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Pattern motion perception: feature tracking or integration of component motions?

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Abstract

A key question regarding primate visual motion perception is whether the motion of 2D patterns is recovered by tracking distinctive localizable features [Lorenceau and Gorea, 1989; Rubin and Hochstein, 1992] or by integrating ambiguous local motion estimates [Adelson and Movshon, 1982; Wilson and Kim, 1992]. For a two-grating plaid pattern, this translates to either tracking the grating intersections or to appropriately combining the motion estimates for each grating. Since both component and feature information are simultaneously available in any plaid pattern made of contrast defined gratings, it is unclear how to determine which of the two schemes is actually used to recover the plaid's motion. To address this problem, we have designed a plaid pattern made with subjective, rather than contrast defined, gratings. The distinguishing characteristic of such a plaid pattern is that it contains no contrast defined intersections that may be tracked. We find that notwithstanding the absence of such features, observers can accurately recover the pattern velocity. Additionally we show that the hypothesis of tracking 'illusory features' to estimate pattern motion does not stand up to experimental test. These results present direct evidence in support of the idea that calls for the integration of component motions over the one that mandates tracking localized features to recover 2D pattern motion. The localized features, we suggest, are used primarily as providers of grouping information - which component motion signals to integrate and which not to.

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1 Introduction

Plaid patterns generated by superimposing two independently moving gratings have often been used to study 2D motion perception in primates [Movshon et al, 1985; Adelson & Movshon, 1982; Ferrera & Wilson, 1990, 1991]. These experiments rest on the observation that when two gratings moving in different directions are superimposed, the resulting plaid pattern is (under certain conditions) seen to move coherently in a direction quite different from that of either grating's (figure 1(a)). Two basic schemes have been proposed to address the question of how pattern motion velocity (direction and speed) is computed. The first relies on the presence of distinctive contrast-defined features such as grating intersections which may be tracked to straightforwardly recover their (and the overall pattern's) motion (figure 1(b)) [Lorenceau & Gorea, 1989; Rubin & Hochstein, 1992]. The second scheme involves integrating the separately estimated ambiguous motion estimates for the two gratings (figure 1(c)) [Adelson & Movshon, 1982; Hildreth, 1984; Wilson & Kim, 1992]. There is no clear consensus as to which of these two schemes is actually used by the primate visual system. The question is made especially difficult by the fact that the most widely accepted scheme for integrating component motions [Adelson & Movshon, 1982] produces identical pattern velocity predictions as the intersection tracking scheme.

