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Introduction

Every so often experimental psychologists attempt to approach experimentally and operationalize constructs that have already been the subject of philosophical inquiries. For example, they have delved into the origins and nature of human intuitions about natural numbers (Carey, 2009), the geometrical properties of points, lines, and figures (or Euclinean intuitions, e.g., Spelke, Lee, & Izard, 2010), causality (e.g., Hubbard, 2013c, 2013d, 2013e; Michotte, 1963), force and resistance (e.g., Hubbard & Ruppel, 2017b; White, 2011, 2012), similarity (Medin, Goldston, & Gentner, 1990; Tversky, 1977), and opposition (e.g., Kelso & Engstrøm, 2006). All of these attempts have provided evidence that logical-physical-mathematical descriptions of a "stimulus" are independent from the "corresponding" psychological correlates that characterize human experience.

Just as experimental studies of similarity have approached the subject from different perspectives – i.e., from the perspective of a perceptual relationship (e.g., Goldmeier, 1936/1972), a lexical relationship (e.g., Miller & Fellbaum, 1991; Murphy, 2003), a structural relationship (e.g., Gentner & Markman, 1994; Markman & Gentner, 1993), and a category formation process (e.g., Goldston, 1994; Sloutsky, 2003) – the experimental investigation of contrariety, opposition, and contrast has also been approached from various points of view and within different domains, i.e., cognitive linguistics (e.g., Croft & Cruse, 2004; Mettinger, 1994; Paradis & Willners, 2011), the psychology of perception (e.g., Bianchi & Savardi, 2008a), inductive reasoning (e.g., Gale & Ball, 2012), insight problem solving (e.g., Branchini, Bianchi, Burro, Capitani, & Savardi, 2016; Branchini, Burro, Bianchi, & Savardi, 2015), counterfactual thinking (e.g., Byrne, 2005; Roese, 1997), and relational reasoning (e.g., Dumas & Alexander, 2016; Goodwin & Johnson-Laird, 2006). The oppositional basis of the human direct experience of space has been demonstrated in a series of studies (Bianchi, Savardi, & Kubovy, 2011), which have shown, firstly, that the structure of space that people experience is based on a number of oppositional dimensions, each of which is anchored to two contrary properties; and secondly, that these oppositional dimensions have a precise structure that is defined by the nature of their components that are either gradable or defined by specific points (i.e., the two opposite pole properties and the intermediate region). For instance, *closed, still, full, parallel*, and *neither above nor below* are all point (single) properties, while *open, divergent, large*, and *neither full nor empty* are all gradable properties.

There are a number of interesting questions that arise when we start to analyze the human experience of space in terms of these (perceptually grounded) oppositional dimensions. For example, are observers consistent in defining the boundaries of one property and its corresponding opposite – that is, when does a person's experience of *near* end and their experience of *far* begin? Is the boundary between two opposite properties sharply defined? Are the experiences that are perceived as neither one pole nor the other really equidistant from the two poles or are they perceived as more similar to one pole? These are all empirical questions, and some empirical answers have already been provided (Bianchi, Burro, Torquati, & Savardi, 2013; Bianchi et al., 2017; Bianchi & Savardi, 2008a; Bianchi, Savardi, & Burro, 2011; Bianchi, Savardi, & Kubovy, 2011; Savardi & Bianchi, 2009).

Given this premise, we will now zoom in on the role of opposites in the perception and cognition of space by looking at mirror reflections (starting from how people directly perceive them to how they think about them) and showing how the oppositional nature of space is the bedrock on which the relationship between an object or body and its reflection rests.

Bedrock Architecture

Before looking specifically at mirrors, let's put the general claim we are making in this chapter concerning modeling space perception in terms of oppositional dimensions within a theoretical context that has been proven to be capable of accounting for the complexity of ecological experience of space. A reading of Gibson's (1979) ecological optics from this perspective provides evidence in support of the claim that opposites constitute the bedrock architecture of human spatial experiences.

To start with, a salient experiential contrast is that perceived between a region of space that observers recognize as pertaining to the observer *himself* or *herself* and an *outside world* or *surrounding environment* (Koffka, 1935, p. 322; Gibson, 1979, p. 317; see Figure 14.1, top left image).

Another basic opposition that is evident in the organization of the visual field relates to *viewpoint* and *vanishing point*. Everything that falls within an observer's visual field is necessarily seen from one viewpoint (i.e., that of the observer). But it is also true that every single viewpoint necessarily corresponds to its own individual vanishing point.[1] This basic opposition is manifested not only in terms of the location in space of these two points (they are the two opposite *endpoints* in the line of sight) but also in terms of the *divergence* vs. *convergence* of the perspective lines that are clearly evident in the organization of the visual field. These are the lines to the left and right of the observer that converge toward the vanishing point and diverge with respect to the viewpoint; the same goes for the perspective lines above and below the observer.

