THE RING OF TRUTH

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AN INQUIRY INTO HOW WE KNOW WHAT WE KNOW

PHILIP AND PHYLIS MORRISON

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In Introduction

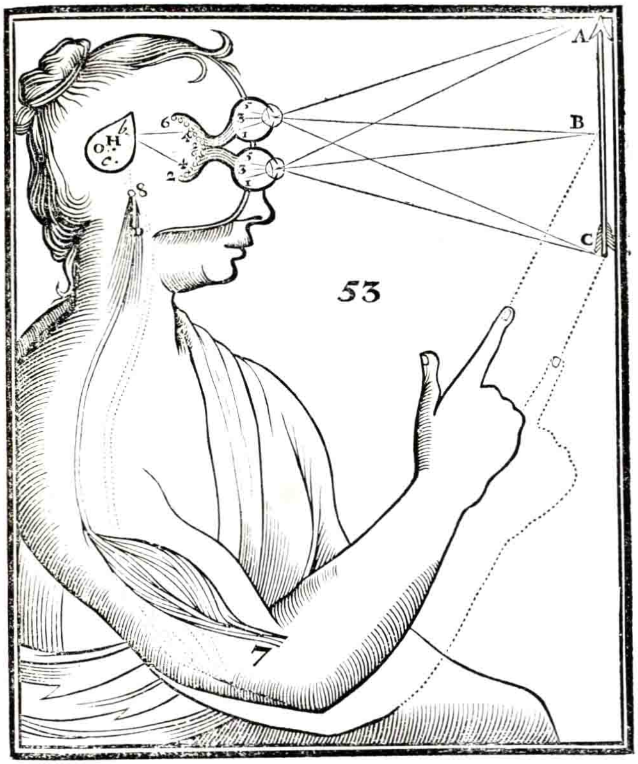
THIS TEXT AND ITS IMAGES SEEK TO PRESENT a simple but somewhat inside look at parts of the natural sciences from the stance of one who asks, "How do we know?" That question can arise out of simple ever-ready skepticism—the position of Missourians, we are told—but it can also flow with hope and pleasure out of a more positive desire to share in the most important of intellectual tasks, at once difficult and delicious, that of gaining and assessing knowledge.

I am a theoretical physicist, fifty years in physics since my student days. Now and then my hand has turned over the years a little to engineering, especially the improvised but fateful nuclear engineering we undertook in World War II. Beginning about thirty years ago the new astronomy all but captured me, along with many another physicist. Teaching at every level from elementary school to graduate studies has given me the chance to watch in fascination how different people begin to face the activities and concerns of any science.

I do not plan mainly to cite the high authorities of science or to dwell on their strange and grand results. That would not be looking inside science at all. Instead I propose to share openly some of the experience that lies behind any result that has persuaded me, and the major links of argument that surround and follow experience. It is then up to you to ask yourself whether you, too, are persuaded, or not persuaded, by what is before you. Only in such a personal way, the evidence at hand, does anyone come to grasp usefully the new results, the theories, the new devices as they arise, and not simply to learn—or be bewildered by—their intriguing names.

The experience of science can be wonderfully wide: as everyday as a pair of eyeglasses or the hot kitchen oven, as unexpected as the enormous meals of the racing cyclist, as beautiful as the worked gold of ancient craftsmen, or as novel as a video rainbow that discloses the motion of a distant galaxy. We will seek meaning in every experience, to draw out some of the main conclusions—and the doubts as well —of today's natural science.

In the printed word there is an obvious gap in time between authors and readers. No one is in any doubt of that, and in print—not so easily in speech, though the remedy is there in questioning—the reader is not even bound to follow



Descartes' eye is the organ of our sense of sight, whose complexities were touched upon in one of his seventeenth-century essays, an early point of view on the senses as inbuilt instruments.

