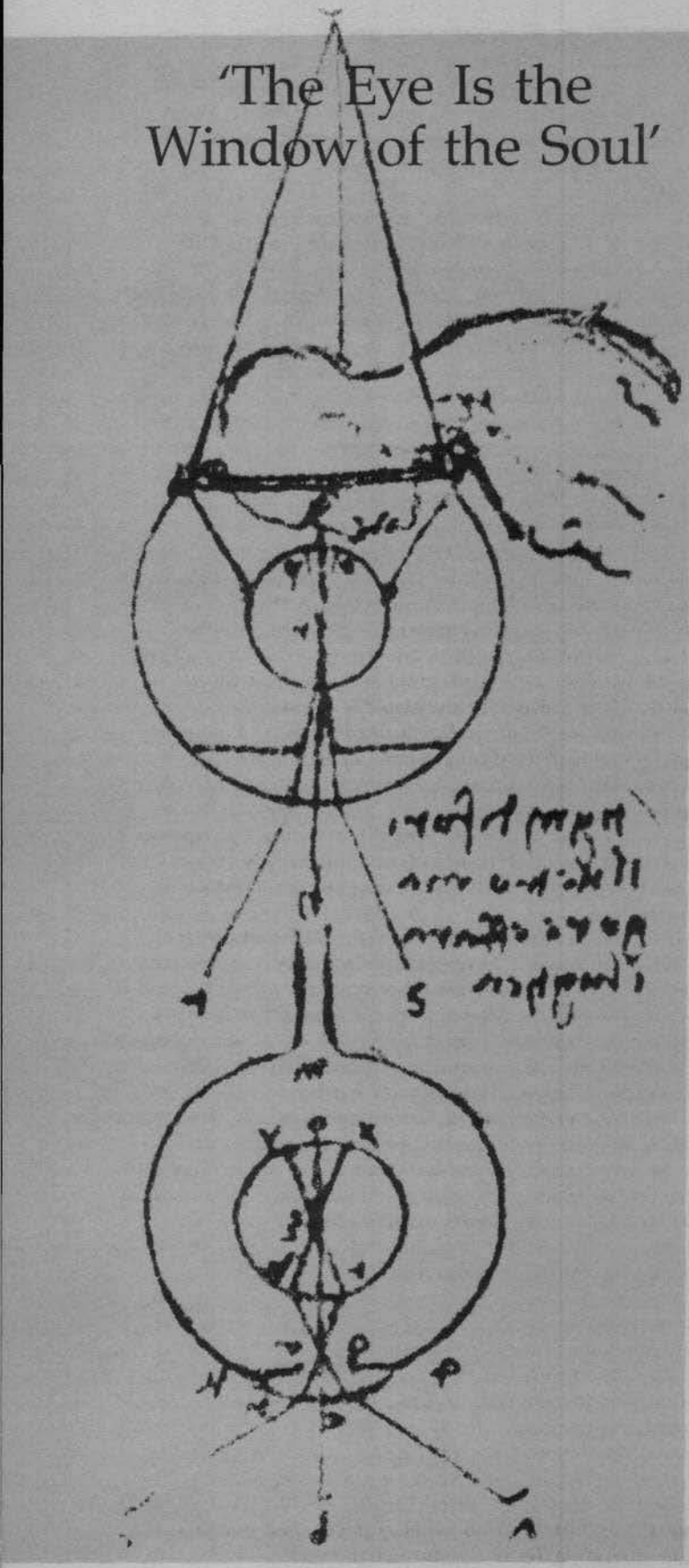



# Leonardo da Vinci's Science of 'Prospettiva'

*The ancient theory of human vision, based on the soul, is confirmed by Leonardo.*

by Robert L. Gallagher

Leonardo da Vinci's advances in the science of perspective developed from his penetrating investigations into optics and human vision. In Leonardo's Italian, *prospettiva*, usually translated today as perspective, simply means optics, and by Leonardo's definition, optics or *prospettiva* "is nothing else than a thorough knowledge of the function of the eye." [A. 3a; Richter 50][1]

The theory of vision Leonardo adheres to and elaborates is very different from the modernist theory with which the reader may be familiar. Leonardo's *prospettiva* cannot be grasped unless it is approached from the theory of vision that guides his work.

From ancient times through the Renaissance, most thinkers held that perception is the result of an act of the soul outwards, to form the image seen or the sound heard out of a sensory continuum.[2] The eye is conceived of as an instrument of the soul, not a passive receiver of images. These views flow from the perspective that the soul is ontologically prior to all bodies that subsist in discrete time and space. While all things change with different temporal and spatial conditions, the soul undergoes change only in time, and because of that is prior to all bodies, writes St. August-

ine in his *De Musica*: "The form changeable only in time is prior to that changeable both in time and place." [6,14,44][3] This Augustinian view of vision is part of the Renaissance culture that produces Leonardo and guides the work of his predecessors in optics, for example, John Pecham, whom he studied.

In contrast, the modernist theory of vision rejects the Christian view that the metaphysical nature of the soul is the basis of human vision. The modernists assume that objects imprint their images on the mind as though it were a blank slate, a Lockean *tabula rasa*. They make no distinction between sensation and perception, and deny there is a need for a judgmental process of the human mind to form complete images out of raw sense data. For the modernists, focused images arrive already formed on the surface of the retina by virtue of the optical characteristics of the atmosphere and of the eye. The retina serves only as a passive viewing screen for the brain, as in a *camera obscura*.

The modernists posit a point-for-point correspondence between images on the surface of the retina and the visual field, with the brain analyzing this digital image as a computer would. By this theory, the human mind and soul are at best mere epiphenomena of the mechanics of sensory stimulus and motor response.

The modernist view appeals to naive prejudice: We "see" only complete images; we are not conscious of a judgmental process. Vision appears self-evident. It seems plausible that images are formed on the retina and that we simply observe them.

Reflecting the modernist theory that the eye is a passive viewing instrument, M.H. Pirenne, one-time lecturer in physiology at the University of Oxford, writes in his *Vision and the Eye*: "The human eye acts like a *camera obscura*, an image of the objects outside being formed on the retina by the transparent refracting media of the eye. The essential principle is the same as a photographic camera. . . ."[4]

Pirenne's beliefs lead him to hypothesize a completely "objective" art, dissociated from human vision and the human mind. He concludes that "the perspective drawing made for a fly's eye will be the same as that for a man's eye."

A completely different attitude toward vision and the senses is expressed by the thinkers who played the greatest role in shaping the Renaissance, of which Leonardo's work is the most advanced expression in science. St. Augustine, for example, argues convincingly that hearing or vision could not exist without the judgmental processes of the soul.[5] Leonardo elaborates this viewpoint, contending that images are not presented to the mind preformed on the retina and that judgment is a necessary function of the human mind. In his "Treatise on the Eye" he writes:

> From this surface [of the retina] . . . the species are taken by the *imprensiva* and transmitted to the *senso commune* where they are judged [D. 2b; Strong 9].
>
> The soul seems to reside in the judgment, and the judgment would seem to be seated in that part where all the senses meet; and this is called *senso commune*. . . . The *senso commune* is the seat of the soul, and the memory is its ammunition [munitione] and the *imprensiva* is its standard of reference, since the sense waits on the soul and not the soul on the sense [W. An. IV 202a(B); Richter 838].

Source: D3b; Keele 206

*A drawing from Leonardo's manuscripts of an experiment with a model of the human eye.*

By this view, the visual image is not formed passively on the retina but rather is synthesized by the human judgmental faculty, which Leonardo situates in a specific ventricle of the brain.

The two views of perception, classical and modern, express fundamentally divergent attitudes toward aesthetics. The important question is: Do the harmonies we experience through the fine arts have their origin in the physical art object itself, that is, the painting seen, or the music heard, or do they have their origin in the soul of the viewer or hearer?

If sensory data act directly upon the mind, with no judgmental process intervening, we would be forced to conclude that the harmonies we experience originate in the art itself as an object or sense datum in discrete time and space. But sense data are ephemeral and have no lasting existence. They could be viewed as characterized by arbitrariness rather than harmoniousness. Under these conditions, how could art inspire us with any appreciation of the lawful nature of the universe? How would art even be possible?

Augustine raises this in *De musica* and resolves this problem by stating that although the world itself is fundamentally harmonic, we can know this only by reference to a standard of judgment that our souls receive from God. From this standpoint, Leonardo embarks on a thorough investigation of optics and vision and establishes anew a scientific basis for the relation of that sense to human knowledge.

### On the Action of Light in the 'Luminous Atmosphere'

Leonardo's work on optics may be divided into several progressive levels of investigation: (1) how light acts in the atmosphere to produce the optical substrata required for vision: (2) how passive optical instruments like the *camera obscura*, lenses, and mirrors function; (3) how the eye functions; (4) Leonardo's *prospettiva naturale*; (5) Leonardo's *prospettiva divina*; and (6) his aesthetics. In the course of elaborating his *prospettiva*, Leonardo develops his critique of linear perspective. These headings are usually considered distinct subjects treated by Leonardo, but as this investigation shows, and like his work in anatomy and physiology, these are not self-standing "sciences" but rather subordinate parts of his *prospettiva*.

In the first part of his investigations Leonardo asks the question: Do objects themselves produce the images that we see with the eye? To the contrary, Leonardo says that images are produced by the action of light in the atmosphere. He begins by describing the optical activity continually taking place in the atmosphere, and he emphasizes that light is continuously interacting upon the surfaces of bodies around us. The same light by which you see this printed page scatters elsewhere in the room where you are sitting, interacts on other surfaces, and conveys, for example, an image of a picture on the wall.

Extending this thought, Leonardo writes that every object in the atmosphere could be said to be covered with the images of every other object in the atmosphere. We can imagine an eye or camera positioned anywhere on any surface, able to see or record images of all other objects. In this way, all surfaces are illuminated by the light that carries the images of other surfaces. In this continuous interaction, only two things about the light change—its color and the geometric form it conveys.