The perception of distance phenomenally consists of another fundamental oppositional structure: *near–far*. Even in a minimal condition of stimulation – that is, in front of an isoluminant surface (*Ganzfeld*) – the perceptual experience of space already contains this opposition (Avant, 1965; Bianchi & Savardi, 2008a, pp. 49–54; Cohen, 1957; Metzger, 1930). The three spatial regions identified by Cutting and Vishton (1995) by means of an

[1] The geometry that relates the viewpoint to the vanishing point has been extensively studied, starting with Euclid's *Optics* (325–265 BC) and continuing on through pictorial studies on perspective (e.g., Alberti, 1404–1472; Brunelleschi, 1377–1446; Piero della Francesca, 1415–1492) right up to the analyses of perceptual fundaments developed in the field of cognitive science (Cutting, 1986; Deregowski & Parker, 1988; Epstein & Rogers, 1995; Hagen, 1980; Kemp, 1992; Kubovy, 1986; Pirenne, 1970). However, nobody has ever emphasized the oppositional elements characterizing it, which is instead the aspect emphasized in our analysis.

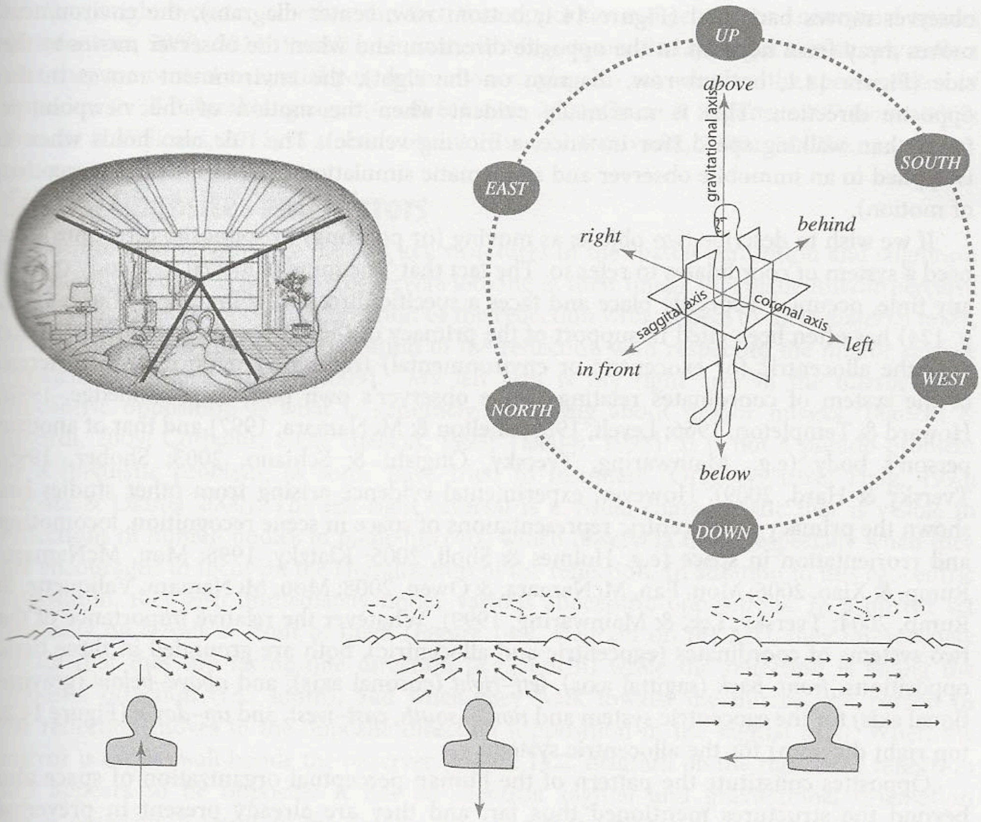

Figure 14.1 Basic spatial oppositions. Top left: Visual field of an observer looking from his/her left eye (adapted from Gibson, 1979). Top right: The egocentric oppositions relating to *front–back, above–below, left–right* based on the persons' body coordinates (adapted from Richards, 1975) in relation to the basic environmental (or allocentric) oppositions. Bottom figures: The opposite direction of the optical flow with respect to three directions of motion of the observer. (adapted from Gibson, 1979)

integrated psychophysical analysis of the relative potency of the various visual cues for distance (personal space, action space, and vista space) pertain to three consecutive regions delineated along the *near–far* dimension.

If we consider all of the visual cues that relate to the *near–far* dimension (i.e., relative size, the height on the visual field, occlusion, etc.) from the point of view of the visual features that make them evident, we realize that they are all manifested by oppositional properties: objects (the projected size of which depends on their distance from the observer) appear *bigger* nearer to the observer and *smaller* farther away, and stimuli that are below the horizon appear to be *low* in the visual field when they are near and *high* when they are far away. Likewise, occlusion depends on whether an object is *in front of* or *behind* another object.

The dynamics pertaining to optical flow are also oppositional. The optical flow always moves in the opposite direction with respect to that of the observer, whatever his/her direction of motion: when an observer moves forward, the environment moves toward him/her in the opposite direction (Figure 14.1, bottom row, diagram on the left); when the observer moves backward (Figure 14.1, bottom row, center diagram), the environment moves away from her/him in the opposite direction; and when the observer moves to the side (Figure 14.1, bottom row, diagram on the right), the environment moves in the opposite direction. This is maximally evident when the motion of the viewpoint is faster than walking speed (for instance, a moving vehicle). The rule also holds when it is applied to an immobile observer and a cinematic simulation (i.e., an induced perception of motion).

