Terry M. Mikiten
Nikos A. Salingaros
Hing-Sing Yu

Pavements as Embodiments of Meaning for a Fractal Mind

Taking as a point of departure one aspect of how the mind establishes a connection with the environment, this paper examines the role of pavement design in the environment as a vehicle for conveying meaning.

Introduction

This paper puts forward a fractal theory of the human mind that explains one aspect of how we interact with our environment. Some interesting analogies are developed for storing ideas and information within a fractal scheme. The mind establishes a connection with the environment by processing information, this being an important theme seen during the evolution of the brain. In particular, in this discussion we assert that pavements play a role in connecting human beings to surrounding structures by acting as a vehicle for conveying meaning. We will argue that the design on pavements transfers meaning from our surroundings to our awareness. Such a connection establishes a positive psychological and physiological state. As an example, the contemporary patterned pavements of Tess Jaray are discussed. We argue that their success is due to the fact that they connect hierarchically, which in turn triggers positive emotions.

Some of these ideas grow out of an earlier discussion on how human beings interact with their surroundings [Padrón and Salingaros 2000]. The perception of public space is linked to the design of its pavement, and the perception mechanism is a natural part of how the human mind operates. The mind establishes connections automatically. This process occurs in any physical space, and it is either helped or hindered by design and texture. We will build up a case for a psychological link between an observer and an open space that depends in part on visual patterns. We claim that the environment links directly to our consciousness, which extends to embrace open spaces via patterns in the pavement. Finally, we provide some very broad guidelines of how pavements ought to be designed in order to achieve this linking.

If we wish to preserve our intelligence in a more permanent form than electrical impulses in biological tissue, we can transfer our thoughts to books; or engrave them on a physical medium such as stone. On a much more fundamental level than language, however, we could impress on open space a geometrical pattern that reflects structures in the mind. A patterned pavement has information content and is durable; it is therefore a sign of intelligence encoded in a structure that uses very little energy, hence is relatively permanent. Moreover, since a geometric design doesn't need language to convey meaning, it is universal, i.e., it can be understood in some sense by any mind that can detect it.

Fractals and Hierarchical Linking

A fractal structure shows some non-trivial substructure at every level of magnification [Lauwerier 1991]. Fractals define a scaling hierarchy that is complex at every level. (Complexity as used here denotes presence of constituent parts, being the opposite of purity or emptiness). The special case of "self-similar fractals" has the additional property that structure revealed at each level of magnification is related by scaling [Lauwerier 1991]. That is, the substructures when magnified by the appropriate factor are all similar to each other. Self-similar fractals are mathematically simple; since their structure is repeated at different magnifications to create the whole, they require only one basic algorithm (design) to generate.

Biological forms are often fractal [Weibel 1994]. Many are obviously self-similar, but we do not exclude complex structures that are not. For example, the mammalian lung is a self-similar fractal in several of its larger levels [Weibel 1994; West and Goldberger 1987; West and Deering 1995]. There is a clear dendritic (tree-like) structure that optimizes – and is a consequence of – the subdivision of the airducts forming the lung. As one gets down to the smaller level of the alveoli, exact self-similarity is lost, because different complex substructures arise as the physical needs for gas exchange and blood circulation take over. The lung is a fractal all the way down to the molecular level according to the broader definition of "statistical self-similarity".

A fractal connects several different levels of scale. There is one basic design in a self-similar fractal that is repeated at different magnifications, and this links all the scales together. In a statistically self-similar fractal some structural property is similar at each scale, thereby linking the different levels of scale. Whether established via similarity of form on each scale, or through some other common qualities such as texture or symmetries, this scale-connectivity property of fractals creates a hierarchical linking. Hierarchical linking attaches forms and textures to geometry, and so to an observer. It is impossible to link forms hierarchically if they are empty, since in that case the absence of substructure leaves too few subscales to link together.

A hierarchically-linked system can encode complexity in a simple fashion. If we relate complexity to the length of an algorithm required to generate a pattern or visual piece of information, then, if the algorithm is short, the pattern is termed simple. For example, if one wishes to draw a fern leaf or cauliflower (normally considered complex structures) using a fractal algorithm, the algorithm is very short, because their design embodies hierarchical scaling (as described in many textbooks [Lauwerier 1991]). We are going to utilize this concept to propose that what appear to be complex processes in the human mind and its interactions with the environment could in fact be very simple in a fractal sense. Fractal processes and designs can provide the basis for connecting ideas, memories, architecture, and urban elements [Padrón and Salingaros 2000].

