Motion and reverse-phi stimuli that do not drive standard Fourier or non-Fourier motion mechanisms

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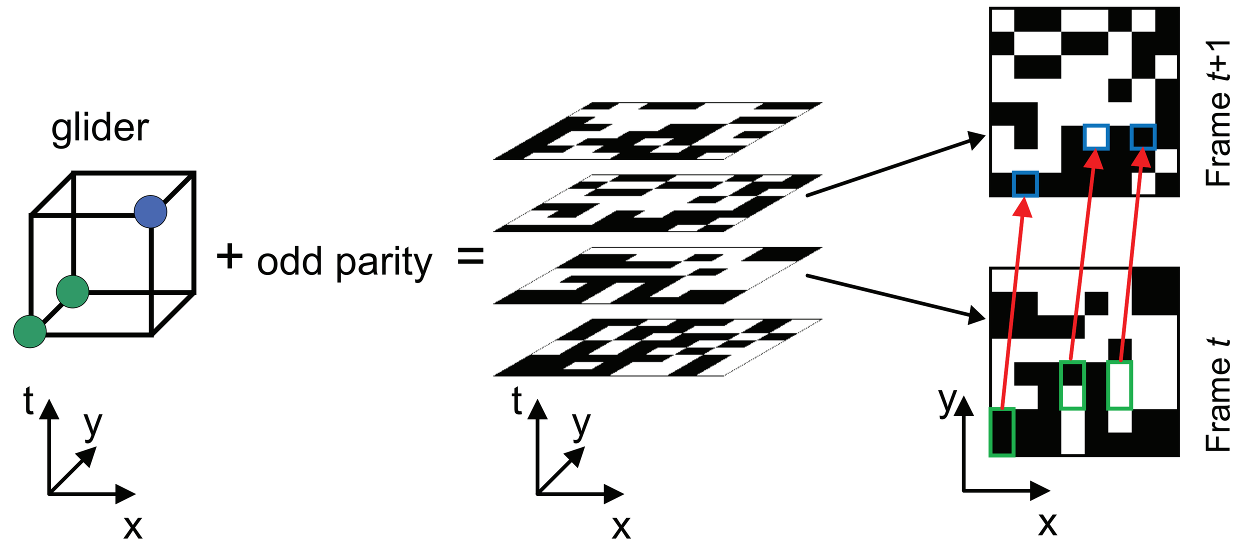
INTRODUCTION

Detection of motion is a crucial component of visual processing, and is generally considered to consist of two stages: an early stage in which local motion is extracted and a later stage at which local motion signals are combined into object motion or flows. Early motion processing is generally considered to be carried out by first-order (Fourier) and second-order (non-Fourier) mechanisms. Fourier motion mechanisms extract motion when the pairwise spatiotemporal correlation of luminance signal is present. Non-Fourier mechanisms are thought to work via local nonlinear pre-processing, such as flicker detection or extraction of unsigned contrast, followed by a spatiotemporal correlation of the resulting signals.

To probe the computations underlying motion perception, we created a new class of non-Fourier motion stimuli: binary movies characterized by their 3rd- and 4th-order spatiotemporal correlations. As with other non-Fourier stimuli, they lack second-order correlations, and therefore their motion cannot be detected by standard Fourier mechanisms. Additionally, these stimuli lack pairwise spatiotemporal correlation of edges or flicker – and thus, also cannot be detected by extraction of one of these features, followed by standard motion analysis.

STIMULUS CONSTRUCTION



Construction of a three-element spatiotemporal glider stimulus. The three-element glider (left) is represented by a wireframe cube with three of its corners colored. The three colored corners of the wireframe cube are the three voxels that form the glider. The coloring indicates the time steps occupied by each voxel: two voxels (green) are at time t, and one (blue) is at time t+1. The stimulus is constructed by applying an odd parity constraint to the number of black checks within all occurrences of the glider. The checks outlined in color in frame t and t+1 on the right illustrate this parity constraint for three placements of the glider. The red arrows show that, with in a glider, the color of a check in frame t+1 is determined by the color of other checks in frame t.