If we wish to describe two objects as moving (or pointing) in "opposite directions," we need a system of coordinates to refer to. The fact that "the mind is locked in a body that, at any time, occupies a specific place and faces a specific direction" (Tversky & Hard, 2009, p. 124) has often been cited in support of the primacy of the egocentric frame of reference over the allocentric (or exocentric or environmental) frame of reference, both in terms of the system of coordinates relating to the observer's own body (e.g., Golledge, 1992; Howard & Templeton, 1966; Levelt, 1989; Shelton & McNamara, 1997) and that of another person's body (e.g., Mainwaring, Tversky, Ohgishi & Schiano, 2003; Shober, 1995; Tversky & Hard, 2009). However, experimental evidence arising from other studies has shown the primacy of allocentric representations of space in scene recognition, locomotion and reorientation in space (e.g. Holmes & Sholl, 2005; Klatzky, 1998; Mou, McNamara, Rump, & Xiao, 2006; Mou, Fan, McNamara, & Owen, 2008; Mou, McNamara, Valiquette, & Rump, 2004; Tversky, Lee, & Mainwaring, 1999). Whatever the relative importance of the two systems of coordinates (egocentric and allocentric), both are grounded in three basic oppositions: *front–back* (sagittal axis), *left–right* (coronal axis), and *above–below* (gravitational axis) for the egocentric system and *north–south*, *east–west*, and *up–down* (Figure 14.1, top right diagram) for the allocentric system.

Opposites constitute the pattern of the human perceptual organization of space also beyond the structures mentioned thus far, and they are already present in preverbal stages of human development (Casasola, 2008; Casasola, Cohen, & Chiarello, 2003; Hespos & Spelke, 2004; McDonough, Choi, & Mandler, 2003; Quinn, Cummins, Kase, Martin, & Weisman, 1996). From a phenomenological perspective, all characteristics of space involving extension, shape, orientation, or location lay on oppositional dimensions, and the psychophysical structure of these dimensions is consistent among individuals (Bianchi et al., 2013; Bianchi et al., 2017; Bianchi & Savardi, 2008a; Bianchi, Savardi, & Burro, 2011; Bianchi, Savardi, & Kubovy, 2011; Savardi & Bianchi, 2009). Not only are things perceived as near or far away (or neither near nor far away) but they are also perceived as long or short (or neither long nor short) and high or low (or neither high nor low). They might appear to be regular or irregular, symmetrical or asymmetrical, rounded or angular, straight or bent, or open or closed. A road is uphill or downhill (at various inclinations) or it is flat. An object can be at the top of a mountain or at the bottom of it, or in many intermediate locations that are neither at the top nor at the bottom. It may be in front of us or behind us, or neither in front nor behind if it is to one side. And, if the latter is the case, it can be to our left or to our right. An organized space such as this is the framework not only for our field of vision but also for any movements we make or actions we perform. Within this space gestures are made and people interact with objects and with other humans (and also with mirror reflections). Therefore, it is not surprising that people are immediately intuitive about what doing the opposite means (Bianchi, Savardi, Burro, & Martelli, 2014), in addition to imitating (e.g., Heyes, 2011; Iacoboni et al., 1999; Prinz, 2002).

One might wonder whether the fact that opposites are central to conceptual spaces (Gärdenfors, 2000, 2014; Paradis, Hudson, & Magnusson, 2013) might not simply reflect that they are central to spatial perception. We might also ask whether the special status of opposites in all natural languages (Croft & Cruse, 2004; Cruse & Pagona, 1995; Jones, 2002; Paradis & Willners, 2011) is a result of this (Bianchi & Savardi, 2008a, 2012b).

Spatial Opposites and Mirrors

Opposition and identity are the two key structures in the spatial perception and cognition relating to mirrors. What naive observers looking at their image in a plane mirror perceive (and report) is the opposite orientation of the reflection with respect to their material body, in addition to the opposite localization of the reflection with respect to the mirror surface (Bianchi & Savardi, 2008b, 2009). "My left arm is my right arm in the mirror": this egocentric opposition is what is genuinely intriguing about mirror images (Bianchi & Savardi, 2009; Corballis, 2000; Ittelson, 1993; Takano, 1998). It is not a pseudo-problem or a linguistic problem, as some have tried to insinuate (Gregory, 1996; Haig, 1993; Tabata & Okuda 2000). The left-right reversal is a visual characteristic that is visible in reflections of human bodies in plane mirrors, which observers notice especially when they are encouraged to focus on the lateralization of the reflection. In addition to this egocentric opposition, they also immediately notice various allocentric oppositions. In a mirror set vertically on a wall in front of them (Figure 14.2, diagram on the left), they immediately notice that they are facing one direction (e.g., north) while the reflection is facing the opposite direction (i.e., south), and when they walk toward the mirror, the person in the reflection moves in the opposite direction (opposition in the sagittal axis). When the mirror is on the wall beside the observer (Figure 14.2, diagram on the right), the reflection still appears to be opposite: it has an identical sagittal and gravitational orientation but is opposite in terms of the coronal axis, and if the person moves laterally to his/her left (e.g., westward), the reflection moves in the opposite direction (i.e., to the right and eastward). If the observer then positions him/herself on top of a mirror lying on the floor (Figure 14.2, center diagram), he/she again perceives the reflection as being opposite. This time the opposition is along the gravitational axes, as the reflection is upside-down.

