- **This is an old version of my paper and will be extensively revised soon. In particular, I'm planning to completely remove section 4 that overlaps with "Pictorialism Must Go."**
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The Geometry of Visual Space and the Nature of Visual Experience[1]

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My concern in this paper is with the aspect of the phenomenal character of visual experience that pertains to its spatial dimension. I shall refer to this aspect as visual space.[2] Kant famously claimed that the representation of space is the a priori form of the faculty of sensibility. This claim is sometimes interpreted as the view that visual space is a pictorial canvas contributed by the mind on which sensations such as color experiences are organized. This reading, whether it is correct or not, consists of at least two independent claims. First, visual space is contributed by the mind. Second, visual space is a pictorial canvas. Both of theses claims, of course, demand further explication. However, it would not be far off the mark to say that a number of contemporary disputes about the nature of spatial experience revolve around them. Some contemporary theorists, for example, hold the view that the natural properties of objects in the world are the source of the phenomenal character of perceptual experience, and our perceptual access to these

[1] I have benefited from discussions with Arash Afraz, Ned Block, Baktash Babadi, David Chalmers, Reza

[2] Some philosophers think that there could be perceptual states that are not phenomenally conscious. On such views there could also be unconscious representations of space. Here, I am not concerned with unconscious perceptual representations, whatever they might be. Thus, whenever I talk about visual space, I am talking about a phenomenally conscious visual space

properties can be understood in a naturalistic framework.[3] I shall henceforth call this view naturalistic objectivism. Naturalistic objectivism conflicts with the idea that the mind is the source of visual space. The first three sections of the paper focus on naturalistic objectivism. After unpacking the various commitments of the view in detail, I'll go over a few classics in the scientific literature on the geometrical characteristics of visual experience to argue that they conflict with naturalistic objectivism. The last two sections of the paper focus on the thesis that visual space is a pictorial canvas. I shall refer to this thesis as pictorialism and the views that accept it as pictorialist views. I shall argue that under the most plausible way of understanding the thesis, pictorialism also implies that visual experience must have certain geometrical properties that conflict with empirical findings. I conclude by considering what sorts of theories of visual space can best respect the empirical findings that undermine naturalistic objectivism and pictorialism.

I. Objectivism

When you see a ripe tomato, you typically have a visual experience with a reddish quality, a quality commonly referred to as the phenomenal character of your experience. A very influential line of thought holds the internalist thesis that the facts in virtue of which your experience has this quality reside within the boundaries of your skin.[4] Thus, if you want to understand why your experience has its reddish quality you look inside these boundaries, and if you have naturalistic leanings you will look for a naturalistic explanation. Many, however, have argued that the prospects for an internalist explanation of the phenomenal character of experience in naturalistic terms are dim.[5] As the argument goes, there are principled reasons to hold that the phenomenal character of experience cannot be explained in terms of the processes in the brain or the body. Thus internalism seems to lead us to the conclusion that the phenomenal character of experience poses a hard problem for our naturalistic world-view.

Recent philosophy of perception, however, has witnessed the emergence of a radically different approach to this problem that promises to be able to rescue the naturalist. On

[3] I shall say more about what I mean by naturalism shortly.
[4] Here, and in what follows, my use of 'in virtue of' signifies a constitutive relation.
[5] See Nagel (1974), Jackson (1982), and Chalmers (1996).

this approach, the reddish quality is not an intrinsic quality of your experience. Rather, it is the quality of the ripe tomato that you are aware of in virtue of having the experience. If this view is correct then, at least in the case of veridical experiences, it will be wrong to try to explain the reddish quality of your experience in terms of internal phenomena. In turn, we should give a naturalistic account of the qualities of objects and how these qualities can enter our experience.[6]

The above approach is committed to two sets of theses. The first set articulates the objectivist idea that the properties of mind independent objects are the source of the phenomenal character of experience. The second set articulates the naturalist idea that the sources of the phenomenal character and our mode of access to them are both natural. I shall call the two sets of theses objectivism and naturalism respectively. My main target is a view that combines the two, thus: naturalistic objectivism.

Naturalistic objectivism consists of four theses:

> (**Inheritance**) The phenomenal character of veridical experience is fully determined by the directly perceived properties and relations of its objects.[7]
>
> (**Mind Independence**) The objects of experience and their directly perceived properties and relations are mind-independent.
>
> (**Property Naturalism**) The objects of experience and their directly perceived properties and relations are natural.
>
> (**Awareness Naturalism**) The relation of perceptual awareness is a natural relation.

According to Inheritance, the directly perceived properties and relations of the objects of experience fully determine the phenomenal character of veridical visual experiences. There are different ways to sharpen the intuitive distinction between what you perceive directly and what you perceive indirectly, and there can be disagreements about whether

[6] This strategy is implicit in the works of many externalists. For explicit discussions of it see Fish (2009) and Langsam (2011).
[7] Here and elsewhere by my use of "experience" denotes perceptual experience unless otherwise indicated.

the distinction sustains scrutiny.[8] At this stage, I shall assume that the distinction sustains scrutiny and can be sufficiently sharpened. But this assumption is not essential for the purposes of characterizing Inheritance. Those who deny the distinction can define Inheritance simply in terms of the perceived properties of objects.

The idea that the directly perceived properties and relations of objects determine phenomenal character should be understood in a constitutive sense.[9] On this reading, there is an intimate metaphysical connection between perceptual experience and its objects: the perceived properties of the objects of experience enter experience and become constitutive components of it. This implies that for all x such that x is the value of a directly perceived spatial property and x is perceived veridically, the phenomenal character associated with the perception of x is identical with x. For example, if a specific shade of red is perceived veridically then the phenomenal character associated with its perception is that specific shade of red.

The reason for restricting Inheritance to veridical visual experiences is that most (but not all) views that accept the intuitive idea that the properties of objects are the source of the phenomenal character of experience want to allow that in the case of non-veridical experiences the phenomenal character of experience can diverge from the perceived properties of its objects.

Quite a number of philosophical accounts of perception are committed to Inheritance. Sense datum theory exemplifies one of these views. On this view, sense data are the direct objects of experience, and their properties enter experience, thereby determining its phenomenal character.[10] Sense datum theory, however, is not the only view that accepts Inheritance. Direct realists and Russellian representationalist also typically accept Inheritance. Direct realists hold that when you have a veridical experience of an ordinary object, some of the qualities of the object become constitutive components of your

[8] See Jackson (1997) for an instructive discussion of this issue.
[9] For the ease of exposition, I shall henceforth use "the properties of objects" in place of the "directly perceived properties and relations of objects". The two locution should be taken as equivalent unless otherwise indicated.
[10] See, for instance, Ayer (1956) and Russell (1997).

experience and thereby determine its phenomenal character.[11] Russellian representationalists hold that a veridical experience of an object is a relation to a content that includes some of the properties of the object. Since Russellians typically hold that contents fully determine the phenomenal character of experience, they conclude that properties of the objects of veridical experiences fully determine the phenomenal character of experience.[12] For example, a veridical experience of a ripe tomato is a relation to a content that includes the redness of the tomato. That is why the veridical experience of a ripe tomato has a reddish character.

A number of contemporary theorists reject Inheritance. Some reject it because they hold that the phenomenal character of perceptual experience is only partially determined by the perceived properties of objects of experience. For example, some Russellian representationalists hold that the phenomenal character of experience is determined partly by the contents and partly by the functional characteristics of the states that represent them.[13] A second group consists of Fregean representationalists who hold that contents are structures of modes of presentation.[14] Theorists disagree on how to understand modes of presentation, but it is common to hold that neither objects nor properties serve as modes of presentation.[15] Fregeans thus deny Inheritance because they hold that the mode of presentations of properties (not the properties themselves) determine the phenomenal character of experience. A third group who would reject Inheritance consists of non-relationalists who hold that the non-relational properties of the subject of experience or her states determine the phenomenal character of experience.[16]

Naturalistic objectivism aims to respect the intuition that the properties of objects in the natural world are the source of the phenomenal character of experience. Inheritance

[11] Campbell (2002), Martin (2002)
[12] Dretske (1995), Harman (1990), and Tye (1995, 2000)
[13] Lycan (2001)
[14] Chalmers (2004), Thompson (forthcoming (a), forthcoming (b))
[15] McDowell (1984) and Travis (2005) dispute the reading of Frege that attributes to him what I am calling a Fregean view.
[16] Non-relationalism can be divided into adverbial and state views. Chisholm (1957), Sellars (1963), and Kriegel (2007) defend adverbial views. Block (1996, 2003) defends the state view.

takes an important step in this direction. To provide a genuine alternative, however, this view should avoid construing the perceived properties of the objects of experience as mind-dependent. If a tomato is red in virtue of having the disposition to cause reddish experiences, then an explanation of how one's experience has a reddish character will ultimately appeal back to internal items. Naturalistic objectivism should thus combine Inheritance with the idea that the relevant properties of objects are mind-independent. This is the rationale for adding Mind Independence.

