ISODIPOLE TEXTURES IN SPACETIME: A NOVEL NON-FOURIER AND REVERSE-PHI MOTION STIMULUS

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Introduction

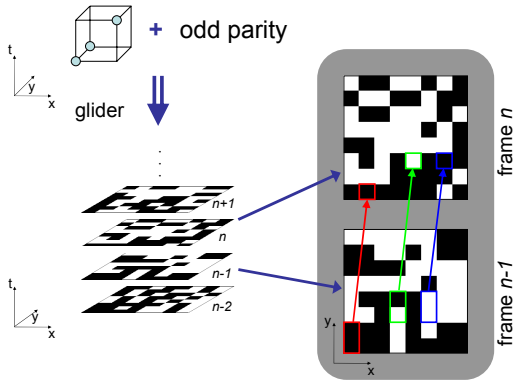
Early motion processing is generally considered to be carried out by "first-order" (Fourier) and "second-order" (non-Fourier) mechanisms. The former extracts motion when pairwise spatiotemporal correlation of luminance signals is present. The latter extracts motion under other circumstances, and is often modeled as local nonlinear pre-processing, such as flicker detection, followed by spatiotemporal correlation of the resulting signals.

To further investigate the computations underlying early motion processing, we created a novel set of spatiotemporal movie stimuli that doesn't fall into either of the two categories. Because these stimuli have no spatiotemporal correlation at second-order, their motion cannot be detected by "first-order" mechanisms. Moreover, there is no second-order correlation between the locations of checks that flicker, or the presence of edges, so their motion cannot be detected by standard "second-order" motion mechanisms. That is, motion cannot be extracted by pairwise spatiotemporal correlation of image luminance, or within a derived local feature map (e.g., of flicker or edge).

Nevertheless, as we show here, these stimuli do generate consistent percepts of apparent motion. For some of the stimuli, reversing the contrast polarity reverses the direction of apparent motion. These results indicate that standard computational models of motion extraction may need to be revised, to allow for additional interactions of luminance and spatiotemporal contrast.

Stimulus construction

Here we describe a novel set of movie stimuli that have high-order spatiotemporal correlations. Our approach generalizes the "isodipole texture" method for creation of stimuli with high-order spatial correlations. The isodipole texture algorithm (Victor and Conte, Vision Research, 1991) is as follows: a "glider", consisting of several nearby checks, is chosen – such as three checks that form an L-shaped region. Then, the texture is colored with black and white checks, with the requirement that within any glider, the total number of black checks have a particular parity (even or odd).

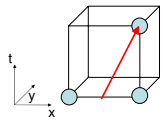


To extend this idea to movie stimuli, a glider consisting of three or four nearby spatiotemporal voxels is chosen. The movie is then colored with black and white voxels, with the requirement that within any glider, the total number of black voxels must have a particular parity (even or odd). Checks that cannot be determined by the glider rule, such as the initial frame's checks or boundary checks, are randomly assigned to black or white. As in this example, if the glider has a spatiotemporal slant, then the resulting stimulus has an unambiguous spatiotemporal direction that can be extracted from its high-order correlations.

Supported by EY9314 and EY7977

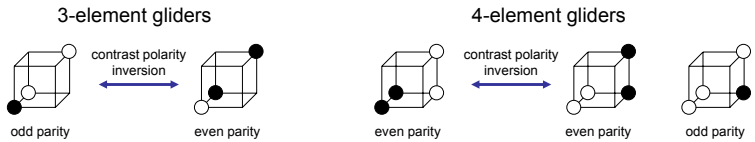
Properties of the stimuli

An example of a stimulus constructed from a three-element glider. At each time, the image frame appears random. A spatiotemporal slice reveals a strong directionality. But since this spatiotemporal slice is an isodipole texture, only third- and higher-order correlations contribute to this directionality. In the psychophysical study (right side of poster), this veridical spatiotemporal direction is defined as the "correct" answer.



veridical spatiotemporal direction vector

Relationship between number of glider elements, contrast polarity, and parity

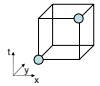


Inverting the contrast polarity is equivalent to reversing the parity (even to odd). For many stimuli, this reverses the direction of apparent motion, even though the veridical direction (defined above) is unchanged.

Inverting the contrast polarity does not change the parity. However, reversing the parity (even vs. odd) results in a different kind of stimulus, with the same veridical direction of apparent motion.

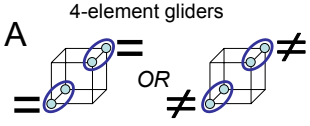
Relationship to standard motion stimuli

First-order (Fourier) stimuli have pairwise correlations in spacetime. Such stimuli can be generated by a two-element spatiotemporal glider. This produces a constant random checkerboard, moving rigidly: a very strong standard motion stimulus.



