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HOW TO REVIVE EMPIRICISM

In recent years empiricism has been under persistent attack, and serious questions have been raised about the ability of empiricism to provide the basis for a viable philosophy of science. The attack has been sufficiently vigorous, and in some quarters sufficiently successful, that many now maintain that empiricism is dead. My aim in this paper is to argue that, rather than being ready for embalmment and emplacement in the museum of philosophic oddities, empiricism is very much alive, and the central thesis of empiricism remains the cornerstone for any viable philosophy of science. This is not to say that the recent attacks on empiricism have been without a point; rather, they have put anyone who would defend empiricism in the position of having to rethink many datails of the empiricist viewpoint. But it is the details, the way in which empiricism has been elaborated by its proponents, not the central empiricist insight, that must be reconsidered.

What I referred to above as the central insight of empiricism is simply the thesis that we cannot acquire knowledge of nature *a priori*, that if we wish to learn about the world around us, we must do more than just think—we must observe. But given this central claim, the question that immediately arises is, "What is observation?" and here a quite natural series of reflections led the empiricist tradition seriously astray. Since the path is undoubtedly

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familiar, I will summarize it rapidly.

To begin with, we obviously observe by means of our senses, but when we begin to reflect on just what it is that our senses provide, we make some surprising discoveries. Consider first the sense of touch, a sense that seems to bring us into direct contact with physical objects. When I lift a physical object, for example, I normally describe myself as feeling the object's weight, but this is not strictly correct. What I actually feel is a sensation of tension in my muscles, and it would seem to require some inference to get from an experienced sensation to a property of a physical object that exists apart from our sensations. Yet if I now ask what this inference is, no acceptable answer is forthcoming. It cannot be a deductive inference, because there is no step which will take us necessarily from the sensation to a property of a physical object: it is logically possible for me to experience that sensation without any physical object acting on my body. Nor can it be an inductive inference. Other problems about induction aside, an inductive inference from *A* to *B* requires as a premise a previously established correlation between *A's* and *B's*. In the present case this would require a correlation between the weight of the physical object and the muscular sensation I am presently experiencing, but since I experience only the sensation, never the weight of the physical object, no such correlation can be established, and the inference we are seeking cannot be an inductive inference.

If we now examine sight (or any other sense) the same result appears. I will not rehearse the time gap argument, the causal argument, or the argument from illusion, but I will underline the conclusion that presumably follows from these arguments: strictly speaking we do not observe a physical world made up of objects that exist independently of our awareness of them, but only our own ideas, or impressions, or sensations, or sense-data. As for the original thesis that observation provides us with a means of access to the world around us, four responses would seem to be available: the sceptical conclusion that we cannot know anything about the physical world; the semi-sceptical conclusion that while we cannot know anything about the physical world, such knowledge is unnecessary for either science or our daily lives, since these require only a knowledge of the correlations between sensations; the bold conclusion that there is no physical world that exists above and beyond our sensations, and that there are thus no grounds for scepticism since we are capable of knowing all there is to know about the world around us; and finally, particularly in this century, attempts to reanalyze the notion of a physical world in terms of logical constructs out of our sensations.

This is not quite the entire story, for there is a second line of argument that converges with and supports the position outlined above. This second line of argument derives from the theory of meaning, and begins with the thesis that the meaning of an empirically significant term is just the set of sensations with which that term is correlated. We learn to use the word "red", for example, by learning to utter that sound in the presence of the appropriate sensation. There is nothing more involved in the meaning of the term beyond its having been correlated with sensations of that type, and if I have not experienced the relevant sensation, I cannot know the meaning of that term. More complex terms, e. g., "person," "galaxy," or "electron," must be correlated with a complex set of sensations, but the meaning of each of these terms, too, is just the set of sensation types with which it is correlated. Thus not only are we limited to the observation of our own sensations, but insofar as our utterances are to have empirical significance, we are limited to talking about our own sensations: all such utterances must be translated into claims about what we have sensed or predictions of what we will sense.

