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WHY DO MIRRORS REVERSE RIGHT/LEFT BUT NOT UP/DOWN? *

PEOPLE who ask this question rarely know just what question it is that they are asking. I shall argue that there are many interpretations of the question, and that they fall into two general categories: (1) interpretations on which the correct response to "Why do mirrors . . . ?" is: they don't; (2) interpretations on which mirrors *do* reverse right/left and not up/down, but where one can explain why they do through an examination of the concepts 'right', 'left', 'up', and 'down'.

I

One example of an interpretation of type 1 is the following. Suppose I have a placard such as that pictured in A.

(A)

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Why is it that the mirror image of this placard, viz., B, reads from

(B)

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right to left instead of left to right, but still reads up to down as before? I shall call this interpretation of "Why do mirrors . . . ?" interpretation 'R' for "reading." When contrasting the notion of reversal deployed by interpretation R with other notions of reversal, I shall call it "reversal$_R$." (All the notions of reversal and the interpretations of our original question discussed in this paper are listed below in the appendix.) What is puzzling here is that the

* I am indebted to George Boolos, Michael Devitt, Hartry Field, Paul Horwich, Jerry Katz, and Richard Miller for comments on an earlier version of this paper.

mirror seems to treat the horizontal axis differently from the vertical axis.

But notice that B is by no means "the" mirror image of A. For example, another possible mirror image of A is C.

(C) BUT NOT UP\DOWN?
WHY DO MIRRORS REVERSE RIGHT\LEFT

The reason B appears to most of us to be *the* mirror image of A is as follows. Imagine you are facing the mirror while holding the placard in front of your face reading it in the normal way. You then rotate the placard 180° so that it faces the mirror. Now most of us tend to turn the placard to face the mirror by rotating it about its vertical (y) axis. Thus we see B in the mirror. But if we rotated it about its horizontal (x) axis, we should see C.

But C reads normally on the x axis (left to right) and abnormally on the y axis (down to up). So if this way of turning the card were more natural than the other way, people would perhaps be tempted to ask: Why do mirrors reverse up/down but not right/left?

Suppose you are in a room, one wall of which is a mirror; attached to the opposite wall is the placard A. You stand facing the placard. You then turn to the mirror. What you see is B. But the puzzle now seems reborn, since the placard and the mirror are stationary, being attached to the walls of the room: neither has been rotated. But notice that though the placards have remained stationary, *you* have turned about your vertical axis (see Figure 1). Had you

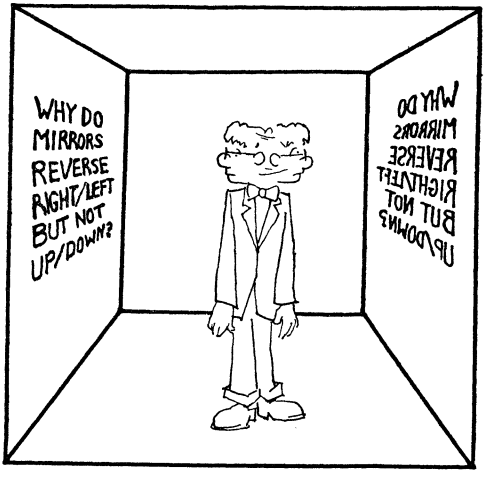

FIGURE 1. View of the room from the side.

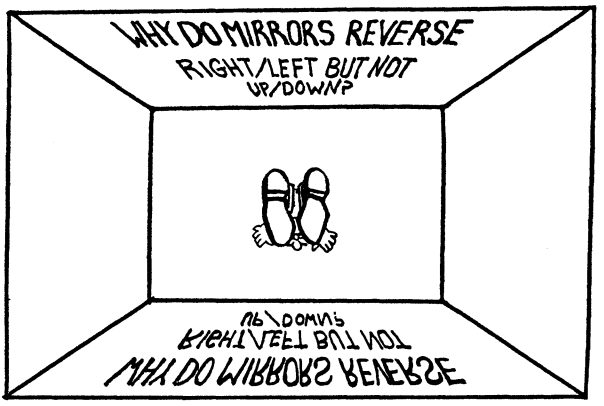

FIGURE 2. View of the room from the top. You see the reflection just as the person standing on his head does.

turned by flipping over backward or by bending down and looking through your legs, you would have seen C (Figure 2).

Now there are two quite different ways of describing this situation. One way would be to say that the mirror reverses the placard right/left but not up/down in one circumstance—if you rotate the placard (or yourself) 180° about the y axis (case B)—whereas the mirror reverses the placard up/down and not right/left in another circumstance—if you rotate the placard about the x axis (case C). A second description is: the mirror *appears* to reverse right/left in one case, whereas it *appears* to reverse up/down in the other, but *actually* the mirror reverses neither right/left nor up/down in either case. I incline toward the latter description for two reasons. First, to say that the mirror reverses the placard right/left is to say that *the* mirror image of the placard reads right to left—even if one specifies that the placard be rotated a certain way. And to say *the* mirror image of the placard reads right to left is to presuppose (falsely) that there is a unique mirror image of the placard.[1] Secondly, to say that the mirror actually reverses right/

