The Dutch painter Piet Mondrian (1872–1944) was one of the founding members of the Amsterdam De Stijl art movement. This group of painters, sculptors, architects and poets interacted closely with the Bauhaus art movement in Germany and the Russian avant-garde. Mondrian developed his own characteristic style of “neo-plastic abstraction” [1], which aspired to capture “pure beauty” by the use of lines and basic colors in “pure relationship” [2]. Mondrian proposed six “neoplastic laws” of aesthetics in his essay “Neo-plasticism in Pictorial Art” [3], one of which prescribes the use of cardinal orientations for lines and rectangular shapes to achieve constant equilibrium. The first—somewhat lofty and warped—manifesto was published in the journal De Stijl in 1918 [4], proclaiming a new, universal and abstract aesthetic that was no longer constrained by physical limitations [5]. Mondrian [6] saw the interior as an enclosed space, an artistic object that should follow the same “pure” principles to create equilibrium, putting beauty above utility. Many of these ideas are presented as intuitive claims, such as the need to overcome the dependence on perspective that is inherent to architecture [7].

Mondrian’s paintings, rectangular grids of black lines on white ground and rectangles filled with primary colors, undoubtedly belong with the icons of twentieth-century arts. The 1998 catalogue of his works [8] shows 83 distinctive patterns of pure abstraction created by the artist between 1920 and 1941, many as variants of the same basic design [9]. Mondrian’s passing interest in interior design is shown by the intentional staging of his paintings in his studios [10]. Following manifesto goals toward inseparable aesthetics of art and life, he purposefully arranged paintings, color plates and pieces of furniture in his studios, locked to a specific camera viewpoint (Fig. 1a). In his Paris studio he even worked around an oblique wall by placing occluders [11]. Inspired by Seuphor’s Dada play L’Ephémère est éternel, he designed a stage set with a frame facing the audience in the foreground and exchangeable backdrop scenes painted in his iconic style. A scale model of this austere proscenium could be found in his studio in 1926 [12] (Fig. 1b).

A unique example of Mondrian’s architectural thinking is an exploded box plan and axonometric drawings for a “Salon de Madame B... à Dresden” (the “salon”) from 1926 (Fig. 2). He was commissioned in 1925 by his patron Ida Bie- net for her Damenzimmer in Dresden to become a library and study. The initial version of this plan, kept by Mondrian, was a black-and-white drawing with coloring instructions [13]. Figure 2 shows the color version of the plans from Bie- net’s estate [14], held in the archives of the Dresden State Art Collections museum.

Mondrian never did see the salon completed. In 1970 it was reconstructed in the Pace Gallery, New York, and this prompted questions as to why the plans were never realized form, encapsulated in the Dutch term bouwkunst, where the aesthetic statement is no longer constrained by physical limitations [5]. Mondrian [6] saw the interior as an enclosed space, an artistic object that should follow the same “pure” principles to create equilibrium, putting beauty above utility. Many of these ideas are presented as intuitive claims, such as the need to overcome the dependence on perspective that is inherent to architecture [7].
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The original drawings show some rudimentary pieces of furniture [16], and there is no indication how paintings from Bienert’s art collection would be placed. These details might indicate fundamental issues with the translation of these drawings into three-dimensional space. Mondrian’s firm commitment to cardinal line orientations on planar surfaces would create issues with decorating a cuboid while allowing multiple viewpoints.

The purpose of this article is to explore the role of perceptual mechanisms in an attempt to resolve the apparent conflict between neoplastic dogmatic ideals and projective geometry. To this end, we present three demonstrations: (1) a scale model of the salon that highlights how the corners of the room affect the picture projected on the observers’ eyes; (2) a computer graphics (CG) simulation of being in such space and an alternative configuration that would avoid corner effects; and (3) a physical model of a space in Mondrian-like patterns that create surprising depth illusions, demonstrating perceptual conflict of these patterns with the geometry of surfaces.

