @ 254 dpi). Each GR coil was named according to the element with the largest square and smaller squares were all sequenced according to the E-A-F-W order. For example, Figure 7 (upper image) shows *WATER: Elements Coil 2004-002,* from the *Elements* series second set of collages (denoted by *-002* in the name). Note the order of elements is W-E-A-F (a rotation of E-A-F-W). At each subdivision of the GR, the smaller square was also rotated 90° counter-clockwise to the previous square’s orientation as a coiling movement suggestion of the logarithmic spiral converging on the Eye of God.

Figure 7. Collages from the Elements series by the author. At the top is a GR Coil. In the middle is a $\sqrt{5}$ rectangle and below is an offset proportional square. Color versions of these collages may be viewed at http://www.dougcraftfineart.com. © 2010, Doug Craft. Used with permission.




**Square Root of Five Rectangles—** Figure 6b shows the $\sqrt{5}$ rectangle also revealed in Figure 3. The $\sqrt{5}$ rectangle is formed by overlapping GRs that share a central square and include a GR life image in the center square of the collage with sides that are in $\sqrt{5}$ ratio to a 3400 x 2100 pixel GR. Dimensions of the $\sqrt{5}$ rectangles are 4700 x 2100 pixels (18.5" x 8.3" @ 254 dpi). The collage is named for the element appearing in the central square. The GRs to either side of the central square are identical GR coils that are rotated 180° relative to each other to suggest a circular movement. As seen in Figure 7 (middle image), *WATER – Elements Square Root of Five 2004-004*, the GR coils represent fire, the opposition element of water. The central $GR_{\sqrt{5}}$ rectangle is an image of a leaf surface obtained using a high resolution flat bed scanner as a microscope.

**Offset Proportional Squares—** The offset proportional square (OPS) form, seen in Figure 6c is used as a standalone collage and as a collage component in other *Elements* forms. These collages are 2100 x 2100 pixels (8.3" x 8.3" @ 254 dpi) and are usually presented diagonally rotated at 45° in a diamond arrangement. Naming convention for OPSs is the same as for the GR coils, using the largest square element and following the E-A-F-W sequence convention. These collages, however, do not rotate the smaller element squares and maintain a horizontal perspective for non-abstract images of the elements. Figure 7 (lower right image) shows *WATER – Elements Offset Square 2004-001.*

**Mandalas—** Mandalas are complex circular or symmetrical polygons with a dominant center that can serve as meditation objects. Overlapping GR mandalas (Figure 6d) were created using a life image as the center square with peripheral GRs forming a cross of four repeated source images of the element used to name the mandala. Dimensions of these mandalas are 4700 x 4700 pixels (18.5" x18.5" @ 254 dpi), and I also usually present these collages diagonally at 45°. In the four corners of the mandalas are identical OPSs that are rotated to enhance the symmetry of the mandala. *WATER – Elements Mandala 2004-001*, seen in Figure 8 (upper image), shows the opposition element fire in the corner OPSs. The central life square is a microphoto of a Monarch butterfly wing from a series of similar images I took with a dissection microscope in 2002.

