- Friday, November 7, 1997
  Solution to Leonardo Da Vinci's Paradox by the Visual System

1.0 These are the minutes for the YORKVIS meeting that took place on Friday 7th Nov 1997. The meeting was given by Hiro Ono.

1.1 I have made some small changes to the minutes of Dejan Todorovic's talk on his web page.

1.2 Next YORKVIS meeting is on Dec 5th by Dianne Broussard (Playfair)

1.3 Notable upcoming talks in which you might be interested include:

(i) Friday 21 Nov (10:30) Mimi Galiana, McGill Univ "Most likely a vestibular or locomotion topic" Room 3227 Medical Sciences Building, U of T
(ii) Friday 28 Nov (2pm) Doug Crawford, York "Orienting and perceiving in three-dimensional space" Room 291, BSB, York
(iii) Tuesday Dec 9 (4:15) Mort Mishkin, "Hierarchical organization of cognitive memory" Room 3153 Medical Sciences Building, U of T 1.4 Another upcoming date to note is the ARVO abstract submission deadline which is Friday Dec 5th.
2.0 Good luck to the York graduate students and post-docs who have set up a YORKVIS splinter group. May your meetings flourish.

3.0 Hiro Ono's talk was entitled " The visual system's solution to Leonardo da Vinci's paradox". I apologize for the delay in getting out these minutes, but I have been chatting with Hiro a bit to get it all clear.

3.1 We have two eyes but only one perception of the visual world. The combined views of the two eye views includes information about what is behind an occluder placed between the observer and a background. Not all this information can be seen from a single point.

Leonardo identified this as a paradox because the near object must appear transparent if the area behind it is visible. Leonardo was concerned because he concluded that " it will be impossible to imitate it upon a picture so as to appear with the same relief.." The paradox is also a problem for the visual system because the visual system creates a view as though from a single point midway between the eyes.

3.2 What are the consequences of this paradox for the 'visual direction' of objects? When you (or your brain, anyway) are assigning visual directions to things, objects are related to a 'straight ahead' which comes out of the middle of your head. This is called a Cyclopean representation after the one-eyed cyclops of the Odyssey.

3.3 Experiment 1 addressed this question with a rod occluder far enough in front of a screen so that the rod and the screen could not be fused. That is either the rod or the screen had to appear double.

3.3.1 When you fixate the rod what happens to points that can still be seen but which should be occluded by the rod as seen from the Cyclopean view (that is points between b and e in diagrams 1 and 2)? The answer is the visual directions of these points on the screen are just where you would expect from the Wells-Hering laws of visual direction. For example, point 'e' is to the right of the fixation point of the right eye. In calculating its Cyclopean visual direction, the position of this point is assigned to being on the right of the Cyclopean fixation too, and by the same amount. This leads to an apparent visual displacement (to the right) of that point which can be measured by asking people to point with an unseen hand to that target. Thus there is no paradox for the visual system since everything that can be seen is seen but at displaced positions.

3.3.2 When you fixate the screen the rod is seen double and the visual system solves the paradox by making the two apparent rods appear transparent.

3.4 In Experiment 2, the occluder and screen were positioned close enough together for both the occluder and the screen to be fused simultaneously so that neither appeared double. What happens now to those points that should be seen behind the occluder? Since both the screen and the occluder are fused, neither can appear transparent and a basic Wells-Hering law of visual direction is that no two solid, visible objects can have the same visual direction. Furthermore if the points behind were displaced they would superimpose on other points (shown in green in diagram 5) which is also not allowed. The diagram on the web page shows that there is a little gap between the retinal edge of the occluder and the Cyclopean edge. Points further to the right of the retinal edge are seen binocularly and their Cyclopean positions (as measured by pointing) are veridical. Points to the left of the Cyclopean edge correspond to the perceived position of the occluder. Pointing experiments revealed that the Cyclopean perceived positions of the monocularly visible points behind the occluder were displaced and compressed into this section. This is therefore the visual system's solution to the Leonardo paradox for these conditions.

3.5 So the conclusion from this part of the talk is that the visual system's solution to the Leonardo paradox is to sidestep the problem by compression and displacement of visual space in the vicinity of the occluder such that everything that falls on the retina is available to perception.

4.0 This 'solution' however raises some problems.

4.1 If parts of the image are compressed and displaced perceptually (as a result of the calculation of their Cyclopean visual directions) then the perceptual shape of objects should be distorted as parts of them are displaced and compressed and parts of them aren't.

4.2 In particular, the paradox only applies to the left/right dimension. The up/down dimension should not be affected. So it should be easy to turn SQUARES into RECTANGLES, for example, by judicious placement of partial occluders in front of them.

4.3 But Hiro tested perceptual shape judgements and found no such distortion in 3-D perception. This suggests that the visual system has two independent mechanisms involved in processing partially occluded items: (a) one that represents the monocularly seen area in perception by displacing and compressing parts of the visual field, and (b) another mechanism for shape perception and alignment perception that corrects for the expected deformation.

4.4 Given this suggestion, the question becomes "what triggers this shape-preserving adjustment?" Perhaps some well known illusions such as the Poggendorff might result from the action of the compression and displacement mechanism coupled with a breakdown of the shape-preserving system. This might give us a handle on when the second mechanism engages. As shown in diagram 7, however this (and other) illusions are in the opposite direction to the displacement and compressionexpected from the first mechanism, indicating perhaps even an over-operation of the second mechanism.

4.5 Conclusions: 4.5.1 A first visual mechanism displaces and compresses a portion of the visual field around an occluder ensuring that all visual input is represented in perception.

4.5.2 A second mechanism ensures that shape and alignment of lines are perceived correctly in 3D but causes illusions in 2D.

4.5.3 The two mechanisms produce a geometric inconsistency that can be detected in a laboratory.

4.5.4 The pictorial cue of occlusion, rather than the presence of monocularly seen areas, triggers the second mechanism.

The Basic Wells-Hering Laws of Visual Direction

adapted from Ono, H. and Mapp, A. (1995) Wells-Hering's Laws of visual direction. Perception , 24, 237-252.

Definitions

Cyclopean Eye The Cyclopean eye is defined as a point located on a horopter midway between the two eyes. It is the point where lines of different visual directions intersect. Visual Line. A visual line is any line which passes through an object and the nodal point of the eye. The visual axis is the principal visual line. Common Axis. The common axis is the line which passes through the intersection of the two visual axes (principal visual lines) and the Cyclopean eye. Three Psychophysical Laws of Visual Direction

Law 1. The nodal point of each eye transfers to the Cyclopean eye, and all visual lines that transfer to the Cyclopean eye become visual directions (or Cyclopean visual lines). Law 2. The visual axes transfer to the common axis (or Cyclopean visual axis). Law 3. The angle between a visual line and the visual axis of one eye transfers to the Cyclopean eye in the following manner:

Law 3a(Monocular Viewing). The angle transfers unaltered to the Cyclopean eye. Law 3b(Binocular Viewing). If the two angles (one from each eye) differ by a large amount, they both transfer to the Cyclopean eye, resulting in two different visual directions. Law 3c (Binocular Viewing). If the two angles (one from each eye) are equal or if they differ by a small amount, they both transfer to the Cyclopean eye, resulting in a single visual direction which has a value equal to the average of the two different directions predicted by law 3b above.

Hiro Ono
York University