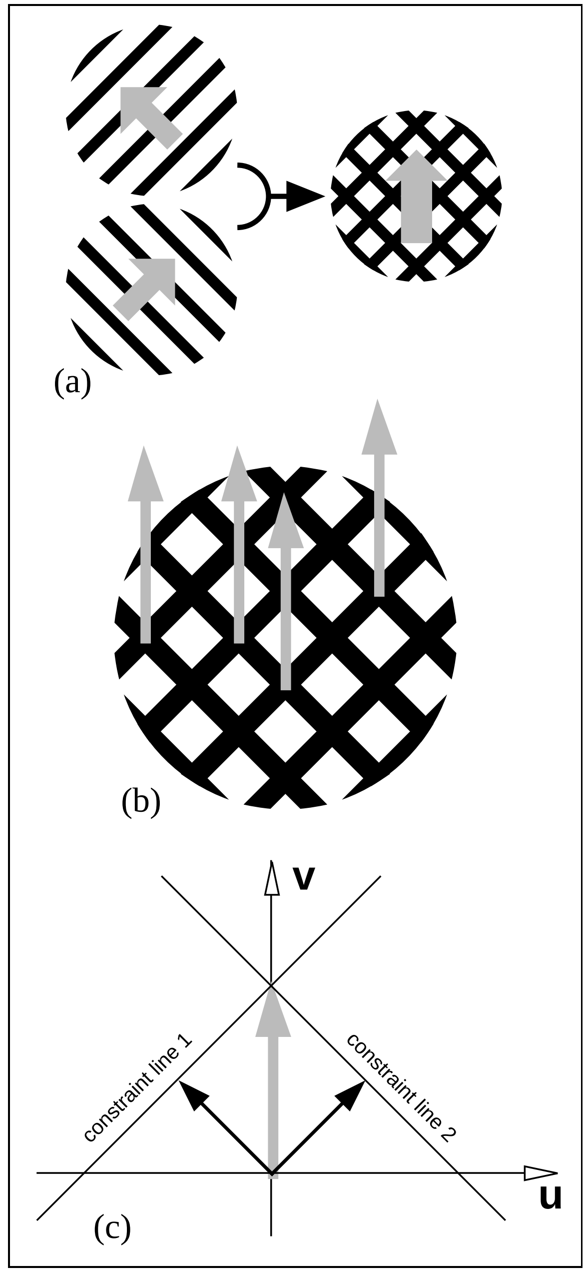

Figure 1: *(a) The plaid-paradigm: under certain conditions, two independently moving and differently oriented gratings when superimposed are seen to move coherently in a direction quite different from either of their individual directions of motion. The motion velocity of a two-grating plaid pattern can be recovered either by tracking the intersection points of the two gratings, as shown in (b), or by appropriately integrating the component motion estimates. (c) shows one popular scheme for motion integration due to [Adelson and Movshon, 1982]. The pattern motion velocity is determined by computing the point of intersection of two constraint lines that represent all possible velocities of the two gratings individually ('u' and 'v' are orthogonal components of velocity and define a 'velocity-space').*

2 Experimental Design

To address this issue, we developed a plaid stimulus comprised of two moving illusory gratings (figure 2). For most of their extents, the bars of the gratings were not defined by luminance contrast or any other physically measurable visual attributes, but were, instead, illusory. As for other illusory figures [Kanizsa, 1979; Petry and Meyer, 1987], the visual system inferred the presence of the grating contours by partial occlusion information. Both gratings individually afforded the percept of square-waves with low duty-cycles (between 0.15 and 0.2) undergoing uniform oscillatory motion in directions orthogonal to their orientations. The distinguishing characteristic of the plaid pattern formed by their superposition was that the grating intersections were completely illusory and, therefore, unavailable to any system designed to track contrast- defined moving features. Furthermore, the amplitude of oscillation of each grating was limited to ensure that the illusory intersections of the plaid were never explicitly visible. The orientation and speed of the component gratings could be varied to yield different pattern velocities.

The feature tracking and component motion integration schemes make very different predictions about the ability of an observer to estimate pattern motion for illusory plaids. Given that an illusory plaid has no localized features moving unambiguously with the pattern velocity, the feature tracking scheme predicts that an observer would be unable to recover the plaid's pattern velocity. The component motion integration scheme, on the other hand, predicts no such handicap.

3 Results and Discussion

To verify these predictions, we tested the performance of four observers on direction and speed matching tasks with illusory plaids. In every trial of the direction matching task, subjects were first presented with an illusory plaid that could move in any one of eight possible directions (evenly spaced about 22 degrees apart from each other; see table 1 for details). This was followed immediately by a conventional contrast-defined grating moving in one of the eight directions. The subjects were instructed to report whether they perceived the plaid pattern as moving coherently and if so, to say whether the plaid and the grating were moving in the same direction.

In the trials of the speed matching task, subjects saw an illusory plaid that moved in a fixed direction with any one of four possible speeds (see table 1) followed immediately by a grating moving in the plaid's true direction (as computed by the intersection of constraints construction [Adelson and Movshon, 1982]) with one of the four speeds (the same set of speeds as for the plaids). For every trial during which they saw the plaid pattern as moving coherently, subjects were asked to report verbally whether the plaid and grating speeds were the same or different. Subjects were not given any feedback during the experimental sessions for either of the two tasks.

The first general result to emerge from these experiments was that under conditions like those required for the coherence of conventional contrast defined gratings, viz., similarity of speeds and duty cycles, illusory gratings were perceived to cohere strongly (figure 3(a)). Second, subjects performed very well on our direction and speed matching tasks (figures 3(b) and 3(c)), suggesting thereby that they could quite accurately recover pattern motion velocity of illusory plaids. (In a separate set of experiments, we determined the direction discrimination thresholds of subjects with illusory plaids following the paradigm of Ferrera and Wilson [1990]. For all subjects, the thresholds were low, averaging about 2 degrees.) It seems valid to conclude, therefore, that tracking unambiguously moving contrast-defined features is not a prerequisite for recovering pattern motion.