[1] It might be objected that (1) the phrase 'the mirror image of the placard when it is rotated about the y-axis' *does* (uniquely) refer, and thus that it is true that (2) the mirror reverses the placard right/left when the placard is rotated about the y axis. Now (1) is true, but (2) is ambiguous; and the interpretation of (2) that (1) supports is not the interpretation that provides an answer to the original question. The ambiguity in (2) is an ambiguity in the scope of 'reverses'. One way of interpreting (2) is as asserting that the mirror reverses *the y-rotated placard.* On this interpretation, (2) is true but irrelevant: for the original questioner wants to know why the mirror reverses *the placard,* not why the mirror reverses the *y-rotated placard* (right/left). The other way of interpreting (2) is as

left but not up/down (even if one specifies a y-axis rotation) is to imply that the mirror treats the up/down axis of the placard differently from the right/left axis. But the mirror does not treat the two axes differently. It is *we* who do so by choosing the up/down axis as the axis of rotation. If these arguments are right, the correct response to interpretation R of "Why do mirrors . . . ?" is: they don't.

II

Another (closely related) interpretation on which right/left reversal is illusory was expounded by D. F. Pears in his "Incongruity of Counterparts." [2] Pears asks us to "imagine that I look into a mirror and then produce a full-length portrait of myself accurately painted over the mirror image. Next suppose that I go round behind the mirror and face the back of it. Suppose also that the mirror is made of some flexible plastic material. Then I can put the portrait of my face on my face like a mask, and the portrait of the rest of my body on the rest of my body like a complete suit of clothes" (78). Let us call the process of putting the plastic on my body "getting into my portrait." Why is it that, when I get into my portrait, it fits vis-à-vis top/bottom, but fails to fit vis-à-vis right/left? (The puzzle assumes that I do not have perfect bilateral symmetry; imagine for example, that my left arm has a cast on it.)

I shall call this interpretation of the puzzle "interpretation G" ('G' for "getting into one's portrait") and (when contrasting this with other notions of reversal) I shall call the notion of reversal it deploys "reversal$_g$." Pears' solution consists in pointing out that the appearance of asymmetry here owes to the fact that the normal way of getting into the portrait involves pivoting on one's *vertical* axis in order to face the back of the mirror. "But suppose that instead of turning in the vertical axis I turned in the horizontal axis about which we pivot when we turn head over heels: suppose that I stood on my head behind the mirror. It is equally clear that, if I got into my portrait in this way, left and right would not be reversed while top and bottom would be reversed" (*loc. cit.*).[3] Of course if I got into the portrait this way it wouldn't fit very well, since I would be putting the "legs" on my head and vice versa. But this bad fit occurs

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asserting that the mirror reverses *the placard* right/left—in a given circumstance (y rotation). But this interpretation presupposes falsely that 'the mirror image of the placard' refers. Thus on one interpretation (2) is not relevant, and on the other interpretation it is not true.

[2] *Mind*, LXI, 241 (January 1952): 78–81.

[3] I would say "appear to be reversed" where Pears says "reversed"; see the last paragraph of this section.

merely because I am not symmetrical above and below the waist. So one correct response—though one Pears himself apparently would not accept (see the paragraph after next)—to Pears' version of "Why do mirrors . . . ?" is: they don't, and the appearance that they do owes to the fact that in "getting into one's portrait" one would normally turn around one's vertical axis. Further, the possibility of getting into one's portrait upside down is obscured by the fact that we are not symmetrical about the plane that cuts a standing figure horizontally at the waist; were we symmetrical about this plane and were it natural to get behind things by flipping upside down, people might wonder why mirrors reversed up/down but not right/left.

Bernard Mayo [4] puts Pears' point slightly more generally. An asymmetrical object and its reflection cannot be made to coincide when one is superimposed on the other. (Such a pair of objects are said to be "enantiomorphs.") But which axis bears the failure of coincidence (and thus appears to be reversed) depends entirely on how one rotates the object and its reflection before one attempts the superimposition. Any axis one chooses can be made to appear reversed by means of a suitable rotation. In terms of Pears' example: if one naturally chose to get into one's portrait by walking behind it and then backing into it (i.e., no rotation at all) it would be the front/back axis that appeared to be reversed, not the right/left or up/down axis.[5] And if one backed into it standing on one's head, all three axes would appear reversed.

With reversal$_g$ as with reversal$_r$, there are two quite different ways of conceptualizing the situation. One way, apparently favored by Pears, is to say that mirrors reverse right/left (and not up/down [6]) if one imagines getting into one's portrait in the usual way, but that mirrors reverse up/down (and not right/left) if one imagines getting into one's portrait frontward standing on one's head. The alternative conceptualization says that mirrors reverse neither right/left nor up/down in either case, even though mirrors may *appear* to do one or the other, depending on which operations are imagined to be involved in getting into one's portrait.

[4] "The Incongruity of Counterparts," *Philosophy of Science,* XXV, 2 (April 1958): 109–115.

[5] Superimposition without rotation produces failure to "fit" only on the frontward/backward axis (when facing the mirror). This may lead some people to suppose that the mirror *really* reverses only frontward/backward. But to suppose this would be to introduce a new sense of 'reverse'—a sense uninteresting in that it gives rise to no puzzle in the first place. See footnote 15.