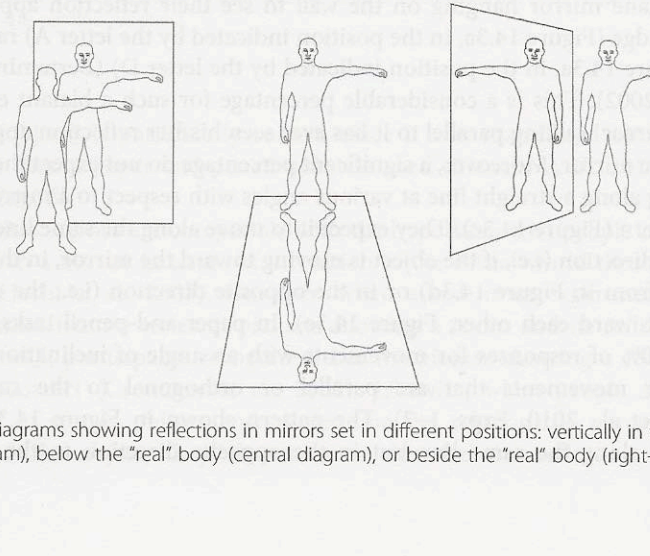

Figure 14.2 Diagrams showing reflections in mirrors set in different positions: vertically in front the "real" body (left-hand diagram), below the "real" body (central diagram), or beside the "real" body (right-hand diagram).

These elements of opposition are prominent in people's perception of the spatial structure of their reflections. What they notice first when they are asked how they perceive the relationship between their body and its reflection is the allocentrically based opposition rather than the egocentric left–right inversion. Bianchi and Savardi (2008b, p. 674) report that "opposite" was the relationship chosen in 87% of the cases when the participants in their experiment were asked to describe the relationship between their orientation and the reflection of themselves in a mirror. When requested to specify which aspect of the scene they were focusing on, they never referred to the egocentric left–right reversal in the gravitational condition (Figure 14.2, center diagram) and only referred to it in a very few instances in the frontal condition (Figure 14.2, diagram on the left). They usually explained their choice in terms of allocentric opposition. The same thing happened when participants in another study were asked to describe the reflections of simple objects and movements in various positions with respect to the mirror surface (Savardi, Bianchi, & Bertamini, 2010, Exps. 4–5).

It is worth noting that many of the errors that people make when asked to predict the behavior of reflections are based on this perception of opposition. Research into "naive optics" (Croucher, Bertamini, & Hecht, 2002), which can be conceived of as a branch of "naive physics" (e.g., McCloskey, 1983a, 1983b; McCloskey, Caramazza, & Green, 1980; McCloskey, Washburn, & Felch, 1983), has clearly demonstrated that when people make predictions about the orientation, speed, or trajectory of moving objects in reflections, they do not necessarily reason in terms of the physical or optical laws they were exposed to at school (e.g. Bertamini & Parks, 2005; Bertamini, Spooner, & Hecht, 2003; Bianchi, Bertamini, & Savardi, 2015; Bianchi & Savardi, 2012a; Croucher et al., 2002; Hecht, Bertamini, & Gamer, 2005; Lawson, 2010, 2012; Lawson & Bertamini, 2006; Lawson, Bertamini, & Liu, 2007). Rather, they use their imagination, but their prediction is then strictly dependent on the scenario they have in mind, and therefore imagining different scenarios can lead to different predictions. The systematic errors made by participants in prediction tasks are interesting because they tell cognitive scientists something about the various different processes underlying predictions. This is what has stimulated 30 years of research on naive physics and more than a decade of research on naive optics – research that is still ongoing.

For instance, 20–40% of people expect a person entering a room and making a parallel approach to a plane mirror hanging on the wall to see their reflection appearing at the mirror's farther edge (Figure 14.3a, in the position indicated by the letter A) rather than the nearer edge (Figure 14.3a, in the position indicated by the letter D) (Bertamini et al., 2003; Croucher et al., 2002). This is a considerable percentage for such a blatant error: nobody approaching a mirror walking parallel to it has ever seen his/her reflection appearing at the farther edge of the mirror. Moreover, a significant percentage do not expect the reflection of an object moving along a straight line at various angles with respect to a mirror to follow a symmetrical pattern (Figure 14.3c). They expect it to move along the same line either in the same allocentric direction (i.e., if the object is moving toward the mirror, in the reflection it will move away from it; Figure 14.3d) or in the opposite direction (i.e., the object and its reflection move toward each other; Figure 14.3e). In paper-and-pencil tasks, these errors occur in up to 40% of responses for movements with an angle of inclination and in 20% of responses for movements that are parallel or orthogonal to the surface of the mirror (Savardi et al., 2010, Exps. 1–2). The pattern shown in Figure 14.3e (where the reflection moves along the same line but in the opposite direction to the trajectory of