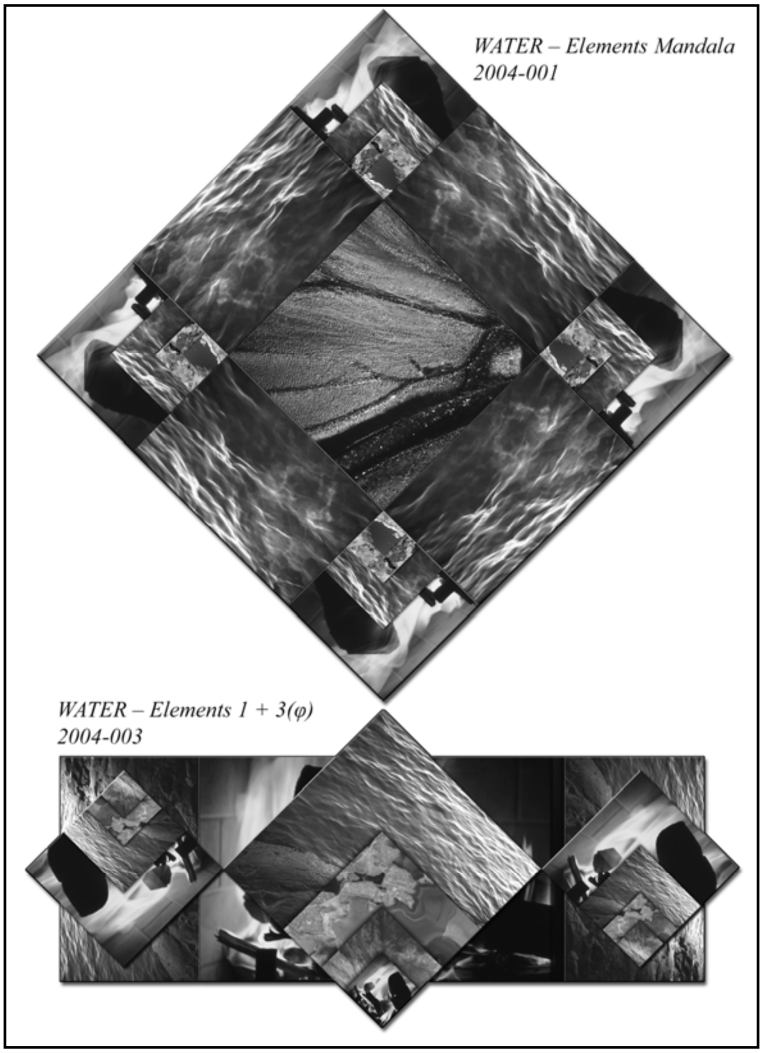



Figure 8. Collages from the Elements series by the author. At the top is a overlapping GR Mandala and below is a 1 + 3(φ) rectangle. Color versions of these collages may be viewed at http://www/dougcraftfineart.com. © 2010, Doug Craft. Used with permission.

**1 + 3(*φ*) Rectangles—** The final form in the *Elements* series is seen in Figure 6e, the 1 + 3(*φ*) rectangle. This widest *Elements* form used a background composed of a central 3400 x 2100 pixel element source image GR plus two identical vertical proportional element source GRs. The background thus had an aspect ratio of 1 : 2.854... The vertical GRs represent the opposition element to the central GR. In the center foreground is a 2100 x 2100 pixel OPS rotated 45° that establishes the elemental name for the collage. The opposition element is in the background. On the GR edges, proportionally smaller OPSs touch the central diamond in the foreground, with the background GRs consisting of the opposition element source image. In Figure 8 (lower image) we see *WATER – Elements 1 + 3(φ) 2004-003*. Note that opposition element fire is the background for the water OPS diamond, and peripheral fire OPS diamonds have water backgrounds. The OPSs on the periphery are rotated 180° to imply rotation about the center.

## SOME PERSONAL CONCLUDING REMARKS

I have practiced art, music, and science for over 40 years, and all three activities have influenced each other. In college I studied chemistry but my electives were in art and spiritual philosophy, and all disciplines provided the inspiration to start painting and creating collage. I worked as a research environmental chemist for over 30 years, and during my career I continued to create art and play music as time and energy permitted.

The applied mathematics, experimental methods, and careful observation I used in my scientific research helped develop my understanding of and appreciation for the structure of nature. In fact, as my experience in science deepened, I was more in awe of the complex organization of nature and how little we truly know about the mystery of causality in the physical universe. Some of these realizations were almost spiritual experiences that have served as inspiration for my art work and my study of aesthetics and the Golden Ratio.

By the same token, my deepening understanding of form in art and musical improvisation carried over into my scientific work. Knowing the value of improvisation and meditative nonpersonal states of mind allowed me to develop and use creative strategies to intuit and understand the dynamic chemistry of a lake or watershed, or the secrets hidden in a complex data set. I found Edward Tufte's work on visual presentations a revelatory experience: good data presentation could be a work of art and should also tell a story. I think that any practicing scientist could benefit from some knowledge and experience with creative strategies, aesthetics and the principles of composition.

I would hope that artists might seek greater knowledge of the science, geometry, and mathematics that can deepen their appreciation of how nature is so abundantly structured. We are not talking about understanding advanced calculus – just some simple geometry and high school algebra will do the trick. This kind of knowledge has its own mystical insights and I think the material in this chapter demonstrates that both science and math can have aesthetic implications.

Over time I have realized that conventional popular distinctions between science and art (science = objective, rational, reductionist, left brain; art = subjective, intuitive, wholistic, right brain) were simplistic and borne out of ignorance of what is involved in the actual creative practice of science and art. I found that being a scientist was a creative endeavor in many ways similar to art and music. Different methodologies and media to be sure, but all involve patience, serious study, routine chores, creative inspiration and intuition, proper application of form, storytelling, post hoc critique, the possibility of rejection, and communication to peers and the public. It's *all* art!

Form and beauty are of central importance to art, science, and life. And beauty revolves around resonance with the forms of nature that are the symbols and archetypes of the mystery of life.

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## KEY TERMS AND DEFINITIONS

**Cantor Set –** A basic fractal created from line segments, built by successively removing the middle thirds of a set of line segments.

**Conjunction** – a term used in positional astronomy and astrology. It means that two celestial bodies appear near one another in the sky as seen from the Earth.