[6] 'Top/bottom' would actually be more appropriate here than 'up/down'.

As with the first type of reversal, I incline toward the second type of description. First, to say the mirror actually reverses right/left is to say that getting into one's portrait requires that the portrait fail to fit vis-à-vis right/left. And to say this is to presuppose falsely that 'getting into one's portrait' refers, i.e., that there is one and only one type of getting into one's portrait. (See the analogous discussion at the end of part I, especially footnote 1.) Secondly, to say that the mirror reverses right/left but not up/down is to imply that the mirror treats one's up/down axis differently from one's right/left axis—even if one specifies that one is imagining getting into one's portrait by turning on one's up/down axis. But the mirror does not treat the two axes differently. It is we who do so by picking one axis as the axis of rotation.

As interesting as the two versions of "Why do mirrors . . . ?" so far discussed are, I doubt that very many people who have worried about why mirrors . . . have had either of them in mind. I claim: (a) Most of those who have any views at all about frontward/backward reversal feel, at least initially, that mirrors *do* reverse frontward/backward (when we face the mirror). (b) Most people who have worried about the problem probably would *not* feel (even initially) that mirrors reverse_r or reverse_g frontward/backward if they understood what reversal_r and reversal_g are.

In short, although mirrors do appear to *reverse,* they probably would not appear either to reverse_r or to reverse_g frontward/backward. So people who have worried about reversal probably have not (in so doing) worried about either reversal_r or reversal_g. My evidence for (a) is simply an informal survey. This type of evidence is not easily obtainable for (b), since most people who have worried about why mirrors . . . have not distinguished among the different interpretations of the question. The arguments I have already given that mirrors actually neither reverse_r nor reverse_g right/left can easily be adapted to show that mirrors neither reverse_r nor reverse_g frontward/backward. But the present point is not about what mirrors actually do, but rather about what they *appear* to do. In the rest of this section, I shall back up (b) by arguing that mirrors do not appear to reverse_r or reverse_g frontward/backward even in the way they *do* appear (misleadingly) to reverse_r and reverse_g right/left.

Reversal_g. The reason mirrors appear to reverse_g right/left but not up/down is that it is natural to attempt to superimpose an object on its reflection by turning the object (perhaps only in one's imagination) about its y axis. As Mayo points out, in order for it to *seem* that mirrors reverse_g frontward/backward, it would have to

be natural to accomplish such a superimposition without such a rotation (and without a combination of rotations to the same effect). In Pears' terms, it would have to be natural to get into one's portrait by backing into it. But what *would have* to be natural is not natural—so mirrors do not appear to reverse$_g$ frontward/backward.

Reversal$_r$. It is not entirely clear what would even count as frontward/backward reversal$_r$ (real or apparent). Imagine (if you can) that, when one wanted to read a placard in the mirror, one pointed the *back* of it toward the mirror—so that what one saw was the blank back. Perhaps in this situation we would have apparent frontward/backward reversal. More intelligibly: imagine that printed objects were transparent rectangular solids that made use of all three dimensions. The convention for direction of reading a simple four-row solid might be: top front row (left to right) then top back row, then bottom front row, then bottom back row. Now if one were to read such a printed solid in the mirror by pointing the back of it toward the mirror, the frontward/backward reading direction would be the reverse of the normal reading direction. For instance, for the four-row solid mentioned above, one would have to read the top back row first, and then the top front row. So, if printed matter in our world were of this sort and if it were natural to look at such a printed object in the mirror in the way described, then we would have apparent (though not actual) frontward/backward reversal$_r$. Of course, the actual world is not such a world. So mirrors do not appear to reverse$_r$ frontward/backward.

I conclude that those who have worried about why mirrors... have probably not often (in so doing) worried about interpretation R or G.

III

Another interpretation of "Why do mirrors... ?" is: Why is it that, when I am facing my image in a mirror, up for my image is the same direction as up for me while right for my image is the same direction as left for me? I shall call this "interpretation D" (for "direction"). What is the puzzle that motivates this question?

Suppose that I am standing facing a mirror. Now imagine a plane passed vertically through my body ear to ear parallel to the plane of the mirror, i.e., a plane that separates me into a front and a back half. Call the horizontal axis in this plane the x axis and the vertical axis the y axis. Call the perpendicular to the mirror which intersects the x and y axis (say somewhere in the center of my torso) the z axis. I shall say that right specifies an end of

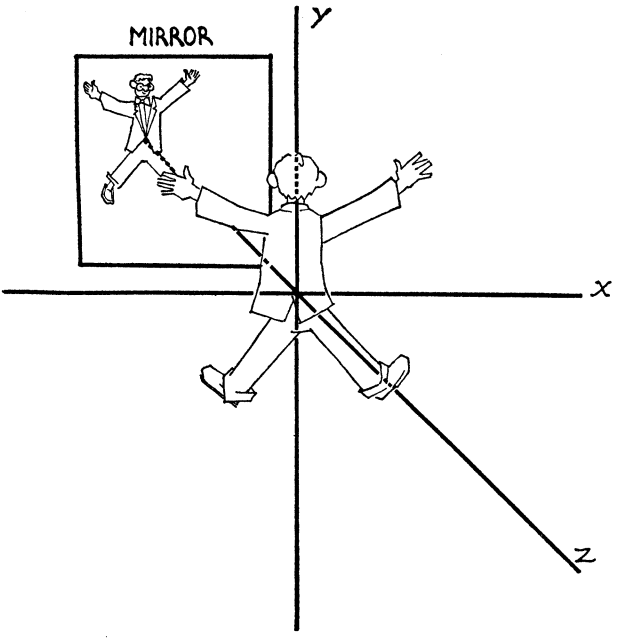

FIGURE 3.

the x axis, up specifies an end of the y axis, and frontward specifies an end of the z axis.