The Concept of the Mind

The brain is known to be a structured system of hierarchically-organized modules. These interacting modules communicate with one another. In turn, the modules contain within them yet other sub-modules which communicate among themselves. This pattern is repeated at several different levels of scale, culminating in what is a molecular and biochemical fractal of interacting and communicating systems [Alexander and Globus 1996]. In a similar way, we can conceive of the mind as consisting of self-similar complexes of hierarchically-arranged modules linked together in a way that can be expressed according to some algorithms. The relationship of mind to brain can be characterized as a mapping problem in which mind and brain map onto each other.

In this conception, the brain can be regarded as a relatively isolated system that communicates with the world via nerve impulses generated by sensory receptors in the periphery. The main discourse among the different elements of the brain accomplishes a synthesis of the information coming in, resulting in the internal generation of what we call "reality". We suppose that the systems of organization that characterize both mind and brain are at least partially fractal in nature. That is, each contains a hierarchically-arranged system characterized by some algorithmic continuity between the successive functional levels of activity.

Must the linking between successive levels of the hierarchy always be the same; i.e., does the mind represent a self-similar fractal? It is possible to imagine a hierarchical system in which clusters of levels may be connected according to one algorithm and others according to some other algorithm. One of the most interesting aspects of the human brain is that it is capable of generating new hierarchical systems as needed. For example, a synthesis of ideas can result in a new collection of ideas. In this setting, we have one hierarchical arrangement of concepts giving rise to another hierarchical arrangement of concepts.

Our essential thesis is that when a fractal system generates a new system, it has the same attributes and characteristics as the generator – especially hierarchical linking. Thus, mental associations that would appear at first to require enormous lengths of code (and consequently be termed complex) may in fact be handled by very short codes. If that is indeed the case, then the human mind could be using fractal encoding as a standard way of coding enormous chains of related thoughts into a single fractal entity. The evidence for this claim comes forth when we see how thoughts are naturally linked to each other internally. A design pattern may well be a representation of an artist's natural expression of these chains of thought in a tangible form.

Memory and the fractal mind

There exist striking parallel properties in neuronal and thinking processes. The mind is synonymous with mental activity and is a subset of neuronal processes [Alexander and Globus 1996]. Since the brain consists of neurons for both involuntary and voluntary activities of the individual, the mind is also aware of both types of processes. Cognition depends on how well information is stored, retrieved, modified, and translated into commands. The memory process is central to neural function and is an example of the basic algorithm that links the brain and the mind. Evidence that comes from memory will help to support our model of meaning and perception developed below.

The nervous system has a massively parallel architecture (i.e., different linked circuits on multiple scales of organization all working simultaneously) based on numerous simple processors called neurons. Memory depends on the network formed among neurons, and artificial neural networks have been able to simulate primitive forms of memory function [Rolls and Treves 1998]. Neuronal pathways linking regions of the cerebral cortex correlate with the construction of long-term memories [Rolls and Treves 1998]. It is evident in a diagrammatic representation of connections within the brain that there are layers of structures with projections from one to the other [Alexander and Globus 1996]. The presence of these prominent recurrent linkages has been correlated with the associative memory operated by neural networks [Rolls and Treves 1998].

Associative memory can be responsible for powerful emotional experiences. In response to a small cue, which can be as trivial as a fleeting odor, we selectively retrieve a specific set of linked memories quickly. Evidently, the architecture of the network is designed in favor of fast information retrieval from multiple locations. In addition, there must be a flexible mechanism that allows new information to be added without losing old memories completely. The brain's multilayered structure has previously been suggested as providing a framework for associative memory [Marr 1982]. We suggest that a fractal-like neuronal architecture provides a filter for selected memories to be stored in a stable layered configuration.

Fractal tuning and communication

Fractal systems give rise to fractal-based communications signals. These, in turn, travel through fractally organized channels. A simple illustration of this would be communications within a biological system. The entire system is fractal-based: the organs that generate the communication signals, the signals, and the receiving devices (the recipient organs) are all fractal in character. A key idea behind this is the concept that the body contains "receptor sites" which are, in effect, "tuned" to recognize certain chemical signals as opposed to others. For example, when the pituitary gland releases thyroid stimulating hormone, the thyroid gland responds to this hormone but other organs of the body have no discernible response. We have hormones being generated by glands, the glands in turn impacting upon the organs at a distant site via the bloodstream, and finally arriving at the target organ where they manifest their actions in a biological way. All these require fine tuning of signal generation and reception at different levels, so as to provide a balanced control of all physiological processes in harmony with the nervous system [Yu 1996].

