Structural order in Japanese *Karesansui* gardens

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We interpret Japanese rock garden design, from a visual psychological stance, to understand how and why design effects are achieved, and how this may relate to the sense of calm typically evoked in these gardens. We found that classical design guidelines attempt to balance the visual prominence of design elements on multiple spatial scales; neither the "whole" nor the "parts" create an unequal bias for visual attention. We analyse the structure of visual figure and visual ground, since visual structure is the foundation of visual perception. The figures (rock clusters) in Japanese *karesansui* gardens approximate vertically inverted, tree-like branching structures that converge away from the viewer, while visual "ground" is essentially an upright, dichotomously branching structure, converging towards the viewer. We conclude that some *karesansui* garden s employ a structural scaffold of the "whole" design to facilitate effortless visual perception, with a claming effect, and specific aesthetic consequences.

Many scholars of landscape design agree on similarities and differences between Japanese and typically Western gardens. Apart from differences in symbolism, the striking symmetrical geometry by which natural elements extend the imposed order of architectural structure in Western gardens is often contrasted with the naturalistic, asymmetrical Japanese designs, where gardens bridge, rather than extend, the transition from man-made to natural worlds (Slawson, 1987).

Japanese gardens evoke a sense of ordered, calm composition. Without deeper knowledge of the effort involved in these designs, one may assume that this results naively from the random placement of natural objects, such as rocks and moss, to resemble a naturalistic scene. While this is not completely incorrect, it neglects the many design guidelines, intimate knowledge of natural elements, and practical skills required in the design and creation of a Japanese garden.

Working with a team of professional gardeners in Kyoto, the authors soon realized that modern visual psychology offers deeper insight into how and why specific garden design effects operate, and how they contribute toward calmness. We base our approach to gardens on one of the main tenets in visual psychology - the realization that the human visual system operates as a hierarchical system that segments the visual scene into possibly meaningful shape "parts" (Koenderink, Van Doorn & Kappers, 1992). The latter are then grouped together into holistic ensembles that correspond to visual "figure" and visual "ground". For example, when viewing the famous image (figure 1A) by Rubin (1958), the visual system either groups the black-white contour parts as a white "vase" figure on a black background, or as two black faces on a white ground. We will return to figure 1.B and C later.

In what follows, we present short sections on the relevance of naturalistic design in Japanese gardening history, analysis of visual figure in Japanese gardens, and analysis of visual ground, in the famous *Ryoanji* rock garden. Unveiling the topological structure in *karesansui* gardens reveals a vein of similarity between Western and Asian gardens that courses deeper than the superficial differences between them.

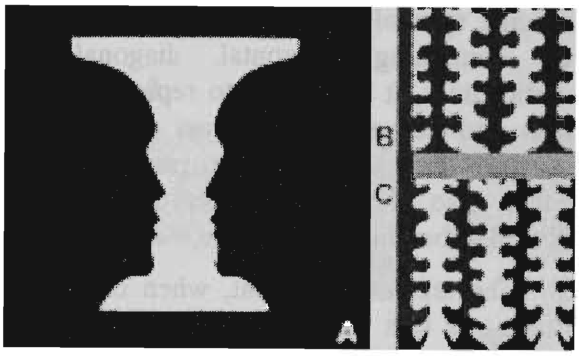

Figure 1.
A: A vase, or two faces (Rubin, 1958)? B,C, The most bilaterally symmetrical shape parts are grouped into the salient `figures` (Bahnsen, 1928).

B and C: Bilateral symmetry dominating our perception of "figure", creating isolated figures that do not easily blend into the whole.

Naturalism in Japanese dry landscape design

Dry landscape gardens refer to minimalist gardens that reached stylistic maturity during the *Muromachi* period (1333-1573). Composed mainly of rocks and moss set on a bed of raked gravel, *karesansui*, or "dry mountain and water landscape", owes its name to the use of appropriate arrangements of rocks and gravel, but not water, to evoke the essence of real streams, ponds and oceans. We investigate the design of dry landscape gardens because they appeared at a time when many Japanese art forms, including landscape design, witnessed a shift towards abstraction. This coincided with the appearance of the first illustrated Japanese gardening manual, the 15^{th} century illustrated gardening manual, *Sansui narabini yagyouno Zu* (Zouen, 1466), which formalized a variety of design techniques, developed during the preceding centuries. Garden designs from this period reflect the extent to which professional gardeners understood, at least intuitively, the visual impact of the design effects used in gardens

The oldest surviving Japanese gardening manual, *Sakuteiki* (translation: Shimoyama, 1976), dating from either the 11^{th} or 12^{th} centuries AD, emphasizes that one must be able to grasp the essence of the natural scene that is chosen as role model for a garden design. This was also true for landscape painting. It is not surprising to find that nearly all the noted gardeners in the history of Japan also excelled at landscape painting (Slawson, 1987). The art of gardening was in many ways an extension of landscape painting into three dimensions. We believe that the ability to "grasp the essence" of natural patterns enabled Japanese artists to produce outstanding work, whether on silkscreen or in gardens.

