# THE DEPENDENCE OF PERCEIVED PICTORIAL SPATIAL STRUCTURE ON THE OBSERVER VANTAGE POINT

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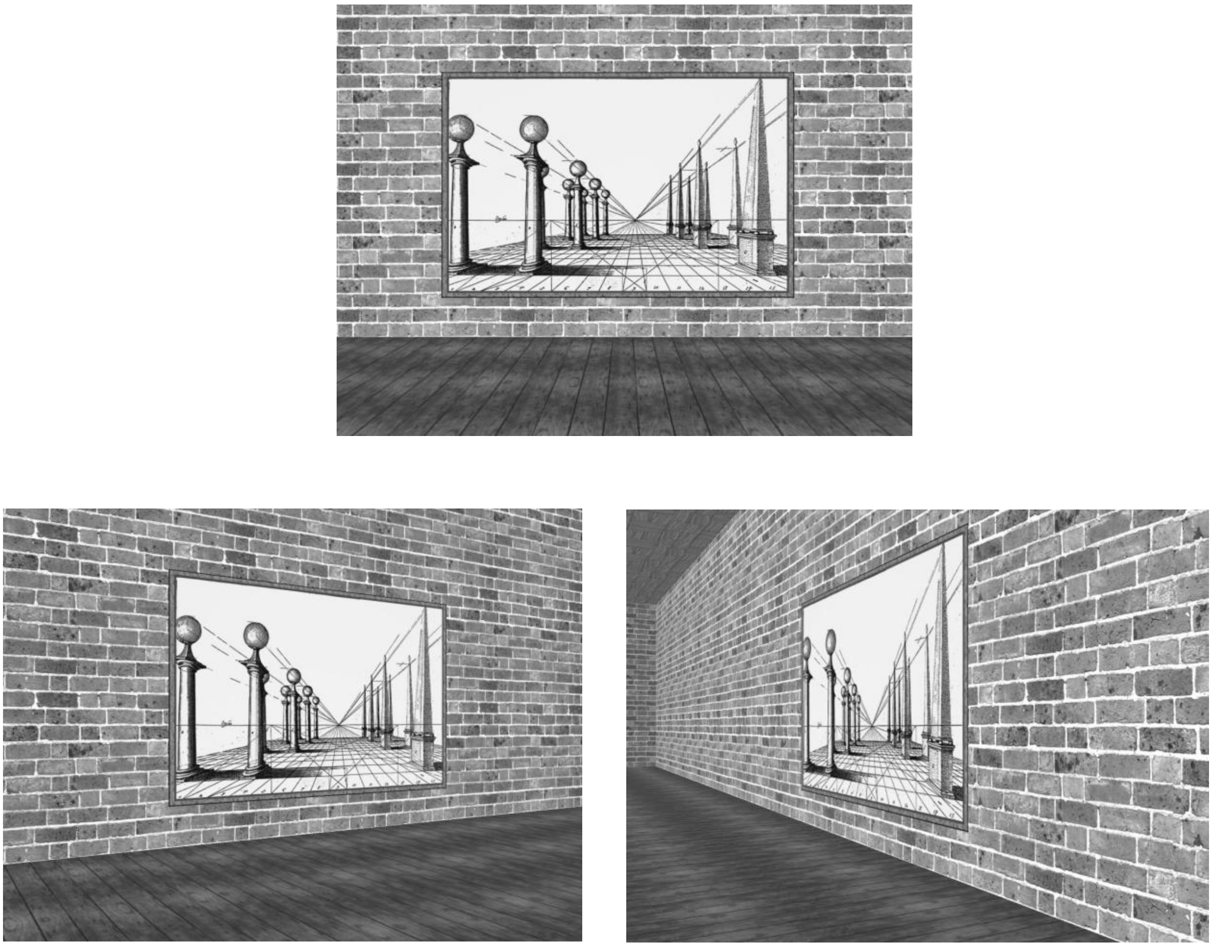
## Abstract

*When the same picture is observed from different locations, perception of 3D spatial directions can change dramatically. Two classes of such vantage point effects are demonstrated and discussed. One class includes the 'egocentric road' effect, in which a painted road is perceived to point at the observer wherever the observer moves. The other class includes the 'Mona Lisa effect', in which a portrait's gaze 'follows' the observer. The phenomena involved in these effects are similar but their geometric bases are different.*

