Infinite Space and Self-Similar Form

in Alchemy and Fractal Geometry

By Laura Strudwick

I believe that scientific knowledge has fractal properties, that no matter how much we learn, whatever is left, however small it may seem, is just as infinitely complex as the whole was to start with. That, I think, is the secret of the Universe.

-Isaac Asimov

The psyche speaks in the paradoxical, metaphorical language of opposites. Mythology follows suit. Recently, so do some branches of science and mathematics, particularly chaos theory and fractal geometry. Alchemy, as an experimental precursor to chemistry and also an inner psychic pursuit that foreshadows depth psychology, represents a strange combination of psyche, myth, and science. Alchemy and fractal geometry take the exploration of opposites as their primary subject matter, particularly the themes of zero/infinity and part/whole. Both fields inhabit the tensions of infinite emptiness and self-similar structure. Practitioners in both disciplines search for a reconciliation of opposites through processes that loop back on themselves. As humans seek to know the secrets of the littlest and largest realms, the micro and macrocosms, we also search within ourselves, in the psyche, for parallels. All paths lead both outward and inward. "That which is above is like to that which is below, and that which is below is like to that which is above," as written in alchemy's primary sacred text *The Emerald Tablet* (Linden 28).

Alchemy uses images to form a symbolic picture of its process and goal. One central image is the uroboros, the snake or dragon eating its tail (Fig. 5). The visual canon of alchemy guided the alchemists in their time, and while these images still fascinate contemporary scholars, they no longer serve as a current metaphorical model for this era. Alchemical images, while still rich and provocative to the imagination, are not common in the collective consciousness. Instead, graphic representations of fractals have recently, in the past thirty years, captured the collective imagination. Fractal geometry has, in many ways, replaced Euclidean geometry as the new sacred geometry for the Postmodern era. Mario Hilgemeier writes, "There is nothing new in the fact that a mathematical metaphor expresses the zeitgeist." The term *zeitgeist*, in this context, means not only "epoch-specific art forms, fashions, lifestyles and values, but also the scientific perception of reality" (138). Hilgemeier believes that the metaphor of iterated systems, with fractals and deterministic chaos as special cases, at least partly expresses "the general intellectual and cultural climate of our era" (138). Benoît Mandelbrot discovered and developed the field of fractal geometry in the 1970's. He invented the term "fractal," meaning fractional, fractured, or broken, to describe in mathematical terms the rough edges of the natural world, such as coastlines, clouds, mountain ranges; blood vessels in the heart, eye, and lungs; and the distribution of galaxies in the universe. By iterating, or continually repeating, a mathematical formula, one can create fractals that resemble those found in nature, much as the alchemists worked to improve Nature through their Art. But to make these fractals, one depends on the computer to speed up time, comparable to the alchemist's furnace. The Postmodern mind can relate to fractals' serrated natural imagery that is supported by mathematical formulas. There is a sense of dismemberment looped with the re-membering of a newly invented product coupled

with reliance on technology that speaks to the 20th and 21st century psyche, and also parallels the alchemical process.

Before explicitly comparing alchemy and fractal geometry, it is helpful to summarize six criteria that define fractals: fractional dimension; recursion; scaling; self-similarity; ordered unpredictability; and bounded infinity. A fractal dimension is a *fraction* between one and two or between two and three. This kind of geometry is not smooth and perfectly Euclidean or homogenous; it is jagged and unpredictable, more accurately reflecting the shapes of nature and humanity. William Jackson refers to Ron Englash's book *African Fractals* to describe the criteria of fractals. Fractals are mathematically generated through *recursion*, also called iteration or feedback. A formula is repeatedly looped and fed back into itself, much like the uroboros. Jackson describes recursion as "a mathematical process of return—the output of one stage is input for the next, making repeated patterns, with variations" (3).

Fractals also exhibit *scaling*, where the shape of the whole is found within the pattern on smaller scales. Along the same lines, the property of *self-similarity* means that the parts are similar to the whole, with variations. Figure 1 is a zoomed-out image of the Mandelbrot set, the poster child of fractals, and Figure 2 shows a series of images that progressively zoom in on a portion of the Mandelbrot set, revealing the scaling and self-similarity that characterize fractals. Fritjof Capra, on viewing the Mandelbrot set with increasing magnification, wrote, "And every now and then we make an eerie discovery—a tiny replica of the whole Mandelbrot set buried deep inside its boundary structure" (150). The Sierpinski triangle is another famous example of both scaling and self-similarity (Fig. 3). Fractals also show *ordered unpredictability*, which relates to chaos and structure.