By a mind-dependent object I mean an object whose existence does not depend on minds, mental states or their supervenience bases. A property is mind-independent if it can be instantiated in the absence of minds, mental states or their supervenience bases.[17] In order to satisfy Mind Independence, both the direct objects of visual experience and their properties must be regarded as mind-independent. Most sense datum theorists would deny Mind Independence by holding that sense data are mind-dependent. Shoemaker (1994, 2001, 2003) and Kriegel (2002, 2011) hold that colors are mind-dependent. Thus these views, even if they accept that color experiences are direct relations to colors, would not count as naturalistic objectivist views.

I shall call one who accepts Inheritance and Mind Independence an objectivist. An objectivist might still reject the intuitive idea that the properties of objects in the natural world are the source of phenomenal character. For example Chalmers (2006) and Pautz (2006) both defend views that accept Inheritance and Mind Independence about colors but they deny that colors and our access to them can be regarded in naturalistic terms. This brings us to the naturalistic requirements of naturalistic objectivism. According to Property Naturalism the perceived properties of objects of perceptual experience are natural properties. According to Awareness Naturalism our awareness of the objects of experience is a natural relation. In calling properties and relation natural I mean that these properties and relations fall within the boundaries of the ontological commitments and explanatory schemes of natural sciences. A lot, of course, depends on how one

[17] Shoemaker (1994, 2001, 2003) and Kriegel (2002, 2011) hold that colors are mind-dependent in the sense that they are dispositions to cause this or that type of experience. On neither of these views are colors worldly in the sense that I am using. Thus these views, even if they accept that color experiences are direct relations to colors, would not count as objectivist views.

understands natural sciences. But I will confine myself to this rough characterization because, as we shall see in section three, the rough constraints that it imposes on naturalistic accounts are sufficient for my argument.

My first target in this paper is naturalistic objectivism about visual space. I shall argue that the view conflicts with the science of spatial perception and should thus be abandoned. This also puts indirect pressure on naturalistic objectivist views of time perception and the non-spatial aspects of other sense modalities, e.g., colors and sounds. As I remarked earlier, this has important implications for the debate over the hard problem of phenomenal consciousness.

The main contemporary proponents of naturalistic objectivism belong to the Russellian representationalist camp.[18] My argument poses a serious challenge for these views. Direct realist views are also threatened by my argument. These views typically accept objectivism but they hardly take a position about naturalism. Still, my argument shows that direct realists cannot embrace naturalism. This, I take it, is a strong challenge for direct realist views.

In general, my argument poses a similar challenge for all objectivist views. The divide between objectivist accounts and their opponents is, in my view, one of the most important divides in historical and contemporary philosophical accounts of the nature of perceptual experience. The divide is significant as a divide in the metaphysics of perceptual experience. The epistemic significance of this divide has also been widely discussed and is a recurring theme in perceptual epistemology.[19]

2. The Geometry of Visual Space

The empirical data that I shall focus on in this paper originates mainly in a body of literature whose aim is to determine the geometry of visual space. In saying that visual space has a particular geometry, G, I mean that facts about experiences of spatial properties conform to the axioms and postulates of G. Suppose that empirical studies

[18] As I said before, one can be a Russellian representationalist but reject naturalistic objectivism.
[19] For example, see the exchange between McDowell (1994, 2008) and Wright (2002, 2008).

show that subjects, faced with three parallel lines A, B and C, frequently report that line A seems parallel to line B, line B seems parallel to line C, but line A does not seem parallel to line C. We take this to indicate that visual space violates the axiom that the relation of parallelity is transitive. Thus we conclude that no geometry that requires this axiom is applicable to visual space. This method is partly empirical because it relies on the reports of subjects and takes the reports to be indicative of how things are experientially. But in other respects the method is the same as the method that a mathematician uses to ascribe geometries to abstract spaces.

What we now regard as axiomatic geometry was born with Euclid's *Elements* where he proved 465 geometrical theorems based on a set of definitions and ten postulates. For a long time everyone believed that Euclid's geometry was the only possible geometry. However, things changed in the 19th century, when Lobatchevsky, Bolyai and Gauss independently developed axiomatic systems for Non-Euclidean geometries. These mathematicians denied Euclid's parallel postulate according to which, from a point outside a line, D, only one line parallel to D can be drawn.[20] According to these geometries, called hyperbolic, from a point outside a line more than one line can be drawn parallel to it.

The invention of hyperbolic geometry created a wave of excitement that was not limited to mathematicians. Helmholtz (1867/1962) argued that since Euclidean geometry was not the only possible geometry, we should rely on empirical studies to determine the geometry of visual space.

Before Helmholtz, philosophers had approached this issue in a different way. Kant had famously argued that we have to accept that visual space is Euclidean in order to explain the necessity of Euclidean geometry. Other philosophers such as Berkeley and Reid diverged from Kant's a priori approach, but their approach did not abandon a priori methods entirely.[21] They started with a few empirically motivated assumptions about our visual apparatus, e.g., that the visual receptive surface can be regarded as a two-

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[20] Euclid's version of the fifth postulate is slightly different, but it has been proven that it is equivalent to what is now called the parallel postulate.
[21] Berkeley (1709) and Reid (1764).

dimensional plane, but then used a priori reasoning to draw conclusions about the geometrical character of visual experience from these assumptions. Both philosophers ended up with the counter-intuitive view that visual space is strictly-speaking two-dimensional.[22] Reid drew the additional conclusion that the geometry of the two-dimensional visual plane was spherical.[23]

Helmholtz, in contrast, tried to experimentally determine the characteristics of visual space. He performed a few experiments to test the hypothesis that visual space is Euclidean.[24] The experiments were not conclusive but triggered a line of research involving psychologists, mathematicians, physicists and philosophers, a movement that has lasted for more than a century and a half.[25]

The decisive test for the hypothesis that visual space is Euclidean came a few decades after Helmholtz. Drawing on earlier work by Hillebrand (1903), Blumenfeld (1913) conducted two experiments whose combined results were widely interpreted as showing that visual space violates Euclid's parallel postulate. During the first experiment, subjects were presented with a pair of fixed luminous points set deep in the visual field and a set of movable luminous point pairs.[26] The task was to configure the luminous points so that they formed two seemingly parallel lines extending from the fixed pair of points toward the subject. This was called the parallel alley configuration (figure 2.1). In the second experiment subjects were asked to organize the pairs of luminous points so that their apparent distance from each other was equal to the perceived distance of the fixed points. This was called the equidistance alley configuration (figure 2.1).

[22] Schwartz (1994) challenges this reading of Berkeley.
[23] Because of this, Reid is sometimes regarded as almost having invented non-Euclidean geometry before Lobatchevsky, Bolyai and Gauss. For an interesting exchange on the proper interpretation of Reid's argument and its compatibility with his direct realism see Van Cleve (2002), Yaffe (2002) and Belot (2003).
[24] Helmholtz showed that when subjects are asked to organize three points on a straight line the resulting configuration depends on the distance of the points from the observer's point of view; it is concave for near points, convex for far points and straight for points located in intermediate distances.
[25] Wagner (2006) provides an excellent summary of the literature on this topic.
[26] The experiments where performed in a dark room.