Systems in the body are "tuned" to generically recognize different kinds of fractal hierarchies. We contend that the brain has special systems which are tuned in exactly this way. The brain's neural patterns are responsible for recognizing structured systems that have a hierarchical organization in which the levels in the hierarchy are defined in a systematic, algorithmic way. Such recognition has an emotive value for the organism in question. In general, when a system recognizes a structured entity in the environment, it attributes "meaning" to it. Organisms create communication signals that have a special structure, which is to say that they share a common language. Languages are characterized by collections of rules defining syntax and semantics. In a system of fractal-based communications, those rules are tantamount to the algorithmic connectivity among the hierarchies in the fractal structures used for communication.

Following the analogy of radio transmission, where tuning the receiver depends on matching a single frequency, fractal tuning represents a more sophisticated process that matches complex signals having a similar hierarchical structure. Brain mechanisms would be especially receptive to such signals, and would screen other signals that have a different algorithmic structure – i.e., any signal that shows no hierarchical linking among its components. This would represent a "filter", allowing us to connect selectively to fractal forms. It also explains instantaneous cognition as a kind of resonance between an external structure and the internal structure of our cognitive system. Such a mechanism has already been suggested by Gibson [Gibson 1979; Michaels and Carello 1981] in his psychological model of "direct perception". Our theory of fractal encoding is thus consistent with Gibson's work.

Problems of Miscommunication

Evidence for structuredness in communications is seen in the use of metaphor as a tool for communicating among people. Metaphorical structures impact the way that people communicate complex ideas [Lakoff and Johnson 1999]. In our system, in which we define linked hierarchies as the central element in communication, a metaphor represents the act of completion of a partial structure which is offered by way of explanation. Confronted with a complex concept, an individual might use only a component of the structure consisting of a set of communicating elements to make a point. Unfortunately, the listener in this dialogue then attaches to the entire construct whether or not this is appropriate in the particular setting. Thus, metaphors give the illusion of meaning and "truth" because they also give the illusion of completeness of structure. When communications channels utilize fractal structures, it is possible that a mixture of rules is being applied at different levels in the hierarchy. Such structures can give rise to ambiguity in communication.

A frequent cause of miscommunication is the certainty of one party that what the other party said is completely understood. One piece of information provided triggers recall of a fractal construction in the other's mind. As different fractal encodings will have common cross-over points, however, it frequently turns out that the completed fractal is not the intended fractal, which results in miscommunication. The problem lies in the completion process itself, which gives a feeling of satisfaction, hence the illusion that one has understood what was said. The emotion associated with fractal generation could be the same thing as the feeling of understanding. This idea is consistent with the observation of a definite physiological (emotional) state correlated with a mental state such as "understanding" [Lakoff and Johnson 1999]. As thinking processes evolved from sensory and motor systems, it is plausible that the brain still uses those networks as a framework for higher functions.

Clearly, the mechanism for miscommunication outlined above depends on the fractal encoding of thoughts, and thus strengthens the idea that the brain could operate in the proposed manner. A fractal encoding scheme can be completed from a single component; other schemes of association will not necessarily work in this way (because they cannot be encoded so compactly). Such miscommunications may also share similar algorithms as the variable emotional responses of different individuals evoked by identical design patterns. The emotional response of the same individual may also vary at different times. Perhaps, different fractal encodings with common cross-over points would create such flexibility.

Shaping the built environment

The built environment reflects structures in human thought, in that it is created by human minds. Thought works by establishing connections between concepts, creating conceptual structures and ideas. We suppose that fractal structures in nature influenced the development of neuronal mechanisms in evolution that could encode and decode these structures automatically. If true, it is reasonable to suppose that the mind, which uses these mental mechanisms, seeks to shape its environment according to the same rules for structural connectivity. Internal patterns of neural nets that form our sensory and thinking processes are organized in a way that reflects similar patterns of organization in the external universe.