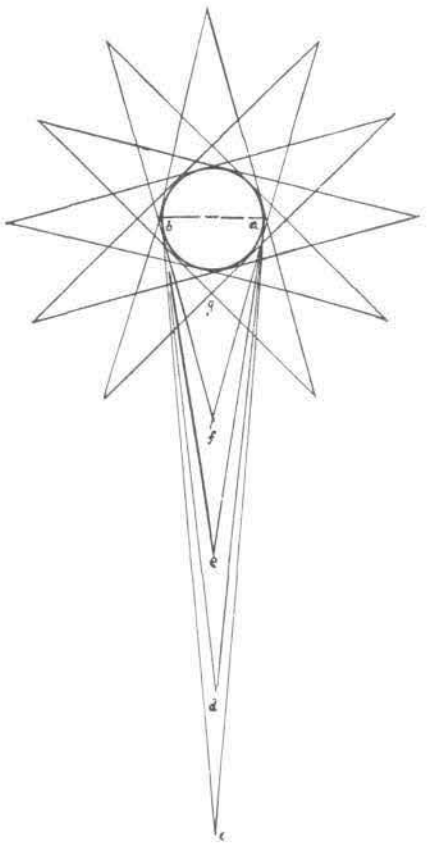


**Figure 1**
**PYRAMIDS OF LIGHT RADIATE SPHERICALLY FROM ALL SURFACES**

*Leonardo describes the action of light using this figure, which shows pyramids of light radiating spherically from the surface of a sphere. He writes: "Every body in light and shade fills the surrounding air with infinite images of itself, and these by infinite pyramids infused in the air, represent this body throughout space and on every side. . . . A circle of equidistant pyramids of converging rays, gives to their object angles of equal size; and the eye at each point will see the object as of the same size. . . .*

*"The atmosphere is full of infinite pyramids composed of radiating straight lines which are produced by the boundaries of the surfaces of the bodies in light and shade placed in the air; and the farther they are from the body which produces them, the more acute they become. . . "*

Source: Ash. I. 27 IIa; Richter 63

To characterize the action of light more precisely, Leonardo develops the construct *pyramid* of light. The interaction and scattering of light upon surfaces produce *pyramids* of light that propagate through the atmosphere and carry optical information on the surfaces at which they were formed. The surfaces of bodies form the bases of these pyramids, which emanate spherically in all directions from an object (Figure 1). Leonardo writes, "Every body in light and shade fills the surrounding air with infinite images of itself, and these by infinite pyramids infused in the air, represent this body throughout space and on every side" [Ash. I. 27 IIa; Richter 63].

At every point in the atmosphere, pyramids converge to an apex where the images they convey can be accepted by the eye or recorded by a camera. Leonardo proved this with the *camera obscura*, a device that admits pyramids of light through a pinhole that may be positioned anywhere in the atmosphere, and displays the images carried by the pyramids on a translucent screen.

Vision, Leonardo writes, is dependent on the formation of optical pyramids in the luminous atmosphere. These pyramids are formed by the scattering of light from "the boundaries of surfaces of bodies in light and shade." However, these boundaries and surfaces are not part of the bodies themselves, he writes. They are only the "medium"—or in modern scientific terminology *the surface of discontinuity*—separating bodies from each other and from the air. These surfaces have no independent material existence.

For example, what is the surface separating your hand from a table top on which it rests? Look at it where your hand meets the table. Is the surface part of your hand or part of the table? Now move your hand. What happened to the surface?

These surfaces seem to have only an illusory existence, yet they play an important role in optics. When light is reflected or refracted, it is turned in its direction of propagation "inside" the surface of discontinuity separating the air from objects or from water. Physicists speak of this surface as the "interface" separating two media of propagation. In reflection, for example, there is nothing to suggest that the bodies of objects themselves have anything to do with the phenomenon aside from being that which is enclosed by the surface of discontinuity that bounds the luminous atmosphere. Surfaces exist only incorporeally, Leonardo explains:

> The boundaries of bodies are the least of all things. The proposition is proved to be true, because the boundary of a thing is a surface, which is not part of the body contained within that surface; nor is it part of the air surrounding that body, but is the medium interposed between the air and the body. . . . The lateral boundaries of these bodies is the line forming the boundary of the surface, which line is of invisible thickness [G. 37a; Richter 49].

The surface is a limitation of a body and the limitation

of a body is no part of that body and the limitation of one body is that which begins another. That which is not part of any body is nothing [Br. M. 131b; Richter 45].

From these remarks we may conclude that material bodies themselves are of discrete time and space but the surfaces by which we see them are not; they originate from the universal, timeless, and metaphysical nature of incorporeal form.

Leonardo elaborates this with respect to that part of a boundary which outlines a figure, from the standpoint of his wave theory of light. The wave nature of light allows us to see around this surface, to see around corners, so to speak. That is, the optical pyramid formed in the atmosphere from the surfaces of bodies—and by which we see objects—contains light reflected from surfaces that are not exposed to direct view and do not lie in a straight line with the eye or the apex of the pyramid. This is possible because every point of a light wave emanating from a surface becomes a point source for the spherical radiation of further light waves (the so-called Huygens principle). As a result, light waves reflected from a surface that is not on a straight path to the eye can reach the eye though this secondary, spherical emanation of light along the fronts of waves reflected from that same surface.

Consider the surface presented to the eye by the petals of a flower. Peonies present to the viewer a surface composed of a multiplicity of petals, one next to the other. The wave nature of light enables us to see far more of the surface of the petals than would be possible if light traveled only in straight line rays—perhaps as much as 10 percent more.

Because of the wave nature of light, the base of Leonardo's pyramid of vision encloses a greater surface than the surface that lies in a straight path to the eye. The eye is presented with information that enables it to *wrap around* the surface. From an optical standpoint, the pyramid of vision out of which an image is formed includes waves outside the rectilinear pyramid that embraces the light from the surfaces on a direct line to the eye; that is, light waves generated from wave fronts that originate from surfaces not in a direct line. As a result, Leonardo's pyramid extends asymptotically at its base. If it were drawn, it would appear more like a *caustic pyramid*—a surface produced by rotating a caustic about its axis—than a "normal" rectilinear pyramid, but one in which the asymptote wraps about a surface (Figure 2).

This asymptote produced from surfaces not in a direct line of sight constitutes the optical boundary surrounding an object and naturally intermingles with that of an immediately adjacent figure. Therefore, boundary simultaneously conveys *figure, depth, roundness, and connectedness.* Leonardo writes, "The boundary of one thing with another is of the nature of a mathematical line, because the end of one color is the beginning of another color and is not to be called [a physical] line . . . the boundary is a thing invisible" [Trat. 486; McMahon 506].

Many commentators have noted that Leonardo treats boundaries and form in general very differently and more gracefully than other artists, that he makes the boundary of one figure fade or blur into another. Here we have presented the philosophical and scientific basis of this feature of his "technique."

Leonardo regarded the sort of pyramid in Figure 2 to represent the geometry of all fundamental physical processes.

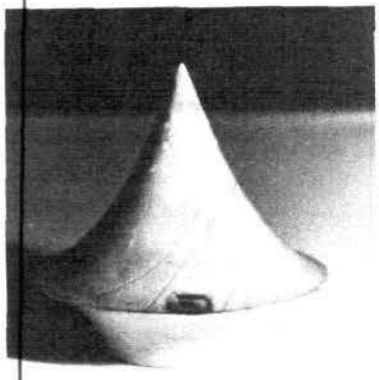
In summary, according to Leonardo, bodies themselves do not produce the optical pyramids that fill the atmosphere; rather, they are produced in the luminous atmosphere by the interaction of light with the surfaces that envelop bodies. With this one investigation, he knocks the props out from under the theory of vision that assumes sight to consist of objects acting upon the human mind. As he writes, "Therefore we may rather believe it to be the nature and potency of our luminous atmosphere which absorbs the images of the objects existing in it, than the nature of the objects, to send their images through the air" [C.A. 133b; Richter 70].

Leonardo sets forth the continual optical activity taking place around us. "Our luminous atmosphere absorbs the images of objects, like a lodestone," he writes. The images are carried by nonlinear pyramids of light produced from the interaction of light with the surface of discontinuity separating objects from the air. Objects themselves do not produce images.

### The Properties of a 'Passive Eye'

Leonardo analyzes an instrument that passively collects images from the atmosphere, in order to lay the basis for understanding what the eye and the judgment uniquely and *actively* contribute to vision. With this he completes his investigations of the optics of the luminous atmosphere.

Leonardo uses a *camera obscura* (dark chamber) to view



Dino de Paoli

**Figure 2**
**THE CAUSTIC 'PYRAMID'**

*The wave nature of light transforms the shape of the "pyramid" of vision from a rectilinear pyramid of rays into a nonlinear caustic surface. A caustic is an optical surface produced by the action of a spherical lens or mirror. (See Figure 7.) The model in the photo was built by the 19th-century Italian physicist Eugenio Beltrami.*

the images carried by the optical pyramids in the air. To construct a *camera obscura*, find a small room with a single window that faces north and seal it from all light; for example, using a frame of wood covered with light plywood. Attach a thin brass plate over a hole in the plywood and drill a hole in the plate "the size of a millet seed." (One photographer suggests using a drill bit 1/64 inch in diameter.) Place over the hole a small box about 6 inches deep and open in front, and replace the back of this box with a piece of white tracing paper.

Assuming there is light outside, the pinhole will serve as a guide for those pyramids of light that happen to converge to a point at the pinhole (that is, their apices coincide with the pinhole). These pyramids pass through the pinhole into the box and then diverge, opening up until they encounter the tracing paper. There they stop and "paint their images" on the screen (Figure 3). A person inside the room would be able to see a live color "movie" of activity and objects outside, displayed on the transparent screen by means of these pyramids of light.