These results, however, do not rule out the possibility of the visual system tracking 'illusory features' - the subjective intersections of our plaid patterns. To test for this possibility we ran our experiments with the stimulus shown in figure 4(a). This stimulus comprised of an illusory plaid overlaid in depth with a mosaic of opaque patches that destroyed the percept of illusory extensions of the grating bars. The different segments of the bars could now only be linked amodally. Subjects were shown this stimulus in stereo. As figures 4(b), (c) and (d) show, while the overall incidence of coherence dropped slightly in this case, subjects could still accurately recover the pattern velocity for the trials in which they saw the plaid moving coherently. The non- availability of the illusory intersections seems not to have affected their performance. This leads us to conclude that it is not necessary to posit the existence of a mechanism for tracking illusory features to account for the recovery of pattern motion.

The drop in the incidence of coherence suggests a weakening of the grouping information in the stimulus. A modal presence of the grating bars' intersections apparently is more effective at inducing the visual system to group the component motions than an amodal presence. We can generalize this observation and suggest that for conventional contrast defined patterns too, the visual system uses the localized features as providers of grouping information. This idea is consistent with the recent experimental reports of Stoner et al [1990, 1992] who found that the luminances of a plaid pattern's intersections determined whether or not the motions of the component gratings were perceptually grouped into a coherent motion.

The general conclusion that we arrive at, then, is that tracking unambiguously moving localized features is not a prerequisite for recovering pattern motion. The visual system can recover pattern motion velocity solely by integrating component motions. The localized features, however, play a role in the integration process by providing information that determines which (and whether) component motions are to be grouped together.

The demonstration that illusory gratings cohere is interesting in its own right. In some of our recent experiments we have found that coherence is obtained even with gratings comprised of completely contrast balanced contours (see figure 5). An interesting physiological implication of these results concerns the relationship between cortical areas V2 and MT. The former has been shown to have a large population of cells (many of them directionally selective) responsive to subjective contours [von der Heydt and Peterhans, 1989; Peterhans and von der Heydt, 1989, 1991] while the latter is believed to play a role in global motion integration [Movshon et al. 1985; Newsome and Pare, 1988]. We wonder if it is possible that MT integrates the responses of V2 cells much as it does the responses of directionally sensitive cells in V1 [Movshon et al. 1985].

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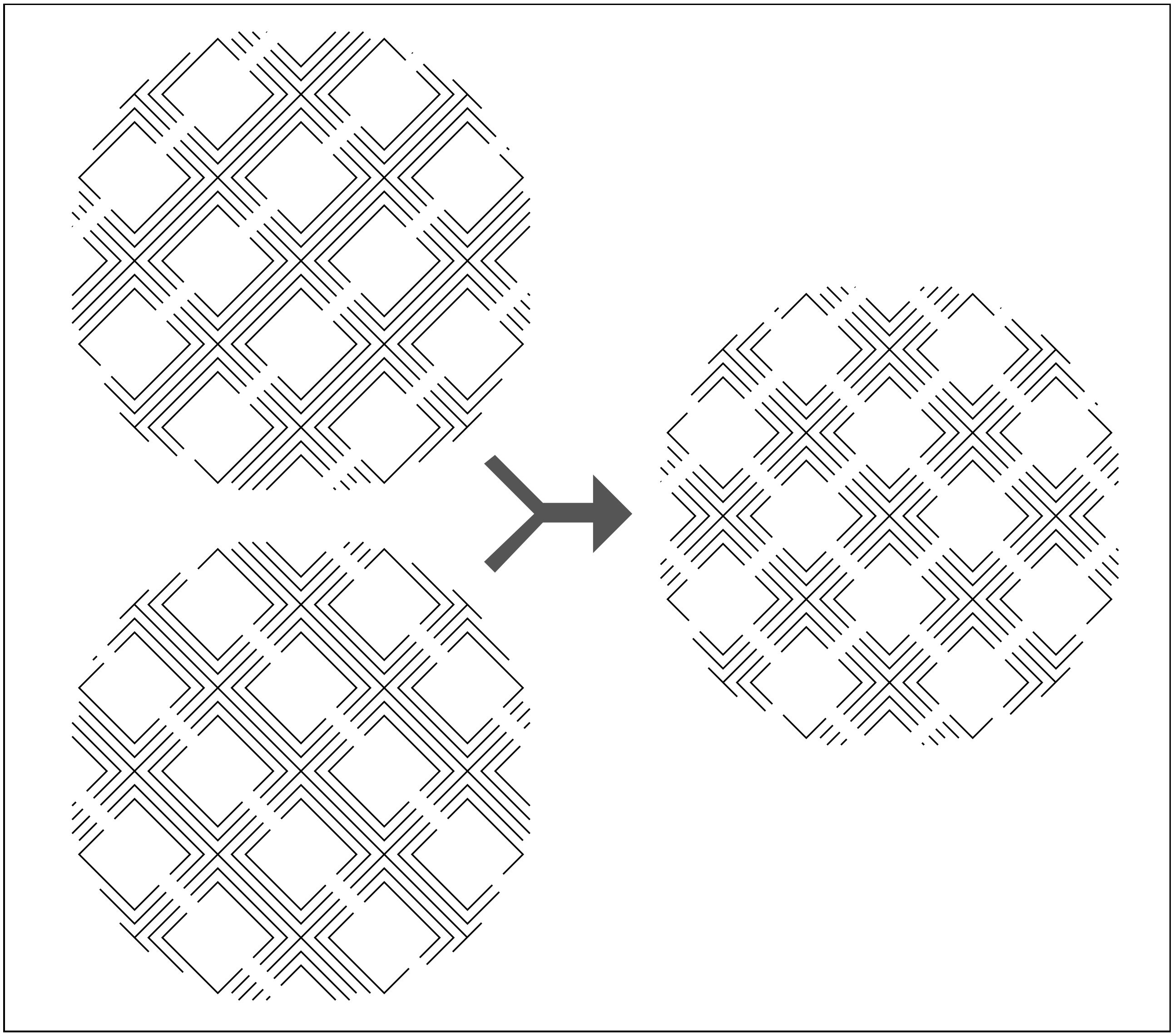