The perception of virtual depth in flat images is a classical topic of visual perception research. Most any perception textbook lists various static pictorial depth cues, such as shading for 3D object shape, interposition for depth relations between objects, texture gradients and linear perspective for the distribution of objects in depth, etc. One topic that has not received much attention is the perception of 3D orientation in pictures. Consider an arbitrarily oriented straight line in 3D. According to laws of linear perspective, its projection upon a plane surface is also a straight line, which has a 2D orientation in the projection plane. The problem is that the projected 2D orientation does not fully specify the original 3D orientation, because lines of many different 3D orientations can project into the same line in the 2D projection. Thus, like size, orientation in pictures is ambiguous, but observers seem to perceive it in relatively definite and usually correct manner. Not much is known about the mechanisms underlying these processes. A conspicuous phenomenon of perception of orientation in pictures is the fact that it can strongly depend on the position from which an observer looks at the image. Here I will briefly review two specific, very different aspects of this issue. Space constrictions preclude any in depth analyses of the problems, and the interested reader is referred to the reference list.

## The 'egocentric road' and related effects

One aspect of pictorial perception is that the apprehension of orientation of depicted elongated structures, such as edges, roads, pillars etc., can depend on the vantage point. For example, when the observer has the impression that a road depicted in a picture is oriented towards him/her, he/she will continue to have that impression from most vantage points in front of the picture. Thus when observers move in front of such an image, they have the impression that the road changes its orientation, that is, that it turns in concert with their own motions, such that it continues to point towards them. I have labeled this effect as 'the egocentric road' (Todorović, 2005, 2008). A demonstration of this phenomenon is presented in Figure 1. It uses a computer-simulated scene, but it illustrates rather well what observers of an image containing a depicted passage way or similar structure would experience when changing their position in front of it, especially if it is a large painting or poster.



(a)

(b) (c)

Figure 1. Simulated photographs, from three different vantage points, of the same perspective drawing depicting a passage way or road lined by colonnades of pillars of different shapes (based on Todorović, 2008). The depicted road appears to point in different directions in the three cases, but it is always oriented towards the observer / photographer. In panel (a) the observer stands directly in front of the picture, and the road seems oriented perpendicularly with respect to the wall. In panel (b) the observer's vantage point has shifted leftwards and the road appears to have an oblique orientation with respect to the wall, as if it had rotated rightwards compared to its orientation in (a). Panel (c) depicts the converse situation.

Another effect of this type is the 'collapsing ceiling' of the St. Ignatius church in Rome by Pozzo (Pirenne, 1980; Kubovy, 1986, Todorović, 2005). The vaulted ceiling of the church contains a painted continuation of the architecture of the church with a fake open roof and the view of the sky above. On the floor there is a marble disk intended as the observer's station point, from which the painted architecture looks as a convincing continuation of the real architecture. However, as the observer moves away, the painted structure looks increasingly at an angle with respect to the real architecture, and the ceiling gives the impression as if it were about to collapse, a fact noted already soon after the completion of the painting early in the 18$^{th}$ century. Still another example is the painted terrace in La Sala delle Prospettive in the Villa Farnesina in Rome, which appears as a convincing extension of the floor of the real room when observed from a certain position, but seems as if positioned at various angles to the room from other viewing positions. Detailed geometrical analyses of these effects were presented by Todorović (2005), and experiments involving related configurations were reported by Todorović (2008, 2009b).

One approach to these issues is the idea that such vantage point effect arise only when ordinary paintings are observed from large distances or for very realistic trompe-l'oeil paintings, when the observer is not aware of the surface of the painting as such, whereas for other images such effects are mostly eliminated by compensation processes similar to shape constancy mechanisms in everyday 3D perception (see Pirenne, 1970; Kubovy 1986, Vishwanath et al., 2005). However, strong effects of vantage points can be easily obtained for simple, not very realistic images as well (Todorović, 2008, 2009b). The geometric bases of these effects have been well worked out over the years (Gournerie, 1859; Doesschatte, 1964; Todorović, 2005). The underlying idea is to predict the spatial structure of different scenes that would project into the same image from different projection centers. What these analyses show, under certain assumptions, is that lateral displacements of the vantage point are associated with oppositely directed lateral shears of the corresponding scene. For example, a road coming from the right side when observed from left (Figure 1b) will project into the same image on the projection plane as a road coming from the left when observed from right (Figure 1c), and both will project into the same image as a road straight ahead, observed head on (Figure 1a). Experiments have shown that observers' judgments of angular directions in such images are predicted to a good first approximation by such analyses, although there are also systematic deviations from the predictions, possibly due to viewing angle effects and lack of stereoscopic and parallax depth cues in flat images (Todorović, 2008, 2009b).

