Technology-Mediated Observation

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Doing something does not imply understanding what we are doing or being conscious of how we are doing it. Talking, remembering, and making decisions are examples of activities we continuously engage in in blissful ignorance of the processes and procedures involved. And the same happens with science. Philosophy of science is the attempt to get some explicit understanding of what we are doing when we engage in science. By science I mean here empirical science, not just mathematics. Whereas mathematical theories are subject only to the constraint of consistency, the theories of empirical science need an interface between our symbolic representations and the presentations of external reality. That interface is provided by observation and experiment.

The whole body of empirical science is built on observations. However intuitively appealing and mathematically educated our theories may be, they only enter the domain of standard empirical science when tested, checked, and confronted with external reality through the means of observations. The entities and facts we talk about in empirical science must have some detectable effects; they must knock at our door (however softly). That makes the big difference between the particles which have been detected (however indirectly), like electrons, or even quarks or W bosons, and the (up to now) purely speculative particles, undetected by any account, like Higgs bosons, photinos or superstrings.

So, the role of observation is absolutely central and constitutive in empirical science. But what is observation? In most Western languages the word corresponding to the verb, "observe" (and hence to the noun "observation"), has two associated meanings: (1) to keep to, to attend to in practice (e.g., to observe a custom, a prohibition), and (2) to watch attentively. The same two meanings are evident in Greek *teréo*, *téresis*, in Latin *ob-servare*, *ob-servatio*, in German *be-ob-achten*, *Be-ob-achtung* (modeled on the Latin anyway), etc. Here we are interested only in the second meaning of observing, i.e., watching attentively, or, in Roberto Torretti's (1986) words, in "the attentive, deliberate, explicitly cognitive mode of perception that goes under the name of *observation*" (p.1).

Personal and Impersonal Observation

We increasingly look at the world through technological extensions of our senses. Many of us are short-sighted or have some other optical aberration in our eyes, and could not observe our surroundings effectively without the help of prescription glasses, which are an early technological device. As early as the 13th century Marco Polo noticed that many Chinese wore glasses to see. At the end of the Middle Ages eye-glasses were common in Europe.

Direct, non-mediated observation through the senses has become the exception rather than the rule, in science of course, but also in our daily life. When we watch something on TV, or listen to the telephone or the CD player, there is a long and complex chain of transformations and transductions of different signals.

Torretti (1986, pp. 2ff) has provided a clear characterization of the difference between personal and impersonal observation. Any type of observation always involves a physical process which links the object observed to the receiver (human body or artifact) in a causal chain, but whereas personal observation is always accompanied by awareness, impersonal observation does not require any awareness. In the case of personal observation, a further difference can be made between the direct object of the observation (something which is before the observer's senses and to which he or she is paying attention) and its indirect object (the observer's main concern, the object of an impersonal observation whose receiver he observes personally).

Our body is the receiver in personal observation. Everything we see through our glasses is already a technology-mediated observation, but the mediation is limited to correcting the focus of ordinary vision. As emphasized by Ian Hacking (1983, pp. 194ff), the situation is very different when we come to a high power microscope, where diffraction and interference are substituted for the reflection and refraction of normal vision.

The verb "detect" comes from Latin *detégere* (to uncover, to expose the secrecy of), which derives from *tectum* (roof). To detect is, etymologically to take off the roof that covers something, to uncover it. In every form of observation some signals, usually in the form of radiation, are detected or received by a receiver or detector. Personal observation in which the receiver is our body or part of it is limited to a narrow range of signals—those signals (like visible light and audible sound) our body is genetically preprogramed to be able to detect. The multifarious receivers used in impersonal observation are designed to detect a much wider range of signals with a much higher level of resolution. If the signals detected are outside of the range to which our senses are sensible, the energy carrying these signals has to be converted or transduced into signals modulated in a different type of energy in a way accessible to us.

The signal-carrying radiation is detected by the artificial detector or receiver as an input. Eventually one or more transducers transform it into a human-accessible or computer-accessible signal as an output which becomes the input of the personal observation of an observer or of an input device of the computer. The source of the original radiation is the object of the observation, the observed thing.