Figure 2: *Two illusory gratings and an illusory plaid formed by their superposition. Stimuli were generated on a Macintosh Quadra 700 computer equipped with an Apple 13" color monitor that had a resolution of 640x480 at 76 dpi. The display programs were written in Symantec's Think C augmented with a graphics library put together at the Harvard Vision Sciences Laboratory [Micro M-L, 1992]. Viewing distance was approximately 80 cm. The circular display subtended 8 degrees at this distance. Subjects were asked to fixate at the center of the circular display during the experiments.*

Plaid #	Component 1		Component 2		Resultant	
	Speed (deg/sec)	Direction (deg)	Speed (deg/sec)	Direction (deg)	Speed (deg/sec)	Direction (deg)
1	±0.87	45.0	±0.87	135.0	±1.23	90.0
2	±0.51	0.0	±1.26	90.0	±1.36	67.9
3	±1.22	0.0	±1.22	90.0	±1.73	45.0
4	±1.26	0.0	±0.51	90.0	±1.36	22.1
5	±0.87	45.0	±0.87	315.0	±1.23	0.0
6	±1.26	0.0	±0.51	270.0	±1.36	337.9
7	±1.22	0.0	±1.22	270.0	±1.73	315.0
8	±0.51	0.0	±1.26	270.0	±1.36	292.1
9	±0.36	0.0	±0.36	90.0	±0.51	45.0
10	±0.73	0.0	±0.73	90.0	±1.03	45.0
11	±1.33	0.0	±1.33	90.0	±1.88	45.0
12	±2.83	0.0	±2.83	90.0	±4.00	45.0

Table 1: *Parameters for the plaid patterns used in our experiments. The spatial frequency of all gratings with orientations of 0 degree or 90 degrees was 0.5 cycles/deg while gratings oriented at 45 or 135 degrees had a spatial frequency of 0.33 cycles/deg. The +/- signs in the speed columns are meant to indicate the oscillatory motion of the gratings and the resultant plaids. The amplitude of oscillation of the different gratings ranged from 0.7 to 1.1 degrees (the precise values were set so as to ensure that the grating intersections were never rendered explicitly visible by overlapping with the background pattern). In the direction columns, 0 degrees refers to the horizontal right. Angles increase counter-clockwise.*