The *camera obscura* is based on producing a one-to-one, point-for-point mapping onto the viewing screen of the optical surfaces on a direct line with the pinhole. Because the pyramids that carry the images come to a point at the pinhole and then diverge to the screen, they paint the images upside-down and reversed in orientation.

The images displayed inside the *camera obscura* have the following properties:

*The images are harmonic.* Harmonic proportion is a characteristic of optics. The action of light in the atmosphere composes an image into optical pyramids in such a way that the part is lawfully related to the whole. Optical harmonics will compose an indefinitely long sequence of equally spaced objects, such as an image of equally spaced railway ties, so that the closest part is in proportion to the next closest, as the whole is in proportion to the remainder.

*The images are all in focus, but at the same time are all slightly out of focus.* All images are in focus to the same extent; there is no differentiation in focus between center and periphery or foreground and background. There is no focal plane in the picture displayed by the *camera obscura*. Also, the focus cannot be changed or directed in any manner.

*The images are somewhat distorted.* If the screen on which the images are displayed is flat, the images directly opposite the pinhole will convey the shapes of the objects they are imaging correctly, while the images peripheral to this area will be *distorted*; the farther they are from the pinhole, the more they will be distorted.[6]

These distortions can be minimized by changing the shape of the surface on which they are displayed. A viewing screen that has a spherical surface with its center of curvature at the pinhole will minimize distortions, limiting them to some curving of linear structures. Other concave surfaces—a parabolic surface, for example—are useful as well.

### The Human Eye

Unlike the *camera obscura*, the human eye displays a tremendous differentiation in visual acuity between the center and the periphery of vision. It produces and shapes

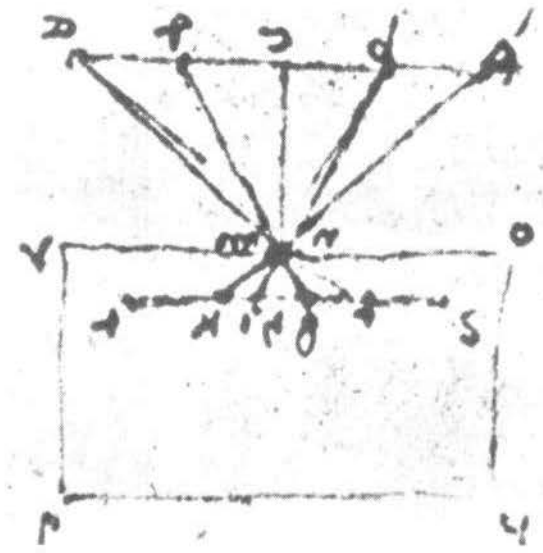


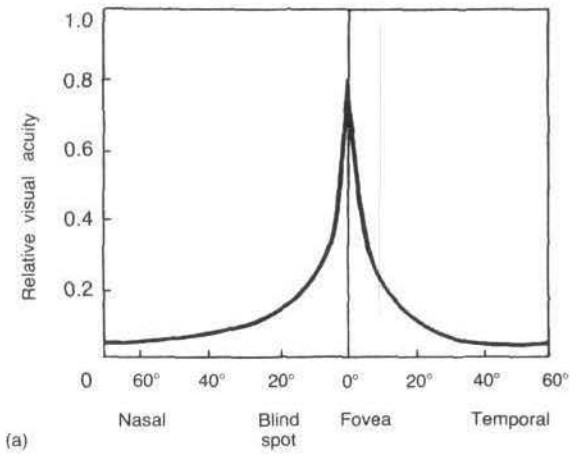
**Figure 3**
**THE *CAMERA OBSCURA***
*One of Leonardo's many drawings of his experiments with the camera obscura. The objects at top are illuminated and their images are reflected through a pinhole into the darkened chamber. Their images appear there upside down and transposed right to left.*

Source: D.8a; Keele 56

a composite visual image by varying the distinctness with which objects appear in the field of vision. It sharply focuses the center of the visual field while deemphasizing the periphery. Leonardo stresses that this is the most important property of the human eye, and he places it first in his "Treatise on the Eye." As he writes, "Nature did not distribute power equally in the visual virtue, but gave this virtue increasingly greater power toward its center" [D. 1a; Strong 1].

Leonardo states that "the power of vision" is greatest at the center or *fovea* of the retina and progressively decreases away from the center, and he compares the shape of its variation to that of a "pyramid." The example in Figure 4(a) from Hochberg's book *Perception* shows this to be a caustic pyramid. The figure shows the rapid fall-off in the ability of a person to distinguish two objects as they are reflected onto the surface of the retina farther and farther away from the fovea. It shows just how differentiated human vision is—unlike the passive *camera obscura*. Rather than accepting the homogeneous visual field that is presented to it, the eye creates discontinuity by creating a focus for vision and organizing the entire visual field around that focus. Were the eye to passively rely on the optical properties of the atmosphere, we would not be able to "see" the way we are accustomed to.

The difference in visual acuity between the center of the retina and the periphery is very great. Leonardo also compares it to the sight of a gun, stating that surfaces directly opposite the center reflect light into the eye as "into the



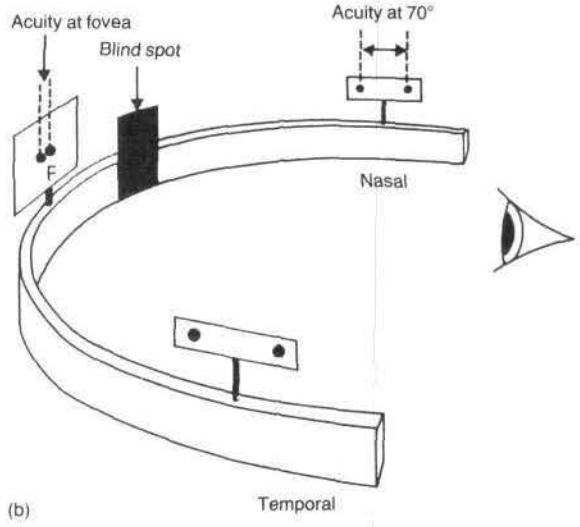




**Figure 4**
**THE CAUSTIC PYRAMID OF VISUAL ACUITY**

*The variation in visual acuity over the surface of the retina has the shape of a nonlinear "pyramid" (a), as discussed by Leonardo in his "Treatise on the Eye." In the experiment shown in (b), the images of two dots are shone onto the surface of the retina from various positions along the curved bar while the subject maintains his focus on F. The spacing between the dots on the bar is increased from zero (where the subject may report that he sees only one dot) until the subject reports that he sees two.*

*The spacing between the dots required for the subject to distinguish between them increases the farther into the periphery the dots appear; their spacing becomes a measure of relative visual acuity. When the dots are shone on the fovea, no spacing between them is required for the subject to tell them apart. Position on the retina is given in angular degrees from the fovea. Visual acuity is expressed on the vertical axis as a fraction of the visual acuity at the fovea.*

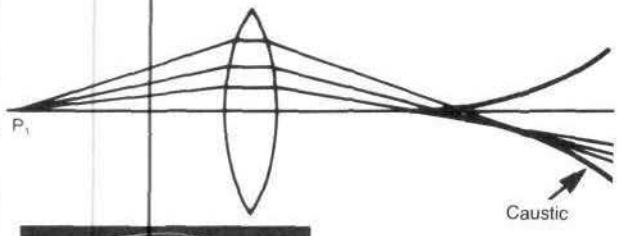
Source: Julian E. Hochberg, *Perception* (Englewood Cliffs, N.J.: 1964), p. 26

barrel of a carbine" [C.A. 220b; Keele 70].

Leonardo does not confine his investigations of the eye to an analysis of subjective acuity; he also investigates how the organ transforms the optical pyramid it finds at the pupil and presents it to the retina—the "visual virtu." He shows rather convincingly that no nicely focused images are formed on the surface of the retina; instead, the optics of the eye presents the retina with spatially differentiated light interference patterns formed from the light reflected from the surfaces of objects. These "are taken by the *imprensiva* and transmitted to the *senso commune* where they are judged"; that is, where the image we see is synthesized.

The light that conveys optical pyramids to the retina of the eye first passes through the lens of the eye. A normal "spherical" lens, like that of the eye, will form the light that passes through it from a "point source" not into a point, but into an interference pattern in the shape of a caustic pyramid or surface. This is a transformation of the surface of the spherical lens into a surface of negative curvature, as shown in Figure 5, from Max Born and Emil Wolf's *Principles of Optics*. Instead of focusing the light to concentrate its rays at a point, a spherical lens will direct it so that the light intersects itself at different points all along the caustic surface. There the light will interfere with itself, with the points of intersection/interference forming a caustic.

Leonardo shows this in the drawing in Figure 6, which illustrates how the lens of the eye forms the point light source *p*—a pinhole through which the image *mb* is constrained to pass—into an envelope of light. Figure 7 is



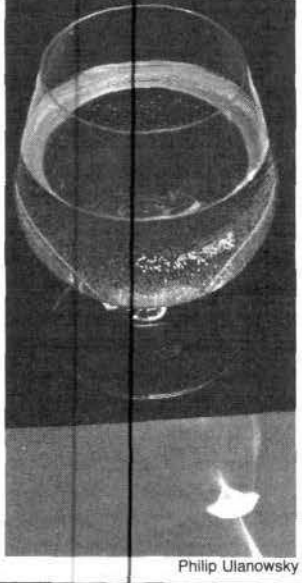




**Figure 5**
**A SPHERICAL LENS FORMS A POINT LIGHT SOURCE INTO A CAUSTIC SURFACE**

*The shape of the image of a point light source ($P_1$) formed by an "uncorrected" spherical lens is not a point, but a caustic surface. (The solid is shown in Figure 2.) As in the photograph, a caustic is produced when a beam of light is directed at a fluid in a glass.*

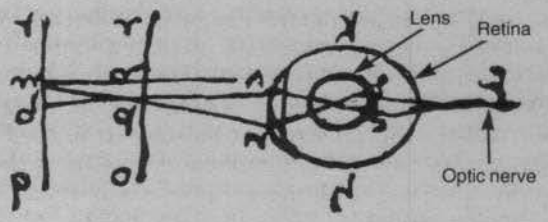



**Figure 6**
**LEONARDO'S DRAWING OF THE ACTION OF THE LENS OF THE EYE**

*This drawing from Leonardo's "Treatise on the Eye" shows that the lens of the eye (the sphere in the center of the eye) forms the pyramid of light emanating from a point of light* p *(shining through a hole in the screen* or*) and brought to a point again by the cornea, into another "pyramid" of light whose base is presented to the retina.*

Source: D. 2b; Strong 9

one of Leonardo's studies of how a spherical mirror forms a point source of light into a caustic surface.