The complexity of natural shapes derives from the fact that they are usually built out of relatively simple forms that recur on many different spatial scales. A fern leaf is a clear example. The pattern of the leaf is literally duplicated as a miniature copy on each of its subdivisions and each of the latter contain smaller copies of the same structure. Not all natural patterns are this explicit. In geological formations, such as a rocky outcrop, one can see how the overall shape of the formation repeats again and again as smaller outcrops within the larger shape, but with various gradations, for example, as one type of sediment changes to another. The transition form one multi-scale pattern to the next may not be visually clearly defined. For the artist this poses the challenge of finding the underlying essence of a pattern which appears complicated.

The famous woodblock print of a tsunami tidal wave by Hokusai ((figure 2), is a good example of an artist's grasp of the essence of a complex natural pattern. Here he depicts a tempestuous wave on the sea. The three close-up images show enlargements of sections of the wave, at increasingly finer spatial scales. Hokusai repeated the same, forward leaning C-shape of the wave, at roughly three scales. A real wave appears far more intricate than this. Hokusai's work is, in a sense, a caricature of this complex pattern.

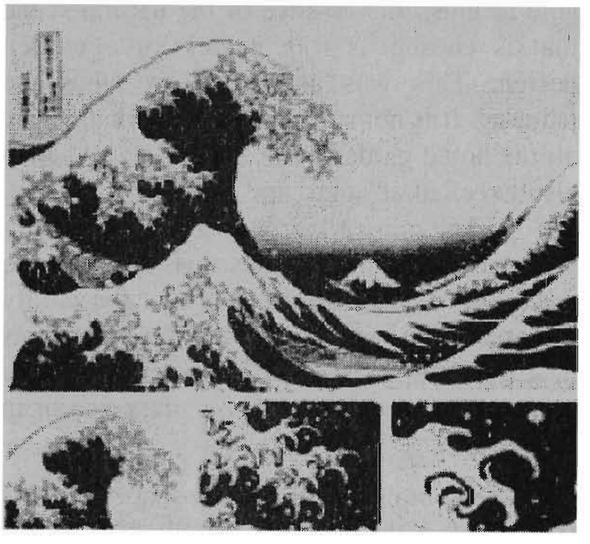

Figure 2
The Great Wave off Kanazawa **by Hokuzai. Three consecutive close-ups (bottom) of the wave shows how the basic shape repeats over spatial scales.**

It is the underlying building block from which the desired multi-scale pattern of the wave can be reconstructed. The result is a simplified wave that not only captures, but even intensifies, the dynamic appearance of the wave.

Visual figure: rocks as the backbone

Ishitate, one of the first Japanese words for gardening, literally means "the setting of stones." The 15th century illustrated gardening manual (Zouen, 1466), explicitly states that rocks form the backbone of any garden design. Rocks are usually the first items to be set in a garden, prior to the addition of gravel, plants or paths. The old manual emphasizes that appropriate rock shapes must be used to depict various features of a real natural scene. It carefully describes how rocks must visually overlap, enhancing the sense of depth to the level of grand visual scenery.

The proposed basic compositional unit for the "backbone" of the garden, with the right pattern of overlap, is a roughly triangular shape. Triangles, or triads, serve a specific symbolic purpose in Zen Buddhism. By combining horizontal, diagonal and verticallines, it is thought to represent earth, man and heaven, or in terms of time and space, near, middle, and far, respectively. It could also depict a master attended by disciples, bowing in reverence.

The text explains that, when creating a triad, one sets the dominant rocks of each cluster first, with smaller stones added later to fill out the triangular arrangement. Although the text is not clear on where in the garden one places the first rock, one can infer from the above that, just as the main stone in each cluster is set first, one would at least partially create the most dominant cluster first. In any event, the technique is strongly reminiscent of the creation of a multi-scale pattern, such as the Hokusai wave.

Various techniques are proposed to round off the composition, after the main clusters are set. *Motoishi*, or "base stones" (figure 3A), can be placed at the foot of the main rock in a triad to "harmonize the balance between the rocks". In terms of visual psychology, this rock effectively reinforces the grouping between visual cues within the cluster (figure 3B). Proximity (Koffka, 1935) influences how the visual system group visual elements into a figure. Without the base stone, the composition literally divides into two separate clusters (figure 3C). Similarly, *suteishi* (figure 3D), or "thrown away stones", are low, inconspicuous rocks used to make a cluster seem "more natural and less contrived". The thrown away stones shown in this case widen the base of the triad, bringing it in closer proximity with other rock clusters to enhance grouping between clusters (figure 3E). Without these stones the cluster seems to stand out much more, and would not blend as smoothly into the whole design (figure 3F).