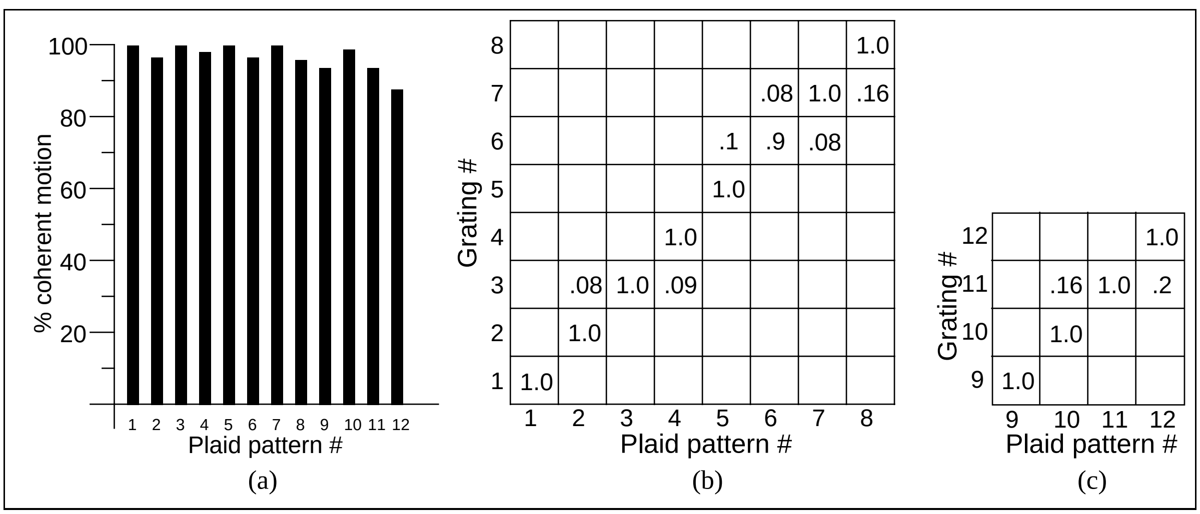

Figure 3: *Results with illusory gratings. (a) Coherence statistics (over all subjects) for the illusory plaid patterns used in our experiments. Almost all patterns were seen to cohere strongly by the subjects. (b) Results of the direction matching task averaged over four subjects. The entries in the cells of the grid show the fraction of trials (3 per subject) during which the subject reported a match in the directions of the corresponding plaid-grating pair. Blank cells denote scores of 0.0's. (Grating #i was designed to have the same direction as plaid #i. The results of a subject who never made any errors of judgement would, therefore, comprise of 1.0's along the diagonal and 0.0's everywhere else.) (c) Results of the speed matching task averaged over four subjects. The entries in the cells of the grid show the fraction of trials (3 per subject) during which the subject reported a match in the speeds of the corresponding plaid-grating pair.*