People have a basic need to naturally extend their consciousness to their environment, something that occurs effortlessly when surrounded by nature. We normally try to shape the artificial environment in a way that we can connect to it. This makes the reasons of why we build complex things, such as cathedrals, less mysterious, because we cannot connect to objects that are either too random, or too simple; we subconsciously use as a template the ordered complexity of our own mind so as to extend our consciousness outside our own body. Human consciousness is linked, through a hierarchy of structures on different scales, to what we build. Such visual connections extend the mind fractally to the physical environment.

Having put forward a theoretical model of how the mind might operate, we now apply the model to evaluate different visual structures such as designs. Passive input creates meaning in the brain, which then generates an emotion. In principle, we have no control over input except movement; one can approach a source that generates positive emotions, and avoid a source of negative emotions. We can control the sources in the man-made environment. We would normally build structures that generate an optimal emotional response, using our experience of what is the most beneficial input. Paradoxically, our intelligence allows us to override negative emotional cues and build structures that repel us.

Pavements and Hierarchy

Architecture has in the past felt a need for pavements that are either patterned, or that embody figurative art. Our perception of space is founded on a connection with the ground via design. In creating an artificial built environment to house themselves and their activities, human beings have always been careful to connect with the ground visually. Methods that connect a pedestrian to the floor, whether inside a building, or in an open space outside include pavements, tilings, textures, mosaics, etc. A pioneering study of interior pavements has been undertaken by Kim Williams [Williams 1998]. The authors are in complete agreement with Williams that pavements are central to mankind's architectural – and intellectual – development. Most twentieth century pavements are plain and empty, arguing the case that there is no functional need for either representation or pattern in a pavement. We will argue the contrary: that pavements can serve the crucial function of connecting an observer to all surrounding structures.

The connection becomes necessary for larger spaces, so this effect is most dramatic in external pavements.

Everyday experience – which calls upon visual scales between 1mm and 1m contained in the human body – serves as the foundation for any fractal design hierarchy. We connect visually and psychologically to an area surrounding our feet. This region defines the first fractal scales in a pavement design, and these external scales become linked to internal scales within our consciousness. Without a deliberate design here, there is a chance that no connection will be experienced. Regardless of the smallest unit employed, whether it be a piece of mosaic, a brick, or a tile, contrast should be used to identify the smallest scale unambiguously. Nevertheless, most urban plazas, and indeed, brick and stone walls of all kinds built in the twentieth century, disguise the smallest scale by repeating a single unit monotonously (e.g., so-called bonded brickwork, which creates a uniform surface).

Spatial coherence requires internal definition on successively larger scales, going up to the size of the entire region. A patterned expanse needs to define several distinct scales to create hierarchical linking. Therefore, while a detailed pattern might connect to the user at the smallest scale, simply repeating the design indefinitely without using intermediate scales will fail to connect the user to the larger space. Successful pavement designs contain similar but not identical regions. An urban space lacking a hierarchical linking can never connect to surrounding buildings at a distance because the jump in scale is simply too large. For this to happen, the buildings must define an additional, larger scale in the same hierarchy. It is therefore necessary for the pavement texture, color, and design to harmonize with the surrounding structures. Similarity between the pavement and buildings relates the scales.

The importance of meaning: structures in the flooring of urban space

One of us has already discussed the properties of urban space, and how patterned flooring helps to define it. Commenting on contemporary examples, we said:

> *Sidewalks, city streets, and street corners*
> *An incredible opportunity to connect the pedestrian to the pavement has been missed all around the world, by using plain, featureless surfaces (even with expensive materials). The standard concrete sidewalk contains no visual information, and anyway, it is far too narrow. Even when brick is used for paving, perceivable patterns are usually avoided. Yet, patterns on the surface of pedestrian paths can make a great difference. Recall, for instance, all the wonderful mosaic and tiled pavements of the Roman world. Among notable historical examples are the pavement of the Piazza San Marco, and the Portuguese architectural tradition of lively sidewalk designs. Some of the most famous modern patterned sidewalks are in Brazil, a former Portuguese colony.*
> [Salingaros 1999: 44]

The design of flooring, as in an open plaza, has to obey the same principles as other, time-honored designs, such as oriental carpets. Methods for connecting different scales are outlined in a model of complexity by one of the authors [Salingaros 1997]. The basic mechanism for linking among units separated either by distance or by scale is similarity in texture, color, and form. Similarity works via translational, rotational, reflectional, and scaling symmetries in the plane [Washburn and Crowe 1988]. This is known by all sensitive artists trying to establish visual and emotional harmony. The coordination responsible for the visual coherence of the whole requires complex ordering, but not simplistic alignment. Symmetric arrangements on a plan do not connect elements across scales.