Observation in Science

Observation in science is often very contrived and indirect. An observatory is a place where observations are made in a systematic way. Astronomical observations often take place in astronomical observatories, but nowadays the telescopes in the observatories lack eye-pieces for direct observation by the astronomer. Instead, nitrogen or helium refrigerated CCDs occupy their place. The astronomers are in a separate room and watch the screens of their computers. When something strange appears on the screen, the astronomer cannot look through the telescope. He has to leave the building and look at the sky, with his naked eye, as did the astronomer who first sighted the 1987A supernova in the European Southern Observatory in Chile. Most of the time the astronomer does not even see pictures of the observed object on the screen, but only graphics representing the computer-generated spectral analysis of its light as detected by the CCD. What the astronomer sees on the screen has gone through multiple transductions of photons into electric charges and currents, and electronic transformations inside the computer, till finally the last electrons are transduced back to photons in the cathode ray tube of the computer screen. Those are the photons that reach the astronomer's eye (eventually through his glasses), not the photons of the astronomical source. So the whole observation or attentive watching by the astronomer is a very indirect affair. But observation nevertheless it is. The whole process has been triggered by photons coming from the source.

The detection or observation of extrasolar planets in recent years goes though CCDs, computer-generated spectroscopy, inference of wobbling of the star, inference of the gravitational pull of the planet on the star, etc. The detection of cosmic ray particles (very energetic protons, electrons, and light nuclei) is achieved through the detection of the so-called secondary cosmic rays (mainly electrons) which result from the decay of the muons produced in the collisions of the primary cosmic rays with atoms in the atmosphere. We usually do not speak of observation in this case because we are unable to identify the source of the cosmic rays.

Another example of very indirect observation was the detection of the top quark in 1994 (front-page news in many newspapers). In 1963 Murray Gell-Mann and George Zweig proposed the quark model, making use of the mathematical theory of groups to introduce order into the zoo of the 200 hadrons then known. All hadrons are composed of quarks and antiquarks. The bottom quark had been detected at Fermilab in 1977. The huge Tevatron accelerator (a ring of 6.4 km) was built there to try to detect its generation companion, the top quark, the last of the six predicted quarks to be discovered. In the Tevatron, protons and antiprotons are accelerated and brought into collision at an energy of 1.8 TeV. In April 1994 it was announced (and in March 1995 it was confirmed) that the top quark had been detected and had a mass of 174 GeV. The top quark only appears once every 10 billion collisions, and decays almost immediately. All in all (and till March 1995), 43 events had been found carrying the signature of the top quark. Every second 250,000 collisions take place and produce a continuous shower of resulting particles, which are continuously detected and analyzed by the computers, which make the decision of which events to record as potentially interesting. Only these are stored on magnetic tape. A top quark can only be produced in a pair of a top and an antitop. Each of them decays instantly into a bottom quark and a W boson, which also disintegrate almost instantly into more stable particles, which are then detected by the detectors and recognized by the computers as signatures of the top.

Loose Speech by Physicists

In the past only personal observations were called observations. Nowadays we also talk of observation in the frequent case of impersonal observation. By directly or personally observing our detecting instruments, we are able to indirectly observe the source of the signals they detect, and so learn about it.

Physicists are careful in the use of their technical terms, but often loose in their general vocabulary (words like seeing, observing, discovering or studying). Cosmologists often talk of "observing" the Big Bang (or its immediate afterglow) in the CBR, despite knowing (or believing) that the photons only stopped interfering with the electrons after the universe became transparent to photons, about 105 years after the Big Bang. Massimo Pauri (1991), Bas van Fraassen (1995), and others think the universe is not even an acceptable theoretical notion, but astrophysicist Robert Smith (1995) writes that his textbook describes "how astronomers observe the universe" (p. 3).

Let us have a look, for example, at some of the linguistic uses in just one article (by Kniffen, Chipman, and Gehrels, "The Gamma-Ray Sky according to *Compton*: A New Window to the Universe") in the collective volume edited by William Wamsteker, M. S. Longair and Yojii Kondo (1994).

Kniffen and colleagues say: "The mission goal for *Compton* is to perform broad-band gamma-ray observations with better angular resolution. . ." (p. 5). "The Oriented Scintillation Spectroscopy Experiment (OSSE) is designed to undertake comprehensive observations of astrophysical sources in the 0.1 to 10 MeV range" (p. 6).