Now the puzzle is that, although the mirror should treat the x axis and the y axis in the same way, it apparently treats them differently; it reverses right/left, a way of specifying ends of the x axis, but it does not reverse up/down, a way of specifying ends of the y axis. Of course the mirror also reverses frontward/backward (since frontward for me is the direction that is backward for my image). But this is not puzzling, since the z axis is perpendicular to the mirror, while the x and y axes are parallel to it. The puzzling thing is that the mirror apparently treats the x and y axes differently, even though they are both *parallel* to the surface of the mirror. Notice that there is no rotation here—as there was in the two puzzles discussed above. So we seem to have a different sort of puzzle.

What could account for this difference between the x and y axes? Perhaps an anisotropy due to the earth's magnetic or gravitational field, or some anisotropy in the mirror? It is easy to satisfy oneself that no such account will do, by noting that one could rotate the mirror or rotate the mirror-person system in any way one

chooses without changing the fact that the mirror reverses right/left but not up/down—so long as the person continues to face the mirror and so long as nothing comes between the mirror and the person. The principles of simple geometrical optics which determine that the mirror produces the image it produces depend only on the geometrical relation between the surface of the mirror and the reflected object. (I assume sufficient illumination.) But the laws of geometrical optics do not treat the x axis any differently from the y axis—so we cannot appeal to them to solve the puzzle.

In looking for an *explanation* of the phenomenon, we are in a way looking for the wrong thing. Geometrical optics tells us why the image is what it is; but geometrical optics will not answer our question. Given a geometrical-optics account of why the image is what it is, one can reasonably reply: "Now I understand how this image is produced, but tell me: why is this image reversed right/left but not up/down?" What we need is an analysis of the key terms in the question: 'up' and 'right'. The reason the mirror appears to treat the x axis differently from the y axis is that we have taken right/left as a specification of the ends of the x axis while taking up/down as a specification of the ends of the y axis. The explanation for why the mirror treats up and right differently is to be found by examining up and right, not the mirror. Up and right are quite different sorts of direction. To see this, note that 'up', on at least one standard usage, is relative [7] to the earth. For example, a definition of 'up' useful on our planet might be: away from the center of the earth. (I shall use 'up' in this sense.)

Right, on the other hand, is not relative to the earth nor to the direction of gravity, but it is relative to the object whose right is in question. Thus, up is the same for my mirror image and for me, since we are in roughly the same spot on the surface of the earth, but right is different for my image than for me because right depends on the orientation of the object whose right is in question, and my image and I have different orientations: we face each other.

One way of seeing this point: Suppose I drill a hole to the center of the earth and place a mirror there facing the mouth of the hole. I then lie down over the hole facing the mirror. The image I see is

[7] In saying that a direction, x, is relative to y, I mean that y (or the direction specified by y and some other contextually determined object) is one of the factors that determine what direction x is. Up is also relative to a contextually indicated location, usually the location of the speaker. So a more complete definition of 'up' in the sense indicated might be: the direction of the arrow whose head is placed at the location of the speaker and whose tail points toward the center of the earth. Of course this definition would not be useful in space.

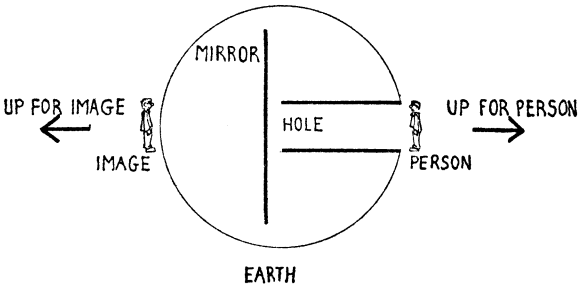

FIGURE 4.

located at a point on the other side of the earth, since mirror images are located a distance behind the mirror equal to the distance from the mirror to the reflected object. So the direction that is up for my image is the direction that is down for me.[8] So with the mirror in this rather unusual position, it *reverses up/down.* And, since it still reverses right/left, it now reverses *both* up/down and right/left.

Consider the direction *clockward,* the direction of the nearest clock. If there is only one clock in the vicinity (and if it is sufficiently far away), clockward will be about the same direction for both my image and me. So then the mirror won't reverse clockward. But if there is one clock immediately behind my image (behind the mirror) and another clock immediately behind me, the mirror will reverse clockward. For the direction from him to the clock nearest him will be the opposite of the direction from me to the clock nearest me. The general point: whether a direction is reversed by a mirror depends on what sort of direction it is, and (usually) on the physical circumstances as well.