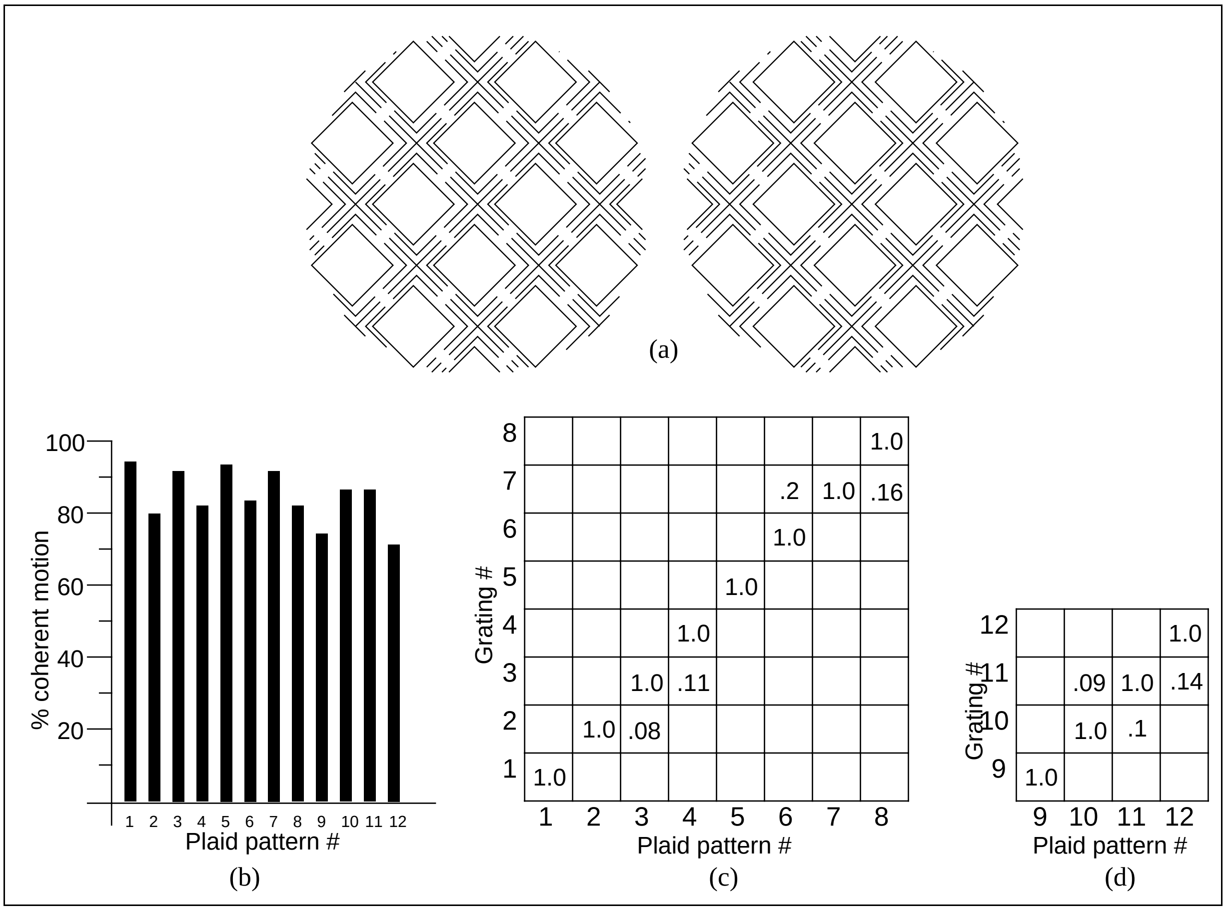

Figure 4: *(a) The modified plaid pattern shown here as a stereo-pair (for cross-fusers). (b) The incidence of coherence dropped a little following the modification. (c) and (d) Results from the direction and speed matching tasks, respectively, averaged across four subjects over trials during which they reported plaid coherence. Performance is comparable to that obtained with the unmodified stimulus (see figures 3(b) and (c)).*

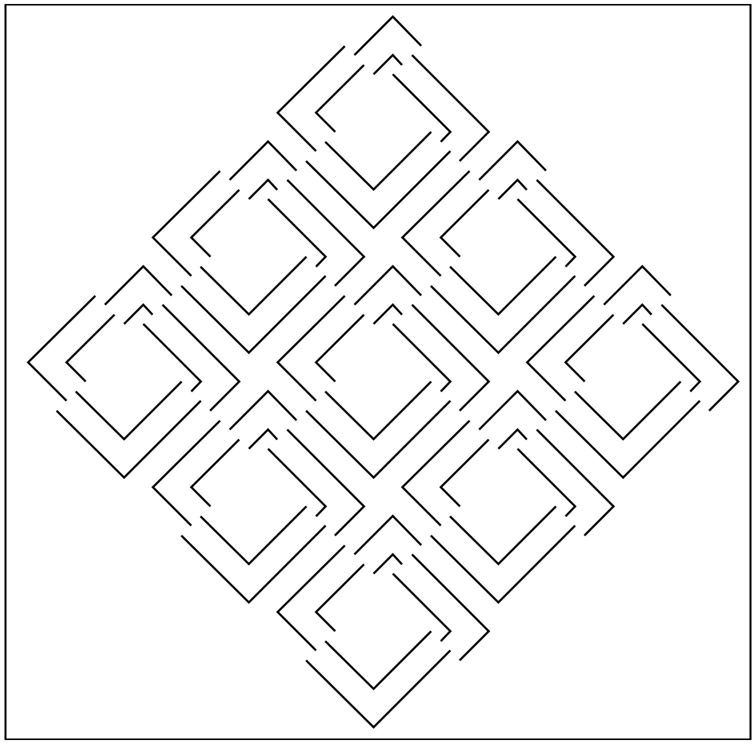

Figure 5: *A plaid pattern made of contrast balanced subjective gratings. Observers often perceive such patterns as moving coherently and are able to accurately estimate the pattern velocity.*

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