Here observation is attributed to the Compton satellite as a whole, and separately to each single instrument on board, like the OSSE. Sometimes, instead of observation, the authors talk of detection, or even of seeing: The Burst and Transient Source Experiment (BATSE) "has so far detected 8 transient X-ray sources" (p. 14). "Only two pulsars were seen in gamma rays" (p. 8). Instruments not only "observe" and "see," they also "discover" and even "study." "In the course of its all-sky survey, EGRET has discovered a whole new class of gamma- ray sources, the extremely luminous gamma-ray quasars" (p. 9). "The study of gamma-ray bursts is the prime objective of the BATSE instrument" (p. 8). "In addition to the distribution of gamma-ray bursts, BATSE has intensively studied the spectra of the brighter bursts" (p. 9). "Pulsars are a class of targets which has been studied by all four *Compton* instruments" (p. 10).

So it is no wonder if, as remarked by Torretti (1986, p. 3), "physicists normally call direct observation much that . . . ought to be called indirect ." Philosophers of science have to pay attention to the linguistic uses of working scientists, but need not follow them in their less than lucid and consistent ways. As noted by Jerry Fodor (1984, p. 234), "Naturalized epistemology is not . . . a merely sociolinguistic discipline."

Philosophical Analysis

We do not have at our disposal any satisfactory philosophical account of the notion of observation which fully incorporates its technology-mediated character in modern science.

What is the difference, if any, between controlled observation and experiment? At least since John Stuart Mill (1843), an experiment is characterized by our capacity to control or stimulate the source of the signals. In an experiment some of the independent variables are under the control of the experimenter, but in mere observation no parameter of the source need be under the control of the observer, who at most is reduced to control and manipulate his own receiving instrument. According to Martin Harwit (1981, p. 5), observation is the most passive means of gathering data. The observer receives and analyzes information transmitted naturally by the system he is studying. The experimenter, in contrast, stimulates the system under controlled conditions to evoke responses in some observable fashion. An n-order experiment is an experiment where the experimenter is permitted to change n conditions or parameters of the system under study. A set of observations is a zero-order experiment. Observation is the simplest form of experimentation. Harwit's notions are clear enough, but nowadays they are usually blurred in the talk of astrophysicists less careful than Harwit, and of particle physicists, as when they talk of proton decay experiments, or of solar neutrino experiments, where we only control some relevant parameters of the receiver, but no parameter of the source of signals or system under study.

John Stuart Mill (1843) warned us about the fallacies of observation, and especially about the difference between the observation and the description of the observation. He was thinking mainly of personal observation. More than three centuries earlier, Columbus thought he was seeing India when he arrived in America. In the 19th century several British explorers (Richard Burton, John Speke, Samuel Baker) were looking for the source of the Nile, and repeatedly reported having seen it, when in fact they saw something else and the Nile even lacks a single source. Of course, Mill's warning is still more appropriate when applied to impersonal technology-mediated observation. From 1894 to his death in 1924 Percival Lowell made repeated "observations" of intelligently designed canals on planet Mars. Several astronomers at reputable observatories also "observed" the canals. Already in our days Halton Arp (1987) has been "observing" (or observing?) physically linked galaxies with very different redshifts where most of his colleagues only admit chance alignments in the line of sight.

Much philosophical discussion has concerned the relation of observation to theory. The logical empiricists had established a deep chasm between the so- called observational and theoretical terms of the language of science. Later authors pointed out that what is observational is relative to the actual state of technology, and so the distinction has to be gradual rather than abrupt. In 1958 N. R. Hanson launched a catchword about the theory-loadedness of observation, often repeated in exaggerated, muddled, and misleading ways. Of course I can observe your nose in a sense in which I cannot observe your super-ego. Or, if it ever makes sense to say that I observe your super-ego, that observation is theory- loaded in a way in which the observation of your nose is not. It is enough to know English to observe your nose; it is not enough to observe or to infer your super- ego, which requires a heavy dose of psychoanalytical theory.

As remarked by Torretti (1986, p. 4), "The observer grasps the object—be it direct or indirect—as a particular instance of some universal." That is also what the speaker does, in general. Hacking, Fodor, van Fraassen and others have resisted the tendency to blur the distinction between observations and mere inferences. It is true that "in indirect (personal) observation the observer must rely on previous knowledge in order to obtain information about the indirect object" (Torretti, 1986, p. 2), but that previous knowledge often concerns only the detection instrument and not the source, the observed object. So, in recent years many gamma-ray bursts have been detected or observed by the orbiting gamma- ray observatories, and no one knows what they are or where they come from. Precisely the observation of unexpected and unexplained phenomena has been the first step in the discovery of new aspects of reality and the development of new theories, as in the case of the discovery of X-rays by Wilhelm Röntgen or of radioactivity by Antoine Becquerel.

