WHAT KINDS OF LOCAL MOTION SIGNALS ARE PRESENT IN NATURALISTIC MOVIES?

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Motivation and Summary

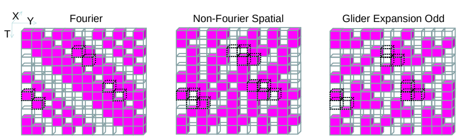
Extraction of motion from visual input plays an important role in many visual tasks, such as separation of figure from ground and navigation through space. Several kinds of local motion signals have been distinguished based on mathematical and computational considerations (for example, Fourier and non-Fourier), but little is known about their prevalence in the real world. Here we address this by examining the strength of each kind of local motion signal in naturalistic movies.

To approach this question, we first note that local motion signals are characterized by correlations in slanted spatiotemporal regions (*Background*). The prevalence of local motion signals in natural scenes can be estimated by determining the extent to which these correlations are present in space-time patches of binarized movies (*Quantification of Motion Signals in Movies*). We apply this technique to several Hollywood movies.

The results show that all investigated kinds of motion (i.e. Fourier, non-Fourier and glider) exist in natural movies. While different kinds of motion signals predominate from scene to scene, the overall pattern of prevalence of the different kinds of motion is similar across movies. Moreover, there are correlations between the kinds of motion signals that are present in individual scenes, and this pattern of correlation is also similar across movies. In sum, movies contain many kinds of motion signals, and with substantial regularity.

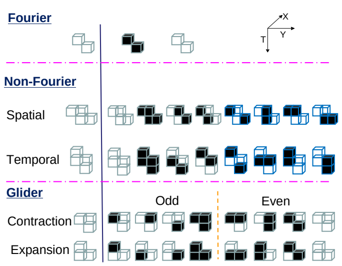
Background

- Stimuli that contain a specific kind of local motion signal can be constructed by introducing correlations into slanted regions of space-time.
- Different region shapes correspond to different kinds of local motion signals.



The question at hand
How much of these kinds of motions appear in naturalistic movies?

Space-time (Y-T) diagrams of Fourier, non-Fourier, and glider motions. Edge pixels are chosen randomly; interior pixels are chosen to be consistent with the relevant correlation structure (see below)



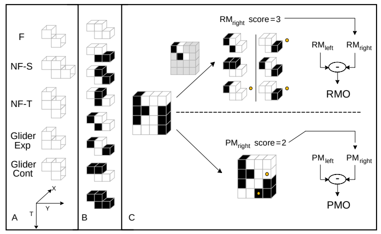
Fourier motion corresponds to pairwise correlation of two checks, arranged on a slant in space-time.

Non-Fourier motion, as identified by Chubb and Sperling (1988), corresponds to motion of a simple feature, such as an edge or a luminance change, independent of the sign of that feature. This is equivalent to a fourth-order correlation in a spatiotemporal parallelogram. We also considered "pure" non-Fourier motion, in which the exemplars containing Fourier motion are removed (blue edges).

"Glider motion" (Hu et al., 2010) corresponds to third-order correlation within spatiotemporal triangles. Parity is determined by counting the black checks.

Correlation regions and exemplars for several kinds of motion. In these examples, the correlation region slants to the right as time unfolds, corresponding to rightward motion. The exemplars show the configurations that are consistent with each kind of motion.

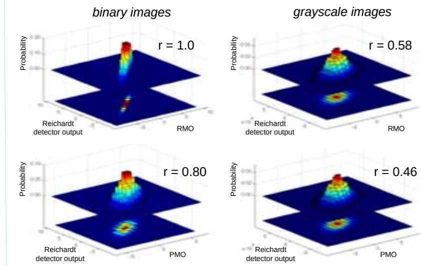
Quantification of Motion Signals in Movies



To quantify the prevalence of local motion signals, we first defined a local score that indicates the extent to which a binarized spatiotemporal 4x4 region of interest (ROI) contains a particular kind of motion signal. We then calculated the normalized sum-of-squares of the local scores across ROI's in each scene (scene segmentation was determined manually).

Calculation of local scores is shown here. Each kind of motion corresponds to parity constraints in a spatiotemporal region of a specific shape (A). Taking spatial non-Fourier motion as an example, we listed all configurations that satisfy the corresponding parity constraint (B, *Background*). Then (C), we determine the match between the ROI and these configurations– either by tallying the number of sub-regions that contain allowed configurations ("rule match"), or, by tallying the minimum number of voxels that must be altered so that only allowed configurations are present ("perfect match"). Tallies are combined in an opponent fashion, yielding perfect match opponent ("PMO") and rule match opponent ("RMO") scores.