Another approach to the point: imagine defining an end of the x axis (call it "right*") which is analogous to up as a specification of an end of the y axis. Define "right*" as *North.* Assuming my image and I are close together and that we are not very near either of the poles, right* for me is (approximately) the same direction as right* for my image, just as up for me is the same direction as up for my image. So the mirror reverses *neither* right*/left* nor up/down. The point is that, if the ends of the x axis and the y axis are specified in sufficiently analogous ways, there is no asymmetry in the way the mirror treats the two axes.

Perhaps the preceding is not quite sufficient to dissolve the puzzle. Perhaps what is needed is: (1) a discussion of just what kind of

[8] Note that I am using 'up' in the sense in which up is the same direction for everyone at a location regardless of his orientation.

direction right is; (2) based on this discussion, a specification of the ends of the y axis, up* and down*, where up* and down* are directions of the same sort as right and left; (3) a proof that the mirror reverses up*/down*, and thus reverses both up*/down* and right/left. This would provide another illustration of my claim that, when the ends of the x and y axes are specified in sufficiently analogous ways, there will be no asymmetry in the way the mirror treats the two axes. This discussion will be postponed, however, because a slightly different form of our original question can be introduced which avoids the dissolution sketched in the preceding two paragraphs.

Call 'headward' the direction specified by the vector that coincides with the vertical axis of a man's body, aimed from his feet toward his head. Why, then, do mirrors reverse right/left and not headward/footward? (I am counting this as a variant of interpretation D.)[9]

Headward, unlike up, is relative to the orientation of my body. Indeed, both my right and my headward are relative to the orientation of my body. Yet if I am facing my image, whereas right for me is left for my image, headward for him is the same as headward for me. That is, in the sense of 'reversal' discussed here (reversal_d), the mirror reverses right/left but not headward/footward. Yet the dissolution presented earlier won't work here, because *both* headward and right are relative to the orientation of my body (and neither is relative to the earth or to gravity). Nonetheless, we can easily dissolve this puzzle as before by noting that right and headward are different sorts of direction, even though both are relative to the orientation of my body.[10] Unlike a definition of 'right', a definition of 'headward' would refer to anatomical features of bodies. An analogous specification of an end of the x axis would be: left** =

[9] An inessentially different puzzle can be formulated by replacing 'headward' by 'topward'—where the top of my body is understood to be that part of my body which is usually or normally up. For people who walk erect, head and top coincide. The reference of 'head' is anatomically determined, whereas the reference of 'top' depends on a regularity in behavior. The discussion of the two puzzles would be analogous. If we had started with a man standing on the mirror instead of facing it we would be discussing the pair—chest, front—instead of the pair—head, top.

[10] 'Right' is actually ambiguous. In one sense it is an adjective applying to a side of my body and some of the organs on that side. In the other sense it is a noun referring to the direction from my vertical axis to my right (in the first sense) side. One might express the latter sense as "rightward." Rightward is the sense intended here.

the direction in the xy plane from the y axis toward the heart.[11] Now right** is the same direction for me as for my image; likewise for headward. So the mirror reverses *neither* right**/left** nor headward/footward. Again we see that, when we have x-axis directions and y-axis directions which are sufficiently similar, there is no x-y asymmetry.

Right** was the same sort of direction as headward; now let us try to frame a y-axis direction that is similar to right, call it "headward*." If we succeed, the mirror will reverse *both* right/left *and* headward*/footward*, thereby again illustrating my claim that, when x- and y-axis directions are specified in similar ways, there is no x-y asymmetry.

First, we must try to frame a definition of 'right'. Let us first investigate whether we can base a definition on our way of telling which side is the right side of an object. Such a tack often produces at least prima facie plausible definitions of "observational" notions. How does one tell the right side of an object? Here is how it seems to me that I do it. I assign to the object in question a bottom and a front. Then I orient the thing or myself in my imagination so that its front points in the direction my front points in, and so that its bottom points in the direction of my feet. Then the side of the object on my right is the right side. But how do I know which of *my* sides is my right side? In my case, I just know. Many people are like me in feeling that they tell their right from left *automatically*. For many others, this process does not seem at all automatic. Many people utilize some anatomical or behavioral asymmetry between their right and left sides. For example, a person may pick out his right hand as the hand that naturally grasps a pen, or the hand with the ring or birthmark. However they do it, most people seem to tell their own right sides in a way quite different from the way they tell the right sides of objects other than themselves. Thus there seem to be *two* ordinary classes of ways of telling which side is the right side of an object. One probably learns one's own right side by an ostension, e.g., by being told which side is one's right, and then one tells one's right from one's left by some method that depends on such a past ostension. On the other

[11] If you do not approve of talk of my image's heart, imagine this discussion taking place while I am undergoing open-heart surgery. Actually, nothing in this paper depends on assuming that images have characteristics usually ascribed only to physical objects. All the puzzles can be described in terms of objects reflected in the mathematical sense rather than mirror images. (x is a reflection of y with respect to a plane P iff for every point of x there is a point of y equidistant from P but on the other side, and vice versa.)

hand, one tells the right side of objects other than oneself by a process that depends on already knowing which side is one's own right side.

If these judgments about ordinary ways of telling right from left (based on informal surveys) are correct, then no satisfactory definition can be based on these ordinary ways of telling. For there are two classes of ways. Ways of telling right from left for objects other than myself won't do, since they presuppose a way of telling my right. And ways of telling my right won't do, since these ways depend on my special features.