## The Mona Lisa effect

A different illustration of the influence of vantage point location is called 'the Mona Lisa effect' (although it has been known since antiquity): when observers have the impression that a portrait is looking at them, they will continue to have that impression from almost any vantage point (Maruyama et al., 1985; Rogers et al., 2005). Figure 2 demonstrates this effect by presenting the same image rotated into different orientations with respect to the observer. Note that if a real 3D bust had been rotated in analogous manner, its gaze direction would have rotated as well, and it would not have continued to look at the observer.

Geometrically speaking, gaze direction involves 3D orientation in space, and the Mona Lisa effect demonstrates that its perception depends on the vantage point of the observer, similar as in the egocentric road and related effects. An important difference is that in these effects the direction information is carried by some oriented elements in the image, whereas gaze direction is an imaginary line in 3D and has no projection in the image as such. How, then, is gaze direction specified? An obvious answer is that this information is provided by the location of the iris within the sclera of the eye, such that centered irises specify direct gaze, whereas irises shifted leftwards or rightwards within the eye opening specify gazes averted to one or the other side. However, a simple demonstration shows that the position of the iris alone in fact carries little information about gaze direction. Look at yourself in the mirror and shake your head as in gesturing 'no', that is, rotate the head about its vertical axis, while continuing to gaze at yourself. You will note that as the head rotates in one direction, the irises will shift their position in the other direction within the eye opening. But although the irises will thus travel all the way from one end of the eye opening to the other, your gaze direction will remain constant throughout, perpendicular to the mirror.

This demonstration suggests that in judging the gaze direction of a 'looker' we have not only to monitor the location of their irises but also the orientation of their head. This fact was shown long ago by Wollaston (1824), using drawings of faces with identical iris locations but different gaze directions, due to different head orientations. The Wollaston