2-element glider that generates a standard first-order motion stimulus

Some standard (non-Fourier) stimuli can be generated by the recursive glider rule as well. One example is the 4-element glider A. This results in a stimulus in which an edge on one frame is correlated with an edge in an adjacent location on the following frame, but the polarities of the edges need not match. As expected, our results show that this elicits a strong percept of motion.



Another example is the 4-element glider B. This results in a stimulus in which flicker at one location and time is correlated with later flicker at an adjacent location.

However, most 4-element gliders result in stimuli that do not contain pairwise correlations of flicker, or pairwise correlations of edges. These gliders include any of the gliders in which three elements are present in one frame, and one element is present in the temporally adjacent frame. These also produce apparent motion.

4-element glider that does not contain pairwise correlation of second-order features

Methods

SUBJECTS:
- N=5, 1 male, 4 females
- Normal acuity or corrected to at least 20/30
- ***qh*** is the first author. ***cc*** is an experienced observer, but is naïve to the purpose of the experiment. ***wyc***, ***jz*** and ***qz*** are novice observers and naïve to the purpose of the experiment.

STIMULI:
- 20-frame movie played at 10 fps (2 sec duration)
- Size: 25 degree square
- Each frame: 64x64 black-and-white checkerboard (each check: 24 min), contrast 1.0
- Viewing: binocularly at 50 cm
- Monitor: 17" LCD monitor at 60Hz, dim background

CONDITIONS:
- Free view, binocular, self-paced
- 10 sets of stimuli generated with 3-element gliders and 14 sets of stimuli generated with 4-element gliders
- Each glider tested with 100 examples of each parity (even and odd) except for the negative control (even parity only). Stimuli with different gliders were intermixed in blocks. Results are pooled across eight sessions of one hour each (~5000 trials/subject).

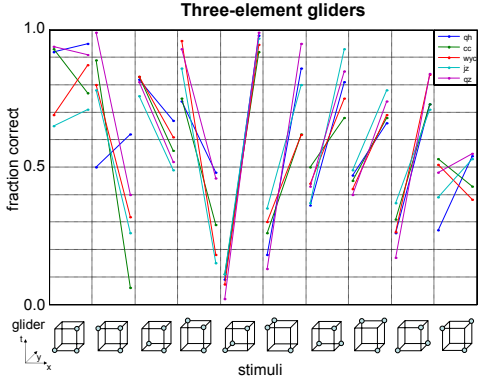
TASK:
Identify the direction of motion (2-alternative forced choice, left or right), respond with keypress

Results

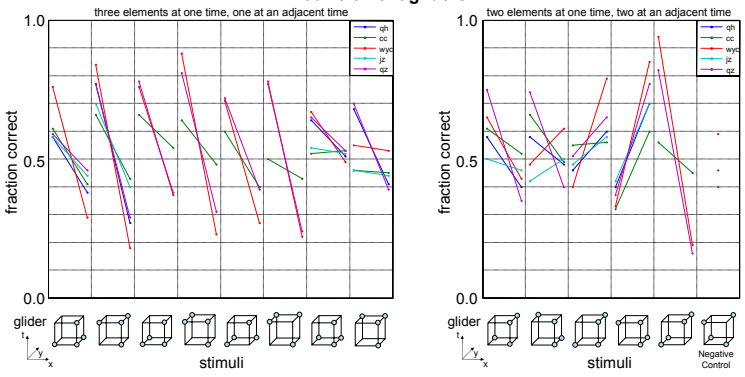
Three- and four-element glider results are displayed with one column for each kind of glider. For each glider, subjects viewed stimuli created with even and odd parities. The fraction of stimuli judged to be moving in the veridical direction is indicated as "fraction correct" for even-parity stimuli (left side of each column) and odd-parity stimuli (right side of each column).

For most gliders, time-reversal results in a stimulus created with a different glider. We show results from pairs of gliders related by time-reversal in adjacent columns.

Three-element gliders



Four-element gliders



Summary and discussion

- Results are highly consistent across all 5 subjects.
- Most stimuli (at least 17/23) were perceived having a definite direction of apparent motion.
- The perceived direction of motion was often not veridical. For most stimuli, changing the parity led to reversing of the perceived motion direction: one parity was veridical, and one was reverse-phi.
- For stimuli constructed with three-element gliders, reversal of parity is equivalent to reversal of contrast polarity – so this finding means that the apparent motion direction depends on contrast polarity.
- Accounting for these observations is a challenge for computational models of motion extraction.