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REFLECTIONS IN A MIRROR

– Damian Cox –

Abstract. In this paper, I develop a solution to the puzzle of mirror perception: why do mirrors appear to reverse the image of an object along a left/right axis and not around other axes, such as the top/bottom axis? I set out the different forms the puzzle takes and argue that one form of it – arguably the key form – has not been satisfactorily solved. I offer a solution in three parts: setting out the conditions in which an apparent left/right reversal of mirror images is generated; explaining why these conditions are so often met; explaining why we are cognitively biased towards the perception of left/right reversal when these conditions are met.

Keywords: mirror-reversal, perception, cognition, philosophical psychology, cognitive bias.

I.

There is a long-standing puzzle about the perception of mirror images. Mirrors, as we ordinarily encounter them, appear to reverse the image of a thing from left to right, yet not from top to bottom. Looking at your face in the mirror, it seems that you encounter a person who reverses your looks left and right: the small scar on your left cheek is on their right; your crooked smile is their crooked smile, except their lips curl to their left, not their right. Although their looks are yours, reversed left and right, you stand eye to eye with them. Why does the mirror *only* reverse your looks around a vertical axis in this way?

This puzzle has entertained philosophers since Plato[1] and yet there seems no end to the confusion it is apt to generate. For example, in *Kant and the Platypus* Umberto Eco urges us to regard the mirror as a prosthesis, like an eye attached to our index finger that can be pointed back towards our face and which 'provides the eye with the same stimuli that the eye would receive were the prosthesis in front of us.'[2] A moment's reflection, or experiment with a video-camera, suffices to unveil Eco's error. The face in a mirror is not the face I would see were my eye attached to my index finger and directed back towards me. An asymmetrical object like an ordinary human face and its mirror-generated image are not identical.

[1] Plato [1982] 46.

[2] Eco [1999] p. 367.

They are mirror images, or enantiomorphs, of each other and our characteristic way of perceiving the mirror generated enantiomorph of a familiar object seems only to be one of left/right reversal.

The optics of mirror reflection does not discriminate between the horizontal and vertical axes of an image, so if we discriminate between apparent axes of reversal of mirror images, this must be a fact about our way of interacting with mirrors. To explain the phenomenon we need a precise account of it. We need an account of the conditions in which the phenomenon occurs, and the processes – physical, cognitive or perceptual – required to generate it. I tackle these three tasks in turn.

II.

Ned Block identifies four different senses in which a mirror might be said to reverse the image of an object and claims that they generate four different kinds of mirror-reversal puzzle.[3] Confusion arises, he argues, because puzzlers have paid insufficient attention to the precise puzzle they seek to solve.[4]

The senses of reversal Block identifies are: reversal_r (in which images 'read' from right to left rather than left to right); reversal_g (in which certain mirror-generated enantiomorphic pairs – most particularly the human form and its mirror-twin – fit together top and bottom, but not left and right); reversal_d (in which I observe phenomena such as that my mirror-pair's right hand points in the direction that my left hand points) and reversal_w (in which I observe that my mirror-pair is opposite-handed, e.g. that they wear their watch on their right hand whereas I wear my watch on my left hand).

Reversal_r is the phenomenon that concerns me in this paper. When they reverse_r, sentences of English will 'read' from right to left rather than left to right. (In Arabic, by contrast, sentences in a mirror appear to read from left to right, rather than from right to left.) Consider a card with the word 'TIM' written on it. If the card is presented to a mirror in an ordinary way – a way I describe below as 'canonical' – then the word we observe in the mirror is 'MIT'. The original word 'TIM' appears in the mirror to be reversed around a vertical axis relative to the word 'MIT'. What we perceive in the mirror is 'TIM' backwards. 'MIT' does not appear to be a reversal of 'TIM' in any other orientation. It is not 'TIM' upside-

[3] Block [1974] pp. 259–277.