Proximity is not the only grouping factor that influences the appearance of the composition. The base stone also increases the self-similarity of the cluster. With each rock approximately triangular (figure 4A), the rock cluster can be considered as a set of triangles presented at a few spatial scales. By adding the base stone, the number of possible triangular groupings within the cluster increases.

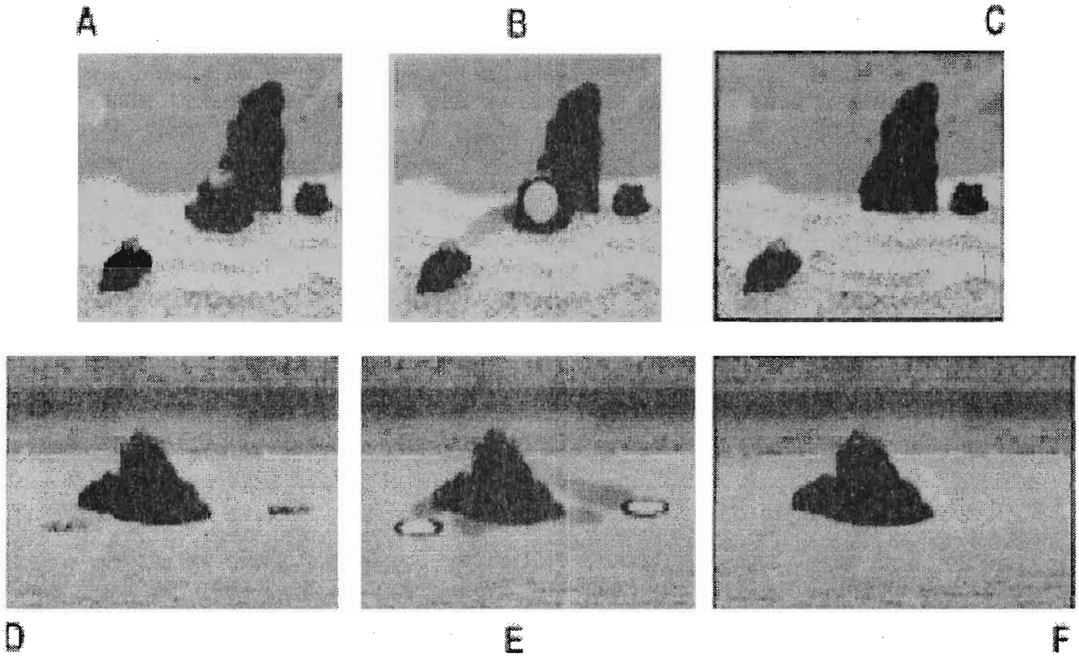

Figure 3
A: A triangular cluster, with base rock, B: The base rock visually binds the cluster together, C: Without the base rock the cluster divides in two. D: A triangular cluster with two `thrown away stones`, E: The latter extends the triangular base of the cluster, F: Without which the cluster seems to stand completely by itself.

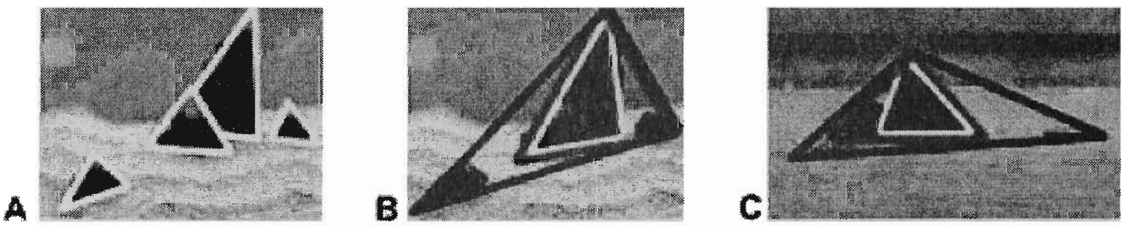

Figure 4
A: Each rock in itself is roughly triangular, B: `Base stones` and C: `Thrown away stones` extend the number and scale of possible triangular relations in the rock cluster

The range of spatial scales at which triangles occur is also larger (figure 4B). Thrown away stones have a similar effect (figure 4C). Note that all the triangles within rock clusters are asymmetrical. This is another important feature in the design of Japanese gardens, which we will return to later.

In the final example on visual figure, we return to the notion of visual overlap between rocks. The old illustrated manual prescribes the use of odd numbered rock clusters to even numbers, the reasoning being that odd numbered groupings look more natural. We interpret this guideline as meaning that the visual appearance, rather than the actual physical number, of rocks in a composition should be odd numbered. In such compositions the visual junctions, an important cue for visual grouping, would then also be odd numbered.