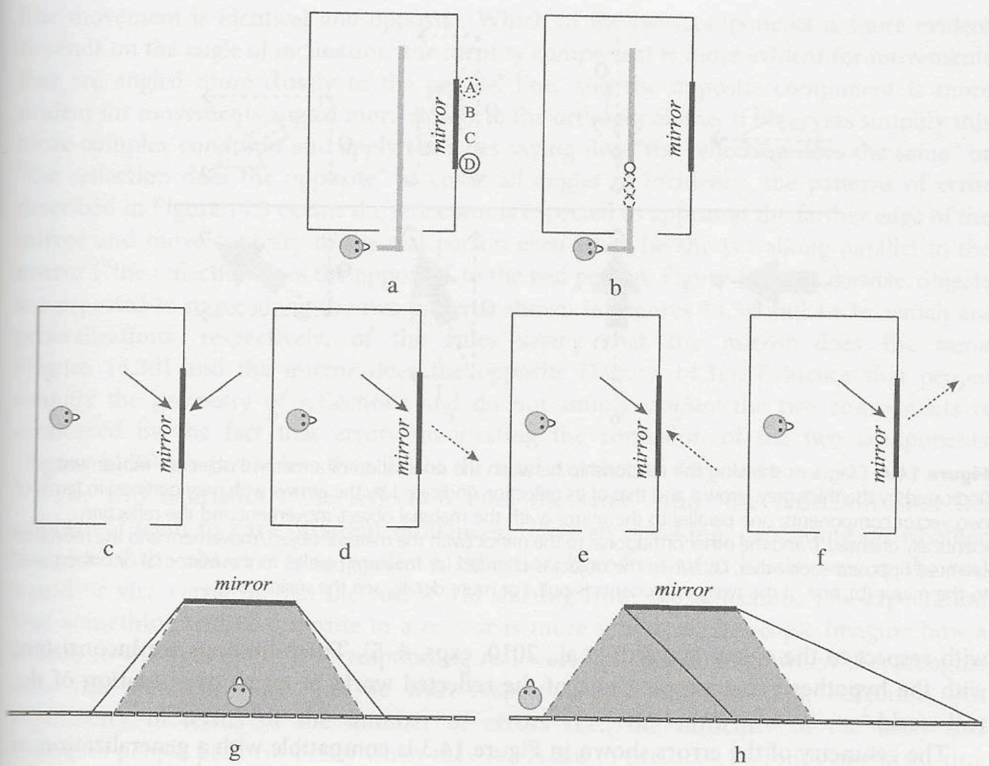

Figure 14.3 Some false beliefs concerning naive optics; all are represented using aerial views.
Top row: Many people expect a person entering a room and walking along the light-gray path to see his/her reflection appear at the farther edge of the mirror in the position indicated by A rather than where it would in reality appear, D (see diagram 3a) or that he/she will see their reflection before reaching the near edge of the mirror (b).
Second row: A good number of people do not expect a person looking at an object moving toward a mirror along the path indicated by the solid arrow (c–f) to see its reflection moving along the correct path (c) but rather to see it moving along the same trajectory with an identical orientation (as indicated in d) or along the same trajectory but with an opposite orientation (e); a smaller percentage of people predict that the movement will follow the path shown in f.
Third row: A person looking in a mirror from a central (g) or eccentric (h) position expects to see more or less the same area reflected (i.e., the gray area delimited by dashed lines) while the correct cone of view is very different (as delimited by the continuous lines).

the material object) is particularly robust, since it was manifested also when a real-life setting rather than a paper-and-pencil task was used (Bianchi et al., 2015, Exp. 2; Savardi et al., 2010, Exp. 3).

Some of these errors are compatible with the hypothesis that people might think of the virtual world in a mirror in terms of a rotation of the actual world through the surface of the mirror (Hecht et al., 2005). However, when asked in an experiment to identify the correct reflection from a series of pictures showing a room and its reflection in a mirror hung on the wall, participants recognized that the picture showing a 180° rotation of the room was incorrect (Croucher et al., 2002). Likewise, when people are asked to look at reflections of simple objects and to describe the relationship perceived between the reflection and the object, they almost never describe the reflection as being rotated

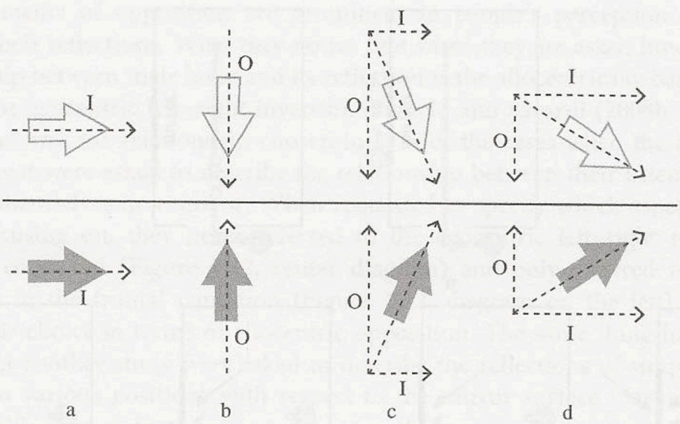

Figure 14.4 Diagrams showing the relationship between the orientation of a material object or movement (indicated by the thick grey arrows) and that of its reflection (indicated by the arrows with grey outlines) in terms of two vector components: one parallel to the mirror (with the material object/movement and the reflection identically oriented, I) and the other orthogonal to the mirror (with the material object/movement and the reflection oriented opposite each other, O). When the object is oriented (or moving) parallel to the mirror (a) or orthogonal to the mirror (b), one of the two components is null. For more details, see the main text.