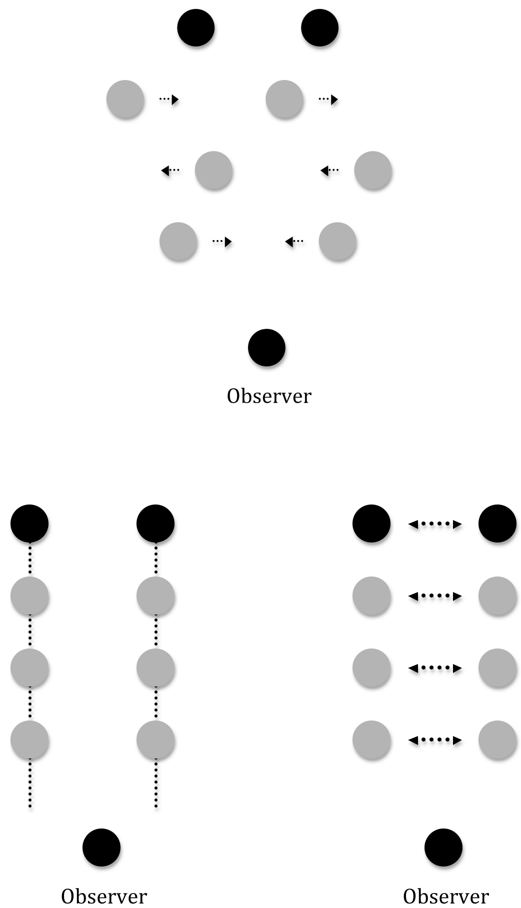

Figure 2.1 Blumenfeld's experiments
Subjects are asked to configure the luminous points (top) as a parallel alley in the first experiment (left) and an equidistance alley in the second one.

The resulting configurations did not form a straight line in physical space in any of the experiments. Both alleys formed curves with the distance between pairs of points gradually increasing as the distance from the observer increased. More importantly, the parallel alleys always fell inside the equidistant alleys (figure 2.2).

The combined results were taken to indicate that visual space is not Euclidean. One assumption behind this interpretation is that the parallel and the equidistant alleys in physical space project two distinct pairs of intersecting lines in visual space. One pair is perceived as equidistant and the other pair is perceived as parallel. This shows that equidistance and parallelity come apart in visual space.[27] This is incompatible with Euclidean geometry.[28]

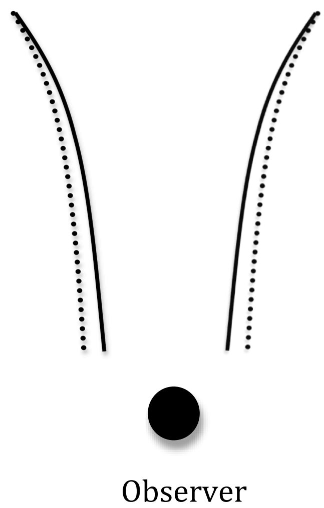

Figure 2.2. The above depicts the configuration that the subject creates in the equidistance (dashed curve) and parallel alleys (solid curve) set up. The subject experiences the curves as straight parallel lines.

The standard interpretation of the above experiments took them at face value and concluded that visual space is not Euclidean. It was assumed that when a subject is instructed to construct seemingly parallel or equidistant lines, that will be how things seem to her at the end of the task. But given that we are not good at judging parallelity or equidistance based on looks, shouldn't we be suspicious about this interpretation? This is an important question to which I shall return at the end of this section.

Luneberg (1947, 1948, 1950) developed an axiomatic system for the geometry of visual space based on Blumenfeld's results. According to this model, visual space has a hyperbolic geometry with constant negative curvature. Luneberg's theory dominated the literature for a couple of decades. But Foley (1972) obtained results that were incompatible with it.

[27] We have to make the additional assumption that the projections are symmetric around the X axis.
[28] Higashiyama, Ishikawa and Tanaka (1990), Indow, Inoie, and Matsushima (1962a, 1962b), and Indow and Watanabe (1984) replicated Blumenfeld's results.

Foley presented subjects with a fixed luminous point, A, and two movable luminous points, B and C, on the right and left sides of the visual field (figure 2.3).[29] The experiment had two stages. First, the subjects moved B to a point where OB seemed equal and perpendicular to BA, and then moved C to a point where OC seemed equal and perpendicular to OB. In the second stage subjects were asked to judge the relative size of OA to BC. The physical configuration that subjects created in the first stage diverged from the way that, assuming they correctly followed the instructions, the subjects must have been perceiving the configuration (Figure 2.3).

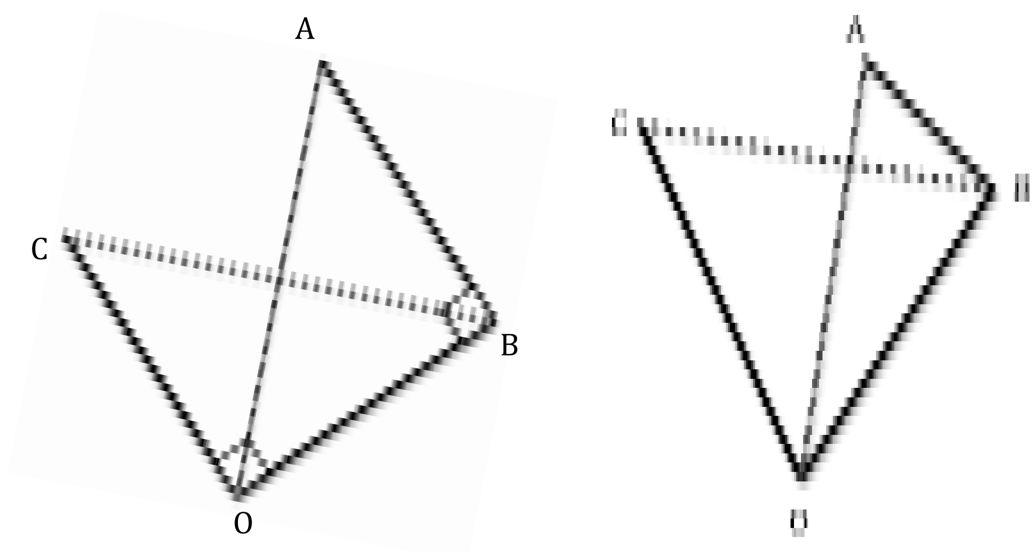

Figure 2.3. Foley's experiment. O is the location of the subject. The left-hand side depicts the way that the subject must be perceiving the configuration. The right-hand side depicts the configuration that subjects actually created in physical space.

The result of the second stage was even more interesting. Of the 48 participants in the experiment, 40 judged BC to be longer than OA.[30] This result violates the axiom of the congruence of triangles. According to this axiom, two triangles, T and R, are congruent if and only if two sides and the angle between the sides of T are congruent with two sides and the corresponding angle of R. In Foley's experiment the two triangles OBA and

[29] The horizontal panel is an imaginary plane that passes through the subject's eyes and extends forward parallel to the ground.
[30] Foley performed the experiments two times, varying the distance of A from the subject. The average ratios were respectively 1.23 and 1.20 for the large and small configurations.

OBC satisfy the condition of the congruence of triangles. But if the two triangles are congruent then all of their sides must be congruent. However, BC and OA are not perceived as congruent. Thus visual space violates the axiom of congruence of triangles. The significance of this finding is its incompatibility with any constant curvature geometry, including Euclidean geometry and Luneberg's hyperbolic model.

The standard interpretation raises a question which is similar to the one that I mentioned about the Blumenfeld experiment. We assume that when a subject is instructed to construct seemingly right angles or lines equal in size, that is how things will seem to her at the end of the task. But given that we are not good at these tasks, shouldn't we be suspicious about this interpretation? I shall return to this issue at the end of this section.

Early reactions to Foley's results were varied. Some sided with him and obtained independent results that confirmed his observations. Wagner (1985) showed that judgments about sizes and angles varied dramatically with respect to the orientation of objects. In particular, objects oriented frontally are perceived larger than those oriented distally. Angles facing away from or toward an object are seen larger than angles that face sideways. Higashiama (1981, 1984) argued that the curvature of visual space is not constant and varies with distance. Ivry & Cohen (1987) obtained results that indicated that the curvature of visual space varies with stimulus configurations. Indow (1988) and Indow & Watanabe (1984b, 1988), continued defending Luneberg's theory.