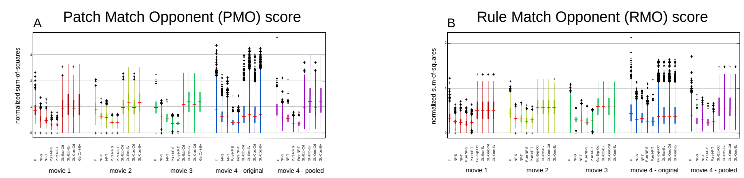
The scores generalize the classic Reichardt detector



For Fourier motion in binary images (left), the RMO score (top) correlates perfectly with the output of the output of a Reichardt detector. The PMO score (bottom) is strongly correlated to the Reichardt detector output, but not identical to it. For grayscale images (right), the output of a Reichardt detector differs from the RMO and PMO scores of the corresponding binarized images.

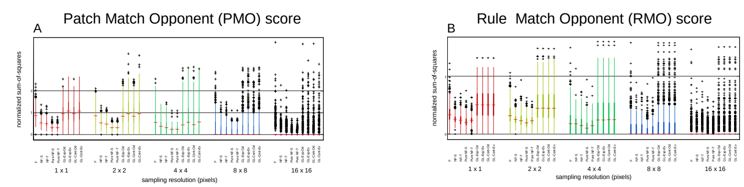
Results: Prevalence of Motion Signals

Similar prevalence of motion kinds across movies



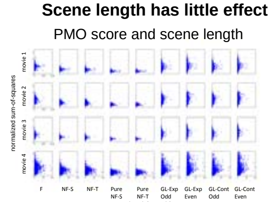
Prevalence of motion signals as measured by PMO score (A) and RMO score (B) for four movies*. Both scores identify all kinds of motions and indicate that their relative strengths are similar across movies. Movie 4 is analyzed twice -- first, in individual scenes, and then with scenes pooled in pairs, so that the resulting segments approximate the lengths of the scenes in Movies 1-3.

Sampling resolution has little effect



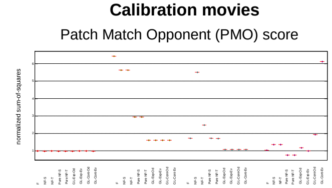
Prevalence of motion signals measured across several sampling resolutions by PMO score (A) and RMO score (B) for Movie 1. Motion signal strength decreases as resolution decreases, but the overall pattern of motion signals remains the same. Here, "sampling resolution" refers to the number of pixels in each check of the 4x4 ROI.

Scene length has little effect



Motion signal strength is independent of scene length for Fourier and non-Fourier motion, and is slightly negatively correlated with scene length for glider motion.

Calibration movies

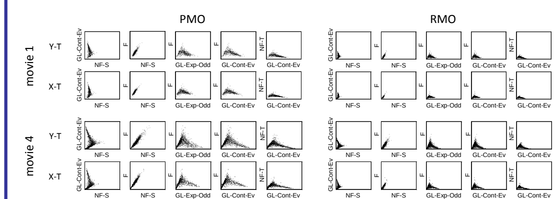


PMO scores identify the motion kinds present in synthetic movies in which one kind of motion is enforced on an otherwise random noise, but some crosstalk is present. RMO scores perform similarly.

* Movies are (1) "The 39 Steps" (1935), (2) "Anna Karenina" (1935), (3) "A Night at the Opera" (1935) and (4) "Mr. & Mrs. Smith" (2005). Movie resolution is 256x256 pixels,24 frames per second.

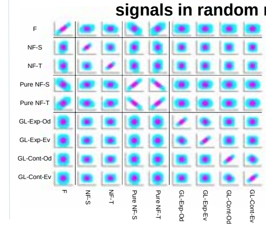
Results: Covariation of Motion Signals

Distinctive correlations of kinds of motion signals in movies



Scene-to-scene correlations between PMO and RMO scores for different motion kinds in two of the analyzed movies. Fourier and non-Fourier motion signals are strongly correlated. Glider motion signals are not strongly correlated with the others, and there are outlier scenes with large amounts of glider motion and little Fourier motion, or vice-versa. These patterns are seen in the other two movies as well.

No correlations of kinds of motion signals in random noise



In random noise, PMO scores for different kinds of motion signals are uncorrelated.

RMO scores show similar behavior.

Conclusions

- Three kinds of local motion signals -- Fourier, non-Fourier, and glider -- are all present in typical movies
- The prevalence of each kind of motion signal is similar across movies
- Movies share a characteristic pattern of how different kinds of motion signals are correlated across scenes

References

Chubb C, Sperling G (1988) Drift-balanced random stimuli: a general basis for studying non-Fourier motion perception. J Optical Soc Am A 5:1986 –2006.

Hu Q, Victor JD, (2010) A set of high-order spatiotemporal stimuli that elicit motion and reverse-phi percepts. J Vis. 10(3):9.1-16.

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