All spherical lenses behave like the lens in Figure 5. They are the easiest lenses to make since they derive from the sphere, a least-action surface; a spherical lens is so composed that any section through its center produces a section of a sphere. Indeed, it is also suggested that the lens of the eye behaves like a spherical lens by the fact that when the lens is removed from the eye, it opens up into a sphere.[7]

A considerable amount of the labor of optical engineers over the centuries has been devoted to "correcting" spherical lenses for use in man-made optical instruments, so that they focus light from a "point source" to a point. This is accomplished by producing a lens with the optical characteristics of the central portion of the lens in Figure 5—the portion that produces the sharp point of the caustic. The process of producing a "corrected" lens can be seen as a geometrical transformation; the lens in Figure 5 is flattened so that it everywhere behaves only as its central portion. Figure 8 gives an example from Pirenne of a corrected lens focusing a point source of light to a point.

The fallacy of such endeavors is revealed by examining the fiction "point light source." In reality, no such thing exists in nature. Every light source takes up space and has geometrical shape. The light that any source reflects makes its shape knowable.

By forming the light from a source into a caustic surface, a spherical lens preserves the spatial variation in the light it reflects. Examine again Figure 5. The area around the point of the caustic is formed from light that passes through the center of the lens from that portion of the source directly opposite it. The surface that proceeds from the point, however, is composed of light that passes through the periphery of the lens from other regions of the source; the farther into the periphery of the lens, the farther along the surface is the light directed, coming from more distant regions of the surface of the source.

"Correcting" a lens destroys this spatial differentiation. Everything is jumbled together and the resulting image is flat and without true optical depth. The "correction" destroys the caustic, which carries the spatial differentiation of the light source.

This all suggests that the lens of the human eye—which is not flattened like a corrected lens and, more important, was made by God and not technicians—acts as a least-action-surface spherical lens and forms a point source of light into a caustic. Modern vision theorists like Pirenne, however, make the arbitrary assumption that the lens of the human eye behaves like a corrected lens, forming light from a "point source" into a point. With this, they maintain the erroneous view that the image we see is formed on the retina, that the eye is a passive instrument and functions like a *camera obscura*, and that the retina is like a movie screen.[8] But if the lens of the eye does not function like a corrected lens, then the eye does not form distinct images on the retina and a human judgmental faculty is required to synthesize the images we see.

Does the eye function "like a *camera obscura*," as Pirenne claims? Leonardo writes in his "Treatise on the Eye" that all the *camera obscura* shows us is how pyramids of light may enter the eye. It tells us nothing of how the eye transforms them.

Unlike the *camera obscura*, the eye does not produce a one-to-one, point-for-point mapping of the objects before it, onto the surface of the retina. The light emanating from a "point source" does not come to a point on the retina. Instead, the eye appears to spread over the surface of the retina an interference pattern of the light reflected from a "point source." Many points of the retina receive light from a single "point" on the surface of a luminous object. It is as though every point of the retina "sees" every point of an object or, as Leonardo writes: "Each point of the pupil sees the whole object and each point of the object is seen by the whole pupil" [D. 2b; Strong 15].

It is the transformation of each "point source" of light into a caustic surface that allows us to see as we do, for this preserves the wealth of sense data carried by the wave interaction of light. This wealth of optical information cannot be utilized by the *camera obscura* because, like any camera, it lacks a judgmental faculty and must present an image that is a mere point-for-point correspondence, a dead thing. The appropriate model for the way light from a "point source" is shaped by the eye is not that of modernist Pirenne in Figure 9, but may very well be that of Figure 6 from Leonardo's "Treatise on the Eye."

### Physiological Vs. Engineering Optics

It is necessary to distinguish between physiological optics and engineering optics. The latter is concerned with the design of devices to produce sharp images for viewing by our eyes—for example, photography and television. These devices do not reproduce the optical process of the eye; if they did, they would be no use to us, since we already have eyes. What photography does provide is a means to reproduce for future reference and at lower fidelity the pyramids of light emanating from a scene at a specific time and place.

Physiological optics, on the other hand, is concerned with the study of how the eye transforms optical pyramids into an interference pattern and how the human judgmental faculty interprets this pattern. The difference between engineering optics and physiological optics is seen whenever we take a photograph of a beautiful sight. The photo never looks as good as the original scene did to the eye because the images produced by photography are formed without the intervention of the synthetic power of judgment.

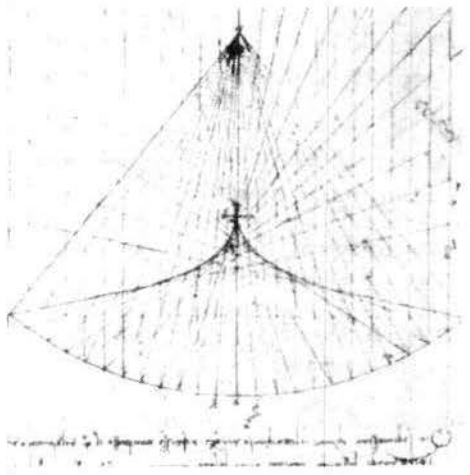


**Figure 7**
**A DRAWING BY LEONARDO OF HOW A SPHERICAL MIRROR FORMS A CAUSTIC**
*Leonardo's drawing shows how a spherical mirror forms light from a "point source" (at top) into a caustic surface.*

Source: Br. M. 87b; Nicodemi 423

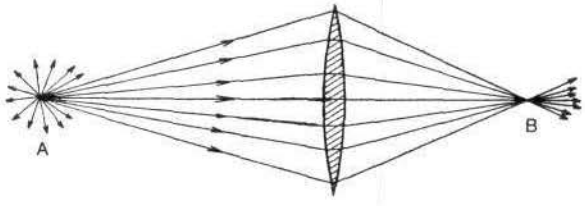



**Figure 8**
**THE ACTION OF A 'CORRECTED' LENS**
*A spherical lens that has been "corrected" or flattened forms "a point source of light" into a point. This may be a useful lens for cameras or movie projectors, but if the lenses of our eyes were to behave like this, everything we see would be lacking in the quality Leonardo calls "roundness."*

Source: Adapted from M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), p. 7

The example of the modern hologram confirms much of Leonardo's optics. Holograms demonstrate that the optical pyramids, by which we see, are produced from surfaces rather than from the objects they surround. A hologram allows us to see a continuous "3-dimensional" image of a scene without the presence of the objects imaged. The image can be "seen" from multiple directions as though the bodies in it were truly there; their surfaces appear completely represented.

The hologram technique, a recording method invented in 1947 by Dennis Gabor, is based on reproducing the light pattern of the apical portions of the pyramids of rays emitted from a scene. The viewer of the hologram display synthesizes the remainder of the pyramids right down to their bases at the surfaces of the objects. He sees the surface without the objects being present—thus confirming that the judgmental faculty synthesizes the images we see.

In a hologram recording process, a light source irradiates the objects to be recorded and, independently, the film being exposed. The light reflected by the objects interferes at the surface of the film with the light that is irradiating the film directly. This interference pattern is recorded on the film. The developed film is then irradiated by the original light source, and the interaction of the light with the interference pattern recorded on the film re-creates the pyramids of light produced from the surfaces of the objects originally, to be seen by a viewer.

The hologram technique is consistent with the hypothesis that the optics of the eye forms the optical pyramids that enter the eye into interference patterns of light that are the raw sense data from which the human judgmental faculty synthesizes images. This hypothesis is also supported by the tremendous plasticity of human vision. An interference pattern carrying sense data of the wave interaction of light with surfaces provides a richer substrata for perception than a digital image. From the many optical pyramids that may enter the pupil, we synthesize a panoramic view of the world around us. The human mind resolves the ambiguities in the optical field in creating this "panorama" by which we

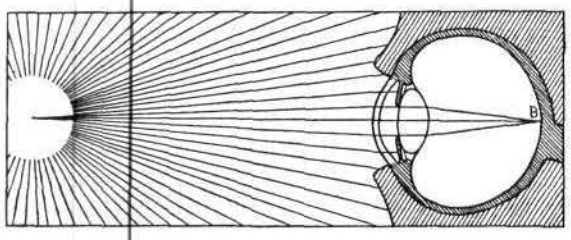



**Figure 9**
**THE MODERNIST MODEL OF HOW THE EYE SHAPES LIGHT FROM A 'POINT SOURCE'**
*The modernist theory of vision holds that the optics of the atmosphere and of the eye forms light from a "point source" into a point on the surface of the retina. The modernists use this assumption to argue that images are formed on the retina as in a camera obscura.*

Source: Adapted from M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), p. 8

see in an outward, directional act, similar to aiming and firing a gun in an imperceptible instant. This is what occurs when we focus.