There is one more point that is required to complete our rapid summary of this tale. Given that the meaning of a term is the set of sensation types with which it is associated, a term that is associated with two (or more) distinct types of sensation must be understood as having two (or more) distinct meanings. The visual and the tactile sensations of roundness are distinct sensation types, and the word "round" is thus quite as ambiguous as, say, "wind" or "lead'. More to the point, we have two distinct concepts, a concept of visual roundness and a concept of tactile roundness, and these concepts have no more in common than the concepts of, for example, roundness and smoothness. It is a striking empirical fact that visual roundness and tactile roundness seem to be constantly conjoined, but this is strictly an empirical fact with no deeper significance.

This, in outline, is classical empiricism. Many of the criticisms

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of this philosophy are familiar, and I will not repeat them here, but there is a recent critique of empiricism due to Paul Churchland that I do want to discuss because it involves a new argument that will help us move toward a more adequate version of empiricism.[1] To a large degree it is the theory of meaning that provides the keystone of the empiricist edifice—especially among those twentieth century philosophers who hold that empiricism is a purely logical thesis, not a psychological hypothesis about the workings of our minds. Churchland's argument focuses on this theory of meaning.

Churchland asks us to imagine a race of beings who are identical to us except for two points of physiology. The more important of the two is that their eyes are sensitive in what we would describe as the infrared portion of the electromagnetic spectrum, a portion of the spectrum that we experience, through other receptors, as heat. We will assume that their visual sensations are qualitatively identical with the range of visual sensations we experience when looking at an infrared photograph, i.e., they run the gamut from black in the presence of objects we experience as cold, through varying shades of gray, to white in the case of objects we experience as hot.

The second characteristic that distinguishes these people from us, is that they have no other means of sensing temperatures; this is introduced mainly for simplicity. We shall also postulate that these people speak a language that is indistinguishable from ours except that it lacks a color vocabulary.

It seems that these people would learn to judge the relative temperatures of objects visually, and that the ability to do this would be of great practical significance. For although they would not feel heat or cold when they came into contact with hot or cold objects, they would be just as subject to physical harm from heat or cold as we are (much as we can be seriously hurt by gamma radiation even though we cannot sense it). They would take the same precautions against sunburn or frostbite as we do, but they would take them solely on the basis of visual information. Similarly, they would accept the same body of everyday beliefs about

[1] Paul Churchland, "Two Grades of Evidential Bias," *Philosophy of Science* 42, 1975, pp 250-259. *Scientific Realism and the Plasticity of Mind*, Cambridge, Cambridge University Press, 1979, ch. 2.

heat and cold that we do: they would refrigerate meat, fry eggs, ice skate, and so forth. They might also develop the same mathematical and physical theories of heat as we have developed, and, like us, they might construct instruments for obtaining more precise information about the temperatures of various objects than they can acquire by unaided use of their senses. Finally, let us imagine that we have not yet come into physical contact with these people, but have been carrying on conversations with them by means of teletype machines—in effect, the two groups have been undergoing a Turing test with respect to each other. One outcome of this interchange concerns us here: the members of the two societies would soon agree that they share the same body of beliefs about temperatures and, in fact, that they share the same system of concepts for dealing with temperatures—that their word "hot" means the same as our word "hot", and so forth—and that this holds in spite of the fact that the sensations they associate with temperature terms are utterly distinct from the sensations that we associate with these terms. Analogous examples could be constructed for the other senses, and it would seem to follow that there is no necessary tie between the meaning of a term and the type of sensation we associate with that term. Let us consider the problems that Churchland's story raises for the empiricist theory of meaning in greater detail.

If we were to accept an empiricist theory of meaning, then we would have to conclude that, the results of our Turing test notwithstanding, we do not share a temperature vocabulary with our new friends. Rather, their use of certain familiar terms requires translation if we are to understand their meaning properly: whenever they say "hot" what they really mean is "white," whenever they say "cold" what they really mean is "black," etc. But there are two reasons why this suggestion is incoherent. In the first place, we would have to cease viewing them as people who function sanely and successfully in their environment on the basis of a set of true beliefs about that environment. Instead, we would have to view them as holding a set of absurdly false beliefs about the world they live in: "Food keeps best in a black place," "People perspire in white environments," and so on. Still, if we came to observe their behavior, we would find that they function amazingly well on the basis of these ridiculous beliefs. For reasons which would seem utterly mysterious, they store their food in places which feel cold to us, and many of these places do not look black. They do not expect to perspire in every white environment, but only in those which we experience as hot, and they also expect to perspire in many places which they describe (in translation) as white, although they do not look white to us, but they do feel hot. We would have to conclude that these people are hopelessly confused, but amazingly lucky, and that is a lot to swallow in defense of a philosophical hypothesis.