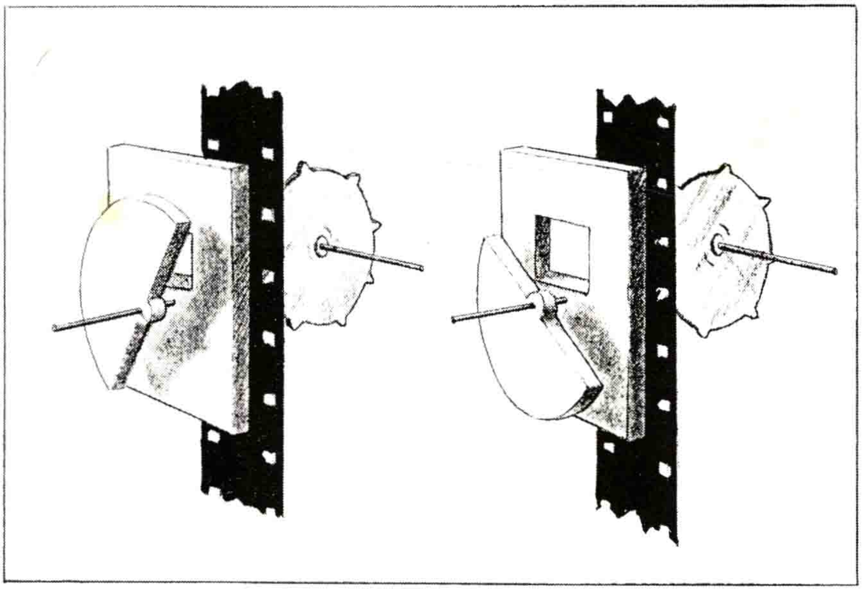
the order of the author's larger design. The coded letters that are strung across the silent page do not in general carry the notion of simultaneity with anything like the force of moving images visible on the screen. Film and television present what looks like the genuine flow of cause and effect, with powerful support from a whole visual context around the center of attention. That richness offers credentials for belief, even though what is there may be, and usually has been, manipulated in ways that range from merely the one-eyed narrow view of the camera to the fully pieced together visual unfolding of a constructed narrative. Words, of course, have similar limitations as evidence, but they do not bring along any external support; they do not much resemble the stream of direct experience we see and hear. Any reader must be more active than the viewer, closer to command over what is going on; that very activity seems to me essential to the gaining of knowledge. It is up to you to decide whether the evidence we present in word and image has that ring of truth.

The mastery held by film and television is in that flow of sewn-together time, obvious in instant replays of TV sports, but present in a great deal of television even when it is by no means evident, even in the nightly news. These powerful channels of communication can ignore cause and effect, or even reverse them. Once the hold of cause is broken, once the unstopping flow of time has been stemmed, it is easy for the filmmaker to piece together into one image the look of different places, and thus to allow us to appear on television to picnic in leisure right among the players of a tense championship ball game that we had never attended at all!

Science is not much concerned with overt deception, as by adroit editors of film and video, whether meant to mislead or simply to entertain. Deception is the fear of a used-car shopper. I am not abandoning the idea of trust. But genuine trust implies the *opportunity* of checking wherever it may be wanted, and trustworthy claims almost always attend to that need one way or another. What science *is* deeply concerned about is something closer to self-deception. It is genuinely hard to make out how the natural world works; any investigator, even a long string of them, can go wrong. That is why it is the evidence, the experience itself and the argument that gives it order, that we need to share with one another, and not just the unsupported final claim.

How We See

IN THIS INITIAL CHAPTER WE TRY TO EXAMINE with some care how it is we all look at the



The semicircular shutter of a movie camera blinks closed for half of the time. During the closed period, the film is moved along in readiness for the next image, which is exposed during the open period when the film is held still. A similar intermittent motion is required when the film is projected for viewing. By clever use of filters and colored glasses, or with timed shutters to view through, it would be perfectly possible to show two different movies on the same screen to people sitting side by side.

world. One might expect to distinguish two sorts of looking, one the everyday task we all habitually perform, the other, the specialized close look of the sciences.

But I will not much distinguish between those. I believe those two ways are in great measure parallel, the one quite continuous with the other. Their similarity begins in the fact that both use instruments without which we rarely can judge events. The everyday way of looking uses the human eye, which is after all simply the built-in instrument of human vision. The other way employs a variety of scientific instruments, from the now-familiar telescope to electronic sensors of many sorts, newly contrived every day. A look at how instruments work—both kinds, the inborn and the artificial—and at what they can and cannot do brings a good deal of understanding, whether we ask how we know what happens in daily life or whether we enter the most arcane laboratory of formal science.

What controls knowledge is more the inner nature of the instruments themselves. Deliberate illusions like that of the picnic on the infield, contrived to display what never happened, are not the most important kind.

EVERYONE WOULD AGREE THAT YOU CAN SEE nothing more than a reddened glow of sunlight through the eyelid, and yet we all blink constantly. The time you spend with a closed pair of eyes amounts to 5 percent of all your waking moments. We entirely ignore the loss. For us the flow of vision seems quite unbroken.

It is a little surprising that the ordinary motion picture camera, the work of twentieth-century engineers, blinks out what it might see much more than does the human eye. The image caught on film can certainly be no more than a fraction of what is moving in front of the lens, for the entering light is so much interrupted by an opaque solid metal shutter that the camera necessarily must leave out a third, often as much as a half, of whatever is going on. Yet we piece that sample together in the eye and the mind, without conscious effort, into a fine smooth unbroken stream of moving images. The camera blink is even less troublesome than is the eye blink.

Maybe that suggests a little of how alike the two instruments are, the one fashioned of glass and metal, the other grown of flesh and blood. We always make our judgments of events from an incomplete account, based on assumptions that are somehow built into all our instruments of vision and interpretation. Of course, the motion picture camera was developed, mostly by trial and error, to match the nature of the finally viewing eye.