Our visual power extends from our eyes to the entirety of the world around us. The 19th century physicist Ernst H. Weber goes so far as to express the view that human vision is so finely developed that it is as if the entirety of the illuminated atmosphere were part of the visual apparatus. Unlike the considerably different sense of touch, in which something must touch or come within microns of the skin to be sensed, vision can sense anything in the luminous atmosphere. It is as if the entire atmosphere were part of our sense organ, Weber says.[9]

The skeptic may argue that we have not explained in detail how or where the visual image is formed, but only demonstrated the inadequacy of the modernist theory of vision. Therefore, the skeptic may say that the modernist model of vision stands unchallenged.

This reminds us of Gottfried Leibniz's marvelous reply to Samuel Clarke, when the latter protested that although Leibniz had raised valid criticisms of the Newtonian "system of the world," he had not developed an alternative explanation for why and how the planets remain in their orbits. Instead of replying at length by describing his and Kepler's vortical model of the solar system, Leibniz chose to make a methodological point about the practice of science and the study of that which we do not know. As far as he was concerned, he said, until some genuine understanding of the movements of the planets were acquired by man, he would have to describe them as "miraculous."[10]

### The Negative Curvature of Human Vision

The curves in Figures 4 and 5 are caustics, cross sections of caustic surfaces that are generated by rotating a caustic about its central axis. In Figure 4, the caustic describes the shape of visual acuity over the surface of the retina. In Figure 5, the caustic is the shape of the interference pattern formed by a spherical lens. Caustic surfaces are surfaces of negative curvature; no matter how we view them they curve away from us in one direction but toward us in another.

The fact that vision, one of the most fundamental intellectual powers of man, is characterized by negative curvature says something not only about the nature of the human intellect but also about the nature of the universe. The negative curvature of vision creates discreteness and focus and organizes all else around it. It picks the forms of objects out of their optical context and highlights them so they appear separate and distinct; in this way, the mind creates discontinuity. However, the image of the object is not a discrete entity; it is the embodiment of incorporeal form that underlies all existence. For the soul, which partakes of incorporeal form as its natural language, the object as perceived is not an "it" or a "thing in itself"—it is nothing other than the embodiment of *plasticity*.

The soul creates discontinuities as the first necessary act preparatory to transforming nature from its present state to one that more closely conforms with the desire of the soul. In other words, the purpose of the negative curvature of vision is to help the soul take the present condition of the world to a higher order. In this way, the geometry of vision conforms to the principle of "negativity" that Nicholas of Cusa and others develop in Christian theology.

If man becomes obsessed with objects of sensual gratification, he reifies the *form* of bodies, freezing them in time and space; he degrades his original noetic fascination with form and refers all of its significance to mere corporeality. In this way he becomes encumbered with a perceptual instinct of "mass."

Readers may ask: If the human soul is required for human vision, what does this say about the vision of animals? Don't animals have souls?

No animal has been able to modify his relationship to nature and change his potential population density the way man has over millennia. This suggests a qualitative difference between the soul of man and the "soul" of animals. We conclude that there is likewise a qualitative difference between the vision of man and the mere sight of animals. Vision is such a fundamental action of the human intellect that it is unlikely that even the apes have anything comparable. This is borne out by Leonardo's further development of *prospettiva*.

### Leonardo's *Prospettiva Naturale*

Leonardo develops his understanding of the special optical qualities of human vision at the same time that he elaborates an image of universal or absolute optics. While he places emphasis on the difference between central and peripheral vision in the human corporeal eye, he develops a notion of vision that transcends that distinction: "Every object sends its image to every spot whence the object itself can be seen; and the converse: The same object may receive in itself all the images of the objects that are in front of it" [C. A. 136a, 412a; Richter 65].

This statement describes the optical connectedness and action of the luminous atmosphere upon itself. It also describes the nature of our visual field. The eye "may receive in itself all the images of the objects that are in front of it." Through this concept of the mutual relatedness and dependency of the visual field, Leonardo begins to develop a concept of focused vision that is not limited to a particular direction or focal plane but can potentially encompass the entire visual field simultaneously and in full central clarity.

Leonardo develops the contrast between particular vision and such an "absolute" vision in the "Treatise on the Eye," where he hypothesizes how the image (*simulacrum*) of the Sun would be reflected in the biblical "sphere of water" that surrounds the heavens and the Sun. The sphere of water would behave as a huge mirror for all light emitted by the Sun; it would "see" and at the same time represent one single, huge, yet complete image of the Sun encompassing all possible vantage points. By contrast, the human eye sees no such universal image, but only an image of the Sun from a single vantage point. He writes:

> The simulacrum of the Sun appears as only one in the whole of the sphere of water, which sees and is seen by the Sun, but it appears divided into as many parts as there are eyes of animals which see [the Sun reflected in] the surface of the ocean from diverse places. This that is proposed, is proved because however

far the eyes of seafarers carried by ships may move through the universe, they behold simultaneously the simulacrum of the Sun through all the waters of their hemisphere in all the movements made in all the aspects. . . .

If the eye were as large as the sphere of water, such water, when seen by the Sun, would appear in its entirety as one single simulacrum of the Sun [D. 6a; Strong 49ff].

With these models Leonardo begins to free our concept of vision from our bodily sense organs. The effort to imagine his example of an "eye," which like the sphere of water could take in a complete spherical image of the Sun from all possible vantage points, suggests that vision is a faculty of the intellect independent in origin and operation from any bodily organs. This is consistent with our discussion to this point.

If the visual image is synthesized by the human faculty of judgment from indistinct sense data presented to the retina, then vision would seem to be a far more universal quality of the intellect than a mere sense that is limited by the capabilities of our bodily sense organs. If it is by the power of the intellectual soul that we organize our vision around a focus upon particular objects, then vision must be a general intellectual faculty and, like the soul itself, need not be tied down to individual objects or particular conditions of time and space, or even the physical presence of light. Vision is based on an *a priori* synthesizing capability of the human intellect that the blind have just as much as the seeing.

The human soul partakes of the metaphysics of form; it reflexively apprehends the world through a cognitive process that elaborates a synthetic geometry as its cognitive instrument. In its purest form, this power is totally spiritual. Under particular conditions of time and space, it comprehends discreteness; it makes our ordinary vision possible.

The task Leonardo undertakes is to concretize this universal concept of vision in a method of perspective in painting, to give the viewer by means of perspective some of the qualities of "an eye as big as the sphere of water"—able to look upon all things absolutely. Such an approach is entirely reasonable. Every theory of vision implies a theory of perspective. Just as the theory that the eye functions like a *camera obscura* underlies the theory of linear perspective, so a notion of universal sight dissociated from all eyes and bodily organs, necessarily produces its own *prospettiva*.

Leonardo begins by analyzing the *prospettiva* of the isolated human glance. He takes a case of vision that embraces a distant horizon as well as near objects as a paradigm for analyzing corporeal sight: "*Prospettiva*, in dealing with distances, makes use of two opposite pyramids, one of which has its apex in the eye and the base as distant as the horizon. The other has the base toward the eye and the apex on the horizon" [G. 53b; Richter 89]. [See Figure 10(a).]

The first pyramid, Leonardo explains, "includes the universe, embracing all the mass of objects that lie in front of the eye." This pyramid encompasses the panorama of our peripheral vision "and thus the pyramid is constructed with base on the horizon and the apex in the eye." The second pyramid represents our acutely focused vision, which converges to a small "spot" on the horizon. Figure 10(b) represents these "pyramids" as caustics.

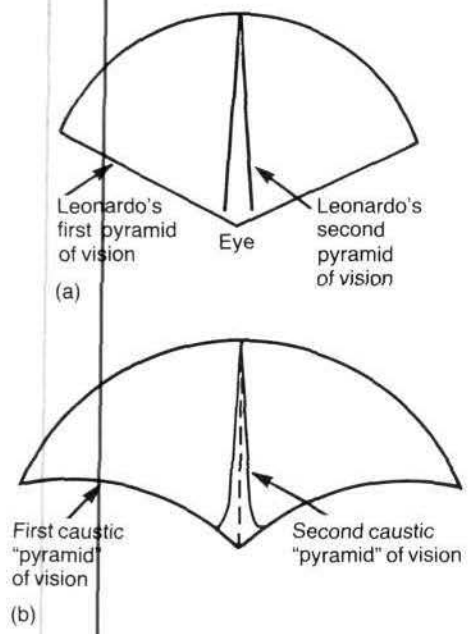



**Figure 10**
**THE PYRAMIDS OF VISION**

*Leonardo writes that prospettiva makes use of "two opposite pyramids, one of which has its apex in the eye and the base at the distant horizon. The other has the base towards the eye and the apex on the horizon" [G.53b; Richter 89]. Both pyramids are shown in (a). The two pyramids of vision are shown in (b) as caustics.*

Leonardo transforms the relationship of central to peripheral vision by introducing movement. He hypothesizes a *prospettiva* in which our eye and the apex of the second pyramid move along the horizon; that is, along the base of the first pyramid:

> If the eye remains stationary, the *prospettiva* terminates in the distance in a point. But if the eye moves in a straight line, the *prospettiva* terminates in a line, for it is proven that a line is generated by the motion of a point and our sight; therefore it follows that as we move our sight, the point moves, and as we move the point, the line is generated, etc. [E. 80b; Richter 223].

By introducing movement into *prospettiva* Leonardo immediately transcends the limited vision of the human glance. He transforms the geometry of vision from a focus around a spot into a focus simultaneous along the entire horizon. In the same way that the point of focus can move along the horizon, producing a *prospettiva* that terminates in a line, so it can move oblique or perpendicular to the horizon, with the result that the total *prospettiva* terminates in each point of a surface. This surface is nothing but the surface of discontinuity separating the objects, individuals,

and landscape before us from the intervening luminous atmosphere. It is this surface that Leonardo and his student Raphael represent in their work.