Consider now a second problem. Every reason our empiricist philosophers could give for insisting that we must translate their "hot" as our "white", provides an equally good reason for their empiricist philosophers to insist that our "white" must be translated as their "hot". Now we are the ones who are confused but lucky, the ones who hold such absurd beliefs as that snow is hot, when anyone can see that it is cold, and who ignore our own observation reports and, for some mysterious reason, take precautions against cold, not heat, when we go out on a snowy day.

As the above discussion suggests, the empiricist theory of meaning generates many more problems than it solves, a conclusion that will already be familiar to those who have followed the twists and turns of the empiricists' attempts to fit the theoretical terms of modern science into their philosophical framework.[2] In sum, the empiricist theory of meaning has little to recommend it. It makes a great deal more sense to acknowledge that our hypothetical friends have the same system of temperature concepts that we do, and that the qualities of our sensations do not determine the meanings of our terms. Rather, sensations provide a guide as to which concepts are to be applied in a given situation; qualitatively different sensations can elicit the same concept, and qualitatively identical sensations can elicit different concepts. Which concept gets tied to what sensation depends on two factors: the nature of the available conceptual system, and the causal factors which generate the sensation in question. The second factor will turn out to be particularly important, but I want to work up to it, as well as reinforce the argument thus far, by leaving hypothetical cases

[2] I have discussed these attempts in Harold I. Brown, *Perception, Theory and Commitment: The New Philosophy of Science*, Chicago, University of Chicago Press, 1979, ch. 3.

and considering some examples of observation in sophisticated physical science. I think that the import of my argument will be clearest if the reader knows in advance the exact conclusion towards which I am working: that the traditional empiricist view of the fundamental role of observation in our knowledge is correct, but that the attendant view of the nature of observation must be replaced.

Consider the first observation of Pluto.[3] The existence of this planet had been predicted by Lowell on the basis of considerations similar to those that had earlier led to the prediction of Neptune, but while Neptune was located observationally the first night that Galle looked for it, the problem of finding Pluto in the skies was much more complex. Recall that Pluto takes about 250 years to complete a single orbit of the sun; if the planet is located in a portion of the sky where observation is difficult, it may be there for a long time. This in fact is what occurred. The predicted location of Pluto put it in the direction of the center of our galaxy, with the result that the observer was quite overwhelmed with images, and could not proceed, even as a first step, by simply looking for a spot of light at a specified position. In order to identify a planet under these circumstances the astronomer must seek a spot of light whose position changes over a period of time against the background provided by the remainder of the spots of light. One thoroughly implausible way of doing this would be to study the relevant portion of the sky night after night, carefully fixing the star patterns in memory, and looking for the speck that has changed location. This is implausible because of the enormous number of images involved: photographs of the relevant portion of the sky were yielding about 300,000 images per photograph and, in fact, it was photography that provided the key to the observation of Pluto. Astronomers located Pluto by taking numerous photographs of the sky and later comparing those photographs, and while some astronomer may have put an eye to a telescope, this was neither a necessary nor even an important part of the observation process.

