No information without manipulation

Olimpia Lombardi – Cristian López – Sebastian Fortin

CONICET – University of Buenos Aires

Abstract

The aim of the present paper is to supply an elucidation of the concept of information in the communicational context. For this purpose, two traditional interpretations of the concept of information, the epistemic and the physical interpretations, will be distinguished, and their specific problems will be considered. In particular, whereas the epistemic interpretation misses an essential feature of communication, the physical interpretation faces difficulties in the quantum domain. The final goal will be to argue that the difficulties of the physical interpretation can be overcome by means of a manipulability conception of causation.

1.- Introduction

Since the mid-twentieth century, the word 'information' began to be increasingly present both in the everyday language as in the scientific discourse. With the explosion in telecommunications and computer sciences, nowadays it seems to be clear that "we live in the age of information." However, there are few concepts whose meaning is as evasive as the concept of information. To borrow the words of St. Augustine: "If no one asks me, I know what it is. But if I wish to explain it to one that asketh, I know not." Due to the elusiveness of the concept, any reflection about the matter should begin by discriminating the different senses of the term, and by delimiting the scope of the discussion.

The first distinction that needs to be introduced is between a semantic and a statistical approach to information. The first approach conceives information as something that carries semantic content (Bar-Hillel and Carnap 1953, Bar-Hillel 1964, Floridi 2011) and, as a consequence, is related with semantic notions such as meaning, reference and truth. According to the statistical approach, information is concerned with the statistical properties of a system or with the correlations between the states of two systems, independently of any meaning or reference. In the present article the discussion will be confined to the domain of statistical information, although it does not imply to disqualify the attempts to add a semantic dimension to a statistical formalism (MacKay 1969, Nauta 1972, Dretske 1981).

However, the focus on the statistical approach is not yet sufficiently specific. In fact, in the domain of statistical information different formalisms coexist and, often not sufficiently stressed, there are different contexts in which the concept of information is defined. In the traditional communicational context, information is primarily something that has to be transmitted between to points for communication purposes. In the computational context, by contrast, information is something that has to be computed and stored in an efficient way; in this context, the algorithmic complexity measures the minimum resources needed for an individual message can effectively be reconstructed (Solomonoff 1964, Kolmogorov 1965, 1968, Chaitin 1966). In this article we will deal only with the concept of information in the communicational context, in which the classical *locus* is Claude Shannon's formalism, designed to solve certain specific technological problems (Shannon 1948, Shannon and Weaver 1949).

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2.- Information in a communicational context

As stressed above, although Shannon's theory is the classical formalism to deal with statistical information in a communicational context, there are other formalisms that try to capture the concept of information from different perspectives. For instance, the Fisher information measures the dependence of a random variable X on an unknown parameter θ upon which the probability of X depends (Fisher 1925); the von Neumann entropy gives a measure of the quantum resources necessary to faithfully encode the state of the source-system (Schumacher 1995). Moreover, when information is linked with uncertainty, it is necessary to take into account that there is a general class of measures of uncertainty, of which the Shannon information is one member (Uffink 1990).

However, in spite of this formal multiplicity in the mathematical definition of the concept of information, there are certain minimum elements that can be abstracted to characterize a communicational context. In fact, from a very abstract perspective, communication requires a source S, which produces the information $I(S)$ to be transmitted, a destination D, which receives the information $I(D)$, and a channel C through which information is transmitted from the source to the destination. Both S and D are systems with a range of possible states, each one with its own probability, in terms which the amounts of information produced and received are computed; these amounts are usually, but not exclusively, measured in bits. The channel C can be characterized by means of the conditional probabilities that link the occurrence of the states of the source and the occurrence of the states of the destination. Although the success of communication is that all the information generated at the source, and it alone, arrives to the destination, in real situations this is not the case: equivocation E is the information generated at S but not received at D, and noise N is the information received at D but not generated at S; the so-called transinformation $I(S; D)$ is the information produced at the source and received at the destination. Therefore, independently of the way in which the amounts of information are computed, the following relation holds:

$$I(S; D) = I(S) - E = I(D) - N \tag{1}$$

Thus, in real communications the goal is to reduce noise and equivocation to a minimum by improving the features of the channel to avoid information loss, and by including filters to block noise.

In general, the information produced at the source is encoded before entering the channel, and decoded after leaving the channel and before being received at the destination. Claude Shannon (1948) and Joachim Schumacher (1995) have demonstrated theorems that supply the optimal coding in the classical and quantum case, respectively. Nevertheless, this aspect will be not central in the following discussion, which can be developed in terms of the minimum characterization of a communicational situation as presented above.