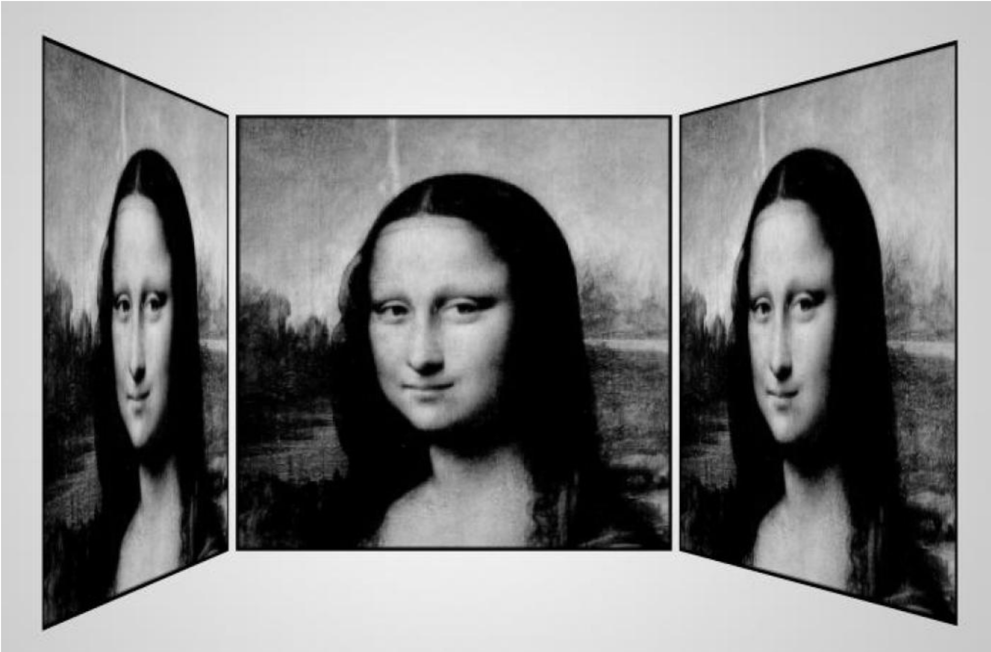
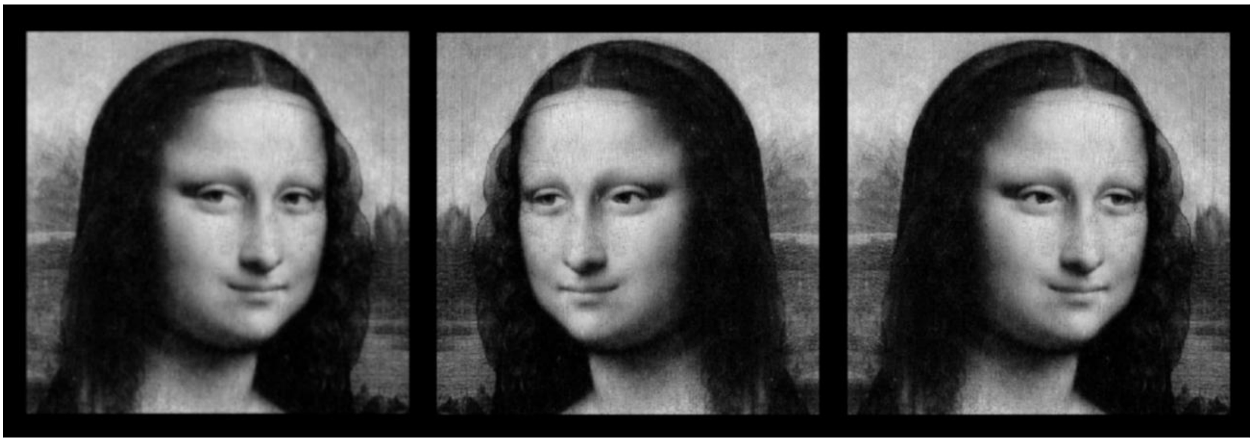


Figure 2. Mona Lisa orientation triptych. For all three projections the portrait appears to look in the direction of the observer (based on Todorović, 2006).



(a) (b) (c)

Figure 3. Mona Lisa mirror triptych. (a) mirror image of the original, (b) only irises are mirrored, head is unchanged, (c) only head is mirrored, irises are unchanged.

effect is illustrated here by the comparison of the original image (middle panel in Figure 2) with the image in panel (c) in Figure 3 (modified from Todorović, 2006). Panel (b) illustrates the obvious effect of iris location on gaze direction: when irises are dislocated with respect to the original image, gaze direction changes in conformity with the new iris location. Panel (c) illustrates the more interesting effect of head orientation on gaze direction. Here the head orientation is mirrored with respect to the original and gaze direction is changed as well, in the direction of the head turn, although the positions of the irises within the sclera are the same as in the original.