[4] Takano advances an analysis of the problem-set that is similar Block's, [Takano 1997]. Takano and Tanaka offer empirical evidence that supports this analysis, [Takano, Tanaka 2007].

down or 'TIM' reversed at an angle of 45 degrees, and so on. This is a comparative judgment on our part. We judge 'MIT' to be a familiar word 'TIM' backwards and we tend not to see it as morphologically related in any other way to its mirror-twin.

This phenomenon of apparent reversal_r generalizes beyond written forms. As I argue below, any familiar bilaterally asymmetrical object will, in the right circumstances, be seen to reverse_r. We appear to have a robust preference for seeing mirror images of familiar objects as those objects presented to us backwards; without considerable prompting, we do not appreciate any other relation between the images. Yet there are other such relations. For example, when observing the mirror-image of 'TIM' we might imagine lining up 'TIM' top to top with our observed image 'MIT' so that the composite image is symmetrical around a horizontal axis midway between them. There is no familiar term for this form of reversal of mirror images, but let me call it being 'topsy-turvy'. 'MIT' is 'TIM' backwards and topsy-turvy. We automatically appreciate its backwardness, but find it hard and unnatural to appreciate its topsy-turvyness.[5] The illusion that concerns me in this paper involves this preference for seeing familiar objects as reversed_r in a mirror over any other of the other ways we might see them. This, I shall argue, has two aspects to it: one has to do with the manner in which objects are presented to mirrors, the other has to do with conditions of perception and processes of cognition that are involved in comparing the shapes of enantiomorphic pairs.

Block's other three senses of reversal are distinct from reversal_r. Reversal_g is apparent when I confront my enantiomorph in the mirror and imagine walking behind the mirror and 'getting into' that form.[6] In doing so, however, I must swap left and right sides with my enantiomorphic twin. I cannot superimpose my left-side on his left-side without turning upside-down, and when I do that all chance of a clean superimposition vanishes. This is the phenomenon Block has in mind with reversal_g and it appears to be an artifact of the approximate bilateral symmetry of the human form, i.e. the fact that left and right halves of the body are enantiomorphic twins of each other, whilst the top and bottom halves are not.[7]

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[5] There is no shortage of similar relations between mirror-image pairs. For example, lining up mirror-twins perpendicular to each other (i.e. so that their top-bottom axes are perpendicular to each other) will generate symmetry around an axis midway between the two images and 45 degrees to each top-bottom axis.

[6] David Pears introduced this way of thinking about the mirror puzzle, Pears [1952].

[7] Nicholas Denyer has offered a convincing explanation of this phenomenon, Denyer [1994]. Martin Gardner has also used the fact the human form is approximately bilaterally symmetrical to explain a mirror illusion, one drawn in terms of reversal_g, Gardner [1982].

Puzzles associated with reversal_d and reversal_w may be solved by examining the concepts of right/left direction and right/left sidedness respectively, along lines suggested by Block.[8] Consider the phenomenon of reversal_w in mirrors. This is a real phenomenon: my mirror-image does reverse my handedness; if I wear a patch on my left eye, my mirror-twin will wear a patch on their right eye. This does not, however, represent a deeply mysterious feature of mirrors, a peculiar way in which we treat mirrors or a general feature of human perception. Rather, it is an inevitable consequence of our concepts of left and right-sidedness. The shape of many three-dimensional objects can be characterized in terms of three kinds of side: front/back, top/bottom, and left/right. Any object will have a right-side and a left-side if and only if it also has a front and back and a top and bottom. For instance, we can specify the right-side of an object as the side to the East when the object is upright and facing North. Any enantiomorphic pair of objects sided in this way will reverse their left-side and their right-side. Enantiomorphic pairs don't reverse top/bottom or front/back in similar fashion because the concepts of top/bottom and front/back are quite different from the concept of left/right. The front of an object – its 'face' – is set in terms of the way we ordinarily encounter it and is identified by the morphological characteristics of the side we ordinarily encounter.[9] The top of an object is set in terms of its usual orientation relative to the ground. The concepts of left and right side, however, are a product of combining these two notions with a set of relatively stable directions, for example, compass directions across the Earth's surface together with the direction upwards.[10] Since the concepts of top/bottom, front/back and left/right are all quite different from each other, it should not surprise us that they apply to enantiomorphic pairs in non-equivalent ways.