Dudley Shapere (1982) has emphasized the separation of the perceptual aspect and the evidential role (its role as a basis for inference) in observation. "Science has come more and more to exclude sense-perception as much as possible from playing a role in the acquisition of observational evidence" (p. 508). Of course, the exclusion cannot be complete. If the chain of physical interactions has to have an observational character, it has to end in some personal observation (some reading of the counter, or some looking at the screen, or whatever).

Shapere on Observation

In 1968 Raymond Davis started his experiment to detect solar neutrinos in an underground tank full of tetrachloroethene (C_2Cl_4), placed in an old gold mine 24 in Homestake, South Dakota. The heavier stable isotope of chlorine is able to capture neutrinos by the inverse beta decay reaction

$$^{37}Cl + \nu_e \rightarrow {}^{37}A + e^-$$

When a neutrino collides (very rarely) with a chlorine atom (^{37}Cl), this is transformed into detectable radioactive argon (^{37}A), which is periodically flushed out and counted. Only the high-energy neutrinos (more energetic than 0.81 MeV) from a rare side-chain of the hydrogen fusion reaction (the8B neutrinos from the reaction $^{8}B \rightarrow {}^{8}Be + e^+ + \nu_e$) are expected to be detected in this experiment. Although the signal-to-noise ratio (strength of the signal relative to the noise) is low and the detections are both indirect and averaged over a period of months, neutrinos have certainly been detected. Unfortunately, the result is somewhat embarrassing, since the detector is direction-blind, and the sun alone is predicted to produce a signal three times larger than that observed.

Some physicists described what Davis was doing as a direct observation of the inner core of the sun. Partially motivated by this usage, in 1982 Shapere published his influential paper on observation. Of course, any detection of solar neutrinos would involve at most impersonal or indirect observation, but he prefers to call them direct observations. Here is his explicit definition: "x is directly observed if: (1) information is received by an appropriate receptor; and (2) that information is transmitted directly, i.e., without interference, to the receptor from the entity x (which is the source of the information)" (Shapere, 1982, p. 492).

Shapere grounds his definition in the analyses of a single example, that of the solar neutrino experiment by Davis. He contrasts the transmission without interference or interactions of the inner solar neutrinos (produced by fusion at the core of the sun) with the transmission with much interference of the inner solar photons. So the interior of the sun would be directly observed through the detection of the solar neutrinos, because neutrinos do not interact on their way from the core of the sun to us; but it would not be directly observed through the detection of the photons formed at the core of the sun, because these photons undergo many interactions on their slow way up through the sun. In the case of the solar photons, only the surface of the sun is directly observed. This sounds more like a contrast between observation and inference than between direct and indirect observation, but authors are free to choose their terminology. Nevertheless, and with the wisdom of hindsight, Shapere's account can be seen to encounter more serious difficulties.

Difficulty 1: Do the detected neutrinos come from the sun's core? We have theoretical reasons to suppose so, but do we observe it? Not in the case of the Davis experiment analyzed by Shapere, as this experiment is direction-blind. Only after 1987 the Kamiokande II experiment was able to discern the direction of the incoming neutrinos. The same problem arises with the non-directionality of cosmic rays. The signals are detected, but the source cannot be localized, at least, observationally.

Difficulty 2: Do the neutrinos reach the Earth without interference, as Shapere states? He writes: "There are possibilities as to what might happen to them [the neutrinos] on their way from the sun that would affect their information- carrying possibilities; . . . they might oscillate between different 'states' while travelling from the solar core to the earth. . . . Despite the fact that they involve only one particle, such events [of neutrino oscillations] are treated in modern physics as interactions, on a par with the interactions between two or more particles. Hence it is necessary to understand the term interference in the second condition of my analysis of directly observed to include single-particle events of the sorts accepted by physics or considered as reasonable possibilities by physics" (Shapere, 1982, p. 499).