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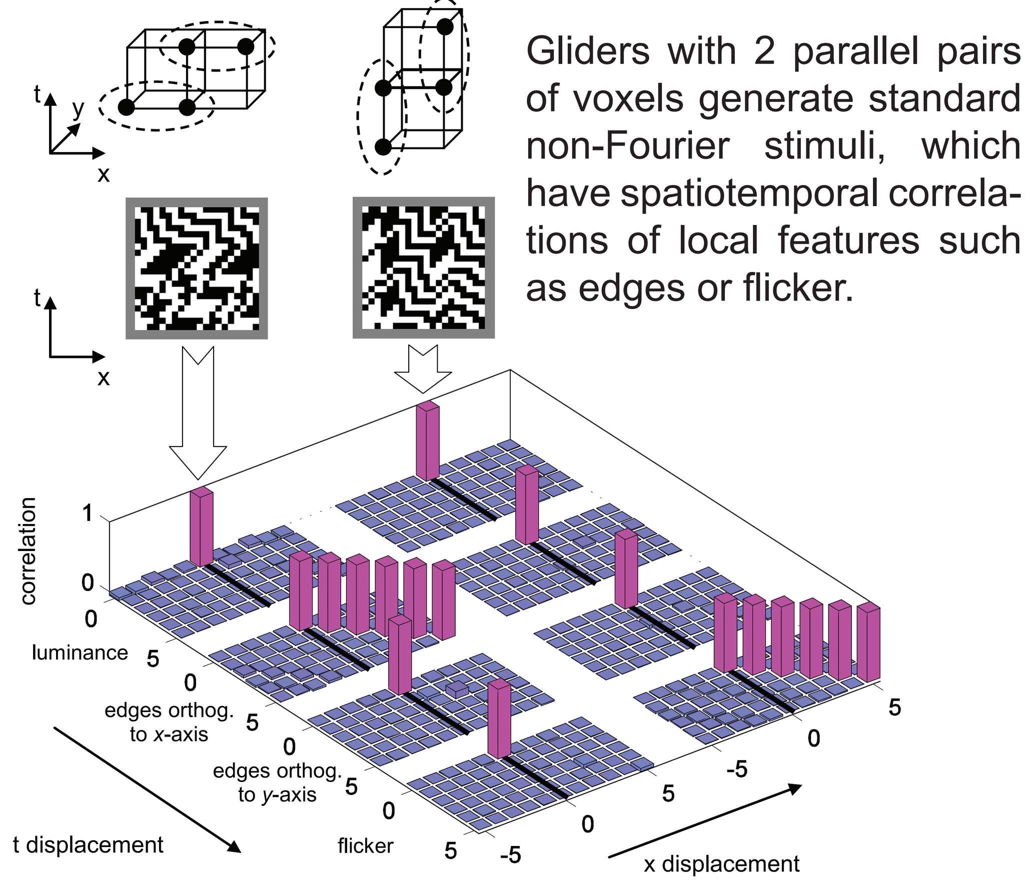
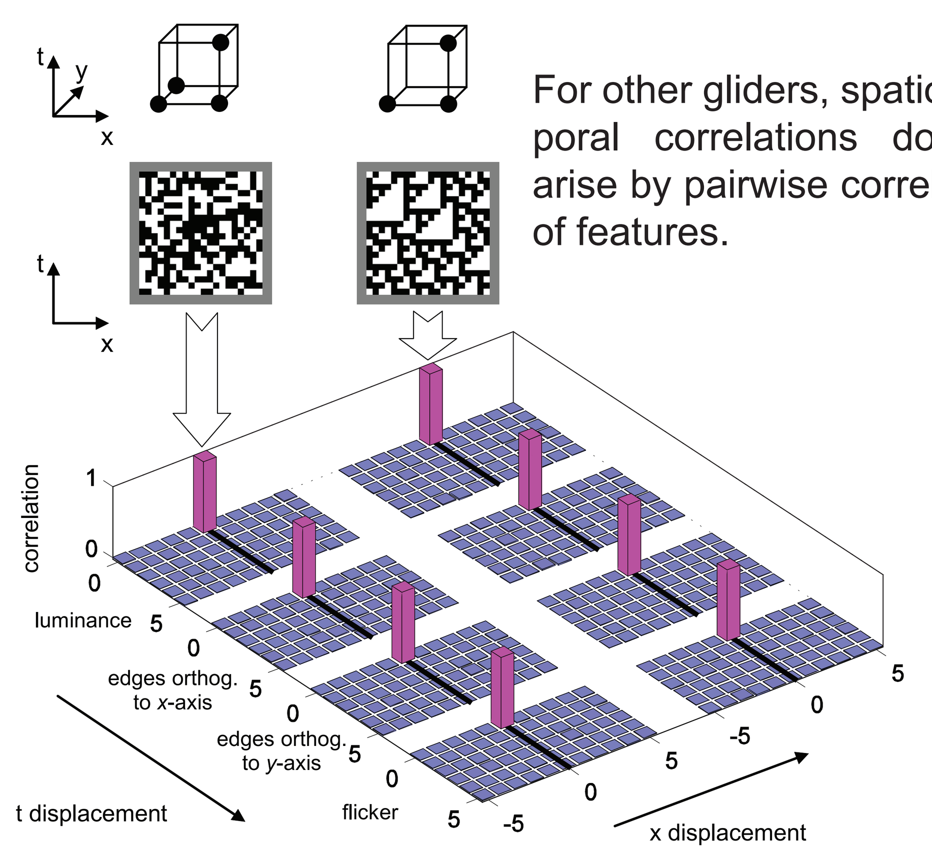
STIMULUS PROPERTIES

