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Abstract

The intrinsic handedness of an object depends on its physical organisation along all axes, and is reversed by reversal of its organisation along any one axis. The attribution of top and bottom or front and back depends solely on the object's organisation along the axes to which they refer. Mirror reflection reverses organisation along the axis perpendicular to the mirror, and so also reverses intrinsic handedness, but does not affect locations along the axes parallel to it. Attempting to label one of the axes as left-> right' in terms of the intrinsic handedness of the object is mistake in that these labels are reversed by mirror reflection, producing an apparent reversal along this axis.

Keywords: spatial cognition, mirror vision, mirror reversal,left-right reversal, perceptual frame of reference, objectperception, frontal encounter.

The Effect of Mirror-Reflection on Chirality and Handedness Can be Explained Without Social Psychology Wed Jul 18 2001 The intrinsic handedness of an object depends on its physical organisation along all axes, and is reversed by reversal of its organisation along any one axis. The attribution of top and bottom or front and back depends solely on the object's organisation along the axes to which they refer. Mirror reflection reverses organisation along the axis perpendicular to the mirror, and so also reverses intrinsic handedness, but does not affect locations along the axes parallel to it. Attempting to label one of the axes as left-> right' in terms of the intrinsic handedness of the object is mistake in that these labels are reversed by mirror reflection, producing an apparent reversal along this axis. 1055-0143 spatial cognition, mirror vision, mirror reversal,left-right reversal, perceptual frame of reference, objectperception, frontal encounter.

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1. The target article (Navon, 2001) confronts the 'paradox' of intrinsic handedness and its reversal under mirror reflection, e.g. why my image in the mirror wears its watch on its right hand when I wear my

watch on my left hand. This reversal is contrasted with the other axis in the vertical plane (bottom-> top) which is not reversed in the mirror image. I argue below that the 'paradox' is due to confusion regarding the 'left-> right' axis through an object (being perpendicular to the bottom-> top and front-> back axes) and the use of the intrinsic handedness of the object to label this axis.

2. A crucial point is that we are dealing with intrinsic handedness: the problem is that the watch is worn on the image's right hand. Extrinsic handedness has not changed: the watch is still on the leftmost hand from the observer's point of view. Intrinsic handedness is a property of the object not dependent on the observer, while extrinsic handedness is defined purely with respect to the observer (e.g. to the left of the object from the observer's point of view). For example, while left and right can be used with either extrinsic or intrinsic meaning (which confusion contributes to the paradox), the port and starboard of a boat only have the intrinsic meaning. That is, since the back-> front and bottom-> top axes of the boat are well defined, we can unambiguously define port as the left of the boat (i.e. to the left of any upright forward-facing person on board), independently of how the boat is viewed.

3. The intrinsic handedness of an object is fundamentally different to its physical organisation along ANY of the orthogonal axes through the object (including the axis referred to as 'left-right'), in that it depends on the physical organisation of the object along ALL axes. By contrast, top and bottom, front and back can be defined with reference only to the single axes to which they refer. Note that the same words 'left' and 'right' can be used in two different ways: either to refer to the intrinsic handedness of an object, or to label the ends of a geometrical axis referred to as 'left-right'.

4. The nature of the dependence of intrinsic handedness on physical organisation is such that reversal of the locations of the elements making up the object along any one axis will reverse the object's handedness. Reflection in a mirror performs exactly that transformation: reversing distances along the axis perpendicular to the mirror and thus also reversing handedness. Thus a mirror on the floor reverses bottom-top organisation, a mirror in front of the object reverses back-front organisation and a mirror to the side of the object reverses left-right organisation. The 'paradox' is simply that the intrinsic handedness of an object is reversed wherever you put the mirror.