Lastly, *bounded infinity* means that one "can trace infinite length within a finite boundary" (Jackson 4), as demonstrated in the Koch snowflake's infinite line length circumscribing a finite area (Fig. 4). The statistical properties of bounded infinity are such that "moments may be zero or infinite," a theme that will reemerge in my later discussion of chaos and structure (Liebovitch, *Intro to Fractals*). The images in Figures 1-4 are mathematical paradoxes, difficult for the rational mind to accept. The baffling Koch curve was initially rejected by the majority of mathematicians and even labeled pathological and monstrous. Benoît Mandelbrot amplified the mythological timbre by calling it the "Chimeric Island" (Gazalé 236). This kind of social rejection is reminiscent of the alchemist as pariah.

In comparing alchemy and fractal geometry, four subtopics reveal themselves, similar to the alchemical stages: chaos with a focus on infinity and nothingness; process with a focus on looping spirals, unpacking and repacking secrets; hidden order with a focus on self-similar form; and, finally, a glimpse of the big picture, the alchemical Philosopher's Stone. Chaos is the space for beginnings. Chaos precedes and pervades creation, in both the creative process and creation as a noun. Disorganized drama that leads to emotional stress is a popular connotation of the word chaos, but the original mythological meaning was different: instead of a sense of overcrowded, swirling, patternless particles, mythological Chaos meant a dark emptiness, an abyss filled with infinite possibilities.

Fractal geometry is closely related to the scientific field of chaos theory, which has a very specific definition, different from the metaphor of Chaos found in mythology. Chaos theory defines chaos as unpredictability that occurs within a bounded range. When a system becomes chaotic, the results are no longer predictable and instead become random, approaching infinity, although the possibilities remain confined to a limited range.

In alchemy, the dark space of chaos corresponds to the *nigredo* stage, the death and blackening that leads to new creation. Robin Robertson, in his study of alchemy and chaos theory as models for psychological transformation, writes about the *nigredo* stage, "It is only from within that chaos that the philosopher's stone could emerge" (94). Within the abyss, like the psychological unconscious, matter is undifferentiated. It is pure, infinite creative potential.

The alchemists called this potential the *prima materia*, the first matter. From the *prima materia*, matter differentiates into the four elements that Aristotle described, or five elements with the addition of metal to fire, air, water, and earth, according to Chinese alchemy (Henderson and Sherwood 6). Isaac Newton wrote on this subject:

And just as the world was created from dark Chaos through the bringing forth of the light and through the separation of the aery firmament and of the waters from the earth, so our work brings forth the beginning out of black Chaos and its first matter through the separation of the elements and the illumination of matter. (Linden 247)

Chaos is the darkness containing all, but also appearing empty, just as the alchemical vessel holds the mystery within its dark empty space. The *Tao te Ching* has often been associated with inner alchemy, the symbolic process of spiritual seeking. Chapter 11 of the *Tao* expresses the usefulness of space as a container:

Thirty spokes share the wheel's hub; It is the center hole that makes it useful. Shape clay into a vessel; It is the space within that makes it useful. Cut doors and windows for a room; It is the holes which make it useful. Therefore profit comes from what is there; Usefulness from what is not there.

Within the emptiness, there is, necessarily, form. A perimeter holds the shape open. This passage

from the Tao emphasizes the usefulness of space-space in the soul for contemplation and

imagination, space within time. Similarly, one of Western alchemy's richest symbols is the uroboros; the snake makes an empty circle with its body, representing that zero open space of chaos and potentiality. Even the dragon's scales in Meier's engraving in Figure 5 seem fractal in their self-similar, repeating pattern. At the same time, the snake continuously eats itself, making an infinite boundary around a finite area like the monstrous Koch snowflake. As he nibbles, he grows, and then he sheds, growing further. It is an impossibility, like the squared circle, yet this paradox touches a deep soul place with some half-glimpsed, cyclic truth.