Consider visual junctions that result from odd and even numbers of objects (figs. 5A,B, respectively), arranged to form a visually enclosed composition. Visual contours falling between objects meet at an odd or even numbered junction, respectively. If presented as line element contours among distractors, even junctions (figure 5C) are more visually salient than their odd counterparts (figure 5D). With a garden as the visual scene, even junctions would grab visual attention, instead of reinforcing and balancing grouping between different parts of the local and overall composition. At its worst, images with many even junctions cause competing figures, with a destabilizing, scintillating effect on visual perception (Marroquin, 1976).

From the literature on boundary ownership we know that odd junctions and so-called T-junctions in particular, serve as a strong monocular clue to perceived three-dimensional depth. A T-junction is a special case of a trilateral odd numbered junction, where two of the three legs of the junction form a roughly straight line.

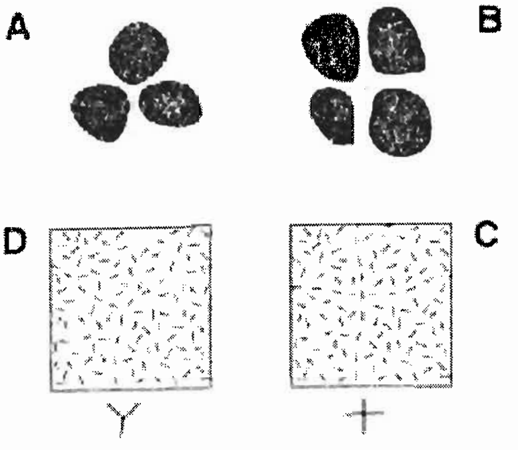

Figure 5

An odd- numbered rock cluster (A), from above and an even- numbered rock cluster (B), from above. The clusters form odd , and even junctions, respectively. Even junctions (C) are more visually salient in textures, than odd junctions (D), because the even junctions form smooth, intersecting contours of greater visibility.

The last example on the multi-scale structure revisits the use of triangles, asymmetry and odd-numbered junctions. Figure 6A demonstrates how similar patterns reappear from a close-up view of rock texture, through various spatial scales to the overall composition of the *Zuihouin Dokuzatei* garden, Kyoto. The comparison does not give a detailed numerical answer, but the repetition of triads is self-evident. Notice that triads are arranged like the scales on a fish, forming many layers of visual overlap. Each "scale" forms a visual trilateral junction. We propose that multi-scale repetition of junctions may be a mechanism to prevent any single part of the composition for grabbing visual attention at the cost of other parts of the same visual scene.