Nowadays many specialists (including John Bahcall) favor the Mikheyev-Smirnov-Wolfenstein (MSW) model of resonant neutrino oscillations, induced by neutrino interactions with electrons in the sun as the only solution to the persistent discrepancies between the number of incoming solar neutrinos calculated in the standard model and the actual counting of detected solar neutrinos in the different solar neutrino experiments now running. This implies some mass for some neutrino types, and the oscillation of the solar neutrinos between the different neutrino flavors or types. If we accepted such proposals (and Shapere is usually prone to accept this type of advanced speculative proposals), then—and according to his own definitions of what is an interaction and a direct observation—the detection of the solar neutrinos would not be a case of direct observation after all. With that, the whole distinction would break down. It is true that he intends his definition to state only sufficient conditions, but, of course, if they are not met, nothing follows from it.

Difficulty 3: Is the condition of no interference ever met? Shapere's analysis of the observation situation is similar to the analysis of noiseless communication in information theory. But there is always some noise in the real world. Besides, the analysis of Davis's experiment fulfills the condition only if it stops at the arrival of neutrinos at the tank and disregards the rest of the steps, in which different interactions and transformations of particles occur (as he himself describes), not to speak of the detectors, etc.

Difficulty 4: Are the conditions quoted in the definition really sufficient? They characterize a certain type of transmission of signals, and that can happen in the absence of any observer (in the intuitive sense). Everything can be conceived of as a transmitter and as a receiver of information. Everything is a receptor of information transmitted without interference. Is the planet Earth observing the source events of the meteorites, cosmic rays, radiations and gravitational waves which impinge upon it?

Shapere (p. 509) considers strengthening his definition by adding a clause requiring that the receptor be somehow connected with human users, but he rejects the suggestion. Perhaps he would point to the word "proper" in "proper receptor," but he does not elaborate on it. One could say that a physical system is a proper receptor if it has been designed by humans to serve as a receptor of a certain kind with some goal in mind. That interface with the observer's intentions is essential for the observational character of the physical process considered. If it is true that every observational system is a physical system, it is no less true that it would make no sense to consider all physical systems or chains as observations. Any information-theoretic account of observation must always take into account that the notions of transmitter, receiver, channel, signal, etc., are all relative to context and intention. "The status of these several items is indeed notional, and depends on the epistemic project which the observation is meant to serve" (Torretti, 1986, p. 17).

Role of Computer Analysis

As far as I know, no satisfactory account of technology-mediated observation is available. For example, none of the proposed accounts does justice to the essential role played by any computer processing of data, or by computational management of the whole experiment, its parts and its stages. From the detection of signals to the collection, analysis, selection and recording of data and the interpretation of results, computers as artificial extensions of our brains interact with the detectors as artificial extensions of our senses in myriads of scarcely analyzed ways.

In high energy particle physics a typical collider detector may have 100,000 wires, each one carrying information from the hardware end in the collision chamber to a sophisticated computer system that, first of all, has to decide whether to record the event or discard it. Since only one event in many tens of thousands (or millions) is interesting and the maximum speed of recording is relatively slow (a few per second), these electronic decisions are an important part of the art and science of detectors (Lederman and Schramm, 1995, p. 205).

The role of computers in astronomical observations is also increasing. In the universe there are around 50 billion galaxies (according to the extrapolation of the deep space sampling of the HST). Margaret Geller's project to map all of them by the end of the 21st century relies not only on the implementation of new detection devices for taking simultaneously the spectra of multiple points of light (galaxies) in the telescope, but also on the design of computer programs able to process all those spectra and numbers, and convert them into a detailed map of the universe. "We are already almost completely dependent on computers for data collection, analysis, and display, as well as much of our modelling and theory. . . . We are increasingly dependent on specialist programmers and large software 'packages'. . . . Highly automated systems are likely to miss completely the unexpected features in the data which might hold the key to the really important discoveries. . . . There is also the danger that the packages written by software professionals do not actually do what the astronomers think they are doing" (Hills, p. 530).

The results of the computer number crunching cannot usually be grasped in any intuitive sense. As emphasized by William Kaufmann and Larry Smarr (1993) they have to be submitted to visualization techniques that display the numerical data in the form of pictures which can then be directly and personally observed and intuitively understood and, so to speak, intellectually digested by the mind/brain of the observer.

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