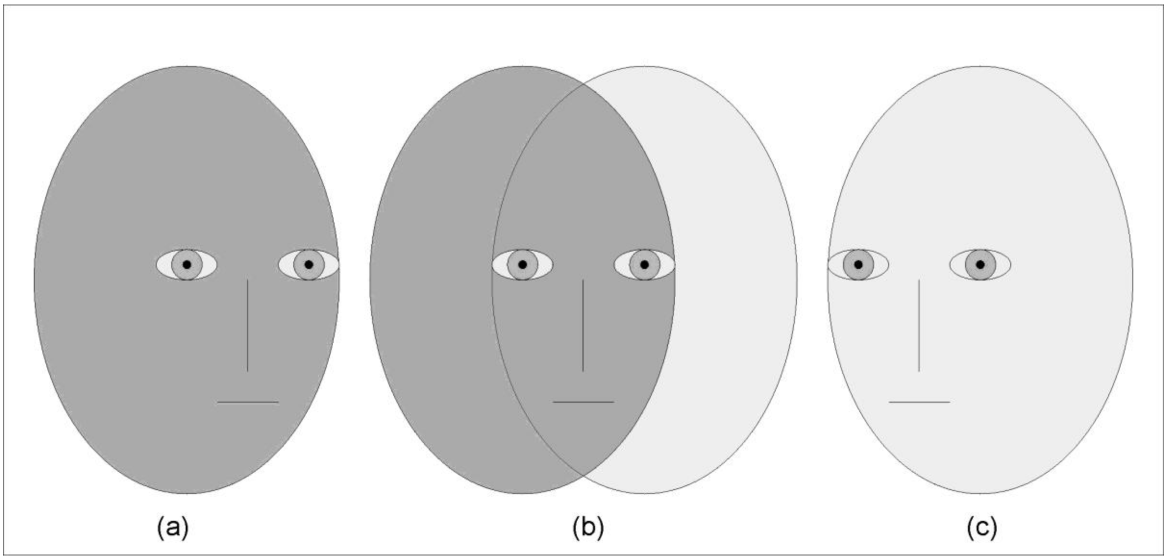



Figure 4. Gaze direction effects in cartoon faces (based on Todorović, 2009a). All three pairs of eyes are identical, with irises centered in the eye openings. Faces (a) and (c) appear to gaze in different directions, due to different perceived orientations of their heads, indicated by the different placements of eyes and other inner facial features within the elliptical head outlines. In face (a) centered irises together with rightwards turned head indicate rightwards gaze direction, whereas the same eyes together with leftwards turned head in face (c) indicate leftwards gaze direction. In (b), (a) and (c) are partially overlapped, sharing the same pair of eyes. Here observers may either concentrate only on the left head in the composite, which will appear to gaze rightwards, just as (a), or, similarly, mentally extract the right head and ignore everything outside of it, and it will appear to gaze leftwards, just as (c).

For an 'en face' portrait gaze direction is well specified by iris location, because in that case centered irises do correspond to direct gazes and ex-centric irises to averted gazes. However, for portraits with angled heads this correlation is compromised, and identical iris locations within the sclera can correspond to different gaze directions, and vice versa, as demonstrated above. What the iris location signifies is not gaze direction with respect to the observer but with respect to the looker, that is, the angle of the turn of the eyes of the looker with respect to his/her head. To specify gaze direction with respect to an observer, what one needs in addition is the information about the turn of the head with respect to the observer.

Figure 4 shows that the effect of head orientation on gaze perception can be illustrated with very basic sketches of faces. For an animated demonstration of this effect, see http://www.perceptionweb.com/perception/misc/p5930/p5930mov.gif ). The animation also illustrates a curious effect of the location of inner facial features on emotional expression.

Experiments with such images indicate that an analysis of perception of gaze direction based on 'iris eccentricity' (placement of iris within eye opening) and 'face eccentricity' (location of projected inner facial features within the face outline) can, to a first approximation, account for the structure of such judgments. (Todorović, 2006; 2009a). However, there are also certain biases in perception of gaze direction, possibly due to misjudgments of both iris location and head orientation (Anstis et al., 1969; Masama, 1990).

Why does the original image of the Mona Lisa (panel (b) in Figure 2) appear to gaze approximately at the viewer? Note that in this image a certain degree of the rightwards turn of the irises is accompanied by a corresponding degree of the leftwards turn of the head (Gibson & Pick, 1963). In the fully mirrored image, panel (a) of Figure 3, the iris positions are inverted with respect to the original, but so is the head orientation, so that the crucial reciprocal relation between iris location and head turn is preserved, and so is perceived gaze direction. Slanting the whole image, as in panels (a) and (c) of Figure 2, leaves this relation unperturbed as well. The invariance of this reciprocal relation with respect to slanting is, I submit, the basis for the explanation of the Mona Lisa effect (Todorović, 2006, 2009a).

The egocentric road and related effects and the Mona Lisa effect involve similar changes of the perceived scene when the observer vantage point dislocates. These are not subtle effects: the perceived angle of the road can easily change more than 90 degrees, and the gaze of Mona Lisa like portraits can 'follow' the observer all across the room. The two classes of effects depend on certain geometric aspects of the images, but these aspects are rather different. In spatial scenes they involve perspective cues, whereas in portraits they involve reciprocal relations of certain facial features.

## Acknowledgements

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