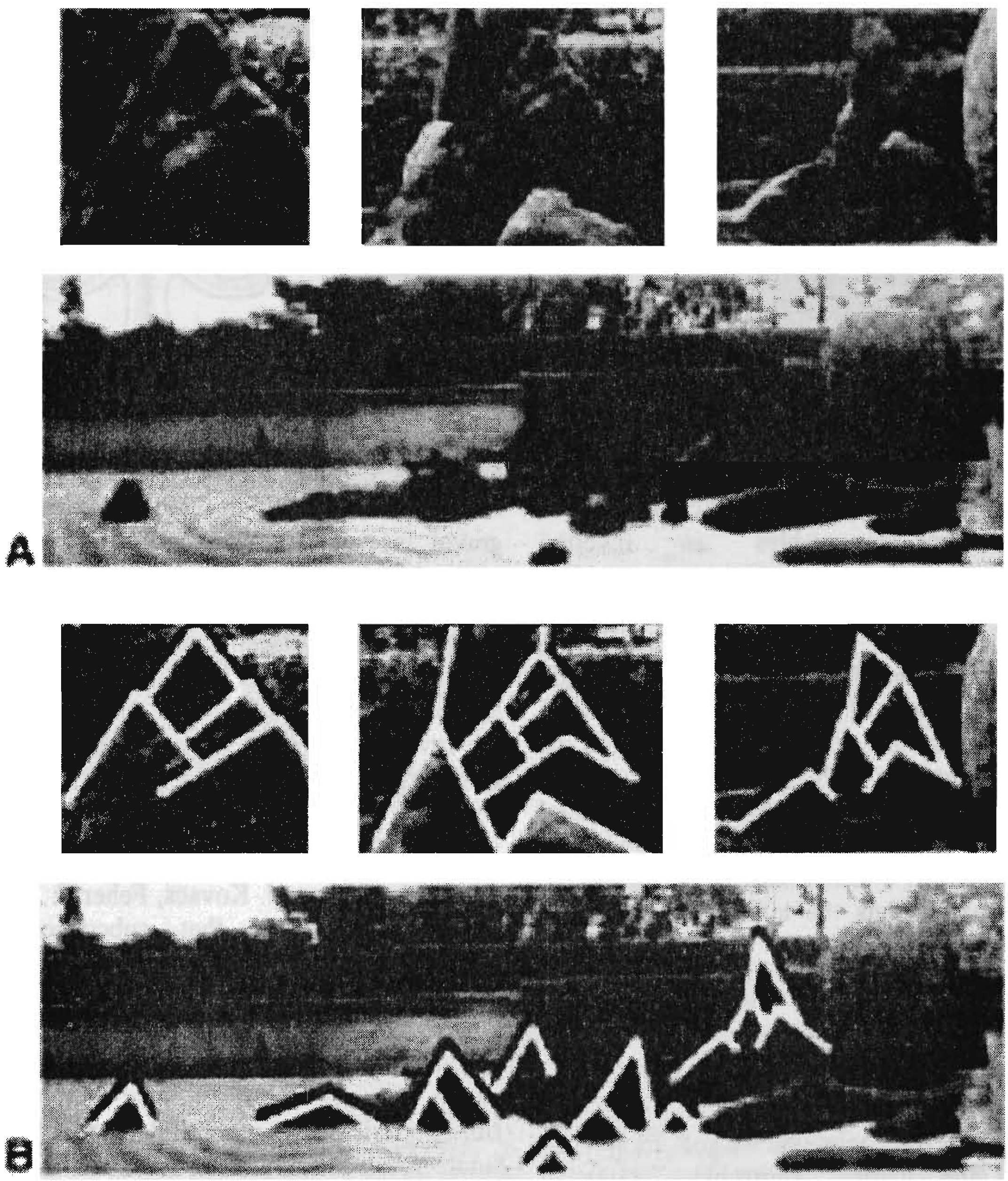

Figure 6
A: From a close-up of texture on rock face, through various scales, to the entire design of *Dokuzatei* garden.
B: Highlighted in white, the contour junctions at each scale approximate an inverted structure of trilateral branches.

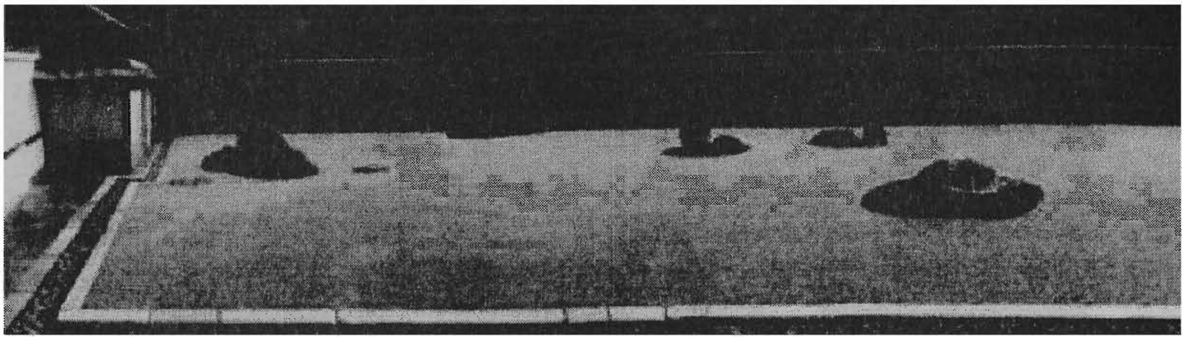

Figure 7
Looking out over *Ryoanji*, from the main viewing verandah. This UNESCO world heritage is widely considered to be the quintessence of Zen garden design. More than seven hundred thousand visitors from around the world puzzle over its strange beauty, every year.

Line drawings of trilateral junctions in this garden (figure 6B) loosely meet up to form what resembles an inverted dichotomously branching tree structure. Note that any mention of tree-structures in our paper refers to a topological, branching structure, rather than a literal "tree". Each individual rock, and rock cluster, explicitly depicts a local, self-similar framework of visual junctions. Over successive spatial scales, interpolation between trilateral junctions forms increasingly larger, implicit tree structures a richly naturalistic structural frame that depicts the holistic shape of the rocky backbone.

Visual ground: subconscious perception of geometrical structure

The famous dry landscape garden at the *Ryoanji* temple (figure 7) in Kyoto is considered the quintessence of minimalist Asian Zen gardens (Nitschke, 1993). It consists of five rock clusters, with moss, on a 30m x 10m expanse of raked gravel. The latter, often considered as "empty space", functions as the visual ground in this type of design.

Gravel is as much a ground cover as moss, shrubs and rocks. In fact, the classical illustrated gardening scroll (Zouen, 1466), clearly states that one should not leave a single part of the garden untouched. An appropriate texture should cover every inch of the garden. With this in mind, the expanse of gravel is not "empty" space, in the strict sense, but forms a relatively uniform texture that contrasts with the figure of rocks. It creates the three dimensional context in which the more global structure of the design can be visually grasped. How can we analyze the structure of the seemingly "empty" visual ground?