Fractal geometry, using the branch of mathematics called complex analysis, leans toward the limits of zero and infinity in fundamental ways. As discussed above in the section on recursion, formulas can be iterated to infinity. Zero played an important role in Mandelbrot's creation of the Mandelbrot set (Figs. 1 and 2). The Mandelbrot set is actually "a single image in the complex plane that would serve as a catalog of all possible Julia sets" (Capra 147). Julia sets use the iterated formula $z \rightarrow z^2 + c$ where z is a complex variable and c a complex constant. To create a graphic representation of a Julia set, one plugs in different numbers for z and c and maps black points for finite iterations and white points for infinite ones that keep increasing. This procedure yields an amazing array of shapes, all with "the jagged look characteristic of fractals" (Capra 147). Mandelbrot discovered that making z=0 would allow him to create his set that included all possible connected Julia sets within it. "To find out whether a particular Julia set is connected [consisting of a single piece when graphed] or disconnected [consisting of several pieces], all one has to do is iterate the starting point z=0." If the result is finite, the set is always connected; if not, it is always disconnected. "Therefore one really needs to iterate only that one point, z=0, for each value of c to construct the Mandelbrot set" (Capra 148). Ironically, Mandelbrot used zero, the place holder of empty space, to test the connectivity and infinitude of each Julia set.

Mandelbrot, through his use of zero and infinity, created a fractal Philosopher's Stone in the Mandelbrot set. The last two stages in the alchemical process, *multiplication* and *projection*, are well-suited to the set's structure. Multiplication relates to augmentation. The key to augmentation, according to the medieval alchemist Sir George Ripley, "is repeatedly 'feeding' the Stone with Mercury," like the iteration of a mathematical formula (Linden 18). Projection is the last of alchemy's twelve gates, "casting the powder upon the base metals to effect transmutation" (Linden 18). When one examines the Mandelbrot set, it appears to flow into and out of itself, as if the powder has just been cast and the transformation is occurring before one's eyes.

Mandelbrot did not know about the newly developing field of chaos theory when he invented fractals, but the two new fields quickly found each other. "Fractals are closely linked to chaos theory. The geometry of chaotic systems over time reveals a fractal structure in space" (Marks-Tarlow 276). Chaos theory studies the chaotic properties of systems. In order to determine whether the chaos in a system derives from determinism or random chance, for example, Liebovitch's PowerPoint *Introduction to Chaos* teaches that one must first turn the time series into a geometric object through the process of *embedding*, and then determine the fractal dimension of that object. If the fractal dimension is high, heading toward infinity, then the result is random chaos. If low, then the result is deterministic, which may be chaotic or non-chaotic, depending on the system's *sensitivity to initial conditions*, a key criteria in chaos theory, popularly known as the "butterfly effect." Liebovitch writes, "Sensitivity to initial conditions means that the conditions of an experiment can be quite *similar*, but the results can be quite *different* [italics mine]," and, "Small changes in parameters can produce large changes in behavior." The physical alchemical process also depends heavily on initial conditions. It seems

that alchemists worked within a chaotic system, striving for ordered results, but were forced to live with unpredictable outcomes. The psyche similarly resists attempts at conscious control.

Psyche's journey often feels chaotic and dark, through a pathless underworld or dark forest of a grail quest, until perspective suddenly reveals an overall pattern in one's life that may be surprisingly fractal in nature, repeating and self-similar in its dynamics. Such a dark forest contains infinite paths that can be traveled, crossed, re-traced, and/or altogether avoided. The depths of the unconscious, with its dreams, nightmares, and various *nekyia*, or chthonic symbols, can feel frightening and pathological. Carl Jung wrote, "But anyone who really knows the human psyche will agree with me when I say that it is one of the darkest and most mysterious regions of our experience. There is no end [infinity] to what can be learned in this field. Hardly a day passes in my practice but I come across something new and unexpected" (Jung 254). The alchemists took this journey through the chaotic system of the psyche, combing through the *nekyia* and salvaging the symbols, carrying them into the daylight, embedding them in their writings and drawings as guideposts along the path.