Great urban spaces were built before the twentieth century, before the wholesale replacement of traditional design criteria. Discarding techniques for connecting human beings to the built environment developed over the previous several millennia, architects now follow a design philosophy that values an emotionally uncomfortable novelty, and which disconnects people from surrounding surfaces [Salingaros 1999]. It is therefore a welcome surprise to see successful contemporary plazas built by the British artist and urban designer Tess Jaray. One sees in her designs a well-defined smallest scale; distinct yet connected designs on different scales; and careful harmonization with the surrounding buildings [Williams 2001]. This paper tries to analyze why her designs are so successful, using the fractal encoding model outlined above. Jaray's pavements provide a satisfactory experience on a number of different scales.

From the informational point of view, an open plaza offers vastly decreased input from surrounding walls compared with a totally enclosed, roofed space. It is therefore critical to connect to the ground via geometry. Thus, the most expressive pavements are to be found in public open spaces around the world. When successful – as in the case of Tess Jaray's pavements - they connect the pedestrian to the ground, and thereby permit the psychological freedom to be alive and move around. This is what determines the success of an open space independently of other factors such as exposure, surrounding façades and density of cross-paths.

Connection establishes a physiological state

We postulate that the intensity of fractal connection corresponds directly to the degree that human beings intuitively feel a space or design to be meaningful or "alive". This model therefore identifies the visual connection of designs and structures with a viewer's emotional state. It is becoming increasingly clear from neurophysiological research that the human conceptual system and the possible forms of reasoning are limited by the wiring of our brains [Lakoff and Johnson 1999]. Moreover, mental activity turns out to be emotionally engaged; i.e, it is likely that we actually feel our thoughts [Lakoff and Johnson 1999].

There exist subconscious processes going on inside our brains, which probably encompass the fractal connections discussed above. Our model of fractal encoding helps explain why we feel emotionally elated standing in a great historical plaza which is paved with some design that harmonizes with surrounding buildings. If all components work to connect and harmonize, we become an integral component of an enormous space because we link hierarchically with it. This could represent one of the greatest architectural-aesthetic experiences for an observer.

The corollary is also of interest. Urban spaces that conform to the contemporary design canon tend to be dead, because they fail to establish a positive emotional connection with the user. One can argue that this effect is not unintentional. A person feels ill-at-ease in such places, and consequently avoids them. This is not simply a matter of choice; as proposed in this paper, nonfractal structures clash with our perceptive process. Not only is our environment thereby impoverished, but the design rules that generate such environments deny and suppress fractal connections. We now have a widely-embraced design philosophy that ignores the need to create structures that elicit a sense that we are in a meaningful place, thereby severely narrowing the range of our emotional experience.

The environment is not separate from us, offering only objects and external sensations that we encounter: it is part of our being [Lakoff and Johnson 1999]. A balanced, healthy mental state requires an understanding of nature that is linked to our human emotions. The mind is much more than a computer; it is also passionate. How are we to understand our sense of belonging to a larger whole? In this paper, we have discussed the experience of meaning from the environment, yet our explanation is limited compared to what is described very well in mystical and spiritual literature. Connecting to a larger, all-encompassing whole can lead to ecstatic participation, or a spiritual experience. Such a state has frequently been described as transcendence.

The nature of meaning

We wish to concentrate on the perception of meaning coming out of visual complexity in the environment. Visual information presented as a coherent image or coded pattern is accessible in a direct manner. There is a mapping function between structures in the world and structures in the mind. When the mapping is faithful to the hierarchical linking (i.e., it preserves the information and its interconnections rather than any overall form), it creates an experience of meaning. Neural structures use information on connectivity to create meaning as an internal state: in our model, meaning is not assigned to external forms. The degree of conformal fit or coherence determines the strength of the sense of meaning and also the strength of the emotional experience. In its simplest aspect, meaning corresponds to a valence in emotion, which is either positive or negative. When two or more meaningful structures are linked together in a meaningful way, we begin to build a system of beliefs.