The authors have selected medial axis computation to elucidate the implicit structure of the visual ground. Kovacs, Feher & Julesz, (1998) have shown that, subconsciously, human visual perception is strongly influenced by medial axes. Medial axes (Blum, 1973, Ogniewicz, 1993) can be visualized as the "skeletons" left after fires sweep through a field of grass. If the outer rim of a field of grass in the shape of a human figure is set alight (figure 8A), the fires will burn inward to stop each other along axes that occur medially along the limbs, head and body. Essentially, this is the medial axis transform of the shape, visible as the skeleton-like internal shading of the human figure in figure 8A.

The visual cortex in the human cerebrum is thought to create compact topological shape descriptions from medial axes, for pattern recognition (Kovacs et al., 1998). Van

Tonder & Ejima (2000) further demonstrated that local maxima, in the medial axis transform of a visual scene, can be used as centroids for possibly meaningful shape parts, to simplify image segmentation, as described in the introduction of this paper.

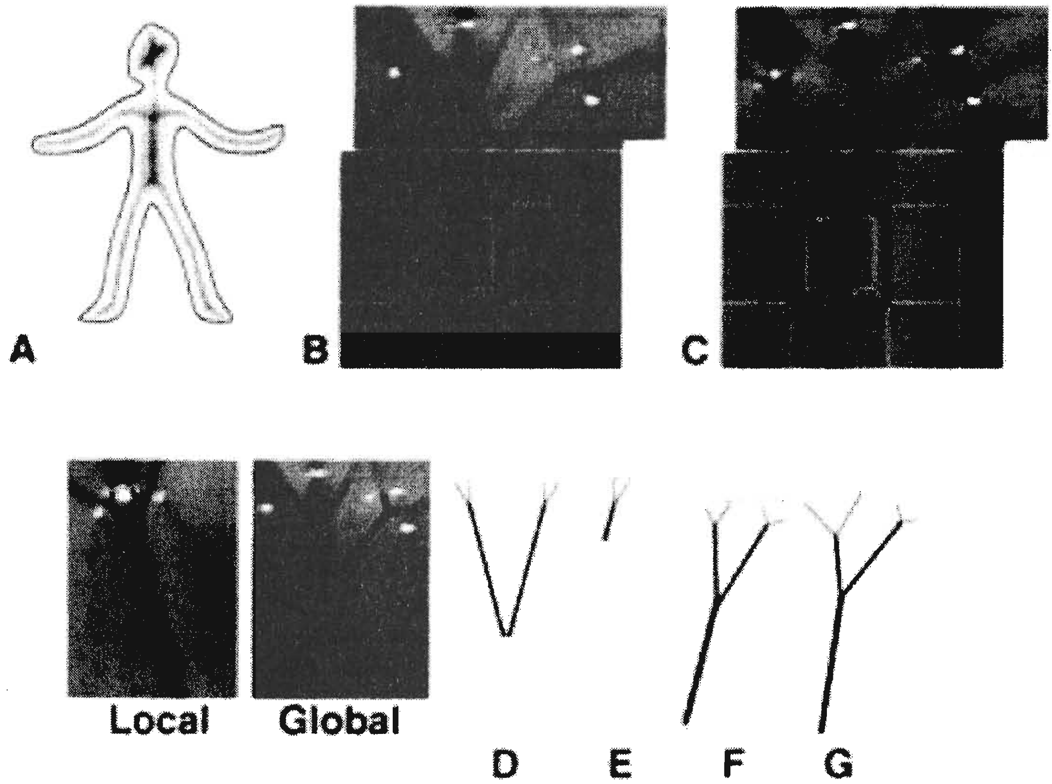

Figure 8
A: A humanoid figure (solid outline), and its skeleton-like medial axis transform (internal shading). B: Medial axis transform of the layout for Ryoanji, after a reconstruction by Oyama (1995). The top rectangle indicates the bed of gravel, with the five rock clusters. Below, the temple building is shown as white lines, with the central viewing room indicated by a bold, dark square. The medial axis transform clearly converges onto the central room. The height of each rock was used to scale its effect on the computation. C: The same transformation, repeated with every rock scaled to have the same effect on the computation. The fundamental tree-like structure remains, with a few small, noisy branchlets introduced. A significant branch now originates from the left-most rock cluster, and converges onto the central room. D: This new, local branch can be horizontally reflected, E, and a section of it F, scaled, to compare, informally, with G, the global tree. Both are topologically identical!

Grass fires, applied simultaneously at each rock cluster in the *Ryoanji* garden plan, will spread outwards and stop burning approximately along the medial lines between rock clusters, thereby tracing out the medial axis transform of the "empty" background (dark lines, figure 8B). As reported elsewhere (Van Tonder, Lyons & Ejima, 2002), the resulting medial axis transform show various non-accidental characteristics. It reveals a tree structure that converges towards the central viewing area in the temple building. The tree is strictly dichotomously branching, but not bilaterally symmetrical. Omissions, additions, and randomizations of spatial locations of rock clusters in the original layout all destroy these non-accidental properties.