A PHYSICAL MODEL OF BIENERT’S SALON

Although Mondrian mentioned in letters that he was experimenting with the design for Ida Bienert and might even build a scale model [17], the project was not realized during his lifetime. In order to get a better idea about how this salon might have looked, we constructed a “shoebox” model (Fig. 3) by following Mondrian’s drawings (Fig. 2a).

It is obvious that in the image plane, horizontal lines on the
walls intersect in the corners at oblique angles, as would be expected in projective geometry. Mondrian’s dogmatic proclamations [18] to use cardinal lines exclusively in 2D contexts (paintings) could be challenged when his patterns are placed in a 3D context; his *L’Ephémère est éternel* stage set could be regarded as the only viable solution where the observer’s viewpoint is restricted to a frontoparallel inspection. In a cubic room, however, the observer is allowed to look from a wide range of viewpoints at the patterns on the walls. Although the room is faithfully constructed to doctrine, in the static retinal image—comparable to a snapshot—the lines on the walls would deviate from cardinal orientations. For demonstration purposes, this is shown as the projection onto the camera lens in a photograph of the shoebox model (see Fig. 3b; cf. to Fig. 2b).

Mondrian created axonometric drawings of the salon as seen from 30° above floor level and from the left. These show a clear deviation from the rectangular doctrine: oblique lines in the vertexes of the room. In the axonometric plot (Fig. 2b), horizontal lines on the wall remain parallel, whereas they are oblique in the realistic photograph (Fig. 3b), as a result of natural perspective [19]. In G. Vantongerloo’s representation of a similar room [20], there are signs of foreshortening—it appears that these artists were struggling with the attempt to preserve parallel lines.

CG VISUALIZATIONS OF MONDRIAN’S INTERIOR DESIGN

Mondrian’s axonometric plots assume an observer position outside the room. We created a 3D model of the salon in LightWave3D (NewTek Inc. 2013) to simulate experiencing the real salon and also to remove walls to render an inside look for any given viewpoint.

Mondrian’s original drawings show that the space was divided into rectangles filled with primary colors, white and several shades of gray (which were abolished in his later paintings). Interestingly, lines were largely reduced to boundaries between rectangles, nothing like the thick black lines in his paintings [21]. We created a CG salon without rectangle outlines as in Mondrian’s original drawings (see Fig. 3b; cf. to Fig. 2b). The other variant has heavy lines, truer to his iconic style (see the online supplemental video A). We assumed the height of doors to be 2 m; using proportional scaling, the salon dimensions approximate 4 × 3.6 × 3 m (L × W × H). The key observations are illustrated with five still frames showing the view captured in 45° rotation intervals (Fig. 4c).

The salon with prominent cardinal lines demonstrates that oblique converging lines are very strong cues to depth perception and facilitate shape constancy; the latter is difficult to maintain under high uncertainty about the shape, perspective and inclination of surfaces in linear perspective [22]. A trapezoidal shape can be seen both as a trapezoid on a fronto-parallel plane or as a slanted rectangle (Fig. 5). However, the correct perspective interpretation of the room is enhanced by the motion parallax information provided in animations.

Mondrian patterns can be unambiguously perceived only if the line of sight is perpendicular to the walls of the salon (Fig. 4, panels c1, c3, c5). The strongest perceptual ambiguity, distortions of rectangular shapes and noncardinal orientations, can be seen in the static retinal image of vertexes of the Salon (Fig. 4, panel c4). Prominent black lines would facilitate shape constancy of rectangles from a range of vantage points, while at the same time more robustly violate the neoplastic dogma. On the other hand, distortions of rectangles in vertexes are more pronounced without thick black lines, as they are more likely to be interpreted both as trapezoids and rectangles (Fig. 4, panels c2, c4; see online supplemental video A).