There is more to this story, but I want to pause for a moment

[3] Cf. George Abell, *Exploration of the Universe* 2nd edition, New York, Holt, Rinehart and Winston, 1964, pp. 319-320.

and raise some typically philosophical questions about the portion of the case that has been described thus far. Let us imagine a number of assistant astronomers working night after night photographing the sky, and developing those photographs (a non-trivial chemical process that impinges on the observation procedure). After a sufficiently large collection of photographs has been accumulated, a call goes out to the master astronomer, and on a day when she has no prior commitments, she comes to the observatory and begins studying these photographs. Assuming that she is successful in locating the shifting image, my first philosophical question is, "At which point in this extended process did the observation of Pluto occur?" Did it occur when the astromer noticed a shift between images on a pair of photographs taken at different times? Did it occur when the astronomer looked at a photograph that contained an image of Pluto, even though the image was not identified? Did it occur the first time someone looked through a telescope and formed a visual image which included an image of Pluto, even though that image was not identified? If the last of these seems plausible, then why was there so much fuss after Lowell's prediction? Astronomers with powerful telescopes had been seeing Pluto for centuries at this point, they just failed to notice it. There may be a sense of the word "see" in accordance with which these early astronomers were seeing Pluto, but that sense is clearly irrelevant to our current concern with clarifying what counts as the first observation of the planet. If none of these answers to our question seems satisfactory, there is a straightforward reason why, for I have posed a complex question whose presupposition—that an observation is a specific event located in a brief time interval—is false. The first observation of Pluto can only be understood as a process extended over a substantial period of time.

One response to this conclusion must be dealt with at once. "Observe," we will be told, is an achievement word, and the claim that an observation must be an event is an analytic proposition which is derived *a priori* from an analysis of ordinary language, or our everyday conceptual framework. There are two ways to respond to this claim. The first is to concede, for the sake of argument, the claim about the ordinary meaning of "observe," and simply note that there is no reason to expect the analysis of ordinary language to provide any insight into scientific procedures.

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Alternatively, if one is convinced that the only legitimate meaning of "observe" is its ordinary language meaning, then we will be led to conclude that much of current science is non-observational, and begin trying to construct a wholly non-empiricist philosophy of science. I think it will be much much more fruitful to defend the traditional empiricist principle that observation is a necessary part of the process of learning about nature, and to try to understand more clearly what constitutes observation in modern science, as well as the historical process by which the modern notion of observation has emerged out of an older notion which is still embedded in our ordinary talk.

I turn now to a second philosophical question: "What role, if any, does the quality of the sensation we experience when we look through a telescope or at a photographic image play in determining the meaning of the term "Pluto?" It seems quite clear that the answer is "None." The astronomers who searched for Pluto had an adequate understanding of what they were looking for before the term had been correlated with any particular sensation. Moreover, if they did not begin with this understanding, the photographs would make no sense to them at all. If I handed you a selection of these photographs, and provided no background information about how they were generated, you would have no way of determining what information these photographs carried: they might be scanning electron micrographs, or I might have mocked them up in my own darkroom. Just as in Churchland's story about the people who see temperatures, so here, what information the photographs yield depends on two factors: the physical processes that generated them, and the body of concepts and beliefs that the person trying to interpret the photographs already has available. This, in sum, is the thrust of the claim that one finds in Kuhn, Feyerabend, Churchland, and others that meaning flows from theory to sensation, not in the reverse direction.

I want to raise one more philosophical question in the context of this example: "When the master astronomer found the shifting image and announced an observational confirmation of the existence of Pluto, what had literally been observed?" I think that the only coherent answer that can be given at this point is that Pluto was observed. This does not, of course, mean that we now know indubitably that Pluto exists, scientific observation is not indubitable. But it does mean that we must reject certain other tempting answers. In particular, we must reject the suggestion that what has in fact been observed is a pattern of white spots on a black background. Once again, those spots play an epistemically significant role in science only in so far as they can be located in the context of an understanding of how those spots were generated. More importantly, if the process which culminates in the detection of a moving spot against the background of a set of stationary spots on a series of photographs is not to be understood as an observation of Pluto, then Pluto has not been observed. There are, of course, some philosophers who would argue that Pluto has certainly been observed, but that the statement "Pluto has been observed" must be analyzed in terms of statements about white dots on a black background. But this claim is only plausible if one accepts an empiricist theory of meaning, and Churchland's argument, along with the myriad other arguments that have emerged over the past few decades, should be sufficient to lay that theory of meaning to rest.