I think that the most general and also the most interesting version of the mirror-reversal puzzle involves reversal_r and takes the form of a visual illusion.[11] When familiar objects are presented to a mirror in the ordinary way, they appear

[8] Block [1974] pp. 265–274.

[9] Defining the concept of the front of an object is a little more complex than I have indicated. For instance, the front-side of an object is sometimes determined by the object's characteristic motion rather than the aspect from which it is ordinarily encountered. Sailors ordinarily encounter the bow of a ship from behind, but it counts as the front of the ship because ships characteristically move forward.

[10] There are alternative ways of characterizing left and right sides. It is possible, for example, to determine the left and right sides of objects relative to the left and right sides of a standard asymmetrical body.

[11] Block claims, on the basis of an informal survey, that most people puzzled by the phenomenon of mirror reversal are not thinking of reversal_r, Block ([1974] p. 264). It seems that he is simply wrong about this. The empirical studies in Takano and Tanaka [2007] appear to bear this out.

to reverse the standard appearance of the object around the left/right axis of the object rather than any other axis: they appear to be a backwards version of the object rather than any other version of it. Before taking a look at previous attempts to explain this, it is important to get clear about the conditions in which it occurs. The phenomenon of unique left/right reversal of mirror images is not always apparent in our perception of objects in mirrors.[12] Certain conditions must be satisfied if an appearance of unique left/right reversal is to be generated. There are four of them.

(1) The object in question must be presented to the mirror in a way that I shall call 'faced'. Faced-presentation to a mirror occurs when an object exhibits a readily observable difference between the side facing the mirror – the front – and the side opposite it – the back. We typically present ourselves to the mirror faced, since we front the mirror and the front of our head is easily distinguished from the back of our head; an ordinary clock makes a faced presentation to us since the front of a clock is easily distinguished from its back. Un-faced presentations to a mirror do not generate the appearance of left/right reversal. Consider an ordinary hairbrush. Holding the hairbrush lengthwise-parallel to the mirror, bristles upwards, will generate an un-faced presentation since the hairbrush will be symmetrical front to back. The hairbrush's reflection will also palpably fail to exhibit left/right reversal.

(2) The object must be presented to the mirror so as to exhibit left/right asymmetry. For example, the letters 'A', 'H', 'I', 'M', 'O', 'T', 'U', 'V', 'W', 'X', 'Y' all fail to generate the appearance of left/right reversal; as will a hair brush presented head-first towards a mirror (so that it's presentation is faced but not asymmetrical).

(3) The object's presentation to the mirror must have a standard appearance with which we are familiar, an appearance in which we are able to nominate a top and bottom and a left-side and right-side.[13] To see why this familiar, standard appearance is essential, consider the following experiment. Without looking, draw a random, asymmetrical doodle on a card and hold it before a mirror. An appearance of left/right reversal will not, of course, be forthcoming. But say that we go to the bother of familiarising ourselves with the doodle viewed in a particular orientation by hanging it on a wall, thus designating sides of the card as left, right, top, bottom. Once the object becomes familiar in this orientation, it becomes possible to hold it to a mirror and observe a left/right reversal. Now say that we disrupt the

[12] Ittelson et al. describe a variety of conditions in which perceptions of objects and their enantiomorphs are not of perceptions of reversal, (Ittelson et al. [1991] pp. 567–584).

[13] For simple objects, the familiarity may be very short term. For instance, I may observe an object face on, turn it to a mirror and immediately observe the orientation of the mirror-image.

process of establishing familiarity with a standard image of the doodle. We hang the card in different orientations at different times, or we arrange to have the hanging-orientation of the card altered at random without our knowledge. Over time, we would become familiar with the object in a sense, but we would not develop a familiarity with a standard image of it. Were we to casually observe our doodle in a mirror, say we glanced at a mirrored wall opposite to it on entering the room, we should not, I think, see any particular kind of reversal. We may recognize the image as in some way unfamiliar – it is an enantiomorph of our doodle – but we would not see it as a left/right reversal. (A left/right reversal of *what* in particular?)