If an image is incoherent, then the information it contains cannot be perceived easily as a whole. There is less meaning because, even though there may be considerable information there, the information is difficult to synthesize. This in turn generates a negative valence which is manifested in negative emotions. Viewers are more receptive to information that is presented in a pattern that is strongly connected to them. Information structured in this way is typically called "natural" or "intuitive". One of us has previously argued that intuition is actually a process involving reasoning with structure [Mikiten 1995]. By contrast, a viewer will not be receptive to information that is presented via a visual pattern (or lack thereof) that fails to establish a strong connection with the viewer. We believe that environmental structures need to be fractal to satisfy the human brain.

Our sense of understanding arises from the way we form conceptual structures in the mind. When a collection of ideas has coherence and a sense of relatedness among its elements, we perceive its structure. When we perceive the structure of thoughts and ideas as a coherent whole, we conclude that they are correct and that the construct is valid [Mikiten 1995]. We remember it as a guide for further thought. We also use it to guide our behavior. Ideas that are neatly linked and have a coherent structure are judged to be valid or "true". The nature of intuition may be understood as the ability to match the structure of a present situation with the structures of problems that have been experienced before. Intuition represents the general ability to reach a conclusion on the basis of less explicit information than is ordinarily required to reach that conclusion [Mikiten 1995].

Conclusion: some guidelines for pavement designs

Rules for creating a memorable open space can be abstracted from studying historical examples. The lesson from our fractal encoding model is that there exists a fundamental similarity between complex structures in the environment and structures in the mind. Designing an open space can be successful if one follows one's basic instinct to ornament, connect, and harmonize different levels of design. In principle, therefore, there is really no need for rules if one is guided by one's deepest feelings. Indeed, one can argue that the closer the match between the architect's felt intuition about a space and the structure that is finally created as an expression of that intuition, the greater will be the meaning of that space for the observer. In a sense, the built place becomes the vehicle for the mental structure of the architect to be instantiated as a mental structure in the observer.

Nevertheless, some pointers are necessary because of the plethora of negative examples of structures in existence. Even though the best pavements depend on engineering principles, they have to balance and synthesize so many factors that the result should be considered a "work of art". A successful pavement will have the following characteristics, and satisfy hierarchical linking:

1. Human-scale design to connect immediately with a user.
2. The smallest units defined by contrast and symmetries that allows the units to be detected.
3. A smallest design scale that is compatible with human dimensions - anywhere from 1cm to 1m.
4. Several levels of design before reaching the full extent of the open space.
5. Intermediate levels of design that are distinct yet strongly linked via similarity.
6. Larger levels formed from ordered combinations of elements on smaller scales.
7. Balance among all regions and scales - every element acting as a connector for the other elements.
8. Harmonization at a distance to link all scales with the surrounding buildings.

If these conditions are satisfied, then a user, on entering the environment, will experience a sense of meaningfulness as all of the scales in the view are seen as a unified whole. There is a fractal (i.e., hierarchical) connection to the entire space. The strength of the component connections determines the coherence of the whole. In a poor design, the smallest elements are not symmetric, and appear as amorphous smudges to which we cannot connect. The connection proceeds from the smallest scales to the larger scales, up to the largest scale which is defined by the surrounding structures. While our description of the connection process was sequential, the actual connection through perception is sudden. This experience is frequently dramatic, and creates a definite and sometimes intensely positive psychological and physiological state.

In conclusion, we have proposed a theory of pattern perception that can explain how patterns generate meaning in the environment. Although this theory is entirely general, it was applied here to discuss pavements. A strictly utilitarian approach to pavements requires no sign of any promise of destination or completion that attaches meaning to built forms and spaces. When the environment becomes more complex, the pavement becomes the guarantee that the environment is planned to embody destinations and connections. A pavement that is designed to have meaning ought to obey the eight rules given above. Pavements as a definition of space represent the highest order of mapping between an architectural theme and a theme that the human mind can understand. Meaning in the pavement thus allows one to "know" the place without seeing all of it.

First published in the NNJ online April 2000

References

ALEXANDER D. M. AND G. G. GLOBUS. 1996. Edge-of-Chaos Dynamics in Recursively Organized Neural Systems. In *Fractals of Brain, Fractals of Mind*, ed. E. MacCormac and M. I. Stamenov, pp. 31-73. Amsterdam: John Benjamins.

GIBSON, JAMES J. 1979. *The Ecological Approach to Visual Perception.* Boston: Houghton Mifflin.

LAKOFF, GEORGE AND MARK JOHNSON. 1999. *Philosophy in the Flesh. The Embodied Mind and Its Challenge to Western Thought.* New York: Basic Books.

