1 Demonstrations and Subjective Observations

Structurally I view this section as a sort of "Experiment 0". To me it has the fewest sequencing problems I describe the stimulus before this section, and if I describe the task after this section. So task description would go into submethods for experiment 1. If I have had some demonstrations before motivating Experiment 1, and for the demonstrations to follow a description of how the stimuli are constructed.

I think I want to talk about subjective observations in a model-neutral matter here, whole perhaps coming back to model-relevant things suggested by subjective appearance later in discussion (under the rubric of "what kind of motion system is this stimulating?")

It is worth commenting about some properties of this type of stimulus that can be subjectively observed, and (so far as we can tell) acknowledged by almost all colleagues we show our displays to, even though we do not attempt to establish them quantitatively.

Subfigure 1a demonstrates the effect of eccentric viewing on the subjective appearance of motion in the display. Two "wheels" are shown, each containing five moving elements. Each element has a short range motion, and a long range displacement. In the wheel on the right, the direction of short-range and long-range components is in agreement (both counterclockwise) whereas for the wheel on the left, the short range component is clockwise while the long range component is counterclockwise. What is striking in this display is that its appearance changes depending on the viewer's gaze. With the eyes fixated on the point in the center of the left wheel, the elements on both wheels appear to orbit counterclockwise. But if gaze is focused on the right wheel, the left wheel now appears to rotate counterclockwise.

Subfigure 1b shows only one element in each circle, but is otherwise identical to Subfigure 1a. In this case the direction of gaze does does not cause a change in the perceived direction of motion of the element on the left. Therefore it would appear that it is not just eccentric viewing that causes short range motion to dominate over long range, but also the *density* of the elements in the stimulus.

Taken together, these demonstrations motivate our investigation of the interplay of three factors in determining motion perception: the agreement of short-range and long-range movement, the eccentricity of the stimulus, and the density of elements contained therein.

The primary phenomenon we will be exploring in this paper is the density-driven reversal of the apparent direction of motion that occurs in incongruent stimuli (those whose short range and long range components are in opposition.) When elements are widely spaced, the apparent direction of motion follows that of the envelopes; as element spacing decreases, the direction of motion changes to agree with that of the carrier.

We will proceed to quantify this reversal effect below. In order to do so we ask subjects to make forced classifications of the stimulus' overall direction (clockwise or counterclockwise.) However, the subjective appearance of our stimulus can be complex, with several properties that change aside from

(a) When fixating at the center of the left wheel, both wheels appear to move in the same direction. But when fixating the center of the right wheel, both wheels appear to move in opposite directions. The appearance of the right wheel's movement reverses depending on the viewing eccentricity.

(b) Same stimulus as Subfigure 1a with only one element used in each. The perceived direction of motion is independent of eccentricity.

(c) As above, but there is no displacement of the envelopes over time. In this case the sensation of motion appears to be affected by fixational eye movements.

Figure 1: Demonstrations of subjective phenomena.

overall direction. Although we do not attempt to quantify these details of the appearance of our stimuli, we feel it is worth describing our impressions of them. Suitable individual adjustments of element spacing and other properties appear to elicit the same kinds of descriptions in everyone we have shown these stimuli to.

When elements are closely spaced, it is generally impossible to see the direction of envelope motion; the overall impression is of motion the the direction of the carrier. However, the amount of subjective flicker does appear to differ between incongruent and congruent motion, with ingongruent motion having more flicker.

Increasing the inter-element spacing somewhat, we approach a critical spacing, where for incongruent stimuli, subjects equivocate in their reports of perveived motion direction, [NOTE: This would be the first introduction of "critical distance."] The subjective appearance of a critically spaced, incongruent motion stimulus is somewhat variable. To some observers, it appears to first move in the direction of the carrier, and then to reverse direction shortly after stimulus onset. Although both the carrier and envelope motions are (considered separately) consistent with an underlying rigid rotation of a surface around the fixation point, or alternately a rotation of the observer, the perception does not appear to obey a rigid body constraint; elements can appear to move clockwise in some parts of the circle and counterclockwise elsewhere.

Further, when motion direction appears to reverse after stimulus onset, the perceptual reversal (and its behavioral correlate) occurs much faster than the perceptual change that occurs when separate moving objects are reinterpreted as a smaller number of rigidly moving bodies [?]. Nor is the perception of movement bistable; a change in perceived direction for some element of the circle does not, in general, cause the perceived motion of the entire stimulus switch direction. Attention does play a role; for incongruent displays with closely spaced elements, it is possible to direct attention to one (or sometimes several) elements in the circle. These elements are seen to move in the direction of envelope motion, but the rest of the circle is seen to move in the contrary direction, making for a somewhat paradoxical percept wherein movement is in opposite directions, but individual elements are not seen to cross over or collide.

Increasing the spacings further to where element motion tends to dominate, observers often describe the motion contained in the stimulus as belonging to two components, one belonging to the motion of the elements themselves, and the other being a kind of "wind" overlaid on top of the elements. This seems similar to the perception elicited by a moving grating superposed on a stationary pedestal [?].

At even wider element spacings the envelope motion dominates the perception. It becomes difficult to even tell the direction of motion of the carrier, apart from the amount of flicker. That is, the "wind" seen at slightly smaller spacings becomes less evident. This "capture" phemomenon was characterized by Hedges et al. for single element stimuli constructed similarly to ours.

The subjective speed of the elements also changes with the element spacing. As element spacing is reduced, the perceived speed of element motion (as distinguished from the "wind") also seems to reduce, until spacing near the critical distance, where the elements almost appear to be at a near standstill over the brief duration of the stimulus.

Thus at very narrow and very wide element spacings it becomes difficult to tell congruent motion apart from incongruent motion via the sensation of motion direction. However, the sensation of subjective flicker and smoothness of movement does tend to tell the two stimuli apart. Incongruent stimuli have more flicker, at both narrow and wide element spacings, and appear to move less smoothly. We have attempted to correlate this sensation of smoothness or lack thereof with reports of the instantaneous position of the elements, without success.

Which demos are necessary to underscore these points?

This next paragraph doesn't really connect to anything unless I perform an analysis of microsaccades in the task....

As a final note, in some instances it appears that small fixational eye movements have some influence over the appearance of these stimuli. This is most easily demonstrated in a where the long range displacement is zero but the carrier has a consistent direction, as shown in Subfigure 1c. Viewing this stimulus with the elements in the periphery, one sees a counterclockwise motion of the stimulus, which appears to fade and slow over time. Hovever, large or small saccades seem to re-awaken the movement, causing it to speed up again. The impression is similar to that seen in versions of the peripheral drift illusion, such as the "rotating snakes" illusion of Kitaoka [**?**]. However, while perceived motion in the peripheral drift illusion appears to be driven by slight shifts of a stationary image on the retina, the construction of our stimulus would tend to rule that out as a mechanism; the motion is directly contained in the stimulus.