Traditional non-Fourier stimuli: motion is carried by edges or flicker



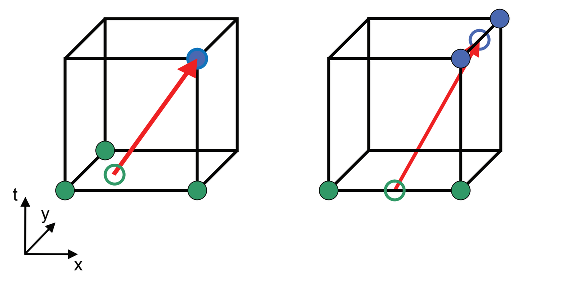
Gliders with 2 parallel pairs of voxels generate standard non-Fourier stimuli, which have spatiotemporal correlations of local features such as edges or flicker.

Novel non-Fourier stimuli: motion is NOT carried by edges or flicker



For other gliders, spatiotemporal correlations do not arise by pairwise correlation of features.

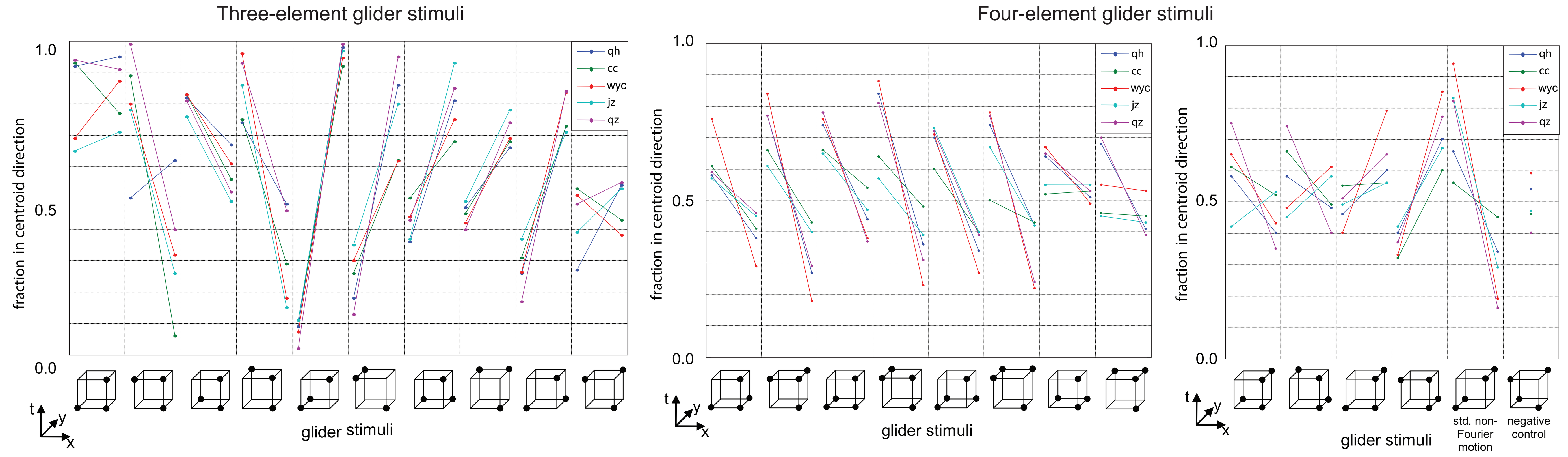
The Centroid Direction



The centroid direction is defined as the vector from the centroid of the voxels at time t (open green circle), to the centroid of the voxels at time t+1 (open blue circle).

The centroid direction is the reference direction in the psychophysical experiment.

PSYCHOPHYSICAL EXPERIMENT



For each glider, responses for the even parity rule are on the left; responses for the odd parity rule are on the right, except for the negative control, where only the even parity was tested. Fraction in centroid direction >0.6 or <0.4 is significant ($p<0.05$, two-tailed).