Through the filtering process of the alchemical Art, Chaos reveals its hidden Order. Similarly, as archetypes emerge through the symbols that the human psyche filters and creates, an individual's life patterns may emerge as more orderly and self-similar than expected. So it also is with society; the collective unconscious has a process that fluxes and flows, with symbols and patterns that recur in a cyclical pattern, emerging and then submerging again. One need only watch a little popular TV, listen to pop songs, follow the news, or surf the Net to locate the current patterns. Fractals can serve as a metaphor for process: "….'[F]ractal' means not only a fixed visual image in space but also a process enacted in time which traces a fractal pattern" (Jackson 2). For example, in studying phase transitions from one state of matter to another such

as from a liquid to a gas, scientists have found that "fractals maintain their characteristics into the fourth dimension, which is time" (Mann 10). The fact that certain metals become magnetic at a specific temperature poses a striking parallel with alchemy. Scientists have found that the metal's molecules do not line up all at once or randomly, but "as the critical temperature is reached, they arrange themselves into fractal patterns" (Mann 10). So the process of heating metals in alchemy actually has a fractal structure; the adepts were engaging with fractals through the alchemical process.

Jung aligned alchemy's stages with the individuation process: a process of discovery, of digging for inner treasure, of Making, of Art. The snake or dragon symbolizes the process in its various guises. The uroboros snake biting its tail is only the beginning of its metamorphosis. It changes throughout the alchemical opus: it forms the vessel as the uroboros, then "burrows into the alchemical egg that begins the process," vanishes, returns, then wraps around the egg that is now the philosopher's stone (Robertson 63). As it disappears and returns, it oscillates, tantalizes, and tricks like Mercurius, exposing bits of secrets, then hides again. Jung visualized the individuation process as a spiral that "seems chaotic and interminable at first. ... Owing to the diversity of the symbolical material it is difficult at first to perceive any kind of order at all. ... But, as I say, the process of development proves on closer inspection to be cyclic or spiral" (277-78). In any process of discovery and creation, be it alchemy, psychological individuation, writing, or scientific experimentation, there is a sense of snaking one's way through a labyrinth, looping back through spiral patterns (recursion) to find familiar images and ideas as the spiral crosses itself (scaling, self-similarity).

The reflections of the micro, macro, and mesocosms come into play through process. Complex systems do not form causal chains but instead "nature forms feedback loops in which

information is constantly fed back into the system. ... We each exist in an eternal moment that in some way contains both everything that came before and everything that will come, linked together in a complex feedback loop" (Robertson 65). When one is inside the process, the pattern mostly remains hidden because perspective is limited when one's position is a point within the system. Chinese alchemists tried to contract the macrocosm to a manageable size: "The seeker not only shrank time but reproduced the dimensions of the universe within the confines of his laboratory. He reduced the operation of the Way to spatial and temporal dimensions that he could encompass in contemplation, in the hope of becoming one with it" (Sivin 238). Mandelbrot and others enact a similar process. While the alchemist's tools are fire, metals, water, and vessels, modern scientists use abstract theories and applied mathematics like quantum physics and fractal geometry, computers to crunch the numbers and produce the graphics, and observation of the natural world. In the fourth century BCE Chinese alchemy expanded the process to include the adept's physical body. One meditated on energy circulation through the body's systems as a parallel to alchemical transformation. "This interiorization of alchemy grew naturally out of the prevalent belief that the body is a microcosm, its vital processes corresponding to those of the physical world, its spirituality embodied in inner gods organized as a mirror image of the celestial and terrestrial bureaucracies" (Sivin 239). As above, so below, and, apparently, so inside of us.

The relationship between opposites is a major theme in the alchemical process; one could argue that it is the underlying structure of alchemy. White female mercury as the moon joins red male sulphur as the sun in a sacred marriage to produce a third thing: the Philosopher's Stone that yields gold. Taoism's Yin Yang (Fig. 6) symbol is a classic image that houses opposites within each other. The Lorenz attractor (Fig. 7), which originated from Lorenz's study of

weather patterns, seems to echo the Yin Yang in its visual representation of dualities that touch and interplay. The process of bifurcation in chaos theory symbolically relates to dualities and unions of opposites in alchemy. A bifurcation is a split into two, which occurs when strange attractors pull a system in two directions at once. The split points divide again and again, as the system's dualities double themselves while approaching chaos (Fig. 8). In a system that approaches chaos through period-doubling bifurcations, when one measures the distance between the split points and then calculates their ratios, that ratio *always* approaches the infinite Feigenbaum constant 4.6692... that is more ubiquitous in nature than its famous sibling π or pi (Robertson 110-11). The opposites continue to oscillate, but are simultaneously reconciled through a mathematical equality. These strange attractors that pull systems into duality are all fractal in nature. Robertson crows, "Chaos does have structure!" (111). Michael Strevens describes the potential for hidden order in chaos theory:

> Chaos theory introduces the serious possibility that these systems may be governed by equations with very few variables. Underlying the complex appearances may be a simple reality. The prospect of finding a hidden simplicity in such complex phenomena as turbulent flows, the weather, the movements of financial markets, and patterns of extinction is what most excites proponents of chaos theory. (132)

The desire for wholeness leads back to Euclidean geometry with its attractive straight lines and perfect circles. Jung's mandalas and concept of the Self beg for holistic order. How intriguing that out of what seems to be such a mess—alchemy, fractal geometry and chaos, the unconscious—order would emerge!

The underlying structure that continues to appear in both alchemy and fractal geometry is that of self-similar form. Alchemical writings emphasize self-similarity when they refer to "kind with kind" or "like with like." For example, Paracelsus writes that "every like thing generates and brings forth its like" (Linden 165); George Ripley, "And onely kinde with kinde can well

redresse/Till filthie originall be clensed from his seate/He likely is to finde our secrets more and lesse./ Therefore worke kinde onely with his own kinde" (Linden 144); Michael Sendivogius, "[L]et every thing act upon its owne like: and then for certaine Nature shall performe her office" (Linden 176); Roger Bacon, "So that things be not made but according to their natures. ... things bring not forth, but only their like, or what agrees with them in nature, each tree its own fruit" (Linden 112). Robert Fludd even uses the term self-same, "I may therefore rightly define Sympathy to be a consent, union, or concord, between two spirits, shining forth, or having their radical emanation from the self-same or the like divine property" (Linden 197). When they mention like to like, alchemists present a paradox to themselves: How can they only work with things that have similar natures when they so often emphasize the joining of opposite natures? It is confounding. Paracelsus offers a hint when he writes of both self-similarity and spontaneous generation: "The white and the red do proceed out of one root, without any medium. Tis dissolved by it self, coupled by it self, albifyes, and rubifyes; is made saffrony and black by it self, marries itself, and conceives in it self. ... All which Operations, are indeed one Operation made by the fire alone" (Linden 167). This discussion simultaneously relates to both process and order. The material reflects itself and reproduces itself-the many out of the one. The theme of like to like explores the ontology of Nature, the metaphysical form, and the alchemists imply that this form is self-similar.

Fractal geometry reveals that the underlying structure of many, many aspects of nature is fractal and therefore self-similar. "Whatever the source of order in the universe may be, fractals are one of its ubiquitous modes of operation. . . . they are what nature relies on when it needs efficient shapes to survive, work, build up, break down, distribute, organize, or enliven with order. . . . Fractals suggest infinity, recursiveness, and repetition of a principle of order on

different scales" (Jackson 2). These processes that Jackson mentions—breaking down, building, organizing—echo the alchemical process. It is incredible that today we have another layer of order to explore. In addition to the atomic level with its quarks, the microscopic realm with its cells and DNA strands, and the telescopic domain with its visions of deep space, now we have fractals. "This similarity of images from vastly different scales has been known for a long time, but before Mandelbrot nobody had a mathematical language to describe it" (Capra 138).

In the 4th century BCE Plato wrote about the Forms as original containers of matter, ideal shapes that express perfect order. Bernard, Earl of Trevisan, a medieval alchemist, later wrote, "For Matter would flow infinitely, if a Form did not retard and stop its Flux" (Linden 138). Much later, in the 20th century, Martin Heisenberg, noted physicist, argued that "ultimate reality is not to be found in electrons, mesons, and protons but in something that lies beyond them, in abstract symmetries which manifest themselves in the material world and which could be taken as the scientific descendants of Plato's forms" (Arden). In the past thirty years, perhaps we have discovered that Form in fractals. The fifth chapter of the Tao te Ching describes a relationship between empty space and structure through process, touching the three sections of my discussion: "The space between heaven and earth is like a bellows. The shape changes but not the form." The process of life heaves and breathes, like a bellows. The space is open and infinite, change occurs in that space, but form, or Tao, remains the same. Interestingly, small variations can occur within the scaling and self-similarity of fractals, as in the Mandelbrot set, "as if some celestial artist kept working with it at every level" (Robertson 39). So it is with alchemy and the psyche: self-similarity does not equal self-sameness. Identities are still unique, though they reflect each other closely.