5. To explore this explanation, consider the chirality of molecules, which is less often confused with organisation along a 'left-right' axis. Imagine two ball-and-stick models of atoms arranged into a vertical helix in opposite senses, i.e. in one model the helix is arranged so that the atoms go around clockwise as you move along the central axis, while in the other they go around anticlockwise, see Figure 1. Given these two models as physical objects to play with it would becomes obvious that (i) they are different, and (ii) the difference between them does not depend on their position or orientation. By a convention exactly analogous to the use of left and right with respect to the sides of our body we define one to have 'right handed' chirality (as with conventional screws/corkscrews etc) and the other to have 'left handed' chirality (as with left-hand screws etc). These shapes show the same 'paradox' of mirror- reflection as people: seen in a vertical mirror, the reflection of the right handed spiral will be 'left handed' and the reflection of the left handed spiral will be 'right handed', but both will be the right way up. The crucial thing to note about chirality is that its 'sense' or 'direction' or 'sign' or handedness depends on the axial and radial organisation of the object. Reversing the object's axial organisation, i.e. moving the atoms along the axis of symmetry so that their order is reversed (the top one becoming the bottom one etc), reverses the chirality of the object. Equally, reversing its organisation along a transverse axis (e.g. moving each atom into or out of the page so that the nearest becomes the farthest etc) also reverses the chirality.

Ball and stick model of a helical molecule, the one on the left has right-handed chirality while the one on the right has left-handed chirality. Note that they are mirror reflections of each other.

6. Reflection in a mirror corresponds to reversal of the locations of the elements of the object (e.g. each atom in the molecule above) along the axis perpendicular to the mirror, as well as a translation into the mirror (which we can ignore as translations and rotations do not affect chirality). Thus reflection in a horizontal mirror perpendicular to the page corresponds to the axial reversal, while reflection in a mirror parallel to the page corresponds to the transverse reversal. Either reflection will reverse the 'handedness'

of the object, and the reason for this is simply physical.

7. Perhaps one reason for the confusion surrounding mirror reflection, as compared to translation or rotation, is that it is not usually possible to effect a mirror reflection of a solid object. One nice example is to put a right-hand rubber washing-up glove pointing towards a mirror with the tip of the middle finger touching the mirror. To produce the reflected glove its physical organisation perpendicular to the mirror must be reversed. This can be approximated by turning the glove inside out, leaving the tip of the middle finger in the same place (removing the mirror). Notice that it is now a left-hand glove. As with chirality, this process has nothing to do with the organisation of the glove along any axis but that perpendicular to the mirror (e.g. the glove need not be arranged with fingers in the horizontal plane).

8. So, where is the paradox? The paradox refers to a set of orthogonal axes ('back->front', 'bottom->top', 'left->right') through the object, and contrasts the physical organisation of the object along these axes with that of its mirror image. If these axes are defined extrinsically (relative to the observer, or indeed relative to any single object), then they form a unique stable set of axes within which to perform comparisons. Geometry works under these axes and, for example, reversing the locations of elements of an object along one axis will have no effect on their locations along the other two axes. In a frontal mirror, the extrinsic left->right organisation of the mirror image is not reversed, nor is its extrinsic bottom->top organisation, and there is no paradox. The mistake is to define the set of axes intrinsically. In this case there is a different set of axes for each object. If the mistake is not realised, one questions why left-right organisation appears to have changed. If the difference is reference frames is realised, one does not expect to find direct correspondence between the physical organisation of two objects each measured relative to different axes.

9. At this point we should abandon any 'paradox' generated by the mistaken assumption that intrinsically defined 'back->front', 'bottom->top' and 'left->right' axes of object and reflected object provided a single frame of reference for their comparison. But, as a commentary on an article concerning the paradox in question, I attempt to explain why the confusion over mirror reflection occurs more often in some configurations of the mirror than others. Finally, I address why confusion more often surrounds the intrinsic 'left- right' axis than the intrinsic 'back->front' or 'bottom->top' axes of an object.

10. Firstly, confusion is least if the mirror is not perpendicular to one of the intrinsic axes of the object. In this case it is obvious that the intrinsic axes of the reflected object are different to those of the object. Thus one realises that 'bottom->top', 'back- >front' or 'left->right' will mean different things for the different objects. This leads to consideration of how each axis is defined for each object and, eventually, why intrinsic handedness is reversed. If the mirror is perpendicular to any of the intrinsic axes of the object then the remaining two axes are parallel to the mirror and the corresponding axes in the reflected object will be parallel to their counterparts in the object. In this case confusion is maximal as a mistaken assumption that the intrinsic axes of both objects correspond to a single common framework is more likely since they are all aligned in an absolute sense (if not in direction). This mistake leads to the reflected object having apparently suffered a reversal of its physical organisation along its left->right axis under this common framework (as opposed to the reality: the intrinsic handedness of the object having suffered a left->right reversal). Finally, if the mirror is perpendicular to the 'left->right' axis of the object, one might expect a change of handedness even while making the mistake of equating handedness with physical organisation along the left-> right axis, and so feel less confused, if for the wrong reason.