LAUWERIER, HANS. 1991. *Fractals: Endlessly Repeated Geometrical Figures.* Princeton, New Jersey: Princeton University Press.

MARR, DAVID. 1982. *Vision.* San Francisco: W. H. Freeman.

MICHAELS, CLAIRE F. AND CLAUDIA CARELLO. 1981. *Direct Perception.* Englewood Cliffs, New Jersey: Prentice-Hall.

MIKITEN, TERRY M. 1995. Intuition-based Computing: A New Kind of 'Virtual Reality'. *Mathematics and Computers in Simulation* 40: 141-147. http://homepage.mac.com/mikiten/intuition.html.

PADRÓN, VICTOR AND NIKOS A. SALINGAROS. 2000. Ecology and the Fractal Mind in the New Architecture: A Conversation. *RUDI – Resource for Urban Design Information.* http://www2.rudi.net/rudiments/ecology/index.html [approximately 12 pages].

ROLLS, E. T. AND A. TREVES. 1998. *Neural Networks and Brain Function.* Oxford: Oxford University Press.

SALINGAROS, NIKOS A. 1999. Urban Space and its Information Field. *Journal of Urban Design* 4: 29-49.

SALINGAROS, NIKOS A. 1997. Life and Complexity in Architecture From a Thermodynamic Analogy. *Physics Essays* 10: 165-173. http://www.math.utsa.edu/sphere/salingar/LifeandComp.html

WASHBURN, DOROTHY K. WASHBURN AND DONALD W. CROWE. 1988. *Symmetries of Culture: Theory and Practice of Plane Pattern Analysis.* Seattle: University of Washington Press.

WEIBEL, E. R. 1994. Design of Biological Organisms and Fractal Geometry. In *Fractals in Biology and Medicine*, ed. T.F. Nonnenmacher, G. A. Losa, E. R. Weibel, pp. 68-85. Basel: Birkhäuser.

WEST BRUCE J. AND BILL DEERING. 1995. *The Lure of Modern Science: Fractal Thinking. Studies of Nonlinear Phenomena in Life Sciences.* Vol 3. Singapore: World Scientific.

WEST, BRUCE J. AND ARY L. GOLDBERGER. 1987. Physiology in Fractal Dimensions. *American Scientist* 75: 354-365.

WILLIAMS, KIM. 1998. *Italian Pavements: Patterns in Space.* Houston, Texas: Anchorage Press.

WILLIAMS, KIM. 2001. Environmental Patterns: Paving Designs by Tess Jaray. *Nexus Network Journal* 2: 87-92

YU, HING-SING. 1996. Effects of environmental factors on the endocrine system. *In Handbook of Endocrinology*, ed. G. L. Gass and H. M. Kaplan, pp. 43-68. Boca Raton, Florida: CRC Press.

The Authors

Terry M. Mikiten (B.A. biology 1960, New York University; Ph.D. pharmacology 1967, Albert Einstein College of Medicine, Yeshiva University) is Associate Dean of the Graduate School of Biomedical Sciences and Professor of Physiology at the University of Texas Health Science Center at San Antonio. He is recognized for his work on synaptic transmission, synaptic plasticity, and informatics. His current research interests include the cognitive underpinnings of the human-computer interaction, cognitive structures and ethics, cognitive structures and informatics, creativity, intuition, and the relation of mind to brain. He is the recipient of an Institute for Scientific Information Lazarow Award in recognition for his contributions to information science.

Nikos A. Salingaros (B.Sc. physics 1971, University of Miami; M. A. physics 1974, Ph. D. physics 1978, State University of New York at Stony Brook) is Professor of mathematics at the University of Texas at San Antonio. He is the author of more than 70 scientific papers on mathematical physics, thermonuclear fusion, and complexity. His current research interests focus on deriving the scientific foundations of architecture and urban planning. This research program is supported in part by a grant from the Alfred P. Sloan Foundation.

Hing-Sing Yu (B.Sc. biology 1979, M. Phil. physiology 1982, Ph.D. toxicology 1988, University of Hong Kong) is Lecturer in both life sciences and mathematics & statistics at the University of Texas at San Antonio, and is president of UniTech Systems, a computing technology company. He has contributed to biorhythm research, toxicological evaluation, and statistical assessment. He is the author of the monograph Human Reproductive Biology (1994) and many research papers and book chapters. His current research interests include the computational modeling of rhythmicity in cellular processes and biological systems.