with respect to the object (Savardi et al., 2010, exps. 4–5). These findings are inconsistent with the hypothesis that people think of the reflected world in terms of a rotation of the real world.[2]

The geometry of the errors shown in Figure 14.3 is compatible with a generalization of the simplified heuristics stating that "the mirror does the same" and "the mirror does the opposite" (Bianchi et al., 2015; Bianchi & Savardi, 2012a; Savardi et al., 2010, Exps. 1–3). But why do we say that these heuristics are *simplified*? Let's suppose that the geometry that naive observers have in their minds regarding reflections in plane mirrors is a lawful combination of two components (see Figure 14.4): one that is parallel to the mirror (relating to the identicalness component, I), and another that is orthogonal to the mirror (relating to the oppositional component, O).

When an object is positioned parallel to a mirror or orthogonal to it, one of the two components is null and the relationship between the real object and its reflection is defined by the other component: i.e., the orientation is identical in the first case (Figure 14.4a – "the reflection does the same") and opposite in the second case (Figure 14.4b – "the reflection does the opposite"). From 75% to 85% of people are able to predict the behavior of the reflections correctly in these two positions (Bianchi et al., 2015; Savardi et al., 2010). But when an object is positioned at an angle (Figures 14.4c, 14.4d), the standard of performance drops and 32% to 51% of responses are incorrect. This is because when an object is positioned at an angle, the two components interact and the result is a combination of the two: the trajectory of the reflection is opposite to that of the material object with respect to the orthogonal component but identical with respect to the parallel component.

[2] The rotational hypothesis has been re-proposed in a less radical version by Muelenz, Hecht, and Gamer (2010), not to explain the errors mentioned above, but to account for the small quantitative localization bias that they found indicating that reconstructions of the virtual world are systematically rotated counterclockwise by an average angle of two degrees.

The movement is identical *and* opposite. Which of the two components is more evident depends on the angle of inclination: the identity component is more evident for movements that are angled more closely to the parallel line, and the opposite component is more evident for movements angled more closely to the orthogonal line. If observers simplify this more complex condition and apply the rules saying that "the reflection does the same" or "the reflection does the opposite" to cover all angles of incidence, the patterns of error described in Figure 14.3 occur: the reflection is expected to appear at the farther edge of the mirror and move contrary to the real person even when he/she is walking parallel to the mirror ("the reflection does the opposite" to the real person, Figure 14.3a). Likewise, objects are expected to move along the two patterns shown in Figures 14.3d and 14.3e, which are generalizations, respectively, of the rules saying that the mirror does the same (Figure 14.3d) and the mirror does the opposite (Figure 14.3e). Evidence that people *simplify* the geometry of reflections and do not simply *confuse* the two components is reinforced by the fact that errors manifesting the confusion of the two components (Figure 14.3f) are rare – less than 7% of the total number of responses.

The two heuristics ("the reflection does the same" and "the reflection does the opposite") seem to have different influences, relatively speaking, depending on whether the task of the observer is to predict a reflection based on what he/she sees in the real world or vice versa, predict the real world starting from the reflection. The expectation that something will be opposite in a mirror is more salient when people imagine how a reflection will relate to the corresponding real world as compared to when they imagine how the material world will be with respect to the corresponding reflection. An asymmetry in terms of the number of errors (i.e., the difficulty of the task) also emerged: people perform better when they are asked to predict a real movement starting from the reflection than vice versa. These two asymmetries (from the point of view of the salience of the two heuristics and the easiness of the task) are related to the geometry underlying the processes involved when people mentally derive the virtual world from the material one and vice versa (Bianchi, Bertamini, & Savardi, 2015). Whether they might also tell us something about a naïve ontology of reflections – and the different roles played by the material and virtual worlds – is not yet possible based on these results. An explanation of this sort has been put forward by Sareen, Ehinger, and Wolfe (2014) to interpret the asymmetry that they found. Observers presented with indoor scenes including mirrors that reflected several objects in the room were asked to label "everything they saw." They labeled reflected objects less frequently than their material counterparts. Moreover, in change detection tasks, the disappearance of a reflected object was less easily detected than the disappearance of its material counterpart. These findings were interpreted by the authors as evidence that people treat the parts of images that represent reflections as somewhat less "real" than the parts that represent material objects/spaces. After all, the reflection is a copy of the visual information that must be available somewhere else in the scene (therefore redundant). And when the material object is not visible (i.e., the reflection is not redundant), the reflection is in any case discounted because mirror information misinforms about the "real" visual aspects of the objects. Whether the idea of reflections as copies (with emphasis on what we call the *identity* element) is more relevant when people move mentally from the virtual world to the material world, while the idea that reflections misinform (with emphasis on what we called the *opposition* element) is more relevant when people move mentally from the real world to the virtual world, would be an intriguing hypothesis to investigate.