Noncardinal orientations and distortions of rectangular shapes can be avoided in a room without corners, such as in a cylinder. We created a CG model of a cylindrical room with the same overall dimensions as the salon (Color Plate B, online supplemental video B). The four walls of Mondrian’s...
Fig. 4. CG model of Mondrian’s Salon using patterns without prominent cardinal lines: (a) Geometry in top view: Field of view (FoV) was 90° horizontally and 53° vertically; viewing distance D set to the length of the longer diagonal of the floor area. (b) A perspective view of the scene layout. (c) Camera view of three walls (C: steps 1, 3, 5) and two corners (C: steps 2, 4); C2 corresponds to the viewing angle in Fig. 3b. © Jasmina Stevanov and Johannes M. Zanker.

Fig. 5. Ambiguity of converging lines: (a) Without oblique converging lines suggesting perspective planes, a trapezoid can be seen both as trapezoid in the frontoparallel plane and as a slanted rectangle belonging to another perspective plane (picture adapted from Kitaoka [45]); (b) Joint ambiguity of shape and perspective: shape constancy is difficult to maintain if estimated from inclination in linear perspective. (Image adapted from Howard [46]. Used by permission of Oxford University Press, U.S.A.)
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In the cylindrical room, there are no vertexes; thus the most obvious conflict with neoplastic composition rules is removed. Throughout the field of view (FoV), vertical lines on the cylinder appear strictly vertical. With half of the cylinder being in the FoV, however, horizontal lines appear horizontal only in the center, but bend upward and downward in the periphery, deviating from orthogonality. These peripheral distortions are further enhanced by more prominent black lines and persist in conflict with Mondrian’s ideal (see online supplemental video B).

The sense of a rectilinear composition could be enhanced by restricting the FoV—for instance, by getting closer to the wall ahead. Within a smaller region of the wall, the number of visible rectangles and lines is reduced, raising the question whether the remaining pattern would still be compatible with the typical Mondrian composition. The analysis of his painting layouts [23] for works created between 1925 and 1935 reveals that in images having the average size of 52 × 58 cm, the average number of lines was 5.2, while the average number of rectangles was 5.5. This means that the number of elements on the wall pattern would need to be inversely proportional to the FoV, by reducing the size of rectangles and increasing the number of elements on the wall. Our hypothetical pattern in a narrow FoV may be alternatively considered in terms of neoplastic doctrine, although it is clear that aesthetic tensions cannot be completely resolved.

Using CG models and animations was useful to demonstrate possible issues with neoplastic aesthetic rules arising from different viewpoints [24] and geometry [25] of the real world. Most importantly, these animations demonstrated how perspective cues from static images and dynamic cues from motion parallax [26] interact in 3D perception. These mechanisms have a long evolutionary history—they can even enable insects to discriminate between 3D shapes [27], suggesting that no high-level cognitive processing is needed to interpret the shapes of objects in space. In the following section, we will demonstrate how the same mechanisms that enforce shape constancy and veridical space perception cannot always resolve perceptual ambiguity of static (pictorial) and dynamic (motion-parallax) depth information.

MONDRIAN COMPOSITION IN REVERSE PERSPECTIVE

Trapezoidal shapes seen in photographs at the corners of objects are typically perceived as representations of rectangles, due to shape constancy; in an extreme case this creates a conflict with motion parallax information that generates the paradoxical experience of a room following the observer sidewise [28]. Following the work of Patrick Hughes [29], we constructed a model in “reverspective” space: Mondrian-like patterns were morphed onto the surfaces of two capped pyramids with a square base (square frustums), so that the original pattern rectangle was stretched to fit into the four isosceles trapezoids of the frustums (Fig. 6b).

Seen from the apex at a distance (reducing binocular depth cues), the frustums are perceived as concave boxes or corridors (Fig. 6a, online supplemental video C). Based on perspective cues, the shorter lines at the apex appear more distant than the longer lines at the base. However, if the observer moves their head laterally, closer regions at the apex move more quickly across the retina than more distant regions at the base, which creates the paradoxical illusion of a rectangular corridor following the observer [30,31]. Perception is biased toward the most likely interpretation by shape constancy mechanisms. Lines can be perceived as parallel and orthogonal when they are part of slanted trapezoids—
and equally when they are part of a tilted rectangle as in the salon. Because the retinal images would appear equal, the interpretations of the retinal images are equal: Lines are seen as parallel and orthogonal. The reverspective model demonstrates the robustness of the shape constancy mechanism. Similarly, different viewpoints for Mondrian patterns would hardly disrupt our stable perception of cardinal lines in the salon. Could this demonstration cast new light on Mondrian’s design of the salon?