But my way of telling the right from the left of objects other than myself suggests a definition based on a random choice of an asymmetrical object (one with no plane of symmetry), e.g., the island of Manhattan. The following definition will serve to specify the right side of an arbitrary object, *O*, so long as *O* is sufficiently small [12] and has a bottom (or a top) and a front (or a back). Here is the definition: The right side of *O* = the side facing the East River Drive when *O* is on 42nd Street with its bottom facing Manhattan's bedrock and its front facing Harlem.[13].

My purpose in defining 'right' was to allow me to define a *y*-axis direction, headward*, which is sufficiently similar to right to allow a demonstration that a mirror will reverse *both* right/left and headward*/footward*. Since we have already seen that, given the sufficiently similar notions right** and headward, mirrors reverse *neither,* we will have a convincing argument that the fact that mirrors reverse right/left but not headward/footward is due to a difference between the two types of direction.

I shall define 'headward*' as follows: my headward* is the side facing the sky when I am on 42nd Street with my front facing Harlem and my heart facing the West Side Highway. Now it is easy

[12] It is a simple matter to generalize the definition to apply to an object of arbitrary size. Simply superimpose a set of axes on Manhattan. Let 42nd Street be the *x* axis; Fifth Avenue, the *y* axis; and the perpendicular to the surface at 42nd Street and Fifth Avenue the *z* axis. Also superimpose a set of axes on *O*, with one end of the *z* axis at the bottom, and one end of the *y* axis at the front. The definition: the right side of *O* = that side of *O* which contains the end of the *x* axis that points in the same direction as the East River Drive end of Manhattan's *x* axis when the *z* and *y* axes of the two objects are aligned as follows: bottom end of *O*'s *z* axis pointing in the same direction as the bedrock end of Manhattan's *z* axis; front end of *O*'s *y* axis pointing in the same direction as the Harlem end of Manhatttan's *y* axis.

[13] Obviously such a definition cannot pretend to capture the "meaning" of 'right' in any sense of 'meaning' that connects meaning with what people have in mind when they use the word. This definition is better viewed as a "rational reconstruction" of the notion.

to see that the mirror will reverse headward*/footward*. For, since my mirror image has his heart on his right, in order for him to have his front toward Harlem while his heart is toward the West Side Highway, he would have to be upside down; thus headward and headward* coincide for me but not for him; so headward* for him is the direction that is footward* for me. Thus we have framed a y-axis direction sufficiently similar to right/left for the mirror to reverse both.

IV

A quite different interpretation of "Why do mirrors . . . ?" is: Why is it that when I wiggle my right arm my mirror image wiggles his left arm even though when I wiggle my head my image wiggles his head and not his feet? Let us call this "interpretation W" ('W' for "wiggles"). Interpretation W might seem to be simply another variant of the sort of interpretation (interpretation D) discussed in the previous section. But this is not so. Notice that, when I face the mirror, the mirror reverses_d frontward/backward. That is, the direction that is frontward for me is backward for my image. But mirrors do *not* reverse_w frontward/backward. For when I wiggle my front, my image also wiggles his front. Since mirrors reverse_d frontward/backward but don't reverse_w frontward/backward, it follows that $\text{reversal}_d \neq \text{reversal}_w$. Another proof of this point: If I turn 90° so that my left shoulder faces the mirror, the direction that is my right is the same direction that is my image's right; so, in this case, the mirror does *not* reverse_d right/left. But if in this circumstance I wiggle my left arm, the mirror image wiggles his *right* arm; so the mirror does reverse_w right/left. Once again, it follows that $\text{reversal}_d \neq \text{reversal}_w$.

Nonetheless it may seem that the resolution of the puzzle given in the last section also applies here. After all, my right arm is just the arm in the direction that is rightward for me. And my image's left arm is just the arm in the direction that is leftward for my image. Since (assuming I am facing the mirror) the direction that is right for me *is* the direction that is left for my image (reversal_d), my image's left arm is opposite my right arm; so of course his left arm wiggles when my right arm wiggles. Thus, whatever explains reversal_d explains reversal_w as well.

To see that this reasoning is oversimple, note the following fact. A suitably curved mirror (see Figure 5) has the property that, when I move my right arm, my image in that mirror moves his right arm. Yet the direction that is my right is nonetheless his left. Thus we have another proof that $\text{reversal}_d \neq \text{reversal}_w$: right/left reversal_d

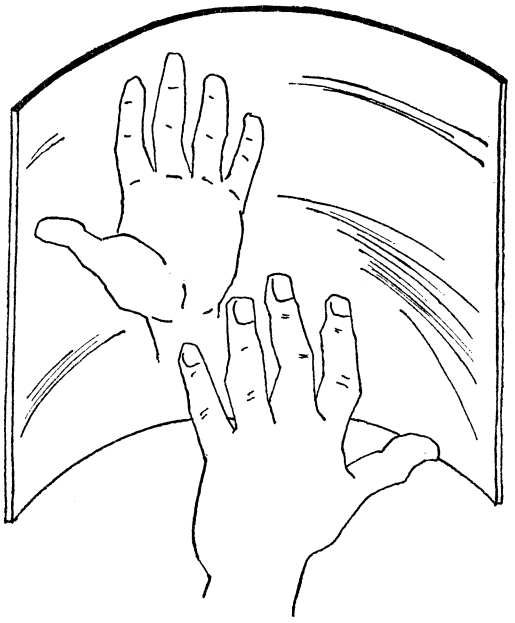

FIGURE 5. After the figure on page 14 of Martin Gardner's *The Ambidextrous Universe* (New York: Mentor, 1969).