Further Simplification Biases

Other errors that have emerged in the literature on naive optics manifest a simplification in the mental models of mirrors that people have in mind. For example, a surprising percentage of observers (62% in Bertamini et al., 2003) make what has been called the "early error" (Figure 14.3b): When asked to predict where a person approaching a mirror from the side and walking parallel to it would start to see herself/himself reflected in the mirror, they predict that they will start seeing the reflection before they actually do, i.e., before reaching the near edge of the mirror (see also Croucher et al., 2002; Hecht et al., 2005; Lawson & Bertamini, 2006).

This error is compatible with another class of findings which came out in various different experimental conditions, from paper and pencil tasks (Bertamini, Lawson, Jones, & Winters, 2010, exp. 5; Bianchi & Savardi, 2012a, exps. 1, 3, 4), to real-life settings (Bianchi & Savardi, 2012a, exp. 2; Lawson, 2012), to photographs (Bertamini et al., 2010, exps. 1–4) and paintings (Bertamini, Latto, & Spooner, 2003). When asked to predict what part of the surrounding space an observer would see reflected in a mirror on a wall, given various viewpoints, two biases emerged. First, when the observer is central to the mirror (i.e., not displaced laterally), adults expect the field of view to be expanded at both of the mirror's lateral edges, but with a smaller angle than it would be in reality (Figure 14.3g). This is an attenuated version of the frontal error found in children who expect the mirror to show what is just in front of it (Bertamini & Wynne, 2009). Secondly, people expect the field of view to be basically invariant whatever the eccentricity of the observer's viewing position: approximately 50% of people in the case of close viewpoints and up to 80% for greater distances expect the observer to see *more or less the same field* for both central and eccentric viewpoints, i.e., the space directly in front of the mirror plus a certain area beyond *both* its edges. The area is represented in Figures 14.3g and 14.3h by the grey areas delimited by dashed lines (the diagrams refer to the study by Bianchi & Savardi, 2012a, but similar results were found in Bertamini et al., 2010, exp. 5). This trapezoidal shape is true for central viewpoints (in Figure 14.3g the straight lines delimitate the correct area of visibility), whereas for eccentric viewpoints the shape of the visual field is different: one sees an expansion at the farther edge while part of the space in front of the mirror at the nearest edge is not visible (Figure 14.3h – "parallelogram" area between the straight lines).

This widespread inability to predict what in effect an observer sees in a mirror (given various positions of the observer and various positions and inclinations of one or more mirrors) is at the heart of what has been called the "Venus effect" (Bertamini et al., 2003; Bertamini et al., 2010). In a number of famous paintings involving a person (usually Venus or a lady) gazing into a mirror, the face in the mirror is located incorrectly, but observers seem to be happy with this artistic license (e.g., Hans von Aachen, *Couple with Mirror*, 1596; Simon Vouet, *Toilet of Venus*, c1628; Titian, *Venus with a Mirror*, 1555; Velázquez, *The Toilet of Venus*, 1647–1651). This underestimation, which characterizes mental models of reflections with regard to the role of the point of view, has also emerged in tasks involving estimates of the size of a reflection and how it would vary as the distance of the observer or the distance of the target object increases or decreases (Bertamini, Lawson, & Liu 2008; Bertamini & Parks, 2005; Lawson & Bertamini, 2006).

It has already been suggested that the fact that people seem to be incapable of taking into account the role of the viewpoint in naive optics can be explained by the fact that, in general, the visual system works to make the outside world constant despite continuous changes in observer position (Bertamini & Parks, 2005; Croucher, Bertamini & Hecht, 2002). It would also reinforce the hypothesis put forward by Bertamini and Parks (2005) and also discussed in Bertamini et al. (2010) that mirrors are treated as devices that capture an image (or a space), and therefore, what fits into a mirror depends mainly on what is contiguous to it rather than on the location of the observer, which is, to a great extent, disregarded.

What is important to note is that (1) a *simplification bias* is invariant to all the errors mentioned in this chapter, and (2) what is generalized beyond the conditions of validity is a *salient perceptual aspect* of direct visual experience. This last statement might sound odd, and one might object that nobody, when walking parallel to a plane mirror, has ever seen their reflection before reaching the nearer edge (Figure 14.3b), or seen it appear at the farther edge of the mirror (Figure 14.3a), or seen it move as represented in Figures 14.3d–14.3f. It is also a fact that nobody has ever seen a mirror reflect only the portion of the room directly in front of it independently of whether the observer is positioned centrally or laterally with respect to the mirror (Figure 14.3g–14.3h). These are, in Lawson and Bertamini's (2006) terms, "conceptual errors" and not "perceptual errors": the latter do not disappear when the experiment is repeated and the participants are asked to look at reflections in a mirror (i.e., visual feedback is provided), since what they *see* is exactly what they had predicted. Conversely "conceptual errors" do in fact disappear when visual feedback is provided, because what people then see does not conform to what they had predicted. In other words, the origin of these errors has nothing to do with what people strictly speaking *see*.