(4) A final condition is that the object be presented to the mirror in a particular orientation. Call this way of confronting a mirror, a canonical presentation to the mirror. Canonical presentation to a mirror has the object face the mirror, upright relative to the observer.

Canonical presentation of any faced, bilaterally asymmetrical and familiar object to a flat mirror will generate the appearance of left/right reversal, or reversal_r. Call the image thus generated a canonical mirror-image. Our puzzle now resolves into two questions. Why are typical presentations to a mirror canonical? Why do canonical mirror images appear to be familiar objects backwards rather than, say, familiar objects topsy-turvy?

III.

Block regards the appearance of reversal_r in mirror images as an illusion generated by the way objects are presented to a mirror.[14] When we present an object to a mirror, says Block, we typically rotate it around a vertical axis. Similarly, if a mirror is behind us and an object in front of us, we typically rotate ourselves around a vertical axis to observe an object in the mirror. The appearance of left/right reversal is an artifact of these rotations. Were we to rotate the object to the mirror around a horizontal axis, the object's mirror-image would appear to reverse the object top/bottom not left/right. The reason that mirror images appear to reverse left and right seems, then, to reside in our mode of turning objects to the mirror.

This solution has also been proposed by Richard Gregory, who calls it the object-rotation account of mirror reversal. Gregory contrasts the object-rotation account with mental-rotation accounts, in which the appearance of left/right reversal in a mirror is generated by our *imagining* an object rotated around a vertical

[14] Block [1974] pp. 261–262.

axis and lined up side by side with its mirror-image. In our own case, for example, we imagine ourselves walking behind the mirror and standing beside our mirror-twin. Were we to imagine ourselves tumbling into the mirror and resting on our mirror-twin head to head, we would conclude that the two figures reverse each other top/bottom, not left right. Mental-rotation accounts rely on the idea that the former, not the latter, procedure is the natural way of comparing figures in our imaginations. According to Gregory, if mirror reversal were an act of biased imagination in this way, it would be a remarkable cognitive phenomenon calling for urgent research. But there is, he claims, little reason to think that the appearance is generated by our visual imaginations.[15]

The motivation behind object-rotation accounts of mirror reversal is not hard to see. Abnormal ways of turning an object to a mirror disrupt the appearance of left/right reversal, so it is natural to account for the appearance by appealing to normal ways of turning objects to a mirror. One trouble, however, is that the appearance of left/right reversal does not require any turning of objects to mirrors. Consider a room with a mirrored wall facing an open doorway and a clock on the wall opposite. I walk towards the doorway to the room seeing only the mirrored wall and the clock-image I observed is plainly reversed left/right rather than top/bottom. I have not rotated the clock at all, and nor have I turned around a vertical axis in order to position myself for the viewing.

Left/right mirror reversal is not simply an artifact of the way an object is in fact rotated to face a mirror. It does, however, rely on the relative orientation of object, perceiver and mirror; mirror-image reversal depends upon the canonical presentation of an object to the mirror. What Block and Gregory are picking up on is the way abnormal rotations of an object to a mirror – say reading a card and flipping it over to face the mirror – generate non-canonical presentations. A canonical presentation to a mirror is necessary for the appearance of left/right reversal, but rotating an object around the vertical axis is not the only way of contriving a canonical presentation.

Recall that there are two questions to be answered: why presentations to a mirror are typically canonical and why canonical mirror images appear backwards. Object-rotation theories offer part of the answer to the first question, they do not address the second question. Merely observing that a presentation (of a faced, bilaterally asymmetrical and familiar object) to a mirror is canonical does not suffice to explain the appearance of left/right reversal. Even in the standard case that Block and Gregory appear to have in mind – in which I observe an object

[15] Gregory [1997] p. 101.

face-on and then rotate it around a vertical axis to face the mirror – my observation that the object is reversed left and right is a comparative judgment. In making it, I must rely, perhaps tacitly, on information drawn from my memory of how the object standardly looks (or perhaps my short-term memory of how it *just now* looked) in order to judge that the image I see is a backwards version of the image I recall. This may not involve any imaginative rotation, but it nonetheless involves a comparison of images and the information contained in them.