Now let me finish the story of the observation of Pluto. Above I spoke rather imprecisely about a process extending over a period of time; in fact it was a period of years. Lowell began searching for Pluto in 1906, and the process was completed by Clyde Tombaugh some time in February 1930, using a pair of photographs taken on January 23 and January 29 of that year. We should also note that the discovery was facilitated by the invention of the blink microscope, a device for studying not the sky, but photographs. Two photographs of the same region of the sky taken at different times can be placed in a blink microscope, and the observer's vision is automatically shifted between the two photographs. An image which changes position against a stationary background will stand out when the photographs are examined in this manner. I now want to consider some hypothetical alternatives to this procedure, and while they may sound like sheer speculation, we will see shortly that they are in fact variations on actual techniques used in some more recent cases of scientific observation.

First, suppose that instead of the blink microscope, there had been available a sufficiently powerful scanning device, hooked up to an appropriately programmed computer, and that these instruments scanned and evaluated the photographs. We might also imagine that the telescope was computer-controlled, and that the process of developing and storing photographs was also automated. Astronomers work at a console entering commands into a computer which then takes over, and when the shifting image is located, an alarm goes off. The astronomers now enter a command into the computer, and the computer constructs an oscilloscope display for their benefit which, using time lag techniques, shows them an image of the motion of Pluto over the past 25 years, reduced to 12 seconds. Has Pluto been observed? Of course it has. The astronomers will have no hesitation in announcing the observation, and the results will play the exact role in the confirmation of Lowell's prediction that empiricists have always argued observation must play in science.

Now vary the story slightly. Instead of an oscilloscope display, let the computer print out the announcement that Pluto has been located, along with a list of the orbital elements. Again, the observation has been made, although the only thing anyone sees is a pattern of black marks on paper. And in this case I do not think that there is any temptation to suggest that other astronomers whose computers print out results in green ink in Greek, or in blue ink in Chinese, or whose more advanced machines report results in speech instead of in print, are actually making quite different observations which, it so happens, are empirically correlated with each other and with those that we are making.

As a final variation, let us enter into the realm of what is, for now, science fiction. Following the suggestion by Goldman[4] and Churchland[5], suppose that the computer does not even yield a readable printout, but rather produces an RNA tablet which, when swallowed, results in my brain and nervous system being brought into exactly the state it would be in if I had examined the photographs in a blink microscope. Or, perhaps the computer controls a new form of radiation that alters nervous tissue in the relevant way. In both of these cases our sense organs have been totally bypassed, but we have the same information that we might have derived by

[4] Alvin Goldman, "Epistemology and the Psychology of Perception," *American Philosophical Quarterly* 18, 1981, p. 50.

[5] Paul Churchland, "Eliminative Materialism and the Propositional Attitudes," *Journal of Philosophy* 78, 1981, p. 88.

means of our senses, and we have observed Pluto. The kindest thing to be said about the traditional empiricist account of observation, at this point, is that it is irrelevant.

I now want to add some much briefer remarks about a number of recent cases of scientific observation, primarily because this will show how little of the above does fall into the realm of science fiction. To begin, consider bubble chamber observations. We may be tempted to picture a scientist sitting in front of the scanner watching images form, but bubble chambers are run under cryogenic conditions, and are completely encased in steel. High-speed cameras are built into the casing, and the observation proceeds through the examination of photographs, not by watching images formed during the experiment. It is not unusual for a bubble chamber experiment to yield several hundred thousand photographs which must be painstakingly studied for many months in search of interesting events. Attempts have been made to develop computerized techniques to scan the photographs, but, as physicist Gerald Feinberg notes, the final step in which the computer also writes the paper has not yet been taken.[6] This last step is one which ought to trouble no one.

Next, I will note that in a major neutrino physics experiment now in process at Fermilab in the United States, the detection process is wholly electronic. Leaving aside many rather complex details, when particles pass through the detector electric signals are generated, and these signals are fed directly to a computer where they are stored on tape until the results can be conveniently examined. Moreover, while the visible output from the computer will often be in the form of an oscilloscope display, this will not be a display of raw data; the computer does a great deal of processing before the parameters for an oscilloscope display have been determined.[7]

As a final example, consider one aspect of the process by which we make observations of Saturn by means of a Voyager spacecraft.