Leonardo called his *prospettiva* "natural" and noted that this surface or nonlinear focal "plane" will cover the entire visual field and always intersect the pyramid from a particular object "at an equal distance from the eye," which "is our constant experience from the curved form of the pupil of the eye" [E. 16b; Richter 108].

With such a universal *prospettiva,* the painter paints as though his bodily eyes were able to look out in all directions so that he paints every thing as though he were looking directly at it. There is no single area of focus. Everything is painted in focus with complete depth and roundness. In such a perspective, the entire visual field is as elaborated and in focus as the center of vision normally is. This *prospettiva* has a powerful effect on the viewer because it confirms to him the intellectual priority of his soul over his mere senses.

As much as our own corporeal vision is superior to the images produced by a *camera obscura,* nonetheless, it is always limited to a single area of focus; and in the periphery of this area of focus, it is more and more out of focus the farther it is from the center. Outside of the focal area, our vision is not fully elaborated.

We have nonetheless an "intuition," a synthetic mental perception informed by our many individual views, of what our vision would look like if, instead of being limited to a single focus, it could look simultaneously at everything around us with "central" acuity. This is none other than the image of continuous vision of all around us, which our soul synthesizes in our daily visual experience.

A system of perspective based on this continuous vision synthesized by the soul would present to our bodily eyes, for the first time, a visual experience and a visual field of such a shape that we previously could enjoy only by means of the intellect. With this, Leonardo thus confirms our intuition, or "learned ignorance" (to use Augustine's expression), that the soul is prior to any particular experience in discrete time and space; he demonstrates that our "limited sight" is only possible by means of the soul.[11] In this way, Leonardo establishes Augustine's principle that the source for the harmonies experienced through art is the soul, which receives them from God.

Compare the perspective of Leonardo's *Virgin of the Grotto* or Raphael's *Alba Madonna* with Botticelli's *Adoration of the Magi,* and see the contrast between an image of continuous vision in which the perspective terminates in a surface, and the fixed, limited sight of a single view that terminates in a point, reducing the Madonna and child in Botticelli's painting to secondary figures in an aggregate of discrete entities.

### Leonardo's *Prospettiva Divina*

In further elaboration of his *prospettiva,* Leonardo concerns himself with the fine detail of execution of painting from nature, simultaneously from the most advanced standpoint of metaphysics and pedagogy. He addresses this topic in many locations in his notebooks. For example, in a reply to those who place little value on painting, he says that the representation of naturalistic detail through painting "brings philosophy and subtle speculation to bear on the nature of all forms—sea and land, plants and animals, grasses and flowers—which are enveloped in light and shade" [Trat. 12; Paragone 13].

From this standpoint, he takes the unusual step of criticizing another painter *by name,* his contemporary Sandro Botticelli, who avoids representing naturalistic detail. Leonardo says that Botticelli's view that the in-depth study of landscape painting is "vain" renders him unable "to finish any detail. The painter of whom I have spoken makes very dull landscapes," he writes [Trat. 60; McMahon 93].

This concern with detail of execution in the representation of nature flows from Leonardo's fundamental view of the task and nature of painting:

> The painter's mind must of necessity enter into nature's mind in order to act as an interpreter between nature and art; it must be able to expound the causes of the manifestations of nature's laws. . . [Trat. 40; Paragone 41].
>
> The divinity that resides in the science of the painter causes the mind of the painter to transform itself into a similitude of the divine mind [Trat. 68; McMahon 280].

Leonardo seems to call upon the painter to represent eternal and divine cause through his art. Is this mysticism? Or can the painter apply the powers of science so that through the painting, the viewer can see every creature not simply for its visual appearance but for what it in reality is: to see in every creature that which created it. St. Augustine speaks of this sort of vision in *The City of God,* where he writes that the soul may "by means of bodily substances behold God, though a spirit, ruling all things."[12]

How is it possible to see "God" through an optical representation? Cusa gives the classical Augustinian answer to this question in his 1440 work, *De Docta Ignorantia* [Of learned ignorance] :[13] "God is the form of being . . . the form of forms. . . . What is attributable to God is the fact that a creature has unity, separate existence, and is in harmony with the universe." Cusa's view is that the Trinity impresses on all of created nature the qualities of unity, individuality, and the order or harmony of all parts. This is the quality of life that exists in all creation. In this way, the Trinity can be *seen,* on one level, in every creature. This notion of vision is integral to the culture that produces Leonardo.

That Leonardo indeed seeks to represent all of nature as shaped by the action of God is shown by his explanation of why he works, in a reply to some who criticize him for working on his science of *prospettiva* on holy days:

> Let the reprovers be silent, for this is the way of knowing the Performer of so many wonderful works, and this is the way of loving so great an Inventor, because in truth a great love springs from a deep knowledge of the Being that one loves, and if you do not know Him, you may love Him but little or not at all [Trat. 74; Nicodemi 33].

Commenting on this, Giorgio Nicodemi says:

> In this profound passage wherein the meager and false religiousity of his contemporaries is contrasted to his own absolute purity of faith, Leonardo not only shows his conviction that God is the source from which the order of all things emanates, but also affirms his certainty of a continual, intimate contact with God. This is the source of his naturalistic aesthetic [Nicodemi 33].

Are there other possible explanations for Leonardo's devotion to the representation of naturalistic detail? For example, is there anything that prevents us from concluding that Leonardo was simply a pantheist? First, Leonardo holds that the human soul is superior to the human body and all corporeal nature. Second, he holds that human action is ultimately nothing but the expression—in whatever mysterious way—of the soul's desire to unite with God, the giver of life: "This desire is the very quintessence, the spirit of the elements, which finding itself imprisoned with the soul, is ever longing to return from the human body to its Giver" [Br.M. 156b; Richter 1162].

Leonardo begins to show man the nature of his "Giver" by representing naturalistic detail to reflect how the action of the Trinity shapes all creation. Having stirred his viewer's soul with his "absolute" *prospettiva* and his naturalistic aesthetic, he wants to direct its intellect more directly toward "its Giver" to satisfy its "longing," for ultimately it is only through recognition of God that man experiences beauty. For Leonardo, this "Giver" is knowable to man only through Christ, who made human spiritual progress, and thus the Renaissance, possible.

Leonardo presents this vision in the most startling way in his unfinished masterpiece, *Adoration of the Magi*, which dramatically portrays the complete overthrow of pagan history by the nativity of Christ. The painting captures the historic turning point for mankind, caught in the pagan domination of the Roman Empire, but offered the possibility of salvation with the coming of Christ. The figures in the painting approach the Virgin and Child scratching their heads, uncertain of the ground beneath their feet, and in this way call attention to the singular nature of the birth of Christ. The ruins of the pagan era already appear in the background—which seems dominated by chaos within its extreme linear order—as the birth of Christ makes its overthrow inevitable.

Approaching the same theme in a different way in the *Virgin of the Grotto*, Leonardo portrays, through the richness of the naturalistic detail and the entire setting of the composition, the metaphysical principle that the coming of Christ is a necessary event in the history of the universe, one without which the world would not exist; that Christ exists from the beginning of all time to the end of all time.

In depicting the Christ child ordaining the infant John the Baptist, Leonardo calls us all to view the purpose of our lives and of everything about us, to be nothing other than that which helps bring creation to its complete fulfillment. Thus Leonardo's *prospettiva divina* enters also into the content of his painting.

His last painting, *St. John the Baptist*—considered by some a last, enigmatic self-portrait—encapsulates this outlook with a simple portrayal of the Baptist pointing to the cross of Christ. Nicodemi comments that Leonardo believes "that human knowledge and effort would be most perfectly fulfilled in art, which in turn was so bound to faith that it must be regarded as the highest possible means of serving God. . . . Thus it was possible for Leonardo to unite in art . . . a fervent religiousity and philosophical speculation" [Nicodemi 19, 22].

### Leonardo's Aesthetics

Leonardo holds the view that the purpose of science is to develop ways to educate the layman of the eternal, metaphysical truths that underlie the nature of the universe. He reasons that since all human beings are by nature conversant with the "languages" of the senses, the highest form of science is the development of means of communication that use these languages (such as painting and music) for the purpose of educating man of the eternal. Since vision is "the highest sense" and painting satisfies vision, it is "more noble than music, which only satisfies the ear" [Trat. 31b; Paragone 34a].

Unlike poetry or music, the presentation of painting does not require the passage of time; it is not dependent on the concentration span of its audience; and it gives the ego no span in which to defend itself. In painting, "The features react together and simultaneously, in order to produce that divine harmony which often so captivates the spectator that he loses his liberty" [Trat. 32; Paragone 35]. Painting is therefore the greatest science.

Because Leonardo holds that the primary purpose of science is to "communicate" ideas through painting, he considers the purpose of detailed scientific investigations—such as his work on anatomy—as nothing other than to develop the tools and knowledge required by painting. Nicodemi writes:

> By his contemporaries . . . Leonardo was considered an investigator who became so engrossed in each artistic problem confronting him that he made it a field of scientific research. In order to represent the human body, he studied its anatomy. . . . In order to paint plants, he delved into the laws of botany and geology; and so he was in turn geologist, physiologist, mechanical or hydraulic engineer, and astronomer [19].