In the previous simulations (figure 8B), the contour values of each rock in the input matrix were scaled with their relative height (after the accurate plan drawings by Shigemori, 1936-39), to approximate the visual salience of each rock, and hence its contribution to the medial axis transform. To test if our result critically depends on this choice, we repeated the simulation for uniform contour values, i.e. where each rock has an equal effect on the final outcome. Figure 8C shows the result. As expected, the medial axis transform is now more scattered, because even the smallest rocks strongly affect the computation. Nevertheless, the overall structure of the tree remains roughly the same and the alignment of the trunk with the temple architecture is not influenced by the perturbation.

Surprisingly, a second trunk now also passes close to the center of the main hall (figure 8C). At first glance this may seem insignificant, but for visual psychologists it raises questions about how fixation on any single rock cluster would affect the structure of subconsciously perceived medial axes, as studied by Kovacs et al. (1998). It is logical to assume that visual fixation on one rock cluster would enhance the visual salience of each individual rock in that cluster, analogous to assigning more equal contour values to each rock in our input data. Under such conditions we find that only the rock cluster on the left of the garden shows a strong effect. The other clusters do not introduce new branches into the viewing area. Figure 8, bottom left, shows an enlargement of the local branching pattern of the left most rock cluster.

To compare local and global trees more carefully, a section of the local tree was reflected horizontally (figure 8D) and then scaled (figure 8E,F). Placed next to the global tree (figure 8G) one finds striking similarities: both are strictly dichotomous tree structures, and hence self-similar in that sense. Both trees have identical topologies, and both are geometrically asymmetrical. This underlines the level of intuitive visual sophistication achieved by the designer(s) of this garden. Note that both converge onto the traditionally preferred viewing point of the garden.

We are not the first to venture in the direction of structural analysis of Japanese gardens. Various other investigations explain the order of structure in Japanese gardens in terms of alignment between rocks and architecture, or the alignment of rocks onto semi-circles, or Chinese written characters, or relative ratios, such as the golden section (Oyama, 1995; Slawson, 1987). Instead of giving precise numerical proof, it provides the qualitative setting for loosely approximating some "rules of thumb" in garden design. To the best of our knowledge, no design strictly adhering to such simple principles exists. Not surprisingly, mathematics shows that such special ratios should be regarded as being due to special cases of more general mechanisms by which complexity arises. If not presented within this context, geometrical ratios lack generality.

We should also point out that various contradictory views exist on the origins of the present garden at *Ryoanji*. We do not attempt to join this debate. Regardless of when, and by whom, the garden was conceived, the fact remains that its medial axes reveals a non-accidental structure, exhibiting a critical alignment with the temple architecture.

Related work

A recent computational analysis of art (Taylor, Micolich & Jonas, 1999) showed that the structure of visual figure in the drip paintings of Jackson Pollock is statistically self-similar, and therefore both naturalistic and non-accidental. Here we applied medial axis transformation to Japanese gardens to uncover the implicit structure of the visual ground. The resultant pattern was found to exhibit various non-accidental qualities, such as self-similarity. An in-depth numerical analysis of multi-scale structure in Japanese gardens will be presented in future work.

It is interesting that not only *karesansui*, but various forms of Japanese art, reached high levels of psychological sophistication during the *Muromachi* period. In earlier work by Lyons, Campbell, et al. (2000), a scientific approach highlighted the visual and psychological sophistication of Noh mask design, which were also refined during the *Muromachi* period.

The analysis of structure in *Ryoanji* shows interesting, although indirect, similarities to the approach developed by Leyton (1992) to interpret works of art, such as oil paintings. Guided by his theorem on the duality of contour and symmetry, Leyton uses contour curvature extrema the points where contours and medial axes coincide as a scaffold from which to analyze the structure of art works.

In continuing work we are comparing the medial axis structure of *Ryoanji* with that of other gardens. Similar converging patterns occur in some cases, although not with the sharp definition found in *Ryoanji.* In most cases there is more than one tree trunk, but nearly each of these sub-trees converges onto a viewing area, such as a verandah, as with *Ryoanji*. In most cases the different trunks meet at a point so deep inside the building that the garden is not fully visible from such "virtual" focal centers. Three examples can be seen in figure 9.

Harmonious visual design

We would like to emphasize how much more harmonious the actual *Ryoanji* composition is than randomly generated or mutated compositions of our experiments. Here, the lines of symmetry run haphazardly in various directions, whereas with the actual garden the local symmetry lines flow naturally like streamlets into a single river basin. This seems a visually poetic representation of the harmony of Nature.