A survey of recent literature on the topic shows that though the scientific community has not reached a positive consensus, Luneberg's theory does not seem to have many advocates.[31] Moreover, following arguments by Suppes (1995) and MacLeod and Willen (1995), some hold that visual space does not have a single consistent geometry and that the attempt to find this geometry is futile. There are still pockets of research that mostly focus on whether visual space satisfies some fundamental axioms that even geometries with varied curvature need to satisfy. But there is a decline in the initial excitement about finding the geometry of visual space. [32]

[31]Some of the latest papers defending Luneberg's theory are Aczel, Boros, Heller and Ng (1999), Heller (1997a, 1997b).

[32] I shall discuss some of these results in the fifth section.

As I said earlier, the standard interpretation takes the experiments at face value. It assumes that when a subject is instructed to construct seemingly parallel lines, seemingly equidistant lines, or seemingly right angles, what she constructs at the end of the task seems to her parallel, equidistant or right-angled. Let me say a few words in defense of this interpretation.

First, taking the experiments at face value does not require the assumption that we have infallible access to the experiential facts that guide action. We can even allow that we are not good at accessing experiential facts. But, given a sufficiently large sample size, the effect of our fallible access would be factored out and our overall performance would reflect experiential facts. The fact that we are not good at judging the size of angles, the length of lines, or their straightness does not pose any threat to the standard interpretation.

Second, in order to support the standard interpretation we need only to assume the absence of non-uniform biased access to experiential facts. Suppose that we have biased access to experiential facts pertaining to angles. For example, angles that are, experientially speaking, right angles are judged to seem smaller. This would not explain the violation of the congruence of triangles axiom in Foley's experiment. We need to assume that our access to experiential facts pertaining to angles oriented sideways is biased in a different way from our access to angles oriented towards the observer. In other words, we need to assume that there is non-uniform bias in our access to experiential facts pertaining to angles. But this would be odd and counterintuitive. Why should our brains form more or less correct representations of angles and then introduce non-uniform bias in accessing this information? In the absence of a convincing answer to this question, we should embrace the standard interpretation.

It is thus safe to assume that empirical research on the geometry of visual space has produced strong evidence that even if visual space has a consistent geometry, its geometry is neither Euclidean (Kant), nor spherical (Reid), nor hyperbolic (Luneburg). Empirical research has also shown that there is a systematic mismatch between our perceptual experience of some spatial properties and the physical values of these properties. The arguments in the next section will rely on these results.

3. Naturalistic Objectivism and the Geometry of Visual Space

In this section I argue that the empirical results mentioned earlier seriously challenge naturalist objectivist accounts of visual experience. The reason, put in a nutshell, is that the results put the objectivist and the naturalist commitments of the view in conflict with each other. Since, these results demonstrate a systematic mismatch between the geometry of visual experience and the geometry of the objects of spatial perception, the objectivist is forced to conclude that visual experience systematically misrepresents physical space. But this is, as I shall argue, incompatible with the naturalistic commitments of the view. I shall present this idea as an argument against naturalistic objectivism, which I shall call the argument from geometrical mismatch.

Before presenting the argument, let me make one thing clear. Modern physics tells us that physical space is not Euclidean. The gravity of very large masses bends light rays and creates a curvature in space. However, this effect is negligible in the small scales that are visually perceivable. Naturally, researchers in the field assume that the geometric structure of physical space is Euclidean in the scales that matter for vision. Following them, I too shall simply hold that physical space is Euclidean and drop the qualification about scale.

Here is the argument from geometrical mismatch:

1. If naturalistic objectivism is true and visual experience does not systematically misrepresent spatial properties, then the geometry of visual experience is the geometry of a mind-independent space determined by the directly perceived spatial properties and relations of objects of visual experience. (Matching)

2. Visual experience does not have the geometry of a mind-independent space determined by the directly perceived spatial properties and relations of objects of visual experience. (Mismatch)

3. Visual experience does not systematically misrepresent spatial properties and relations. (Systematic Veridicality)

4. Therefore objectivism is false.

As we saw earlier, naturalist objectivists are committed to Inheritance, according to which the phenomenal character of veridical visual experiences is fully determined by the directly perceived properties of their objects. Inheritance in conjunction with a few other plausible assumptions entails match. Let me elaborate this with an example.

Suppose we are perceiving three intersecting straight lines in a Euclidean space that form a triangle. Suppose also that we directly perceive intersection relations, the property of being a straight line and the value of angles. Because the space is Euclidean, these properties and relations will jointly satisfy a relational constraint: the sum of the internal angles resulting from the intersecting lines will be 180º. If Inheritance holds and we veridically perceive all of these properties and relations, it follows that what we perceive will be, phenomenally speaking, three intersecting straight lines which form angles that add up to 180º. In other words, our perceived triangle will also satisfy the requirement that the sum of the internal angles of a triangle is 180º. This is because, as we saw in the first section, Inheritance implies that for all x such that x is the value of a directly perceived spatial property or relation, and x is perceived veridically, the phenomenal character associated with the perception of x is identical with x.

This idea can be generalized to all other constraints. In general, Inheritance implies that all the constraints that a set of directly perceived properties and relations satisfy in virtue of their values will also be satisfied by their veridically perceived values. By definition, a set of spatial properties and relations determine a geometry when they satisfy the set of constraints (axioms) that are definitive of that geometry. It thus follows that if Inheritance is true then the geometry that a set of directly perceived properties and relations determine in virtue of their values will also be determined by their veridically perceived values. Furthermore, naturalistic objectivism also entails Mind Independence. If we put all of these results together we can conclude Matching.[33] The first premise of the

[33] To be more precise we should also assume that the geometry determined by the veridically perceived values of properties and relations is identical with the geometry determined by the perceived values of properties and relations that are not systematically mis-represented. This assumption is a background operative assumption of empirical studies and I am assuming it without argument.

argument therefore follows from our definitions and the commitments of naturalistic objectivism. Let us move to the second premise, Mismatch.

According to Mismatch, visual experience does not have the geometry of a space determined by the directly perceived spatial properties of objects of visual experience. On a simple way of looking at things, since objects of perception are embedded in physical space and this space is Euclidean the geometry that is determined by their spatial properties and relations must be Euclidean. Therefore, Mismatch is correct since, as we have seen in the previous section, the geometry of visual experience is not Euclidean. There are, however, two ways in which the geometry determined by the directly perceived spatial properties and relations of objects might fail to be Euclidean, despite the fact that these objects are in a Euclidian space. Nevertheless, I shall argue that neither of these two ways will threaten Mismatch.

It is in principle possible that what is directly perceived in visual experience is too sparse to determine a very specific geometry. For example, suppose that only locations in an egocentric frame are directly perceived. Such a sparse set of properties cannot directly provide sufficient constraints to determine a Euclidean space, because fixing locations does not fix properties such as lengths, angle sizes and relations such as parallelity. Therefore, fixing locations does not fix whether a space satisfies the constraints of Euclidean geometry thought it might provide sufficient constraints for determining very general properties such as the topological properties of a space. Thus one might argue that because only simple properties such as locations are directly perceived the geometry determined by them is too general and is thus compatible with the findings in the previous section. However, despite its possibility, the assumption that we directly perceived only simple properties such as location is false. The science of perception tells us that the visual system detects properties such as orientation, size, shape and angles, in very early stages of visual processing. It is not easy to see how this simple fact can be squared with the claim that we do not directly perceive such properties. Furthermore, these properties are sufficient for determining or violating geometries as specific as the Euclidean geometry. So it is simply false that what we directly perceive is too sparse to conflict with the results mentioned in the previous section.

There is a second way to resist the idea that the geometry determined by what we directly perceive is Euclidean. Some philosophers attribute observer-relative spatial properties to objects. For example, when we see a tilted coin, in addition to its circular shape, the coin also has an observer relative elliptical shape. This elliptical shape is a relational spatial property of the coin determined by projecting the intrinsic circular shape of the coin onto the observer's fronto-parallel plane. Similar claims have been made about other spatial properties of objects. On these views the directly perceived properties and relations of objects are their projective relational properties. Adopting this projectivist view would enable one to argue that the directly perceived properties and relations of objects determine a non-Euclidean space.