In Leonardo's view, because the painter seeks to affect the mind through the sight, he must learn and make use of all that can be viewed and studied by the eye; this includes the entirety of science:

> The eye embraces the beauty of the whole world. It is the lord of astronomy and the maker of cosmography; it counsels and corrects all the arts of mankind; it leads men to the different parts of the world; it is the prince of mathematics, and the sciences founded on it are absolutely certain. It has measured the distances and sizes of the stars; it has found the elements and their locations; it divines the future from the course

*Leonardo's* Adoration of the Magi, *Uffizi*

*Detail from Verocchio's* The Baptism of Christ, *Uffizi Gallery, Florence*

*Botticelli's* Adoration of the Magi, *Uffizi*

*Raphael's* Alba Madonna, *National Gallery, Washington, D.C.*

*These four paintings, plus the* Virgin of the Grotto *on the cover of this issue, demonstrate the principles of optics discussed in this article. Leonardo's first work, the angel at left in the detail of Verocchio's* The Baptism of Christ, *was painted when he was only 17, and already shows Leonardo's unique* prospettiva. *Compared to Leonardo's angel, which appears in full roundness and elaboration of form, the angel at right, by his teacher Verocchio, appears almost flat.*

*The contrast between Leonardo's and Botticelli's paintings of the* Adoration of the Magi *illustrates the fundamental differences of method between Leonardo and his contemporaries. Leonardo's composition demonstrates the principle of "absolute sight": The entire composition emanates spherically from the figures of Christ and the Virgin. That the* prospettiva *is not resolved on the panel highlights the singular importance of the nativity. Botticelli's work, on the other hand, consists only of an aggregate of distinct figures; the* prospettiva *in his composition terminates at a point within the confines of the panel, as an isolated glance terminates at its focus.*

*Leonardo's* Virgin of the Grotto *(see cover) demonstrates the full development of his* prospettiva, *which terminates in a surface. The same optical principles and method of composition were applied by Raphael in his later works such as the* Alba Madonna.

of the stars; it has given birth to architecture, and to perspective, and to the divine art of painting [Trat. 28; Paragone 31].

Since all science begins with vision, and since painting is the greatest science because it educates man through his vision, Leonardo concludes that all the other arts and sciences owe their development to that characteristic of nature that leads to the development of painting.

**Leonardo on Linear Perspective**

Leonardo considered the carrying out of detailed investigations in optics, vision, and other areas essential for serious work in painting. He severely criticizes artists who do not carry out the detailed investigations required to understand the nature of light and vision in order to produce good art. He criticizes those who paint by eye or who merely insert figures into a grid, whether by linear perspective or some other method (like those who today paint by numbers):

> Many who have not studied the theory of shade and light and of *prospettiva* turn to nature and copy her; they thus acquire a certain practice simply by copying, without studying or analyzing nature further. There are some who look at the objects of nature through glass or transparent paper or veils and make tracings. . . .
>
> These practices . . . are reprehensible in whoever cannot portray without them, nor use his own mind in analyses, because through such laziness he destroys his own intelligence, and he will never be able to produce anything good without such contrivance. Men like this will always be poor and weak in imaginative work or historical composition, which is the aim of this science. . . [Trat. 39; Paragone 40].

Leonardo shows that the theory of linear perspective assumes that human vision functions like a *camera obscura*. This is shown in the practice of Leon Battista Alberti to require the viewer of a linear perspective painting to look at it with one eye, through a small hole in the side of a box in which the painting is situated. Alberti's viewing box is simply a *camera obscura* in which the viewer looks through the pinhole to observe a painting that has replaced the viewing screen of the *camera obscura*. The display is arranged in such a way that the viewer can see the painting only if he directs his sight at the vanishing point of the linear perspective representation.

Leonardo sums up the deficiences of linear perspective, as follows:

(1) Linear perspective requires that the observer view the painting with one eye from a determined spot, looking only in the direction of the linear perspective "vanishing point." Binocular vision is excluded and the viewer cannot move his eye about the painting.

These facts are shown by the nature of a linear perspective geometrical construction. The linear perspective construction freezes the *prospettiva* around the fixed vanishing point, and movement of the eye to another position, even along the horizon line, creates another "vanishing point" for vision that is inconsistent with the original construction (Figure 11).

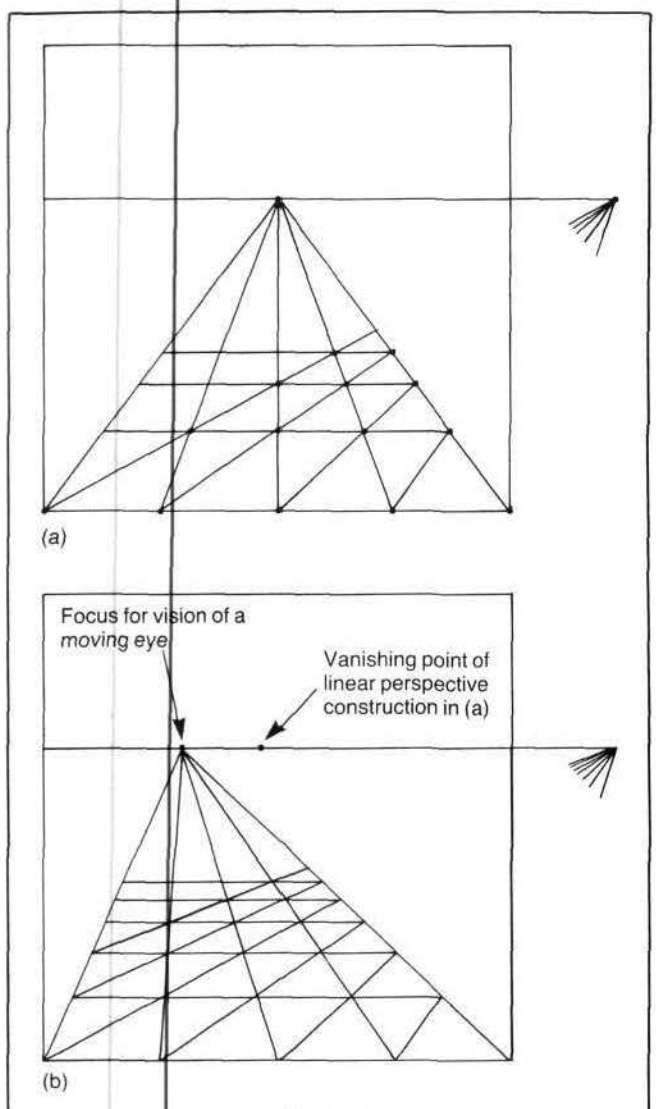



**Figure 11**
**A LINEAR PERSPECTIVE CONSTRUCTION**

*The ground plan of a linear perspective construction freezes the perspective around a fixed direction for vision (a). If the viewer should move his eye, for example, to the left, his own vision assumes a perspective in that direction (b); however, linear perspective cannot subsume both directions simultaneously.*

(2) Linear perspective assumes that all light entering the pupil of the eye intersects at one point, that the pupil does not accept a wider visual angle. This assumption is imposed on the pupil by requiring the observer to view the painting through a pinhole, truncating even that depth perception available to one eye. When viewed by the unhampered eye, the linear perspective representation is flat.

(3) Linear perspective produces the same distortions in the periphery that occur in a *camera obscura* with a flat viewing screen. (See, for example, the photo made with a

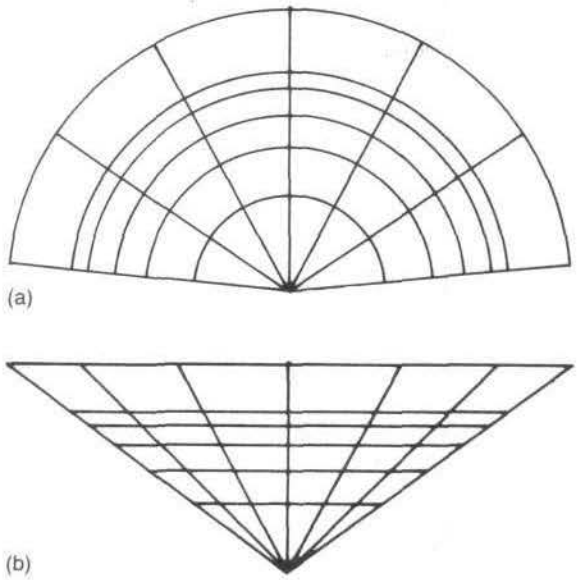
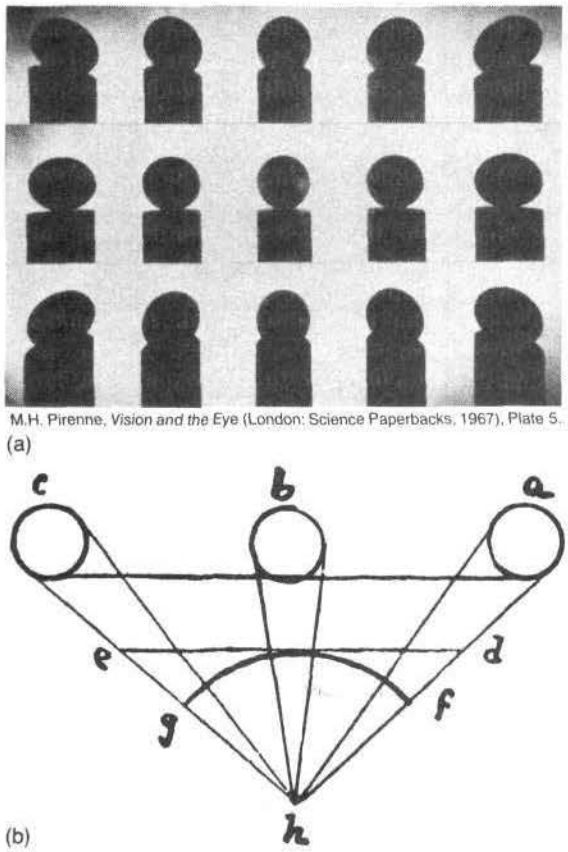



**Figure 12**
**A PERSPECTIVE CONSTRUCTION THAT TERMINATES IN AN ARC OR A LINE**

*In (a), a hypothetical grid or ground plan of a system of perspective "terminates" in the arc of a circle; that is, the concentric arcs recede harmonically from the center toward the arc where the recession "terminates." A hypothetical ground plan for a system of perspective that terminates in a straight line is shown in (b). Leonardo, however, made no use of such grids.*




M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), Plate 5.