A photographer can make a flip book of a simple series of snapshots, taken of a sequence of positions, pose after pose, shutter click after

shutter click. When the snapshots are simply presented in order, only much sped up before the eye, the same old flow of motion appears, even though it was not present at all. (Almost everyone has seen a strip of motion picture film that makes plain that every movie is also nothing more than a long string of still pictures, quick regular snapshots quickly unfolded and held one by one before the eye, twenty-four frames each second, the shutter closing between frames to hide the moving blurred image during the time used for replacement.)

It is pretty plain that the eye and the mind want to pick up smooth motion in the world. They have evolved to do so. A staccato, ratchet-like step-by-step shift of position does not often occur in the sort of events that human beings ordinarily encounter. We feel the hefty baseball bat swing smoothly; even if we sample it visually only a few times during the swing, we still insistently build up for it the look that presents the same smooth continuous action we feel. That is the theory of motion present in the eye and mind.

Those moving images are wonderfully powerful. The eye and the mind have nothing to work on but a sample of snapshots with some interruptions. Just the same, they manage to bring us a convincing presentation of continuous motion. Certainly we inherited this ability, and perhaps we train ourselves in its use as well. It seems fair to say, from what we know of the nature of vision, that we cannot literally *see* smooth motion. Rather we infer that smooth motion is there in the scene, even though the evidence is only those staccato samples, a plain example of the fundamental similarity between everyday experience and the foundations of science: theory extended from experience.

Our everyday, commonsense perception—we recall its subtlety, much more than is in the simple description we have given, and admit also that the system is by no means fully understood—certainly proceeds by the inbuilt instruments we call eye, ear, indeed all the senses. Now compare what the sciences do. There also it is instruments that bring us view after view of various portions of the world around. Scientific instruments are not structures inborn into almost all humans, but devices fashioned over the years by human hands. Often they enable a quite new view that extends and augments those inbuilt senses that evolved biologically, without conscious human aid. The task of judgment that remains, in ordinary affairs as for science, is to fit those many instrumental views together. To pay attention to our ordinary way of looking is at the same time to pay attention to the ways of science, ways that are usually less difficult to fathom than how we all quickly come to know who has entered the room.

Everyday looking is also never a simple task, even though we usually do it quite well. All the

An artful magician can make a crumpled paper ball suddenly disappear—but only to the one person he faces, while every onlooker can easily follow the ball of paper throughout. This skillfully performed sleight-of-hand, so transparent as to seem impossible, depends upon the magician's understanding of how the eye works.

A white square appears here overlapping the four black circles. You will see it if you wait a moment, though it is illusory. Will the effect "work" if the circles are reduced to Vs? How far apart can the circles be? It certainly works for curved contours and contrasts other than black-on-white. Can there be an internal process which infers that what you see is probably another surface, obscuring part of each circle?

same it is instructive to see what happens to our practiced ability to look closely whenever a talented professional appears, one who knows our usual means of looking, but is out to intrigue us by frustrating those familiar expectations we assemble from the sample of the world that we see.

SUCH A PERSON IS THE ENGAGING JEFF McBride, innovative and reflective young mime-magician from New York City. Listen to the conversation we two had not long ago.

MAGICIAN: That's how you can fool our patient subject. The whole audience knows how the trick is done—except for her. For people to understand, not how tricks work, but how their eyes perceive, is the point. If a good magician does an illusion for you, he's going to get you; that's his job. Whereas your job as a scientist is to uncover things, to reveal things, we try to take all of science, but hide as much of it as we can. We use everything that science teaches against our audience.

PHYSICIST: But you see that those are two sides of a coin.

MAGICIAN: Yes, the same coin.

PHYSICIST: The same coin, the coin of perception, whose other side is misdirection, which nature produces even when you, the clever magician, do not.

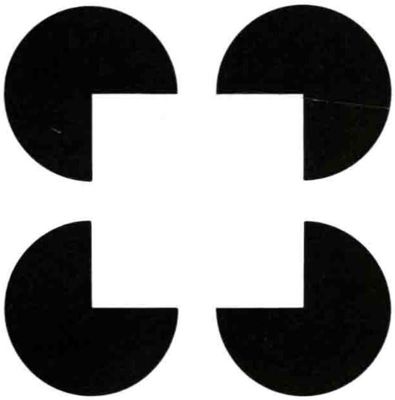
MAGICIAN: We try to reproduce events that cannot possibly happen in nature, using the information drawn from nature through the scientist.

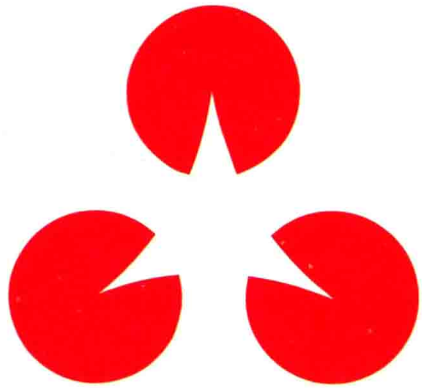
PHYSICIST: Yes, you deal both in causes that are not allowed to have effects and in effects whose causes are concealed. When you put them together, the onlookers think the cause produces the effect even when palpably it cannot. The rabbit is not in the hat.