Object-rotation theories do not fully account for the phenomenon at hand. Mental-rotation theories, on the other hand, over-draw the cognitive performance involved in recognizing mirror-image reversal. Gregory is surely right to be suspicious of an explanation that posits a complex imaginative accomplishment such as the rotation of images around a vertical axis. Most people have patchy abilities of image rotation, and much recognition of mirror-image reversal appears automatic and not mediated by any act of imagination. A patchy ability to imaginatively rotate images might be enough to occasionally create the impression of a left-right reversal, but in the right circumstances – in a canonical presentation of a familiar and bilaterally asymmetrical object to a mirror – the impression of left-right reversal is neither an occasional phenomenon nor is it preceded by explicit imaginative effort.[16] The word 'Frog' presented canonically to a mirror just looks backwards; imaginative processes of image-rotation don't seem to play any role in this recognition. Judging that an image is a backwards appearance of a familiar object does not normally require an explicit act of imagination.

The phenomenon of apparent mirror-image reversal has both a physical aspect and a cognitive aspect. The object-rotation account provides some insight into its physical aspect and mental-rotation accounts are miscued attempts to explain its cognitive aspect. To properly understand the phenomena, however, we need to get clear about both.

IV.

Why do mirror images typically appear reversed uniquely left and right? I have suggested that there are two questions hidden here. Why are canonical presentations to a mirror ubiquitous? Why do canonical presentations of a familiar and bilaterally asymmetrical object to a mirror appear as a backwards version of the original, rather than any other version? Let me address the first question first. This is a question about our habits of handling objects and presenting them to

[16] I wish to thank an anonymous referee for suggesting this possibility.

a mirror for inspection and about our habits of arranging objects around mirrors relative to our typical position and movement as observers. Apart from the special case of observing ourselves in a mirror, the most salient factors generating canonical presentations to mirrors are the uprightness of our stance and the fact that typical observationally-relevant movements, such as turning our heads and turning our bodies, occur horizontally around our vertical axis.

The case of self-presentation to a mirror is easily accounted for. When we observe ourselves in a mirror our presentation to the mirror is necessarily canonical since a canonical presentation is upright relative to the mirror's observer and in our own case we are both object and observer. But what about our presentation of other objects to a mirror? When we intentionally present objects to a mirror we do so as we would to another person standing before us. (After all, there usually is a person standing in the mirror – perhaps we present the object to them!) When we present an object for the gaze of another person standing before us we tend to preserve its uprightness relative to both of us. Thus, when we present an object to a mirror we tend to preserve its uprightness relative to ourselves, i.e. we turn the object around a vertical axis and present it canonically to the mirror. This is the aspect of mirror-presentation that object-rotation accounts pick out. Finally, when a mirror reflects an object in its environment, we usually become familiar with the object's appearance in an orientation determined by our upright stance before it and we tend to preserve this upright stance when observing the mirror (by turning our heads around a vertical axis or walking around upright). In this way, as mirror observers, we generate a canonical presentation of the object to the mirror. For these reasons, the mirror images typically observed by upright creatures such as ourselves are canonical mirror images.

Let me turn to the second of our questions. Why do canonical mirror images of familiar objects appear uniquely to be backwards versions of those objects? In many cases, this is a form of immediate perceptual judgment: it is a matter of *seeing as*; the mirror-image is *seen as* a familiar object reversed left and right. In other cases, the phenomenon is more like a judgment made of a perception: we see the mirror image and it occurs to us, effortlessly, or perhaps with minimal effort, that it is the image of a familiar object reversed left and right. Both sorts of judgment involve a tacit comparison between perceived image and recalled image. We observe an image in a mirror and judge it to be, or see it as, a backwards version of an object we recall.