One attempt in this direction is Reid's idea that the directly perceived space of visual perception is the space obtained by projecting physical space onto a spherical plane. It is not very clear why Reid privileged the spherical plane and thus drew the conclusion that the direct space of visual perception must have a spherical geometry.[34] But whatever Reid's reasons were, the claim that visual space is spherical is incompatible with Blumenfeld's results and must therefore be rejected.

The projectivist, however, does not have to follow Reid in holding that visual space has a spherical geometry. Peacocke (2008), for example, equates the visual field with a cyclopean plane that somehow encompasses our two retinas. It is not clear that Peacocke would equate what he calls the visual field with what I am here calling visual space. He might hold that there is more to visual space than the visual field. However, one can imagine a view similar to Peacocke's that equates visual space with a plane determined by the geometrical properties of our retinas.

Three general reasons, however, suggest that the above view cannot save the naturalist objectivist. First, empirical studies suggest that there are no planes in visual space.[35] If there are no planes in visual space then visual space cannot be equated with a plane determined by the retina or any projective plane in general. The second reason is that it would be very strange if visual space were identical with a space determined solely by the

[34] But see Van Cleve (2002) for a discussion of this issue.
[35] See Koenderink (2008, 2010). Some of these results will be discussed in the fifth section of the paper.

retinas. The retina is, roughly, a concave surface like the inside of a hemisphere. An image of a straight line on this concave surface will look curved to an external observer who is looking into the eye from outside. But our brain does not see this line, because there is no sense in which it can look into the retina. The brain "sees" the line only in the sense that the activation of the retinal photoreceptors is transmitted to and gets "interpreted" by it. For all we know, the brain might interpret some curved lines, e.g., those whose curvature conforms to the curvature of the retina, as straight lines. It is, therefore, very unlikely that the physical shape of the retina determines the alleged projective plane in isolation from its wiring pattern and the processing that happens after its activation. One implication of this is that any alleged projective plane must be determined partly in relation to the processing in the brain. This gives us a third general reason to the effect that the naturalist objectivist cannot appeal to the projectivist strategy. For, it is very unlikely that a plane that that is partly determined in relation to the processing in the brain will satisfy Mind Independence.

There are, therefore, three general reasons against the thesis that visual space has the geometry of a projective mind-independent space. This thesis, in conjunction with the previous observations and the empirically established thesis that visual space does not have a Euclidean geometry, implies Mismatch, the second premise of our argument. Let us turn to the third premise, Systematic Veridicality.

According to Systematic Veridicality, visual experience does not systematically misrepresent spatial properties. But our visual experience of Euclidean physical space is non-Euclidean. Isn't this an obvious case of misrepresentation? Perhaps what motivates this idea is that a veridical experience of a property should resemble it. However, it is unclear that the kind of mismatch suggested by the empirical evidence implies that visual space does not resemble physical space. Resemblance comes in degrees and is relative to the context of evaluation. In many contexts, two-dimensional maps of the earth are correct depictions of it, but the earth is not two-dimensional. Should we say that these maps do not resemble the earth? And if they don't, should we say that they thereby misrepresent it?

The natural way to overcome the above difficulty is to appeal to a theory of content. And this is what naturalistic representationalists do. Such accounts can be roughly divided into producer-based accounts[36] and consumer-based accounts.[37] According to producer-based accounts, we should look at the system that produces a mental representation to determine its representational content. Details aside, these views often attribute representational content to a state by determining what the producers of the representation track in certain conditions. On some views these conditions are normal or optimal conditions of observation. On teleological versions of the view, the properties whose tracking explain why a tracker was selected by natural selection are the contents of a state. Consumer-based accounts, in contrast, hold that the way that the informational content of a state is used by the consumer system determines its representational content.

Objectivist representationalists, I want to argue, cannot regard cases of systematic mismatch as cases of misrepresentation exactly because of their allegiance to naturalistic accounts of content. Let me illustrate this in the case of Foley's experiment in which when asked to create a seemingly 90° angle, subjects create physical angles that are not 90°. Thus there is mismatch between how these angles seem to the subjects and how they are, a mismatch whose extent depends on the orientation of the angle. Now, since these results have been replicated in a variety of contexts, we should conclude that mismatch is not accidental and manifests a fact about the way angles are processed in visual pathways. Thus we have to conclude that the producer of a visual experience that presents an angle as 90° (let us call this the 90° experience) systematically tracks an angle that is not 90°. This, conjoined with a few other plausible observations, supports Systematic Veridicality. Let me elaborate.

Let us assume, for the sake of illustration, that a 90° experience systematically tracks a 75° angle. On a tracking account according to which the content of a state is what it systematically tracks we have to conclude that the content of a 90° experience is a 75°

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36 Dretske (1995), Tye (2000)
37 Millikan (1984)

angle. It follows that, though there is mismatch between the experience and the angle, this mismatch is not a case of misrepresentation because the content of the experience, the constraint that it imposes on the world, is that there is a 75° angle in the world. So a simple tracking account supports Systematic Veridicality.

Furthermore, there is no reason to assume that Foley's experiments are conducted in abnormal conditions. There are no illusion-producing factors and there are no reasons to assume that the visual apparatus is not performing its normal function. Thus, even under tracking accounts according to which the content of a state is what it tracks in normal conditions, we should conclude that the 90° experience caused by a 75° angle is not misrepresenting it, since a 75° angle is what it normally tracks.

It is not clear how making a simple tracking account more sophisticated, e.g., by introducing teleology, would change the situation. Suppose, for example, that we add the teleological qualification that the content of a state is what it was tracking during the period where the content-fixing evolutionary mechanisms where in operation. For example, suppose a state evolved to track ducks. We now take the creature to a new environment where only decoys activate the state. On the teleological view we should still hold that the content of the state is a duck content because that is the content that the state evolved to track. There is no reason, however, to assume that 90° experiences were tracking 90° angles during evolution, but are now tracking 75° angles. For, there is no reason to hold that there has been a change in our natural environment that would preserve the content of a state while changing the properties that activate it. If so, adding teleological considerations does not seem to help the opponent of Systematic Veridicality.

If producer-based accounts cannot construe systematic mismatch as systematic misrepresentation, then it is not clear how shifting to consumer-based views could do so either. Simple consumer-based accounts hold that the way that a state is used to guide behavior determines its content. More sophisticated versions of the view add teleological considerations. It is thus natural to expect that on this account actions that are guided by a state that systematically misrepresents the world must systematically fail with respect to a creature's evolutionary goals. But we use visual experience to navigate the world quite successfully. It is not clear how a consumer-based view could square this fact with the claim that visual experience systematically misrepresents the world.

One might argue that considerations about mismatch threaten both the objectivist naturalist and her opponent. If there is systematic mismatch between the phenomenal content of experience and the world, how can perception sufficiently guide action? Why is it that we do not systematically fail to navigate the world? If so, perhaps everyone should question the cogency of the experimental results.

The answer is that the phenomenal content of experience is much more determinate than the content of experience that guides action. For most of our practical purposes, we do not need to distinguish between, say, a 90° and a 92° angle. So the content that guides action is less determinate than 90° or 92°. But the phenomenal content that is revealed in the above experiments is more determinate. So although there is a mismatch between phenomenal content and the properties in the world, the mismatch does not result in failure to navigate the world.

In a recent response to Pautz (2006) who has also argued against naturalistic representationalist accounts, Byrne and Tye (2006) argue that without knowing the details of naturalistic theories we cannot pass any judgments about the contents that naturalistic theories must attribute to a state. They add to this that at this stage of theorizing we do not yet know the details of the best naturalistic accounts of content.

Byrne and Tye raise an important point. Nevertheless, I think their worry is not threatening in cases where the claims about the predictions of naturalistic theories are based on general theoretical features that do not change by adding details and will very likely remain constant. I believe that my arguments have been of this sort. In these arguments I have appealed to the generic features of naturalistic theories. It is a general feature of naturalistic theories that they should either appeal to the causal factors that produce a state and/or the factors that pertain to its consumption. And it is a general feature of naturalistic theories that they should appeal to causal relations between a mental state and its content that exists now or in the evolutionary past of a species. One cannot predict with certainty that these general features will never change, but in the absence of evidence to the contrary, the idea that future naturalistic theories of content will abandon them has the air of an ad hoc assumption.