The distinction between these two kinds of errors is of course tenable, if only for the fact that the reactions to visual feedback are different in each case. What we are asserting here (see also Bianchi & Savardi, 2014) is that these conceptual errors are in any case shaped by what people see. They are generalizations of some *salient* aspects of perceptual experience, which are widely applied not only to correct conditions but also to incorrect ones. We have already explained this with reference to errors based on people recalling the rule that "a reflection does the same" and/or the rule that "a reflection does the opposite" as their visual experiences have led them to believe. However, this explanation works equally well for the other errors discussed in this chapter. Consider, for example, the error that people make when they expect to see the area beyond the left and right edges of a mirror reflected whatever the position of the observer (Figures 14.3b, 14.3g, 14.3h). When people look in a mirror either intentionally or by chance in everyday life, the incidence of their line of vision is at different angles. Portions of the real world beyond the edges of the mirror are always visible: when an observer is positioned "inside" the mirror edges, this holds for all four edges; when he/she is displaced laterally, this holds for all the edges except the nearest. In other words, people normally perceive an expansion. If they do not carefully analyze what happens at the nearer as opposed to the farther edge of a mirror, they will easily generalize the experience, concluding that mirrors reflect the part of the world that lies beyond their boundaries.[3] It is also very likely that in everyday life people do not carefully analyze what

[3] This is not related to the boundary extension phenomenon, i.e., the fact that people tend to remember that a view contains information beyond its actual boundaries (for a review, see Hubbard, Hutchison, & Courtney, 2010, and also Intraub & Gagnier, Chapter 13 in this volume). Given various eccentric or central viewpoints with respect to a mirror, the reflected scene always shows a field of view that is wider overall than that which is within the orthogonal projections relative to the

happens at the edges of a mirror, since they usually only pay attention to the small area that interests them, i.e., their face if they are shaving or putting on makeup, and tend to ignore the rest of the reflection. Similarly, they will generalize their experience that mirrors show what is positioned directly in front of them (or nearby), and thus every object or observer in this area (Venus included) is expected to have its reflected counterpart visible in the mirror.

Two Final Notes

In this chapter we have focused on some of the many interesting questions about mirrors, which have been raised by cognitive scientists. We have looked at how people perceive reflections or "reason" about them when predicting their behavior (based on heuristics, intuition, mental models, etc.). We have shown that, in spite of different perspectives and the fact that this has been explicitly or implicitly addressed, there is recurring experimental evidence that people recognize an oppositional relationship between a material object/body and its reflection. Beyond presenting various different errors and biases analytically, there are two considerations that we hope the reader has been stimulated to reflect on. These considerations are related to each other.

1. First is the idea that opposition (as well as identity) is a key feature of direct (naive) human experiences of reflections. This has been revealed in perceptual tasks and confirmed by the types of errors that people make when asked to predict the behavior of reflections. If today the "mirror question" (i.e., why does a mirror invert left/right but not up/down?) was to be reconsidered in an empirical context and framed exclusively in terms of directly experienced variables (i.e., the features and relationships perceived by an observer), we believe it should be discussed within the mind-set of the perceptually evident and cognitively salient relationships of identity and opposition. Contrary to what Tabata and Okuda (2000) maintained, this means that we must get rid of all considerations concerning the physics of reflections, since they do not make the problem disappear for cognitive scientists (Bianchi & Savardi, 2008b; Takano, 1998). We should instead focus on the whole set of perceptions of identity and opposition experienced by observers when they look in a mirror. These are anchored not only to the material object's or body's egocentric coordinate system (i.e., on the observer's right, on the left in the reflection) but also to an allocentric spatial frame of reference (i.e., the reflection is oriented and moving in an opposite direction with respect to the orientation and movement in the material world).
2. Second, a surprising number and variety of errors are made in very simple prediction tasks (i.e., those that do not make use of convex or concave mirrors or involve complex movements in complicated scenarios). This is particularly surprising if one considers that people are daily exposed to mirrors and reflecting surfaces. The correspondence between the real world and the reflected world is easy to see. We see it every time we recognize something *as* a reflection. Mirrors look like windows in that they "show something on the other side." But there is a complexity to the apparently simple geometry of mirrors that naive observers are not able to fully come to terms with, independently of whether or not they have explicit knowledge of the physical

rules regarding reflections. We would suggest that what makes the geometry of mirrors difficult is specifically related to the oppositional structure inherent to reflections that cannot be eliminated. Reflected objects and spaces are oriented and located oppositely in relation to their real counterparts. This means that they look identical, but in reality they are not the same: they "match" in the same way as your right hand matches your left hand – i.e., they are enantiomorphic, not "the same." Moreover, reflections are spatially perceived *beyond* the frame of the mirror (just like windows), but we understand that what we see is not physically located there but is on the same side of the mirror as we are, along with all the counterparts of everything contained in the reflection. So in order to make the two worlds match, we have to "fold back" the reflected world visible beyond the mirror, at the same time mentally getting rid of the internal enantiomorphic opposition. It is these oppositional elements embedded in the impression of identity that characterize direct experiences of reflections that make the mental transformation complicated. This is the reason why people make mistakes, but it is also the reason why we will always be fascinated by the world in the looking glass.