Judgment that an image is of a familiar object backwards, is a highly structured judgment. Our alighting on this judgment is not inevitable. We might instead judge mirror images to be a familiar object topsy-turvy. Recall that an image

is a topsy-turvy version of another if, were they both lined up top to top, they would exhibit symmetry around a horizontal axis midway between them. Judgment that an image is a topsy-turvy version of familiar object is co-extensional with judgment that it is a backwards version of the object. However the two judgments are intentionally distinct in the sense that they are arrived at in a distinct ways and experienced in different ways. Canonical mirror images are both backwards and topsy-turvy. But why is it obvious to us that they are backwards while it usually has to be pointed out to us that they are topsy-turvy?

The answer appears to be that judgments of backwardness are facilitated by perceptual/cognitive mechanisms we employ in shape comparison whereas judgments of topsy-turvyness are not facilitated by these mechanisms. It is highly unlikely that we evolved a special-purpose mechanism for judging backwardness. What advantage would be earned by such a thing? Nonetheless, our perceptual and cognitive mechanisms of shape comparison exhibit a clear preference for backwardness over topsy-turvyness. Judgment of backwardness is an easy and sometimes automatic affair whereas judgment of topsy-turvyness is an awkward thing, requiring explicit and attention-driven cognitive work. We have to look for topsy-turvyness; backwardness comes looking for us.

It is hardly surprising that upright creatures have evolved in this way. Our normal mode of observing the world is to swivel our heads and rotate our bodies around a vertical axis, so image-comparisons that preserve uprightness have become, in one way or another, second-nature to us. Image-comparisons that involve inversion around a horizontal plane are of little use to upright creatures. How often is it useful to us to look at an object in front of us and compare it to an object behind us by bending over and peering between our legs? There is not a lot of adaptive advantage to be gained by getting to be especially good at doing that. So, there is no good reason to think that our perceptual/cognitive systems have evolved to be good at judging topsy-turvyness and every good reason to think that they have evolved to be good at judging backwardness.

Our preference for backwardness perception over topsy-turvy perception might also be a developmental affair. Because we are upright creatures with heads that swivel, we have, in the ordinary course of a life, occasion to become very skilled at comparing shapes while preserving uprightness and hardly any occasion to become skilled at comparing shapes via horizontal inversion. Perhaps we just don't bend over and look between our legs often enough to get any good at comparing shapes in this way.

V.

Why do mirrors appear to reverse the image of an object left and right and not top to bottom? The answer has three parts. First, the objects in question are faced, bilaterally asymmetrical and familiar (if any of these factors are absent, left/right reversal will not be apparent). Second, objects are typically presented to a mirror canonically (i.e. facing the mirror, upright relative to the observer of the mirror). Third, in comparing the shape of a perceived image with that of a recalled image we tend to hold the uprightness of the images constant. In effect, we ask how the two images would compare were they lined up side by side. This is a cognitive accomplishment and also a cognitive bias. It involves the conservation of uprightness in comparative visual judgment and a capacity to judge certain relatively simple relations between upright images independently of the explicit and effortful use of visual imagination. The rest, one might say, is geometry.

What kind of perceiver might be prone to see mirror images as reversed top/bottom rather than left/right? As there are two aspects to the phenomenon of apparent mirror-reversal, there would be two ways of bringing this about. One sort of creature would typically effect mirror presentations in just the right, non-canonical way to generate the phenomenon. Consider a creature that only moved around a horizontal axis; one that could not turn left or right. Imagine a deep-sea creature caught in a horizontal nutrient-stream and shaped so that one rotation left or right would spin them out of the stream and into a place they will starve. They recognize the force of gravity, and so possess a top/bottom axis, but move by tumbling along the nutrient-stream rather than swimming upright. If such a creature had need of mirrors, and the cognitive means to work with them, they might puzzle over the question: why do mirrors reverse the image of thing top to bottom, but not left to right? Another sort of creature would inhabit our kind of environment, but have developed rather peculiar habits of comparative visual judgment involving automatic exploitation of an upending-bias when judging comparative shape. They would see writing in a mirror and jump immediately to the conclusion that it is ordinary writing topsy-turvy. Of course, they would be right.

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