MAGICIAN: The rabbit is not in the hat. You use people's information against them. People have only two eyes, and they move together, only in a single direction at a time. They can't focus on two things at once. What I do in this particular effect is seduce their eyes with a slow motion by one hand, while the other hand is moving very quickly. When you are looking here into my hand you can't see the ball of paper go out of play right over your head.

But then again, you've been watching this paper ball go up and down all morning; whenever it was tossed, it just plain vanished from sight. Now you know how that happens, so what we have to do is recognize that and exploit your preconception of how that paper acts. Then I will change it, so what you expected to vanish quietly became all of a sudden a startlingly visible transformation!

Here the Magician indeed fooled and star-





tled the ingenuous physicist, exactly as he had promised. Instead of the tossed ball of paper, moving away from me as gently as it had arched before the onlookers time after time, there was a contrasting event that I had never expected. A burst of white confetti streamed out from my startled gaze. The substitution was spectacular, if obvious enough after the fact.

The magician had exploited one more piece of his insight. How could his confetti fly out so swiftly from a light toss of the hand? That was not a simple tangle of paper ribbon; the paper tape turned out to be loaded at many points with tiny lead shot, whose weight very much speeded the motion of the white streamers through the air.

YOU ALWAYS LOOK STRAIGHT OUT TOWARD THE wall ahead of you to see your own face; a mirror there has bounced the light back. If it were not so commonplace, it would seem a paradox to see by looking away. A mirror of glass put frankly into the light path can certainly influence the visual judgment, but there it is, external, visible, tangible, and somehow easy to understand.

Visual judgments require internal processing in the eye and the brain. Sometimes that is conscious; sometimes it is a process subjectively quite unknown to us, but it is pretty surely present. Some effects found only during the last decade or two make that evident. The drawing shows four pielike black disks, well arranged on a completely fresh and blank sheet of paper. Look closely for a few seconds at the group of disks to allow time for internal processing. A second sheet faintly lighter than the background seems to cover the segments of the four disks, and the lighter superimposed sheet can be made out at its boundary as well. That appearance is internal. It is not in the paper; it is not in the disks. It is inside the viewer.

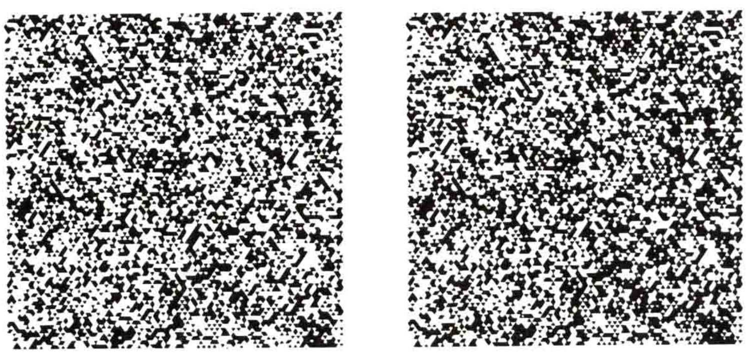
We can change the variables. Try red instead of black contrast disks; the cuts are curved instead of straight; three disks form a triangle, instead of four to make a square. Once again you need to allow a little time for the internal processing that is unconsciously carried out in the eye and brain. The superimposed screen appears again, perhaps with less contrast than with the black disks, but now with a curved edge contour, no longer a simple straight line. A remarkable kind of processing is going on.

These illusions, discovered by Gaetano Kanizsa at Turin, have been studied well by now. What has been learned can be explained by the following simple proposal. The visual system inside the eye and the brain somehow intends to describe what we see in these patterns by an act of unification, imposing a single screen above the cut disks, as if it were a second sheet of paper appearing a little whiter, a little different from the background. In a way the scene is carried into the third dimension.