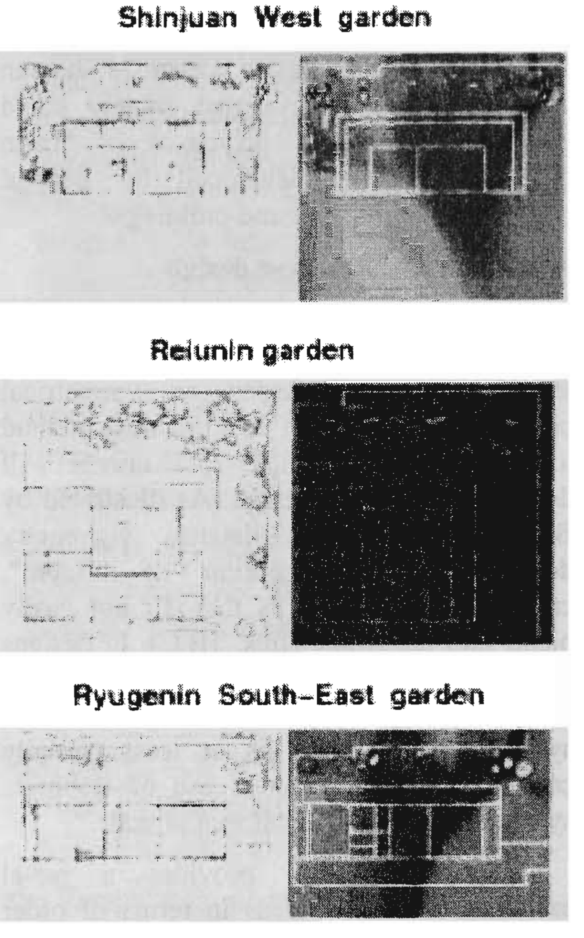

Figure 9
Examples of medial axis transformations in three other Zen karesansui gardens. Note the tree-like patterns in each case, and how and where there confluences occur. Plan drawings were taken from Shigemori (1936-39).

Patterning the empty ground of the garden into an object with a visually connected, hierachical topology, may ease perceptual grouping of the five clusters of the garden, into an indivisible whole. Careful consideration of this hierarchy of medial axes minimizes cognitive load by reducing the demand on attentional resources of the human viewer, without compromising the amount of visible information. The harmony of the symmetry lines and the ease of grouping due to the patterned visual ground leads to further reduction of the perceptual effort required to gain access to the a minimal use of the information processing resources of the visual system. In this sense gardens are a "calm technology" designed to optimize human well-being. We believe that society could benefit if analogous principles of "calm design" could be developed for general planning of landscapes and buildings.

Asymmetry in Japanese design

None of the garden examples of the preceding sections has any bilaterally symmetrical shapes, cluster of shapes, or symmetrical branching structures. It is a practical method to ensure that no single rock cluster will dominate the whole design. As illustrated by Bahnsen (1928), bilateral symmetry dominated our perception of "figure", creating isolated figures that do not easily blend into the whole (figs. 1B,C). In designs rich in symmetry (Tyler, 1996), such as classical French gardens, the effect of symmetrical sub-parts is at least partially countered by the repeated use of elaborate symmetrical order at each spatial scale.

Our presentation provides a novel extension to earlier ideas in terms of order and complexity in the garden (Arnheim, 1966). He asserts that while each rock cluster of *Ryoanji* shows its own structural hierarchy, there is no such global hierarchy to give an overall structural frame to the design. Perhaps Arnheim neglected the structure of the visual ground. Even if perception of medial axes is subconscious, the branching structure in the visual ground could qualify as an holistic structural hierarchy for the design. Moreover, though *Ryoanji* has an asymmetrical design, its underlying organization is based on a convergent hierarchy, and thus related, albeit abstractly, to a classical French garden!

Medial axis transformation in design aesthetics

Designers work with both objects and the empty spaces between them, and have to solve the whole problem simultaneously. Good designers probably do this effectively, already. However, we would like to suggest reverse conceptualization, where the structure of empty space is designed first, rather than the objects themselves. This may sound counter intuitive at first, but since empty space subconsciously plays an important role in our perception of holistic composition, it is a potential tool for the creation of more harmonized designs. The well defined structure of local symmetry axes may provide a formal guideline for beginners, or offer insight for more advanced designers to better understand processes they may already use semi-intuitively.

Our sense of aesthetics is closely linked to perception, which in turn depends on how we understand visual structure. This investigation provides a new interpretation of the visual structure of empty space in Japanese garden design. Hopefully, this will contribute to a constructive debate on the elusive topic of design aesthetics.

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The authors personally hope that this work will inspire South African designers to make greater use of their wealth of local naturalistic patterns, ingrained with the local landscape.

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