We can reasonably conclude that neither consumer-based nor producer-based accounts of content can deliver the result that systematic mismatch is systematic misrepresentation. Objectivist representationalists thus have to either give up their naturalism and embrace a mysterious primitivist account of representational content, or accept Systematic Veridicality.

Direct realists objectivists do not appeal to naturalistic accounts of content. They often regard our perceptual relation to the world as sui generis. But there is a dialectical reason to think that direct realists, naturalist or non-naturalist, should not regard visual experience as systematically non-veridical. Proponents of direct views often deny that veridical and non-veridical perceptual experiences are of the same metaphysical kind. While adopting objectivist account of veridical experiences, they either refrain from offering a positive account of non-veridical experiences or offer non-objectivist accounts. If we add to this the claim that everyday perceptual experiences are systematically non-veridical it will follow that direct realists are not objectivists about everyday perceptual experiences. The direct view is about circumstances that hardly ever obtain. The view thus looses most of its appeal. Where we wanted a metaphysical account of the nature of our everyday perceptual experience, we get a view that is only true of a small fraction of our experiences. Thus the direct realist brand of objectivism has a strong reason to embrace Systematic Veridicality.

We thus have a good case against naturalistic objectivism. First, if objectivism is true and visual experience does not systematically misrepresent spatial properties then visual experience has the geometry of a mind-independent space determined by the directly perceived spatial properties of objects of visual experience. As we saw, this follows from Inheritance and Mind Independence. Second, visual experience does not have the geometry of a space determined by the directly perceived spatial properties of objects of visual experience. This follows from what empirical science has taught us. Finally, visual experience does not systematically misrepresent spatial properties. As we saw, the main two brands of naturalistic objectivism are forced to accept this. The three premises thus imply that naturalistic objectivism is false.

Section 4. Pictorialism

If naturalistic objectivist accounts of visual space are incorrect, then it is tempting to resort to the view that visual space is something like a mental canvas, a pictorial mental frame contributed by the mind to experience. This view, which I call pictorialism, is also incompatible with what we have learned from the science of perception. Before defending this claim in the next section, I will clarify what I mean by pictorialism.

For pictorialists having visual experiences consists in filling in a mental frame or canvas with color sensations. On this view, having a visual experience of a blue patch next to a red one consists in creating a phenomenal mental picture in which a patch of blue sensations is placed next to a patch of red sensations on the mental canvas. Pictorialists equate visual space with this mental canvas and hold that the canvas is pictorial. What does it mean to say this canvas is pictorial? The answer to this question has been the subject of some philosophical controversy that has not produced much consensus.[38] I shall proceed by proposing a necessary condition that a mental representation needs to satisfy in order to count as a pictorial representation. My proposal is that having a pictorial geometry is a necessary condition for being a pictorial mental representation. By a pictorial geometry I mean a geometry in which fundamental pictorial notions such as points, lines, planes and distances are well-defined. This, in turn, requires the satisfaction of a certain set of fundamental axioms.

Mathematicians represent the conditions for the applicability of a pictorial notion to a space as a set of axioms that the space must satisfy. In the remaining of this section, I will explain a set of central axioms that are required for the applicability of the notions of distance and planes to a space. This will prepare the ground for determining whether pictorial notions are applicable to visual space by determining whether visual space satisfies these axioms. The next section argues that visual space violates these axioms.

[38] See Block (1983) for an overview of some of the proposals.

Mathematical approaches to the geometry of a space are divided into analytic and synthetic approaches. The analytic approach characterizes the features of a space in terms of a fundamental magnitude, e.g., distance. This magnitude is introduced in terms of the conditions of its applicability. For example, the notion of distance is applicable to a space that satisfies a set of axioms called the metric axioms. The notion of distance is not applicable to a space that does not satisfy these axioms. The metric axioms are:

- Identity: For all points x and y, d (x, y)=0 if and only if x=y.
- Positivity: For all points x and y, if x is not identical with y then d(x, y) > 0
- Symmetry: For all points x and y, d(x, y)= d(y, x)
- Triangle inequality: For all points x, y and z, d(x, z) + d (z, y) is equal to or greater than d (x, y).

Here, d(x, y) is the distance between two arbitrary points x and y. The first three axioms have strong intuitive support. Here is the reason for accepting triangle inequality. Suppose you have three points x, y and z that falsify this axiom, e.g., d(x, y) > d (x, z)+ d(z, x). It follows that the path that connects x to y through z is shorter than d(x, y). This would contradict the idea that d(x, y) is the length of the shortest path between x and y. Thus, the notion of distance, understood as the shortest path between two points, would not be applicable a space that violates triangle inequality.

Unlike the analytic approach that takes magnitude as a fundamental notion, the synthetic approach takes notions such as points, lines, planes, as well as relations such as congruence and incidence, as fundamental. The other features of a space are then analyzed in terms of these notions. Like the analytic approach, these notions are characterized by their applicability or well-definedness conditions. One particularly relevant axioms which determines the condition for the applicability of the notion of a plane to a space is the famous Pasch axiom:

- Pasch axiom: let A, B, C and D be four distinct points in a space. The lines AB and CD intersect at a point, if and only if the lines AC and BD intersect at a point.[39]

In principle, one can always find four points in a space that do not fall on a plane. But if the points are such that the lines connecting them pairwise intersect at one point, then the four points must be on a plane. But if this is the case then the other pairs of lines connecting them should also intersect (assuming that parallel lines intersect at infinity).[40] This is the intuition behind imposing Pasch axiom as a condition for the applicability of the notion of a plane to a space. Figure 4.1 illustrates this point.

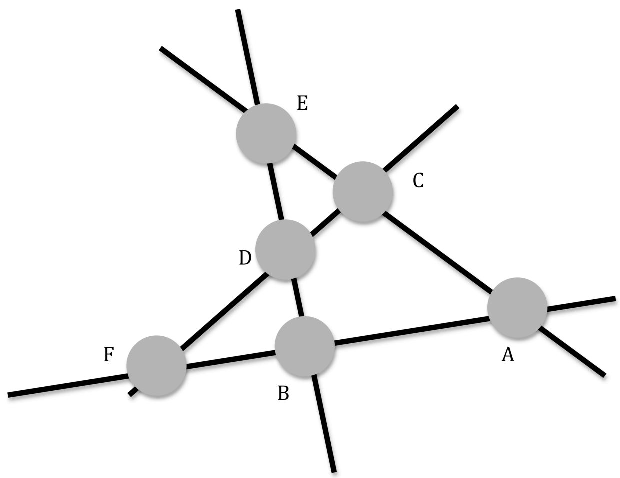

Figure 4.1 Pasch Axiom

The metric axioms and the Pasch axiom together yield some of the conditions for the applicability of the notions of distance and plane to a space. Since visual space cannot be regarded as pictorial unless the notions of distance and plane are applicable to it, visual space must satisfy these axioms to count as a pictorial space. The next section draws on classic and recent empirical literature to argue that visual space indeed violates these axioms.[41]

[39] We are assuming here that parallel lines intersect at infinity. Otherwise, this axiom would have trivial counterexamples.
[40] If we did not make this assumption, the Pasch axiom would have trivial counterexamples.
[41] One might try to reject pictorialism by arguing that visual experience includes aspects that cannot be explained in a pictorial way. For example, some hold that we experience causal relations, categories, affordances, conformity to action plans, expectations, or satisfactions or dissatisfactions of them, etc. It is also common to assume that these experiences are not pictorial experiences and conclude from this that

5. Does Visual Space have a Pictorial Geometry?

Since Stevens (1956), psychophysicists have agreed that the relationship between the perceived value of a parameter and its real value can be described by the following power function:

- **Power function: $P = S.R^E$**

Here, P is the perceived value of a parameter, e.g., perceived size, S is a scaling constant, R is the real value of the parameter, and E is the exponent of the power function. For example, assuming that S=1 and E=1.02, the power function predicts that the perceived value of the length of a 5 inch line must be about 5.16 inches.