occurs with both flat and curved mirrors, but right/left reversal$_w$ requires flat mirrors. All a mirror need do to reverse$_d$ me right/left is produce a right-side-up image facing me. The curved mirror (in the proper orientation) does this as well as the flat mirror. But, in order to reverse$_w$ me right/left, the mirror must do something more: it must produce an image that moves its left arm when I move my right arm.

But the suggestion of the paragraph before last is *roughly* right. What it leaves out is: optics. Geometrical optics dictates that, when I face a (flat) mirror and move part of my body, the part opposite it in the mirror moves; but, since 'right' and 'head' are different sorts of notions, the part opposite my right arm is my image's left arm, even though the part opposite my head is my image's head. So, to answer question W, one needs the same considerations as for question D + optics.

Perhaps another example will clarify the role of optics in answering questions like W. Consider the following question: why is it that, when I point up, my image points up too, but, when I point to my right, my image points to his left? The answer: optics dictates that, when I point in a plane parallel to that of the mirror, my

image points in exactly the same direction—as specified by the angle with respect to a fixed set of axes. But because up and right are the (different) sorts of directions they are, up is the same direction for both me and my image, whereas right for me is left for my image (reversal_d).

V

All the published discussions I have seen of our question (Why do mirrors . . . ?) either are limited to version G or else confusedly discuss one or another version simultaneously without distinguishing among them. For example, in his discussion of the problem in *The Ambidextrous Universe* Martin Gardner says:

> Curiously, the answer depends on the fact that our bodies, like the bodies of most animals, have only one plane of symmetry . . . We describe the reversal as a left-right one because it is the most convenient terminology for distinguishing a bilaterally symmetrical figure from its enantiomorph. In a strict mathematical sense, *the mirror has not reversed left and right at all,* it has reversed front and back [emphasis added] . . . . We can summarize it this way. A mirror, as you face it, *shows absolutely no preference for left and right as against up and down* [emphasis added]. It *does* reverse the structure of a figure point for point along the axis perpendicular to the mirror. Such a reversal automatically changes an asymmetric figure to its enantiomorph. Because we ourselves are bilaterally symmetrical, we find it convenient to call this a left-right reversal. It is just a manner of speaking, a convention in the use of words. (29–31).

Jonathan Bennett in his "The Difference between Right and Left" [14] says

> Failure to grasp the conventions underlying our use of "left" and "right" has generated the mildly famous "mirror problem": why does a mirror reverse left/right but not up/down? Martin Gardner (pp. 29–32) presents the only clear account I know of the solution to this: the answer to "Why does a mirror . . . etc.?" is *It doesn't!* Your image in a normal mirror is a visual representation of an incongruous counterpart of your body, and we conventionally describe this sort of relationship as a "left/right reversal." But this convention does not pick out one dimension as privileged over the other two: it is merely a natural and convenient way of expressing the fact of enantiomorphism in a case where each member of the enantiomorphic pair has—like a normal human body—a superficial over-all bilateral symmetry. (Of course an object which was precisely and totally bilaterally symmetrical could not have an enantiomorph.) If we are to

[14] *American Philosophical Quarterly,* VII, 3 (July 1970): 175–191.

> describe what an ordinary mirror does, in a way which really does select one axis of the body in preference to the other two, then we must say this: if you face the mirror, it reverses you back/front; if you stand side-on to it, it reverses you left/right; if you stand on it, it reverses you up/down. These facts, once they are properly described, do not offer a problem. They are explained by routine optics. For some deeper aspects of this matter, see the paper by Pears (181).

What version of "Why do mirrors . . . ?" could Gardner and Bennett have in mind? They insist that mirrors reverse frontward/backward (when you face the mirror). But as I pointed out (end of sec. II, and beginning of sec. IV) it is not the case that mirrors either reverse_r or reverse_g or reverse_w frontward/backward. Nor do mirrors even *appear* to reverse frontward/backward in senses R, G, or W. So it would seem that Gardner and Bennett cannot be using 'reversal' in sense R, G, or W. That leaves D. But Gardner and Bennett also insist that mirrors reverse right/left when you stand shoulder to the mirror and up/down when you stand on the mirror. See the fourth sentence from the end in the quotation (above) from Bennett. Gardner is adamant about this point. He says:

> . . . the mirror . . . has reversed front and back . . . execute a right face and stand facing east, your left side touching the mirror. As before, the mirror reverses only along the axis perpendicular to it. Because of the way you are standing, this is now in truth your left-right axis. *Now* you can say, in a strict geometrical sense, that the mirror has reversed your left and right sides, leaving unaltered your up-down and front-back axes. Imagine a mirror on the ceiling or on the floor. Again, as always, the mirror reverses only the axis at right angles to its surface (30/31).