SEEING DEPTH WHERE NONE EXISTS

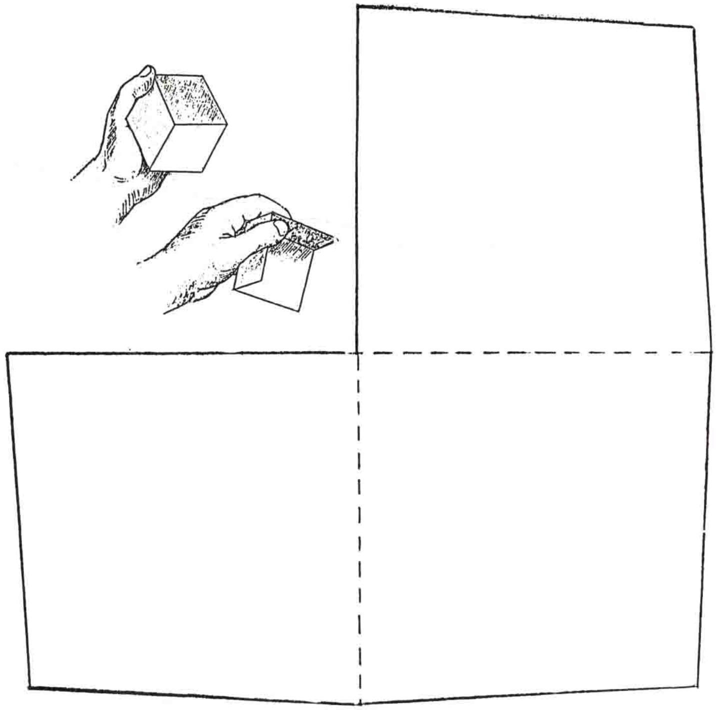
An impression of depth, of the third dimension, is built up for nearby objects by the way we use our two eyes. The distance between the eyes allows us to see slightly different aspects of the same nearby scene; inner computations on those paired images give us strongly our sense of the distance of objects, and of their three-dimensional shape. At greater distances, other clues take over, such as making out detail and the atmospheric graying of distant objects. We are not born with all that skill: as infants we must experiment, reach for the crescent moon, try, fail, and slowly come to know the shape of the world, especially at some distance. The nearby stereo judgment seems inborn.

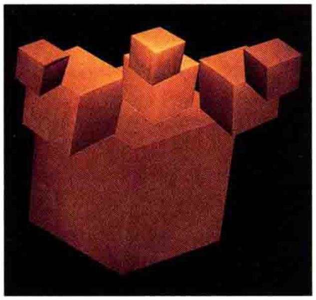
But the pair of images presented here make a strong challenge to such a system. If you look at them with a hand lens, you will see they are made up of many little triangles, black and white. They are arrayed identically in the two images, except that in the center of the right pattern a whole triangular array is shifted somewhat to the left. As you look at the images one at a time, it is difficult to tell where the shift is, where its edges are. But if you look with a stereoscope, or fuse the two images into one by the method described here, somehow you sort out without conscious effort the complete pair of random patterns, and see a large speckled triangle floating above a speckled backdrop. Many minute differences and similarities of the whole array have to be processed to do that. But it takes a little time before that image appears, a sure sign that an internal process had to work its way through and correlate the positions of all those speckles.



A random-pattern stereo pair. It is sometimes possible to see a stereoscopic effect without an instrument made for that purpose. Pretend to look *through* the two pictures, focusing distantly. Keep each eye from seeing the other's picture by holding a sheet of paper between your nose and the book. Have bright, bland light fall on the images.

A personal corner-box can be made by copying this pattern on paper, then cutting, folding and taping it into shape. Cradle it, corner pointing away from you, in the palm of your hand. Hold it at arm's length and close one eye. After a moment or two the inside corner-box should appear to be the protruding corner of a solid cube; then move it slowly from side to side: your eye will see one motion, although your hand will know another. The exhibit of many fixed corner-boxes looks the same; it is lighted from below.





To cover one hand with the other requires a little thickness, if not very much. The superimposed screen we add here, like the two hands one on the other, extends a little out of the flat two-dimensional surface of disks and paper. That third dimension—only a little of it—is what we appear to add on our own in the unconscious internal processing we all carry out upon such images.

THE SET OF BOXES PROVIDES A STILL MORE overt test of our perception of three-dimensional space. Most people will see the boxes in the photograph as lighted from above. In fact they are lighted from below; a hand from below can cast a shadow, from above it will not. These are not the outsides of small boxes, they are hollows, the interior corners, the insides of cubical boxes. When I confronted the real three-dimensional set of boxes with one eye closed—as the camera is one-eyed—I saw the box tops lighted, the corners protruding toward the viewer, a dozen ordinary cubical boxes arranged for one to see. When I moved my head the falsely seen boxes moved quite strangely, as if they followed my own motion. I had simply inverted the true nature of their bright little geometrical world.

It is easy to make a simpler version, just as striking. All you need is a part of a cubical box made of paper or cardboard (the pattern is on the page), only three of the six cube faces, held in the hand to present the interior corner. If I hold the corner in my hand in almost any lighting I can easily persuade my open eye (one is closed)—in fact I can hardly do otherwise—that I am looking not into an interior corner, but at an outside corner of a cube. The conviction is so strong that when I move the piece slightly before my eye its motion seems entirely contrary, as though it were an animate thing in my hand. My eye and brain have inverted the facts of 3-D space, and with that inverted the appearance of motion. (The reader ought not to miss the riveting experience of building the little cube to try it out.)

What has happened is in part quite plain. The two-dimensional retina cannot gain enough geometrical information from the simple bland white cube to decide which way that corner faces, inward or outward. It has made the wrong three-dimensional inference. We always try to judge a three-dimensional world from inadequate cues; sometimes we judge wrongly.