**DISCUSSION**

**The Problem**

In his discourse with De Stijl, Mondrian [32] published his plan for a salon to illustrate his vision of neoplasticist architecture: a fusion of many simultaneous planes into a balanced 3D object. The fact that the salon was never realized could have been due to logistic and financial reasons but also could reflect his dissatisfaction with dependence on perspective and laws of projective geometry. We have demonstrated that vertexes in the salon might be in conflict with Mondrian’s ideal of cardinal lines, and we have suggested that unwanted distortion could be reduced in a hypothetical cylindrical room. Such a room could provide a partial workaround but would remain far from a universal guidance for neoplastic architecture.

**A Proposition**

In the nineteenth century, scientific understanding of subjective human experience emerged with the advance of experimental psychology and the new discipline of psychophysics [33]. An idea to study beauty by focusing on basic forms and relations had already been pioneered by Fechner and his reductionist “aesthetics from below” [34], studying colors and simple geometrical shapes as stimuli that could be precisely controlled and manipulated. In the twentieth century, Gestalt psychology provided comprehensive insight in perceptual representation [35], which has influenced the development of a “vocabulary of pictorial representation” in art [36]. Early claims about the relevance of psychophysics for aesthetics [37], however, attracted surprisingly little attention. The scientific approach was embraced by some members of the Bauhaus [38], and although Mondrian interacted with the Bauhaus [39], he seems not to have taken particular interest in scientific evidence [40].

The conflict between the neoplastic ideal of beauty and the human interpretation of the 3D world results from a direct interpretation of static retinal images. However, oblique distortions in the retinal images are corrected by perceptual mechanisms (e.g. shape constancy), generating veridical perceptual representations of space [41]: The characteristic relationship between physical space, the rules of perspective for a given viewpoint and their effortless 3D interpretation from projections on a single plane are well understood. We used a reverspective object here to demonstrate how the mind makes sense of the outside world in the presence of conflicting depth cues.

Five years after publishing the neoplasticism manifesto, Mondrian pointed at a mysterious way for the mind to detach from the physical body: “Man’s eye is not yet free from his body . . . only the mind knows anything of the fourth dimension and detaches itself from our poor physical bodies” [42,43]. Could this be a hidden or unintended hint at relaxing the composition rules, taking into account mental representation? A scientific framework can put some of Mondrian’s comments about the future of architecture into a new perspective.

Mondrian strictly believed that universal beauty could be defined solely by the properties of objects. A century later we think that aesthetic judgement arises from the interaction between object features, properties of our visual system and processes of value attribution [44]. While the corners of the salon might have frustrated Mondrian’s appetite to work on perspective challenges, we propose a simple solution: Aesthetic judgment should be based on our perceptual representation rather than static retinal images. Another rather crude alternative would be to accept that the Mondrian-type space is just not beautiful, as it falls short of strict neoplastic ideals of beauty. Although Mondrian-type space may not have been considered beautiful at the beginning of the twentieth century, we should not easily adopt that verdict in the 21st century—after all, the beauty is not in the eye, but in the mind of the beholder.

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COLOR PLATE B: EXPLORING MONDRIAN COMPOSITIONS IN THREE-DIMENSIONAL SPACE

CG model of Mondrian-like cylindrical salon without prominent black lines. A view at the cylinder from outside: (a) Geometry in top view: FoV was 90° horizontally and 53° vertically; viewing distance R set to the length of the cylinder diameter; (b) A perspective view of the scene layout. (c) (1–5) Still frames from the animation; step 2 corresponds to the viewing angle in Fig. 3b. (© Jasmina Stevanov and Johannes M. Zanker) (See article in this issue by Jasmina Stevanov and Johannes M. Zanker.)