However, mirrors do not reverse_d *you right/left when you stand shoulder to the mirror.* Right for you is the *same* direction in this case as right for your image. In sum, Gardner and Bennett insist:

1. Mirrors reverse frontward/backward when you face them.
2. Mirrors reverse right/left when you stand shoulder to them.
3. Mirrors reverse up/down (they mean something like headward/footward) when you stand on them.

Sense D makes 1 and 3 true; sense W makes 2 true, but I cannot think of *any* reasonable sense of 'reversal' which makes all three claims come out true *and* which yields a reasonable interpretation of "Why do mirrors . . . ?" I do not claim to have thought of *every* possible sense of reversal (nor have I mentioned every sense I have thought of), but if Gardner and Bennett had some odd sense of

'reversal' in mind they surely would have told us about it. Moreover, I suspect that what Gardner and Bennett *do* have in mind is the following: Suppose arrow *A* is *parallel* to the surface of the mirror, and arrow *B* is *perpendicular* to the surface of the mirror. Arrow *B* will be reversed in the sense that its image will point in the opposite direction from it (relative to a fixed set of axes). The image of arrow *A*, on the other hand, will point in the same direction as arrow *A*. *In this sense, the mirror could be said to reverse neither the x nor the y axis, but only the z axis.* (See Figure 3.) But, if this is the solution, what is the problem? Nothing said in the last five sentences yields a sense of 'reverse' on which our question "Why do mirrors reverse right/left but not up/down?" is of any interest at all. No one in possession of his senses would ask: why does the image of a right-pointing arrow (parallel to the surface of the mirror) point left, whereas the image of an up-pointing arrow points up too? For it is manifestly false that the image of a right-pointing arrow points left.[15]

Moreover, even if Bennett and Gardner had had a reasonable sense of 'reversal' in mind, their 'resolution' of the original question would be very odd. They say mirrors do not reverse right/left when one faces the mirror because "right/left reversal" is a "conventional description." But then they go on to say that, if I stand with my shoulder to the mirror, *real* (presumably non-conventional) right/left reversal occurs. But why should it be that the description "right/left reversal" is conventional (and false) as applied to a person facing the mirror, but nonconventional (and true) when he turns 90 degrees?

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[15] There are other senses of 'reverse' on which the mirror could be said to reverse only the z axis—but these senses of 'reverse' also fail to give rise to any version of our puzzle. For example, I pointed out in discussion of the Getting-into-the-portrait version that, if I am facing the mirror and I superimpose myself on my image without rotation, I fail to "fit" only frontward/backward. If my shoulder is facing the mirror, I fail to "fit" only right/left, and so on. Thus we have a sense of 'reverse' (the mirror reverses me x/y = When I superimpose myself on the image without rotation, the image fails to fit x/y) on which the mirror could be said to reverse only the z axis. But notice that, on *this* sense of 'reverse', no one could reasonably wonder why mirrors reverse right/left but not up/down in the first place.

INTERPRETATIONS OF "WHY DO MIRRORS REVERSE RIGHT/LEFT BUT NOT UP/DOWN?" DISCUSSED IN THIS PAPER

(R) *Reading Interpretation*
Why is it that while both the placard and its mirror image read up to down, the placard reads left to right while the mirror image of the placard reads right to left?
(G) *Getting-into-the-portrait Interpretation*
Why is it that when I get into my portrait it fits vis-à-vis top/bottom but fails to fit vis-à-vis right/left?
(D) *Direction Interpretation*
Why is it that when I face my image in a mirror the direction that is up (headward) for my image is the same direction as up (headward) for me, while the direction that is right for my image is the direction that is left for me?
(W) *Wiggling Interpretation*
Why is it that when I wiggle my right arm my mirror wiggles his left arm even though when I wiggle my head my image wiggles his head too?
CORRESPONDING SENSES OF 'REVERSE'
The mirror reverses_r the object x/y = The object reads y to x while the mirror image of the object reads x to y.
The mirror reverses_g me x/y = When I get into my portrait it fails to fit vis-à-vis x/y.
The mirror reverses_d x/y = The direction that is x for my image is the direction that is y for me and vice versa.
The mirror reverses_w me x/y = When I wiggle my x part my image wiggles his y part and vice versa.
For purposes of intelligibility, these interpretations and corresponding senses of 'reverse' have been simplified; in no case is question X really equivalent to "Why do mirrors reverse_x right/left but not up/down?"

INCONGRUOUS COUNTERPARTS, INTRINSIC FEATURES AND THE SUBSTANTIVIALITY OF SPACE

KANT argued, as part of his argument that space is an a priori intuition, from the existence of incongruous counterparts (such as right- and left-handed gloves otherwise alike) to the existence of space as an entity over and above the material objects in it and their spatial relations to one another. Peter Remnant and John Earman have argued that Kant's argument is incoherent.[1]

[1] Remnant, "Incongruent Counterparts and Absolute Space," *Mind*, n.s., LXXII, 287 (July 1973): 393–399. Earman, "Kant, Incongruous Counterparts, and the Nature of Space and Space-Time," *Ratio*, XIII, 1 (June 1971): 1–18; parenthetical page references to Earman are to this paper.