PERSPECTIVE

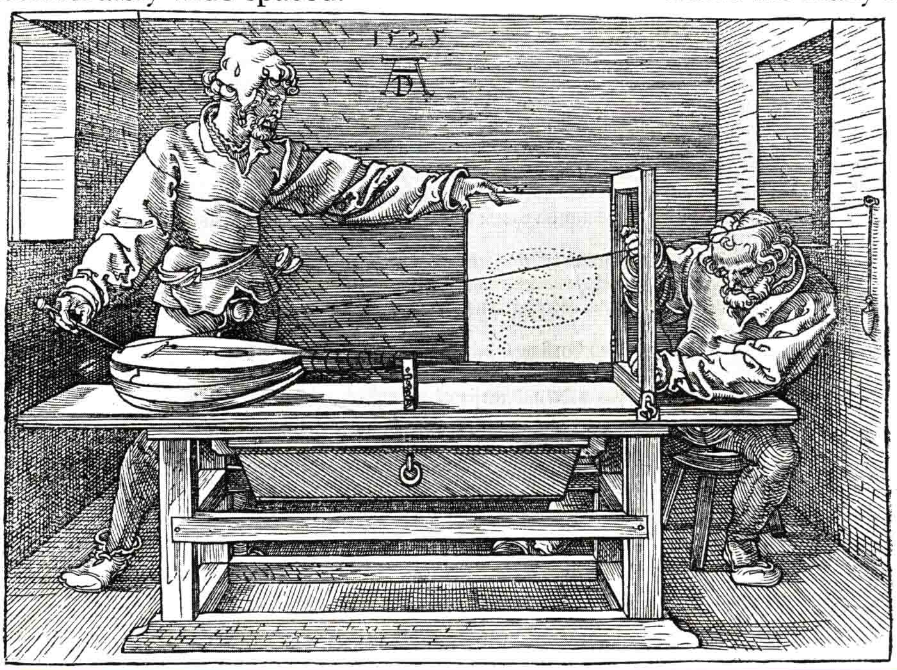
An infant reaches eagerly for the bright moon, "very like a sixpence." The child does not yet grasp perspective, we might say. The image of the moon we catch in the eye is about the same as that of a coin or a ball that is well within reach. Experience teaches us that the moon is far beyond our grasp (save by three-day rocket trip), but a little person who cannot walk about does not know that.

The nub of the idea of perspective is the perception of three-dimensional space by the use of a mere surface-thin image that falls on a screen behind a lens, whether it falls on a human retina or on the film in the camera. It is a rather abstract notion, as the history of painting makes clear. The painters of ancient and medieval times, and to a degree Asian artists even much later, did not employ this particular abstraction. It arises from the cone of rays along which the light from a distant object comes to the watching eye. By that piece of geometry the two rails half a mile down the railroad track are set very close indeed, while those at our feet are comfortably wide-spaced.

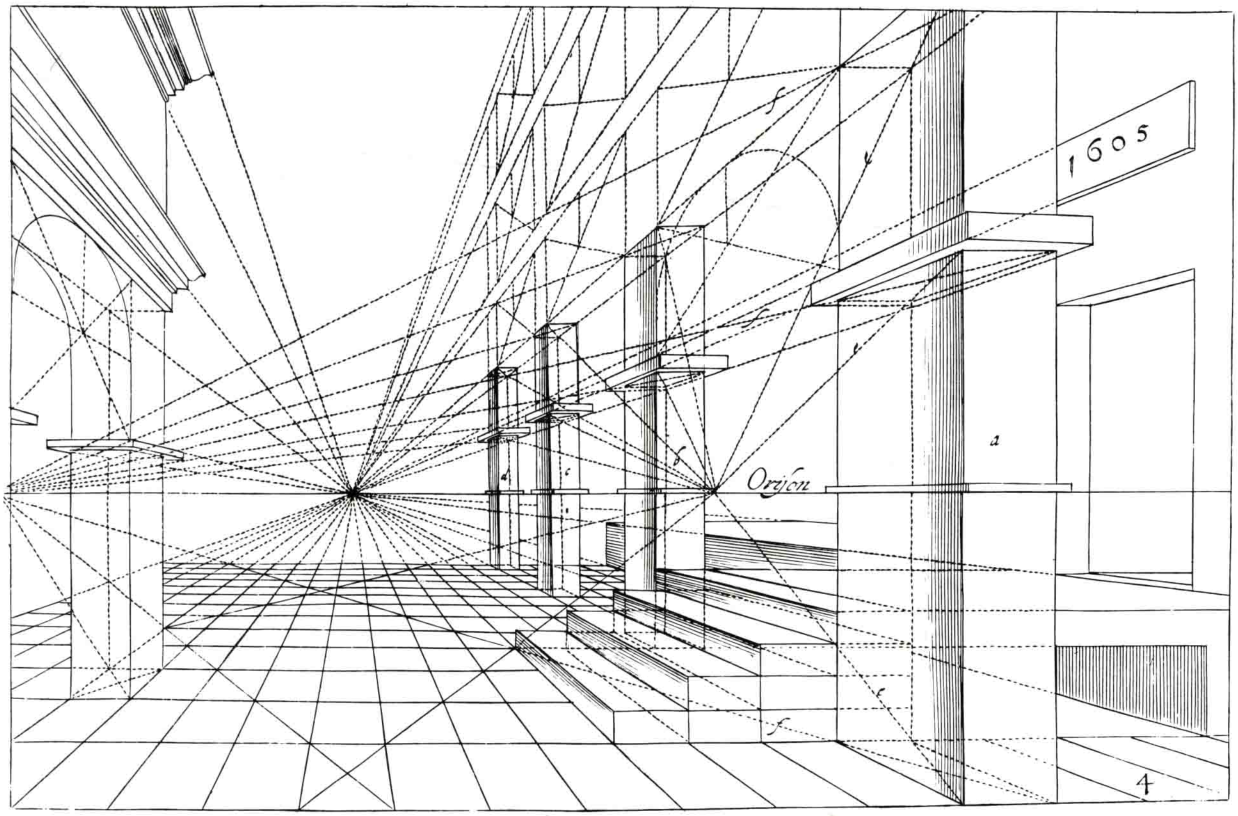
The camera agrees with the eye, of course, and so did the clever painters of the Renaissance who first of all codified the rules by which such a structure of converging lines is made pretty faithful to the scene. Some such rules are built into the lens-retina system as well, for we see the same converging track the camera shows. But you can be sure that no Amtrak locals ever rattled down such a narrowing track.