**Figure 13**
**DISTORTION PRODUCED BY THE *CAMERA OBSCURA* AND IN LINEAR PERSPECTIVE**

*A photograph produced by a "pinhole camera," a* camera obscura *whose viewing screen is replaced with photographic emulsion (a). The figures that are photographed are spheres on top of cylinders, but the pinhole camera distorts the ones that are farther from the pinhole into ellipsoids and ellipsoidal cylinders.*

*Leonardo analyzed the circumstances of this distortion with a figure (b) that occurs frequently in his manuscripts. He shows that spheres like* c, *which is peripheral to the pinhole, are image distorted because the back of the pinhole camera or* camera obscura, *represented by the plane* ed, *cuts the pyramids imaging the spheres obliquely, producing an ellipse instead of a circle.*

Source: E16a; Richter 108

*camera obscura,* Figure 13). The eye does not notice these distortions while it is viewing a linear perspective painting in a box, because it is constrained to direct its central vision at the vanishing point while its peripheral vision is too indistinct to notice the distortion.

For all these reasons, Leonardo labeled linear perspective *prospettiva accidentale*. Indeed, Filippo Brunelleschi and Leon Battista Alberti, the inventor and the popularizer of linear perspective, respectively, were acutely aware of its limitations: After producing a few paintings by that method, they concentrated their artistic energies on architecture.

Nonetheless, it is frequently asserted (for example, by Pirenne) that Leonardo used linear perspective in his paintings. Clearly, Leonardo's *prospettiva* is of a different order. Linear perspective recognizes only one of the two pyramids with which Leonardo analyzes vision; namely, the one with its base at the eye and its apex at the vanishing point—see Figures 10(a) and 11(a). In the linear perspective technique, the pyramid of vision with its base on the horizon does not play a role in the construction. If we were to construct a "ground plan" for a perspective that terminates in a line rather than in a point, it would look like Figure 12, not the linear perspective grid of Figure 11a.

Leonardo's method, however, is not formalized in any way; he makes use of no "grid" with which to slice up the space of a painting, as Alberti recommends, because the imposition of a grid hampers the eye's capacity for vision. There are no tricks or short cuts in Leonardo's method because it is concerned with nature, and nature cannot be forced into a formal schema.

Leonardo's method transcends all of his investigations. Although his technique is ultimately grounded in the re-

sults of his investigations, it is not dependent on them but rather is confirmed by them. Long before he conducted the many investigations into optics and vision that underlie his *most advanced reflection on aesthetics, he had already* formed in intuition the basis of his method.

This can be seen by looking at the similarity in method of composition between his first work, the angel he painted at the age of 17 for Verocchio's *The Baptism of Christ,* and his later work, such as the *Virgin of the Grotto.* How is it that the angels that Leonardo paints in both pictures are so different from those of other artists—and so similar to each other although they are produced so many years apart? What is the unique quality that unites his painting of the angel in *The Baptism* with his larger work?

Here formal, technical considerations necessarily merge with metaphysical and philosophical ones, so that the "how" of Leonardo's method is an expression of the "why" or purpose which he assigned to his art. This is Leonardo's *prospettiva divina.*

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**Notes and References**

1. All excerpts from Leonardo's writings are referenced in two ways: (1) the manuscript collection where the original text can be found; (2) a reference to an English-language source. The translation sources are cited by paragraph or page number. The manuscripts are cited by the conventions followed in *The Notebooks of Leonardo da Vinci* edited by Jean Paul Richter. The specific translation sources used are:

   *The Notebooks of Leonardo da Vinci,* Jean Paul Richter, ed. (New York: Dover, 1970), cited as Richter and paragraph number.

   Leonardo da Vinci, *Paragone, A comparison of the arts*, trans. by Irma A. Richter (London: Oxford University Press, 1949), cited as Paragone and paragraph number.

   Kenneth D. Keele, *Leonardo da Vinci's Elements of the Science of Man* (New York: Academic Press, 1983), cited as Keele and page number.

   Giorgio Nicodemi et al., *Leonardo da Vinci,* (New York: Reynal & Co.), cited as Nicodemi and page number.

   Leonardo da Vinci, *Treatise on Painting*, trans. by Philip McMahon (Princeton, N.J.: Princeton Univ. Press, 1956), cited as McMahon and paragraph number.

   Donald S. Strong, *Leonardo on the Eye* (New York: Garland Publishing, Inc., 1979), cited as Strong and paragraph number.
2. We do not here refer principally to the theory of the Greeks that "in the act of seeing the eye *sends forth* toward the object a hail of small projectiles, the *species*, and when this jet of *species arrives* at the object, there is vision of the object. Leonardo overthrows this theory." (From "Leonardo's Optics" by Domenico Argentieri in Nicodemi et al.)

   Leonardo's point of view toward the fine senses, is best expressed in ancient times by St. Augustine in his *De musica.* Augustine holds that the soul is the seat of judgment, that it synthesizes images out of sense data presented to it by the world through the body. In developing his aesthetics, Augustine draws distinctions between the proportions or "numbers" sounded in music or represented in painting, those produced in the senses, and those that the soul receives from God by which it judges the others; he calls the first "sounding numbers," the second "corporeal numbers," and the third "judicial numbers." Augustine writes:

   > Why do we hesitate to prefer sounding and corporeal numbers? . . . Because the soul is made better through lack of those numbers it receives through the body, when it turns away from the carnal senses and is reformed by the divine numbers of wisdom. So it is truly said in the Holy Scriptures, "I have gone the rounds, to know and consider and seek wisdom and number (2 Eccle. 7.26)." And you are in no way to think this was said about those numbers shameful theaters resound with, but about those, I believe the soul does not receive from the body, but receiving from God on high, it rather impresses on the body.
3. St. Augustine, *On Music*, trans. Robert Catesby Taliaferro, Vol. 4, Fathers of the Church Series (Washington, D.C. Catholic University Press, 1947). Citations include the number of the book, chapter, and paragraph from this edition.
4. M. H. Pirenne, *Vision and the Eye*, 2nd ed., (London: Science Paperbacks, Chapman and Hall, 1967), p. 9.
5. In *De musica*, Augustine writes:

   > It must be carefully considered whether there is really anything called hearing, if something is produced in the soul by the body. It is very absurd to subordinate the soul like matter to the body as an artisan. For the soul is never inferior to the body, and all matter is inferior to the artisan. The soul, then, is in no way a matter subordinate to the body as an artisan. But it would be if the body worked numbers in it. Therefore, when we hear, numbers are not made in the soul by those we know in sounds [6,5,8].
   >
   > For each of these passes away with the time of its operation. But the judicial remain certain in the nature of man. [6,7,18].
6. Replacing the back wall of the box with a piece of photographic emulsion transforms the *camera obscura* viewing box into a pinhole camera that can record these distortions. See Figure 13.
7. Cited by Argentieri; see note 2.
8. Therefore, Pirenne says, "all the light originating in the point source and entering the eye is reunited in B, so that no other point of the retina receives light from this source." (See Figure 9.) This assumption is disproven by Leonardo.
9. Ernst H. Weber, *The Sense of Touch* (New York: Academic Press, 1978), p. 150.
10. "The Controversy Between Leibniz and Clarke" in Leroy E. Loemker, ed., *Gottfried Wilhelm von Leibniz: Philosophical Papers and Letters, Vol. II* (Chicago: University of Chicago Press, 1956), p. 1112.
11. There is a remarkable similarity between what Leonardo actually did and Cusa's prescriptions concerning vision and optics in his 1453 *De visione dei* (*On the Vision of God*) [ (New York: Frederick Ungar, 1960). Keele is of the opinion that Cusa had a direct influence on Leonardo [Keele 103].

    In *De visione dei,* Cusanus contrasts "limited sight" with "absolute sight":

    > If I examine sight in the abstract, so that I have dissociated it in my mind from all eyes and bodily organs, and consider how abstract sight is in its limited state—that is, as is sight in seeing persons—how it is narrowed down to time and place, to particular objects, and to other life conditions, while sight in the abstract is, in the same way, without these conditions and absolute, then I well perceive that it is not of the essence of sight to behold one object more than another, although it inhers in sight in its limited state, to be unable to look on more than one thing at a time, or upon all things absolutely. . . .
    >
    > Sight that is freed from all limitation embraceth at one and the same time each and every mode of seeing, as being the most adequate measure of all sights, and their truest pattern. For without Absolute Sight there can be no limited sight; it embraces in itself all modes of seeing, all and each alike, and abides entirely freed from all variation. All limited modes of seeing, exist without limitation in Absolute Sight. . . .
    >
    > Absolute Sight exists in all sight, because through it, all limited sight exists, and without it, limited sight is utterly unable to exist.

    Cusa prompts our intuition of "absolute sight" in a meditation he presents on a painting. Using the image of the all-seeing eye of the painting, Cusa puts forth a perspective identical in form to Leonardo's:

    > This picture, brethren, you shall set up in some place, let us say, on a north wall, and shall stand round it, a little way off, and look upon it. And each of you shall find that, from whatsoever quarter he regards it, it looks on none other but you. And it shall seem to a brother standing to eastward as if that face looks toward the east, while one to southward shall think it looks toward the south, and one to westward, toward the west. First, then, you will marvel how it can be that the face should look on all and each at the same time. For the imagination of him standing to the eastward cannot conceive the gaze of the image to be turned unto any other quarter, such as west or south. Then let the brother who stood to eastward place himself to westward and he will find its gaze fastened on him in the west just as it was before in the east. And, as he knows the image to be fixed and unmoved, he will marvel at the motion of its immovable gaze.
12. St. Augustine, *The City of God* (New York: Modern Library, 1950), Book XXII, section 29.
13. *Nicholas of Cusa, Of Learned Ignorance* (New Haven: Yale University Press, 1954), book II, section 2.