[6] Gerald Feinberg, *What is the World Made Of?*, Garden City, New York, Doubleday Books, 1978, p. 160.

[7] See Dudley Shapere, "The Concept of Observation in Science and Philosophy," *Philosophy of Science* 49, 1982, pp. 485-525 for an analysis of the continuing solar neutrino experiment. Shapere's results are completely consistent with the position developed here.

After the primary instruments have done their job, a process of the following sort occurs: the output from the instruments is translated into digital form, and then, into the form of modulations of electromagnetic waves which are transmitted back to earth, where they are detected by antennae and converted back to digital form for storage on computer tape until the observers are ready to examine them. Even when the results are published as photographs, these are photographs that have been reconstructed by the computer, which will often use image-enhancing routines in the process. It is only this highly-processed image that anyone ever looks at.

The main goal of the discussion thus far has been to emphasize the fundamental role of instruments in modern scientific observation, and to suggest some of the ways in which the need for these instruments in science requires that we rethink the entire question of what counts as scientific observation. I now want to reargue the point from a different perspective, one which will give us some deeper insight into the reasons why a revived empiricism must take the role of observing instruments in science very seriously indeed.

It will be useful to go back for a moment to the seventeenth century, a time at which both science and philosophy were undergoing a number of major revolutions; I want to focus on two points here. The first of these is the attack on one feature in particular of the Aristotelian-Thomistic epistemology: the thesis that our senses are perfectly adapted to showing us the nature of the world around us, a view which takes it for granted that the natural world contains neither more nor less than we can discover by means of unaided sense perception. The crucial break with this belief comes with the emergence of the distinction between primary and secondary qualities in Galileo, Locke and others. A number of lines of argument led to the drawing of this distinction, but in the case of Galileo it was closely associated with his systematic use of the telescope. The telescope is an instrument of the modern sort, i. e., it is interposed into the causal chain between our sense organs and the physical world, and as a result of its entry into this causal chain, it permits us to detect things we cannot detect without it. Perhaps the oldest instrument of this sort is the magnetic compass, which literally permits us to see the direction of the earth's magnetic field, but the telescope was the first such instrument to be systematically deployed as a tool for scientific research. The emergence of instruments of this sort is the second feature of the seventeenth century that I want to note here.

Now, given that such instruments were new, and that there emerged a conflict between, for example, the heavens as shown to us by our senses, and the heavens as revealed by the telescope, it made perfectly good sense to ask which of these views of the heavens is more reliable. Galileo had no doubt of the superior reliability of the telescope, and he attempted to resolve an outstanding problem of Copernicanism by arguing that the telescopic version of the heavens supports the Copernican view, and that the naked eye view of the heavens is unreliable because of an inherent defect in our eyes, a defect that the telescope corrects.[8] Thus for Galileo our unaided senses are insufficient for the study of nature: they generate illusions, and lead us to believe that the world around us has different characteristics than in fact it has, but these illusions can be dispelled by the use of appropriate observing instruments.

Descartes and Locke, among others, arrived at the conclusion that our senses do not provide an unreservedly reliable guide to the constitution of the physical world by different routes than Galileo. Locke's version of this position was encapsulated in his distinction between primary and secondary qualities, and there is one feature of Locke's distinction that is of particular interest to us here. Locke's secondary qualities are properties which occur in our perception of objects, but which are not copies of the properties that these objects have in their own right. Thus our senses are not completely reliable guides to the features of the world around us because there is *more* in our senses than is to be found in nature. But as science developed, a rather different perspective emerged. For while it is still arguable that many of the properties we sense do not characterize the physical world apart from our experience, it has become much more important to recognize that the major limitation of our senses in scientific research derives from the fact

[8] The problem derived from the fact that the Copernican view predicted much greater variations in the brightness of the planets over the course of a year than was predicted by Ptolemaic astronomy. Naked eye observation was consistent with the Ptolemaic prediction, while telescopic observation supported the Copernican prediction. *Dialogo sopra i due massimi sistemi del mondo, Le Opere di Galileo Galilei* VII, ed. Antonio Favaro, Florence, G. Barbera, 1897, pp. 361-364.