Psychophysical studies show that the value of the exponent of the power function varies depending on stimulus conditions and experimental methods, but is almost never equal to one.[42] This value is often greater than one and in judgments that are based on memory it is lower than one.[43] Wagner (2006) uses these results to argue that visual space consistently falsifies the triangle inequality axiom.[44] Here is Wagner's line of reasoning.

Suppose you are looking at a line AB, which is twenty inches long. The line is divided, by a point C, into two parts AC and CB with respective lengths of 5 and 15 inches. Suppose the value of E is 1.05 and S=1. The power function formula predicts that the perceived lengths of AC, CB and AB should be:

- P (AC)= S. $15^{1.05}$ = 17.17
- P (CB)= S. $5^{1.05}$ = 5.41
- P (AB)= S. $20^{1.05}$ = 23.23

However, the sum of P(AC) and P(CB) equals 22.58, which is 0.65 inches less than P(AB).

pictorialism does not fully capture the richness of visual experience. We should note, however, that rich accounts of visual phenomenology are compatible with the view that visual experience has a pictorial core that is responsible for the experience of simple spatial properties. Denying pictorialism would require denying the existence of this pictorial core. It is one thing to adopt a thick view of perceptual phenomenology; it is another thing to reject pictorialism.

[42] See Wagner (2006) for a meta-analysis of over a 150 articles that measure the exponent of the power function in different experimental settings.

[43] Ibid pp.76-86

[44] Ibid pp. 62-65

In other words, the sum of the perceived values of AC and CB is smaller than the perceived value of AB. But triangle inequality would hold in visual space only if the perceived value of AB is equal to or lesser than the sum of the perceived values of AC and CB. We thus have a violation of triangle equality.

What we see in the above example is not an isolated finding. We can generalize Wagner's observation to prove that as long as the value of the exponent of the power function is greater than one triangle inequality is violated. The proof goes as follows:

Let AB be a line divided by point C into two segments AC and CB.

1. $P(AC)+ P(CB)= S.AC^E+S.CB^E$ (from Stevens law)
2. $P(AC)+ P(CB)= S.(AC^E+CB^E)$ (from 1)
3. $x>0, y>0, e>1: x^e +y^e < (x+y)^e$.
4. $E>1$ (assumption)
5. $P(AC)+ P(CB)<S.(AC+CB)^E$ (from 2, 3 and 4)
6. $P(AC)+ P(CB)<P(AB)$ (from 5 and Stevens law)

Therefore, if $E>1$ then $P(AC)+ P(CB)<P(AB)$.

The first premise applies Stevens law to our hypothetical case. Premise three is a simple rule of arithmetic according to which, for any real number e that is greater than one, and for all positive numbers x, y, $x^e +y^e < (x+y)^e$. Premise 4 is the assumption that the exponent of the power function is greater than one.

The argument shows that as long as the exponent of the power function is greater than one, the perceived size of a line is always greater than the sum of the perceived size of any arbitrary pair of complementary segments of the line, where an arbitrary pair of complementary segments is obtained by dividing a line into two segments by an arbitrary point on it. Thus as long as the exponent of the power function is greater than one we have a violation of the triangle inequality axiom. Since psychophysics tells us that in most circumstances the value of the power function is greater than one, we should conclude that in most circumstances visual space violates the triangle inequality axiom. But this axiom is one of the conditions of the applicability of the notion of distance to a space.

Since pictorialism requires the applicability of the notion of distance to visual space, pictorialism is in trouble.

The conclusion that distance is not applicable to visual space is very puzzling. How should we square this result with the intuition that we visually perceive distances? We should note that the type of violation that we see here is in effect the violation of the conditions for the applicability of a unique notion of distance to a space. These results are thus compatible with a view according to which we perceive distances, but the mathematical nature of perceived distance changes depending on contextual factors such as orientation, part-whole relations, magnitudes and locations. Threfore, the result does not imply that we do not perceive distance; it rather shows that our perception of distance is not uniform. This is not a very counterintuitive result, but it is incompatible with pictorialism, which holds that the nature of visual distance must be uniform.[45]

The pictorialist thus has to deny that Stevens law correctly predicts the perceived value of size in all conditions. This can take different forms. One is to hold that the law only applies to the perception of what sometimes is called intensive magnitudes, such as brightness or sound amplitude, but it does not apply to the perception of distance.[46] Another way to resist the argument is to hold that the law does not predict the perceived value of size in all circumstances, specifically in the presence of contextual clues.

The above are interesting reactions that should be taken seriously, an undertaking that goes beyond the scope of this paper. But let me mention a few lines of response. First, it is very likely that Stevens law is the result of a general feature of perception, namely that perception is subject to restrictions of just noticeable differences (JND) and JND is a function of stimulus magnitude. This is to say that: (a) the difference in the values of two perceivable magnitudes should be more than a threshold in order for us to be able to perceptually distinguish them and (b) this threshold is a linear function of these magnitudes. If it is correct that Stevens law results from facts about JND (something that I think can be proven mathematically) then the law should apply to all perceivable qualities

[45] There are ways to weaken pictorialism in order to accommodate non-uniformity. I shall come back to this issue at the end of this section.
[46] I have not seen this view in writing, but some psychologists have brought it up in conversation.

that admit of JND, whether they are intensive or extensive. Second, we have at least shown here that pictorialism conflicts with the applicability of an important psychophysical law that one can find in most psychology textbooks. In order to defend her view, the pictorialist has to show, by empirical studies, that this law is either false or its application is highly limited. Third, the result that visual space violates pictorial axioms is supported by empirical evidence that is independent from Stevens law.[47] In what follows I shall describe a recent result by Koenderink et al. (2010) that indicates that visual space violates the Pasch axiom.

Koenderink's experiment is divided into two steps, which each contain two tasks. In the first step, the subject is provided with three spheres A, B and C, which form a triangle facing the subject. B and C are farther away from the observer. In the first task the subject is asked to move another sphere, D, to a location where it seems collinear with A and C. The second task involves moving another sphere, E, to a location where it seem collinear with B and C (see figure 4.2).

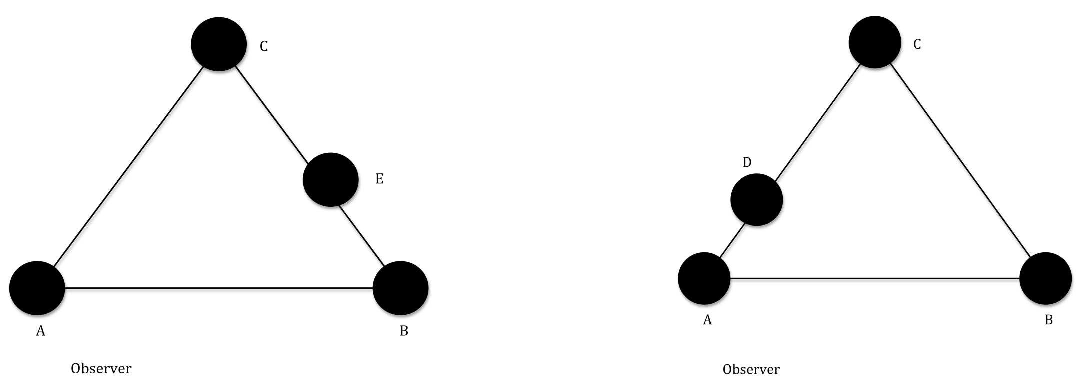

Figure 4.2
The subject is asked to move E where it seems collinear with B and C, and move D to a point where it seems collinear with A and C.

[47] Indeed, Koenderink et al. (2008) argues that the perceived direction of lines in visual space is not determined by their perceived locations. Ehrenstein (1977), Indow & Watanabe (1988), Indow (1990, 1991), and Koenderink et al. (2002) show that the geometry of visual space is task-dependent. Zimmer (1998) presents findings that show that visual space does not have a consistent geometry.

We now have a triangle ABC upon which the subject has placed points E (on BC) and D (on AC). Based on this configuration, the experimenter places a sphere, X, on a visual ray extending from the observer's point of view through the point where lines BD and AE intersect. In the second step of the experiment, the subject is first asked to move X forward to a point, P, where it seems collinear with B and D. In the second task the subject is asked to move X from its original position to a point, P', where it seems collinear with A and E (see figure 4.3). The experiment is done in a monocular setting on a two-dimensional display. The only depth cue is the size of the luminous points. The subject moves the luminous points in depth by changing their size. This enables the experimenters to compare the perceived depths of P and P' by comparing the size of X at P with its size at P'. As it turns out, the perceived depth of P and P' are not the same (see figure 4.3).