That is only one way of adding a three-dimensional meaning to the eye's grasp. The eye is fooled by the moon, an object so far and large as to lie outside ordinary rules. The eye is fooled when it examines a piece of architecture—built first by the waggish architects of the Baroque, and later even more carefully by Adelbert Ames at Dartmouth—which avoids equal-length columns, horizontal ceilings, and rectangular windows, but introduces instead all sorts of slants and distortions to generate a projected image that fits exactly the message the light would bring from a normal set of solid shapes.

There are many remedies for this misper-



The rules of perspective drawing were soon mastered by the artists. Here are examples by two adepts of the art, the Flemish de Vries and the Nuremberg master Albrecht Dürer. The method for getting a highly foreshortened image shown in Dürer's woodcut is one he invented himself.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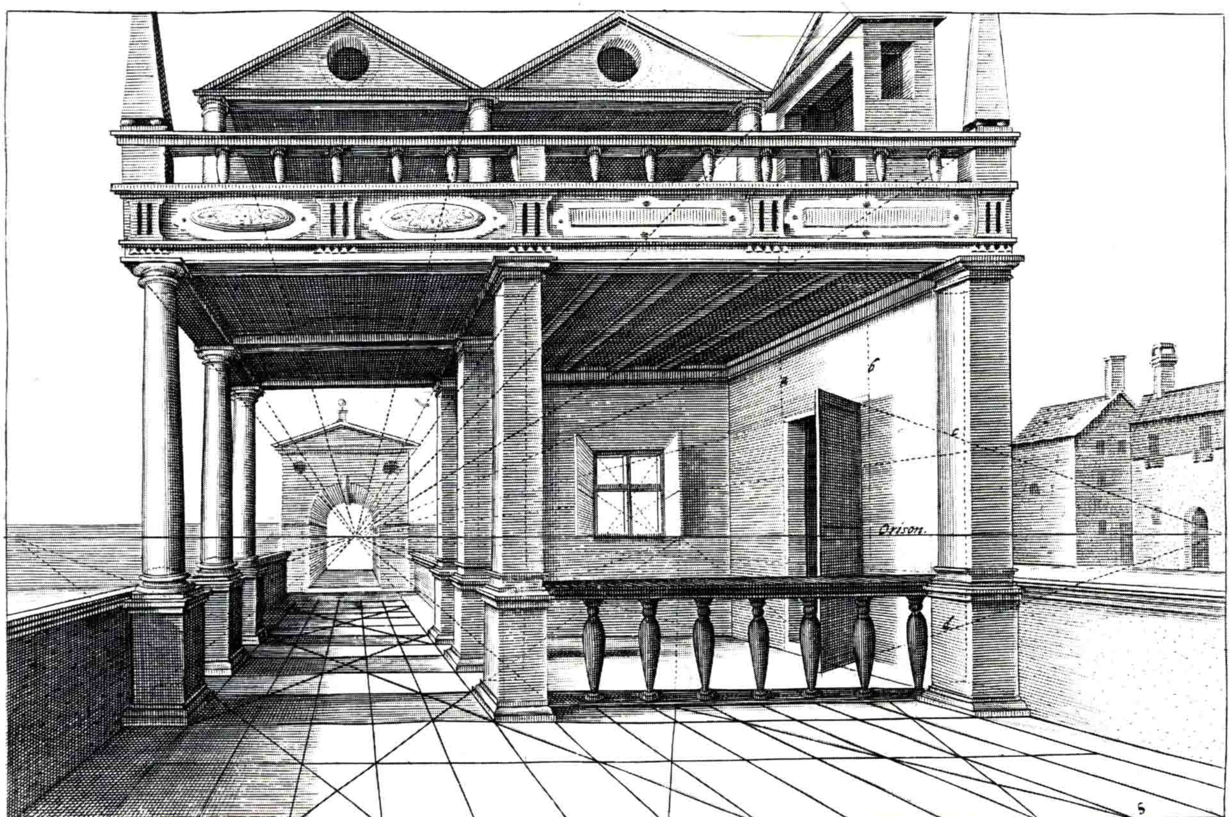
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ception. Some of them are built into our own sensory system: the eye lens tries to focus according to distance, the two eyes see slightly different views, and the computer of retina and brain contrive their 3-D stereoscopic explanation. Nearby objects tend to obscure the sight of more distant ones. Above all, the viewer is not constrained to act like an immobilized Cyclops but can take up several points of view spaced wider than any pair of eyes. Even the moon then comes out from behind the hill; it is certainly farther away.