that there is much *less* in our senses than in the physical world, i. e., that the universe is full of things that we cannot detect without the aid of instruments. And this is meant in a strong sense. When Galileo turned his telescope on the heavens, he did discover stars and satellites that could not be seen without the telescope, but these are features of the world that we could detect with our eyes if we were located elsewhere. In more recent times, science has regularly been discovering features of the universe which our unaided senses are incapable of detecting under any circumstances. Again, the magnetic compass can serve as a simple example. Human beings have not evolved receptors which allow us to detect the direction of the earth's magnetic field directly, but the compass provides an additional link in the causal chain which permits us to see the direction of this magnetic field. Modern scientific instruments are progressive elaborations on this idea, and the use of such instruments has permitted us to observe features of the world that we could not observe without their aid. I want to explore a further example from contemporary science in some detail because it will help to indicate how much richer and how much more intriguing a place the universe has turned out to be than we could ever have guessed without the aid of instruments.

The example I wish to explore is the electromagnetic spectrum, and I will begin with some preliminary remarks. First, recall that the electromagnetic spectrum consists of radiation that can be characterized by a single parameter, either frequency, wavelength or energy, these being functionally related. Second, there are two portions of this spectrum that we can detect without the aid of instruments, although for most of human history we were unaware that we were detecting electromagnetic radiation. We have sensors for a portion of the infrared spectrum, which we experience as heat, and we have sensors for the visible spectrum, which we experience as light. Within the visible spectrum, most of us are capable of distinguishing different frequencies, which we experience as colors. Third, there are no intrinsic distinctions in this spectrum corresponding to our distinctions between infrared, light, X-radiation, and so forth. As we have discovered different portions of the spectrum we have given them labels, but the various portions of the spectrum shade into each other on a continuum. Different beings, with different senses, different interests, or a different history, might divide up the spectrum differently. Finally, if we consider the history of astronomy we find that while this discipline has, throughout most of its history, been concerned with the detection and analysis of visible electromagnetic radiation, since the 1940's there has been a dramatic extension in the astronomer's observational range. With the development of radio astronomy, infrared astronomy, ultraviolet astronomy, and X-ray astronomy, it is now possible for astronomers to make observations throughout the electromagnetic spectrum, and the results of these observations are changing, yet again, our understanding of the universe.

Consider the panorama of the night sky, and note particularly that the same stars, in the same patterns, appear to us year after year, and seem to stand, with occasional exceptions, as unchanging features of the universe. Quite understandably, people in many cultures have been impressed with the stability of the heavens. But this viewpoint is based on observation in the visible range, and it is now clear that the stars are neither solely nor even primarily generators of visible light. Stars radiate throughout the electromagnetic spectrum. They have no special interest in producing radiation detectible by our eyes, and the heavens include many objects that we cannot see because their primary radiations do not happen to be in the visible range. Churchland's beings with infrared eyes would see an equally impressive, but different spectacle as they studied the night skies, and beings with X-ray eyes (and no atmosphere to prevent the radiation from reaching them) would see a very different spectacle. Many objects that are powerful X-ray radiators are also subject to wide variations in the amount of radiation they emit in this range. As a result, these beings would be treated to a nightly show of the heavens made up of spectacularly fluctuating objects, with whatever impact this display might have on their early science, their philosophies, and their theologies.

I want to emphasize the main point of these remarks about astronomy. Stars, galaxies, quasars, etc. radiate throughout a large portion of the electromagnetic spectrum, and while we are understandably most familiar with those objects that radiate strongly in the visible range, there is no reason, given the present state of science, to believe that the visible objects are especially important for understanding the structure of the universe, nor even for believing that, among the visible objects, the visible portion of their radiation is particularly important for understanding what they are and how they function. Our senses obviously provide information about our environment which has allowed us to survive and develop on the surface of this planet, but we have no reason for believing that these are the only senses possible, and no reason for believing that these senses provide a special source of insight into the nature of the world around us. But we are not limited to taking data in the range in which we have sense organs, nor to interpreting that data in terms of the range of properties we can detect through our senses. The notion that the range of our knowledge is limited by the range of properties we can sense is itself an artefact of tying our philosophy to a pre-twentieth-century stage of science. Philosophers such as Descartes and Locke were extremely sensitive to the science of their day, and there is no good reason why *we* should insist on continuing to do epistemology in the context of seventeenth-century science.