Eight of the sixteen subjects in the experiment perceive P and P' as located in different depths at a 5% confidence level. This result clearly violates the Pasch axiom. To be compatible with this axiom, the points P and P's should be perceived as located at the same place. Here is why. Consider points A, B, E and D. Lines AB and BE are perceived to intersect at C. It follows from the Pasch axiom that lines BD and AE should also intersect each other. But since P and P' are not perceived to have the same depth, BD and AE do not intersect each other.

Koenderink's result thus implies that the notion of a plane is not well-defined in monocular visual space. We should conclude that monocular visual space does not have a pictorial geometry. And it would be very strange if binocular visual space was pictorial while monocular visual space were not.[48]

[48] Indeed, Koenderink et al. claim that their result conforms to the results of Foley (1964), in a binocular setting.

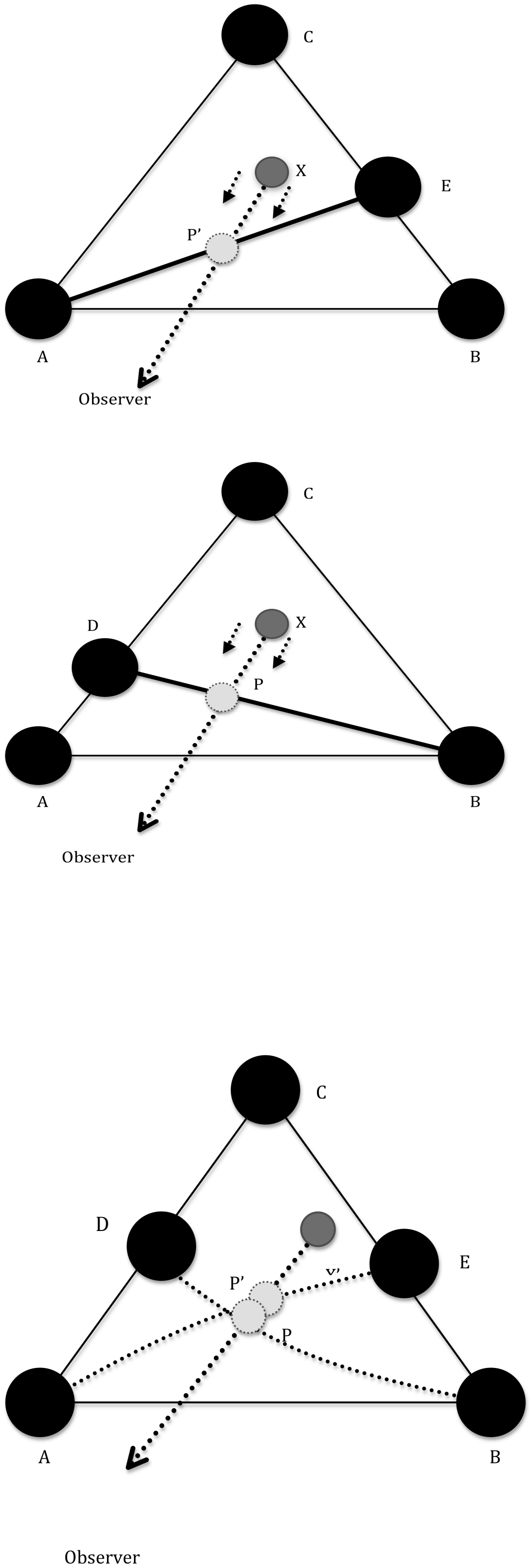

Figure 4.3. Step 2

The subject is asked to move X to the location, P', such that it is perceived to be collinear with A and E (top). The second task is to move X to a location, P, so that it is perceived to be collinear with B and D (middle). The results show that subjects do not perceive P and P' to have the same depth (bottom). This shows that subjects place P and P' on arcs BD and AE which do not intersect. This violates Pasch's axiom.

Steven's law and Koenderink's experiment thus imply that the idea of a pictorial visual space is problematic. As I said earlier, a body of independent experimental results also point to the same direction. Indeed it would have been strange if visual space satisfied the pictorial axioms. Neuroscience tells us that information about different spatial properties is processed in different pathways and is subject to different contextual influences. The neural correlates of the representations of spatial properties such as lines, angles, edges, shapes and orientations causally interact with each other. But the existence of a unified visual space with a consistent geometry would require that the contents of these representations be forced to fit into one single set of axioms determined by one single geometry. This seems very unlikely.

The pictorialist might try to save her view by holding that visual space consists of a multiplicity of pictorial canvases. We cannot judge this general strategy before seeing it developed in detail. But let me say a few words by way of raising a general challenge. We experience visual space as a spatially unified field. Thus the multiple canvas view has to explain what phenomenally binds the multiple canvases together. Now, it seems that the pictorialist has two options to answer this question. Either she holds that these canvases are bound together by a pictorial meta-canvas or that they are bound together by a non-pictorial binder. The first strategy would take us back to the idea of a single pictorial frame.

On the second strategy, what binds the multiple canvases together is not pictorial. But now we can ask if this phenomenal binding relation is a phenomenal spatial relation. It seems to me that the pictorialist cannot answer this question negatively, because what seems to make visual space a unified field is that we see things as located in the same space. So the phenomenal binding relation must be a phenomenal spatial relation. But if the pictorialist accepts that the phenomenal binding relation is a phenomenal spatial relation and at the same time argues that the binder is not pictorial she has to accept that some phenomenal spatial relations are not pictorial. This would be, at best, to give up pictorialism in favor of a hybrid view.[49]

[49] I think hybrid views would run into the problem of accounting for what we might call the homogeneity of visual space. By this I mean the claim that visual spatial relations seem to be phenomenally of the same type. I shall leave this issue for future research.

5. Conclusion

Empirical research shows that visual experience does not have a Euclidean, spherical or hyperbolic geometry and systematically violates some fundamental pictorial axioms. In this paper I have argued that these results have significant philosophical implications about the nature of our perceptual experience. In particular, they put pressure on both naturalistic objectivist and pictorialist accounts of visual experience.

In reaction to the challenges in this paper objectivists can give up naturalism. An analogous claim about color experience is that colors are not instantiated in our world and color experiences are non-veridical.[50] Another option is to hold that the direct objects of spatial perception are mind-dependent properties. Some philosophers hold a similar view about color experiences. Both of these options seem at least initially much less appealing than their analogues about color experience, because the motivation for these views about color partly comes from the difficulties in naturalizing colors and this motivation is absent in the case of spatial properties.

It thus seems that we should look for other accounts of spatial perception. Fregean representationalists and non-relationalist views are candidates. But these views are general frameworks rather than specific theories. To have a positive account we need to know what Fregean modes of presentation or phenomenal spatial properties are in non-pictorialist terms. In fact, non-pictorial alternatives have a long history. Descartes and Malebranche, for instance, both seem to have rejected pictorialism in favor of the view that space perception is a form of judgment.[51] Berkeley also rejects the pictorial account, claiming that visual experiences acquire their spatial content by way of association with tactile and motor experiences. Kant, as I said earlier, is often regarded as a pictorialist. But it is not clear to me that this interpretation captures the gist of his view. An interpretation according to which visual space is constituted by consciousness of the rules that govern the synthesis of the manifold of experience is an option worth exploring.

[50] See Chalmers (2006) and Pautz (2006).
[51] I find the claim about Descartes to be strongly supported by textual evidence, but I have realized in conversation with experts in the field that many regard Descartes as a pictorialist.

Analogues of some of these historical views exist in the contemporary literature in various forms. One might regard Pylyshyn's computationalist accounts or even Dennett's multiple drafts view as the contemporary analogues of the views that I have ascribed to Descartes and Malebranche. Others have attempted general Berkeley-style accounts.[52] There is also room for a Kantian account along the lines that I have suggested above. Though these views have their own problems and challenges, I believe that they point at a direction where philosophical progress can be made.

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[52] Noe (2004) and Schwartz (1994) are good examples.

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