- Results are highly consistent across all 5 subjects.
- Most stimuli (at least 16/23) were perceived having a definite direction of apparent motion.
- For 14 of the 16 stmuli for which there was a motion percept, the perceived direction of motion depended on the parity of the glider.
- For 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.

METHODS

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

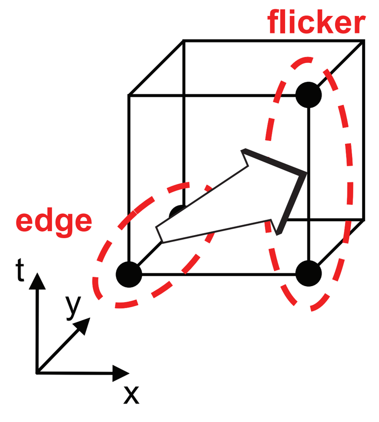
SUBJECTS:
- N=5, 1 male, 4 females
- Normal acuity or corrected to at least 20/30

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

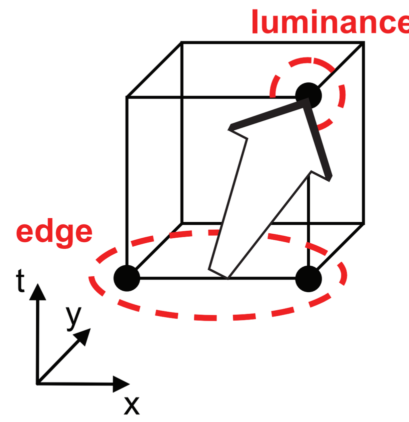
CONDITIONS:
- Free view, binocular, self-paced
- 10 sets of stimuli generated with 3-element gliders and 14 sets of stimuli generated with 4-element gliders
- Each glider tested with 100 examples of each parity (even and odd) except for the negative control (even parity only). Stimuli with different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