The so-called linear perspective, an approximation to what we inherited with our eyes, seems to have become first consciously understood in the city of Florence soon after 1400 A.D. within the circle of the friends and acquaintances of Filippo Brunelleschi, the architect who designed the dome of the great cathedral there. For a couple of hundred years the single view dominated the painters of Europe, and in our photographic world that style is even more familiar, although now we recognize with Duchamp and Picasso that there are other powerful ways to draw.

Indeed, the old Florentines knew that very well. Perspective is the means used to content the eye by treating the picture surface as a kind of window. But there are other means to represent the world, from the ingenuous way the old artists painted Pharaoh very large among his quite small peasants, to the crisp and cold multiple drawings, scaled like little maps, of the architect and the engineer.

The painter can happily lay out a tiled floor with big tiles nearby and small distorted ones fading into the distance. But the architect, the builders, and the client who foots the bill know very well that the distant tiles are made exactly like the near ones, all of them equal squares. The world we live in is solid, three-dimensional; what we see and photograph is not solid, but literally surficial, and the visual perception of depth within it is governed by subtle rules approximated long ago in painter's perspective. We best reconcile the two worlds by action, by moving about; a change in point of view is a real help to understanding, even in matters far beyond visual representation.

A distorted room made to the specifications of Adelbert Ames in the Science Museum of Virginia. This room looks perfectly rectangular, all as it should be, as long as you view it with one eye from a carefully placed peephole. But if two people enter the room and go to opposite corners, you see an astonishing sight! The room continues to deceive you even when they exchange places. It is not easy to make out what the shape of the room really is, but the final picture shows something nearer to what is really there.

The study of human perception is one of the deepest of sciences, yet in it every human being is an informed participant. The few cases we examined brought surprising results, yet very sensible ones. Take the perception of motion: we do not accept motion as a staccato occupation of point after point—even when that is all the eye sees. On the contrary, we find smooth, coherent changes in the position of moving solid objects. That is the way the world is usually built; the mind and the senses together try to infer a consistent world from our partial perceptions. In space, too, we have similar results. We will not accept any simple projection into the two dimensions of the retina as what we see. No; instead we try to construct a three-dimensional world the best way we can, to infer the world of depth that we expect from what partial information the shallow retina of the eye can bring us.

What we perceive is more than the sense organs can directly tell; it is limited by their structures, it includes the assumptions and the experiences of our kind, both inherited and individual. With scientific instruments as well, such interpretation is almost always a requisite. For science as for everyday, the world is to be inferred on the basis of the signals the instruments get. What we learn is rarely given as a free gift; some effort of our own must enter the transaction.

The determination of the eye-brain to choose a plausible 3-D fit to what is only a 2-D image, or to generate continuous smooth motion out of a sequence of snaps, is rather newly recognized. That recognition belongs to our own age, the time of the computer. Some computerlike features of the human nervous system are at work; we do not know quite what. We know that the process is organic, subtle, intricate.

The most widely used of optical instruments—beyond the looking glass—is a pair of reading glasses. Their task is simple enough, in no way organic or intricate. All the same they arose out of an early interaction between the inbuilt organs of human vision and the growing skills of craftsmen. They augment human vision at the simplest of levels. They allow a sharper focus by an aging natural eye lens by adding another external lens of glass.

Spectacles were first made seven centuries ago, surely from the chance experience of some keenly observant artisan, and not out of any new understanding of the nature of the eye. What is more remarkable is that the very same careful form, the same unusual material, and the same elegant skills that make spectacles commonplace around the world gave rise to an extraordinary landmark among scientific instruments. That was no helpful everyday device at all, but an instrument of rich discovery that rapidly transformed our whole conception of the universe in which we live. What the spectacle makers finally found was the telescope.