Warren Weaver coined the term "organized complexity" to express the post-1900 scientific outlook, as opposed to the emphasis on simple systems prior to 1900. Perhaps there is more room for metaphor and complexity now, as science and myth merge through imagination and creativity. Perhaps even the symbolism of alchemy could be more accepted today on a mainstream level, without the literal interpretation of what we would call erroneous science. William Blake's popular lines from his poem "The Marriage of Heaven and Hell" call for flexibility and open-mindedness: "If the doors of perception were cleansed every thing would appear to man as it is, infinite./ For man has closed himself up, till he sees all things thro' narrow chinks of his cavern" (67). Blake's image recalls Plato's "Allegory of the Cave," where human perception is necessarily narrow, seeing only the shadows of the Forms illuminated by the sun's fire. Humans "see through a glass darkly" and crave to see more fully, though mythology abounds with warnings against the sun blast of full perception. Zeus fully appeared to Dionysos's mother Semele at her request, for example, and exploded her to dust. Both fractals and alchemy offer glimpses rather than full vistas, and the spiral recursive process ensures that connections will be made, but we see only parts of the whole. Human perception is limited, but it can grow. Like the underlying paradox of chaos theory, humanity has infinite potential that is bound to a limited field. The perimeter of the Koch snowflake and the uroboros are infinite, but hold open a finite inner space. The psyche is similar with its depthless unconscious realm and limited conscious awareness.

Part of the alchemical process involves cultivating and refining one's perception. People need metaphorical images as visual aids. Fractals are a beautiful portrayal of brokenness within a whole. They are fascinating symbols of inner contemplation and outer perception. Today fractal geometry, like alchemy in the past, acts as a dynamic image and, simultaneously, a way of

seeing. By zooming in and out, changing the focus from giant to medium to tiny perspectives, one sees the macro, meso, and microcosms contained in the whole. Margaret Arden describes her perception of the Mandelbrot set, specifically, and fractal geometry as a field, "Looking outwards, the single element could be said to represent the infinitesimal smallness of a human being in the cosmos. Looking inwards, it can be a representation of the infinite complexity of the human mind." If people can catch a glimpse of the fractal web that connects and reflects everything, then society's perspective can shift and open. "To play one's part in reflecting the whole in an age of alienation and dysfunction is a great challenge. Fractals offer a variety of visual images to help the faltering imagination picture anew the meanings of wholeness and participation" (Jackson 33). Fractals and alchemy, in their searches for the secret patterns of the universe, inspire a kind of sacred marriage of science and imagination. The paradox of opposite and same may be the essential nature of the philosopher's gold.

Appendix



Figure 1 Graphic representation of the Mandelbrot set



Start





Step 2



Step 3



Step 4



Step 5



Step 7



Step 8





Step 10

Step 11

Step 12

Step 13

Step 14

Figure 2 Stepwise exploration of infinitely repeating and self-similar structures of Mandelbrot set, similar to the ever-deepening alchemical process



Figure 3 Sierpinski Triangle. "Originally constructed as a curve, this is one of the basic examples of self-similar sets, i.e. it is a mathematically generated pattern that can be reproducible at any magnification or reduction." *Wikipedia.org*



Figure 4 The first four iterations of the Koch snowflake, which doubles the number of triangles in each section at each iteration. The result is a paradox: an infinitely long perimeter enclosing a finite area.



Figure 5 Uroboros engraving by Michael Maier, a central image of alchemy, simultaneously representing zero and infinity.



Figure 6 Taoist Yin Yang symbol associated with both alchemy and fractals



Figure 7 A plot of the Lorenz attractor for values r = 28, $\sigma = 10$, b = 8/3. The image suggests a potential resolution of dualities.



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