11. Secondly, why is the intrinsic 'left-right' axis of an object harder to think about than the other intrinsic axes such as 'back-> front' or 'bottom->top', what is special about it? The answer to this is that, while the sense of bottom->top and front-> back axes can be defined independently of organisation along any of the other axes (see 12 and 13 below), the handedness of an object and thus the sense of its intrinsic 'left-> right' axis depends on organisation along all axes. As with chirality, intrinsic 'left' and 'right' are arbitrary labels for the fact the two ends of the 'left-> right' axis have different positions relative to the organisation of the object along the bottom-> top and back-> front axes. Thus, if an intrinsic 'left-> right' axis is treated like an independent axis, mistakes will be made because changes along other axes DO affect intrinsic handedness. For example, reversal along the back->front axis, as in a frontal mirror, does change

handedness, and thus changes the sense of an intrinsic 'left-> right' axis. Some examples of independent definitions of 'bottom->top' and 'back->front' follow.

12. An extrinsic bottom-> top axis for an object may be defined with respect to gravity and/or the orientation of the viewer's trunk. The 'top' of the object might be defined as that furthest from the floor (as defined by gravity) - or by translating the foot->head axis of your body onto the object and taking the head-end. For familiar objects there will be effects of learning, so that if an object is usually viewed in a particular orientation, one may come to associate one end (as defined by its perceptual features) as being the 'top' of the object. Thus objects that are familiar, or analogous in some way to familiar objects, can be assigned an intrinsic bottom-> top axis.

13. An extrinsic back->front axis can be defined by nearness to the viewer, or (visually) by occlusion of the back by the front. For familiar objects there will be effects of learning, so that if an object is usually viewed in a particular orientation, one may come to associate one end (as defined by its perceptual features) as being the 'front' of the object. Thus objects that are familiar, or analogous in some way to familiar objects, can be assigned an intrinsic back-> front axis.

14. The 'prototypical frontal encounters' stressed by Navon apply to attempts to relate intrinsic left-> right to extrinsic left-> right in the same way as for bottom-> top and back->front in paragraphs 12 and 13 above. However the fundamental error that gives rise to the 'paradox' concerns not so much how this definition should be done, as attempting to do it in the first place. The failure to realise that intrinsic handedness cannot be related to any one axis is the root of the problem.

15. The above arguments also apply to 2-dimensional symbols such as words and letters (and idealised clock faces). However the definition of intrinsic back-> front and bottom-> top axes deserves a special mention for these 'objects'. Being most commonly encountered as 2- dimensional symbols on an opaque background, the intrinsic back-> front and bottom-> top axes are assumed to be the same as the extrinsic axes. Thus the intrinsic front and top of the letter 'b' are assumed to be as viewed, we do not consider that it might be a rotated 'q' or a reflected 'd' or 'p'. Thus, when a letter is seen with back-> front axis reversed, as when reflected in a mirror parallel to the page or when seen from the back of a transparent page, its intrinsic handedness is also reversed. This is also true if the bottom-> top axis is reversed (as in a horizontal mirror).

16. I have demonstrated the physical explanation of the effect of mirror reflection on the handness and chirality of familiar and unfamiliar objects, including humans and text. I have also suggested physical explanations for why we are more often confused by the effect of mirror reversal than by rotation and translation, why some mirror orientations are more confusing than others, and why 'left-> right' is the most confusing intrinsic axis. I have shown where Navon's argument fits into this explanation and suggested that, while it may well describe some of the processes/preconceptions behind some people's surprise at mirror reversal, these processes only apply after making two more fundamental mistakes. These mistakes are the assumption that intrinsic handedness depends on physical organisation along one axis alone, and that the intrinsic axes of object and reflected object form a common frame of reference for comparisons. Even given the subordinate role of Navon's explanation, I am not convinced by its generality. For example, I am not convinced that when I look at a corkscrew or a washing-up glove in a mirror, my perception is being swayed by 'prototypical frontal encounters' with them. Nor am I convinced that change in handedness after reflection in a horizontal mirror is explained by prototypical encounters with upside-down things. In summary, if you want to understand handedness and mirror reflection you may be better advised to go and play with as rubber glove than to read all these articles.

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REFERENCES

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