MODELING

Motion signals generated by heterogeneous feature correlations

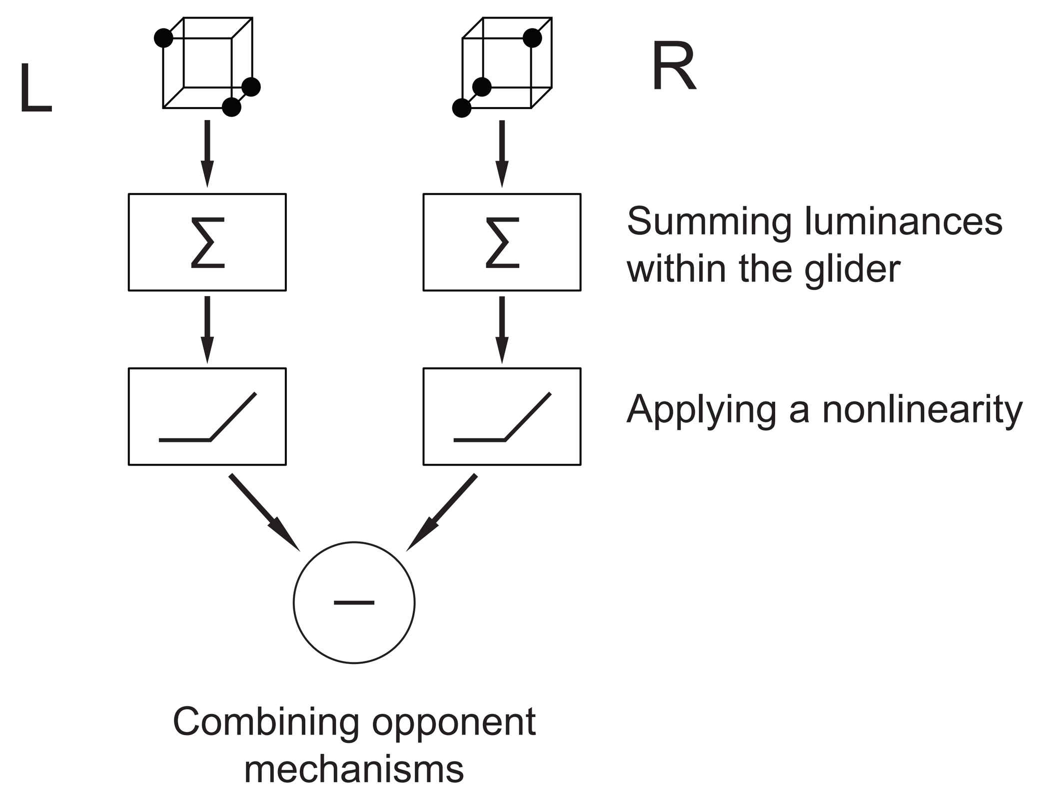


A four-element glider produces a correlation between an edge in one location and flicker in another location at a separate time.



A three-element glider produces a correlation between an edge in one location and the luminance in another location at a separate time.

Motion signals generated by opponent mechanisms based on summation followed by a nonlinearity



nonlinearities	three-element gliders		four-element gliders	
	even	odd	even	odd
x	0	0	0	0
x^2	0	0	0	0
x^3	-0.44	0.44	0	0
x^4	0	0	0.26	-0.26
$\lvert x\rvert$	0	0	-0.25	0.25
$\begin{cases} \lvert x\rvert, x \ge 0 \\ 0, x<0 \end{cases}$	0	0	-0.18	0.18
$\begin{cases} x^2, x \ge 0 \\ 0, x<0 \end{cases}$	-0.23	0.23	0	0
$\begin{cases} \lvert x\rvert^{0.72}, x \ge 0 \\ -0.08\lvert x\rvert^{0.72}, x<0 \end{cases}$	0.11	-0.11	-0.21	0.21

Entries in the table are normalized size of the motion signal. Positive values mean that the net average signal is in the centroid direction, negative values means that it is opposite to the centroid direction. Zero means that no motion signal is generated.

These models generate a motion signal but...

1. Predicted motion direction has a fixed relationship to the centroid motion of each glider, but this is not true in the perceptual data.
2. Reversing the parity of the glider rule always results in a reversal of motion direction, but this is not true in the perceptual data.
3. Both models only generate a strong motion signal when the summing area has the same spatiotemporal shape of the glider, which is not very physiologic.

SUMMARY

1. We observed consistent motion percepts with stimuli created using 3rd and 4th order spatiotemporal correlations.
2. The direction of perceived motion can change by changing the parity rule of the gliders that generate the stimuli, without changing the spatiotemporal configuration of the gliders themselves.
3. For three-element glider stimuli, this means that the perceived motion direction can be reversed by reversing the contrast polarity.
4. Preliminary modeling only partially account for our results. These simple models can (at most) extract motion signal from the glider stimulus, but cannot correctly predict its direction and strength.