**Diffraction** – the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

**Diffusion** – the process whereby particles being acted on by random forces move from regions of higher concentration to regions of lower concentration. Diffusion can describe how a gas will fill an empty container or how salt or sugar molecules will mix through a liquid.

**Exponent** – Exponentiation is a mathematical operation, written as $a^n$, involving two numbers, the base *a* and the exponent (or power) *n*. When the exponent *n* is a positive integer, the base is multiplied by itself, or *raised*, *n* times. For example $2^5 = (2 \times 2 \times 2 \times 2 \times 2) = 32$ and $3^3 = (3 \times 3 \times 3) = 27$. Exponents may also be negative numbers and these numbers are reciprocals of the positive powers. For example $3^{-3} = 1 \div (3 \times 3 \times 3) = 0.03704$, or $1 \div 3^3$. Exponents may also be non-integers, such as $12^{3.567} = 7070.32$.

**Irrational Number** – a real number that cannot be expressed as a fraction *a*/*b*, where *a* and *b* are integers. Irrational numbers, like the square root of 2, $\varphi$, or $\pi$, are numbers that do not have terminating or repeating decimals and have infinite numbers of decimals.

**Landsat** – The Landsat Program is a series of Earth-observing satellite missions funded by the U.S. government. Since 1972, Landsat satellites have collected photographic and spectral information about Earth from space. This science, known as remote sensing, involves specialized digital photographs of Earth's continents and surrounding coastal regions that are used to evaluate changes in vegetation and land use.

**Logarithm** – the logarithm of a number is the *exponent* or power of a *base* number (base-10 is commonly used), needed to calculate the number. Logarithms of a number, *x,* are usually denoted with the base, *n*, as $\log_n(x)$. For example, $\log_{10}(1000) = 3$, because 10 (the base) must be "raised" to the 3rd power to calculate the number 1000 (*x*). Another example, $\log_{10}(546) = 2.737$, because $10^{2.737} = 546$. Logarithms were discovered by John Napier in the early 18th Century and were commonly used until the advent of computers as a computational shortcut to multiply and divide large numbers.

**Nonlocality** – a property of nature observed at the very small scale of subatomic particles whereby the behavior of a particle, such as an electron, causes a change in another physically separated particle. The change occurs instantaneously (faster than the speed of light), suggesting that the particles are connected at a deeper level or scale of causality.

**Nonlinear** – characterized by curved lines. In mathematics, nonlinear equations usually have a variable that changes in an exponential manner, such as $x^2$ or $x^3$, or in a logarithmic manner, such as $e^x$. Most processes in nature are nonlinear. Nonlinear equations often used in science include power, exponential, logarithmic, and logistic equations.

**Ontology** – the philosophical study of the nature of being, existence or reality, as well as the basic categories of being and their relations.

**Polarizing Microscope** – a microscope used by geologists to identify minerals in very thin rock specimens (called thin sections). This technique uses plane-polarized light filters that interact with crystalline materials to form vivid colors (pleochroism) that change as the microscope stage is rotated. Also called a petrographic microscope.

**Polynomial** – an algebraic equation containing *variables* (usually denoted as $x$, $y$, and $z$) and *constants* (usually denoted as $a$, $b$, and $c$), using only the operations of addition, subtraction, multiplication, and non-negative integer exponents. For example, $3x^2 + 2x - 1 = 0$, where 3, 2, and 1 are constants and $x$ is the variable.

**Quadratic Formula** – a formula used to calculate the roots or solutions to a polynomial equation of the form $ax^2 + bx + c = 0$:

$$x = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$$

**Quantum** – in this chapter this term generally refers to energetic phenomena associated with the atomic and subatomic size scales. The term comes from *quantum mechanics*, the theory that interactions at this scale involve discrete and specific exchanges of energy (quanta), and that the states associated with subatomic matter (electrons, protons, leptons, etc.) are *quantitized*, or restricted to discrete states associated with spin or other novel characteristics.

**Reciprocal** – the inverse of a number, $x$, equal to 1 divided by $x$. Also refers to a smaller and identically shaped proportional polygon created by sectioning of a larger polygon by a gnomon.

**Standard Model** – is the name given to the current version of *quantum field theory*. This theory accounts for the strong and weak nuclear, and electromagnetic force interactions observed in all known subatomic particles. Predictions for the existence of particles such as quarks were an outgrowth of early versions of the Standard Model, and experimental confirmation of quarks led to widespread adoption of the theory. The Standard Model provides a common unified theory for three of the four universal forces observed by physics, but does not yet account for gravitation.

**Synodic Cycle** – a synodic cycle measures successive returns of a planet to its conjunction with the Sun, as seen from Earth. From the Greek *sýnodos* 'meeting'.

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