My discussion thus far has been largely critical, and I now want to offer a positive account of observation. What is crucial about observation is that it provides a means of gaining information about the world around us. In order to develop this point clearly, however, we must distinguish two different senses of the term "information," and this can best be done by means of some examples.

Suppose that, under the aegis of the United States Freedom of Information Act, I request that the FBI send me a copy of any files they have concerning me, and they respond by sending me a copy of a file, but only after having had it translated into Chinese (which they know I do not read). Have they complied with my request? All of the information I requested is present in the documents supplied, so in this sense they have complied; but there is also a sense in which they have at least evaded the spirit of my request, since they have provided the information in a way that is not accessible to me. Still, that information would become accessible if I were to learn Chinese or hire a translator. I will refer to the sense in which the information I requested is contained in the documents as the "ontological" sense of the term "information," and I will refer to the sense in which this information would be available to me if I read Chinese as the "epistemic" sense.[9]

Science provides an unlimited supply of parallel examples. Consider, as a first instance, tree rings. Those who know enough biology to understand the significance of tree rings can extract a great deal of information about the growth history of a tree from a study of tree ring patterns. That information is available to these people; this is information in the epistemic sense. But independently of whether anyone has the background knowledge needed for extracting that information, information about the growth of the tree is present in the tree rings, available to anyone who can extract it; this is information in the ontological sense. Similarly, in the late 1920's and early 30's several physicists had experimental results that we can now recognize as evidence for the nonconservation of parity in weak decays, but these scientists did not give it this interpretation. In fact, they never found an adequate interpretation for their results, and they eventually abandoned that line of work. Only much later, when the idea that parity is not conserved in weak decays had been introduced on quite different grounds, did it become possible to provide an adequate interpretation of those old experiments.[10] All of the information needed to establish the nonconservation of parity was (ontologically) present in those early experimental results, but the information was not epistemically available until the background needed to extract it had been developed.

With this distinction before us, we can now state that all the information we need in order to understand the world we live in is, in the ontological sense, available and waiting, so to speak, for us to discover how to gain access to it; a major part of the observational scientist's task is to figure out how to gain that access. This involves two classes of problems. One of these problems is that of developing the theoretical frameworks that are required to extract different portions of this information. The second class of problems concerns our access to information in a more direct

[9] In *Scientific Realism and the Plasticity of Mind, op. cit.*, pp. 14-15, Churchland draws a distinction between "objective intentionality" and "subjective intentionality" that is, in many ways, analogous to the distinction between the ontological and epistemic senses of "information."

[10] See Alan Franklin, "The Discovery and Nondiscovery of Parity Nonconservation," *Studies in History and Philosophy of Science* 10, 1979, pp. 201-257.

respect, for there is much in the universe that we cannot detect with our unaided senses, even with the aid of the most powerful theories. I have already offered the earth's magnetic field and most of the electromagnetic spectrum as examples, and further examples could be given, ranging from the most esoteric of scientific concerns, such as the solar neutrino flux, to quite practical matters such as the presence of radioactivity or streptococci in our environment.

One of the most striking and characteristic features of science has been the continual development of observing instruments which allow us to detect entities and processes that are not available to our senses. In general these instruments, whether they be magnetic compasses, Geiger counters, radio telescopes, electron microscopes, bubble chambers, or what have you, are best understood as transducers whose input consists of entities and processes that we cannot detect, and whose output consists of entities and processes that we can detect. The development of such instruments is a necessary step in gaining access to most of the universe we live in. To be sure, instruments that are going to be of any use to us must have an output that we can detect, usually by vision, and this provides one important constraint on the design of our instruments, but this is no more than a constraint on the design of instruments. It is not a constraint on the possible contents of the universe or on the possibility of our knowledge of those contents.

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