3.- Epistemic and physical interpretations of information

Although there are several formalisms to deal with information in the communicational context, this is not the main source of disagreements about the meaning of the concept. In fact, even in the case of the adoption of a single formalism, there may be strong divergences about how the term 'information' has to be interpreted. This is particularly clear in the case of the Shannon theory: the wide adoption of that traditional formalism does not imply interpretive agreement (see Lombardi, Fortin and Vanni 2015).

In everyday life, often the notion of information is strongly related to the idea of knowledge: information supplies knowledge. When we read the newspaper, we get information about national and international events, and so we learn something that we previously ignored. In other words, information is something that modifies the state of knowledge of those who receive it. On this basis, it can be supposed that the link between information and knowledge is a feature of the everyday notion of information and not of the technical concept (see Timpson 2004, 2013). However, this is not the case: this *epistemic interpretation* of information is very commonly found in the philosophical and in the scientific literature. For instance, although taking Shannon's theory as the underlying formalism for his proposal of endowing the formal concept of information with a semantic dimension, Fred Dretske establishes a close link between information and knowledge: "*information is a commodity that, given the right recipient, is capable of yielding knowledge.*" (1981, p. 47). This means that information is always in connection with a subject that learns something by means of it: "*A state of affairs contains information about X to just that extent to which a suitable placed observer could learn something about X by consulting it*" (Dretske 1981, p. 45; for an analysis of Dretske views, see Lombardi 2005). Also with the purpose of incorporating a semantic dimension to the statistical formalism, Donald MacKay claims that information is linked to an increase in knowledge on the receiver's side: "*Suppose we begin by asking ourselves what we mean by information. Roughly speaking, we say that we have gained information when we know something now that we didn't know before; when 'what we know' has changed.*" (MacKay 1969, p. 10). Although devoted to the research in formal and philosophical aspects of information based logics, Jon M. Dunn also defines information from an epistemic perspective as "*what is left of knowledge when one takes away believe, justification and truth*" (2001, p. 423).

Also some physicists tend to implicitly adopt this epistemic view when they speak about what we know or may know when dealing with information. For instance, in a traditional textbook about Shannon's theory applied to engineering, it can be read that information "*is measured as a difference between the state of knowledge of the recipient before and after the communication of information.*" (Bell 1957, p. 7), and that it must be relativized with respect to the background knowledge available before the transmission: "*the datum point of information is then the whole body of knowledge possessed at the receiving end before the communication*." (Bell 1957, p. 7). In the field of the attempts to give an informational foundation to quantum mechanics, Anton Zeilinger even equates information and knowledge when he says that "[w]*e have knowledge, i.e., information, of an object only through observation*" (1999, p. 633) or, with Časlav Bruckner, "[f]*or convenience we will use here not a measure of information or knowledge, but rather its opposite, a measure of uncertainty or entropy.*" (2009, pp. 681-682).

These quotes are only some examples that show how often information is conceived in terms of knowledge. Moreover, this epistemic view has been applied in different technical domains, for example, in the attempts to ground a theory of knowledge on informational bases (Dretske 1981), or in psychology and cognitive sciences to modelize human behavior as an information-flow process (MacKay 1956) and to conceptualize the human abilities of acquiring knowledge (Hoel, Albantakis and Tononi 2013).

When information is conceived

From this epistemic perspective, a physical connection between the source and the destination is not required for the transmission of information. All that is needed is that the observer placed at the destination end increases his knowledge as the consequence of receiving the information sent from the source. Nevertheless, the probabilities that link the states of the source with those of the destination cannot result from mere accidental correlations. In fact, when the correlation between two variables is merely accidental, the value of one of them says nothing about the value of the other. For instance, even if the properties P and Q are perfectly correlated – i.e., every P is Q and every Q is P – this does not guarantee that we can know that 'x is Q' by knowing that 'x is P': if the correlation between P and G is a mere coincidence, x's being P tells us nothing about x's being Q. In other words, the mere correlation and even the exceptionless accidental uniformity do not supply knowledge. Therefore, the probabilities involved in the communicational context are not *de facto* correlations, but manifestations of underlying lawful regularities. Indeed, commonly there is an elaborate body of theory that stands behind the attributions of probabilities (Lombardi 2004).

A different view about information is the one that detaches the concept from the notion of knowledge. According to the *physical interpretation*, information is a physical magnitude, something that can be generated at one point of the physical space and transmitted to another point; it can also be accumulated, stored and converted from one form to another (Rovelli 1996). Although with no logical connection, this view appears strongly linked with the well-known *dictum* 'no information without representation': the transmission of information between two points of the physical space necessarily requires an information-bearing signal, that is, a physical process propagating from one point to the other. Rolf Landauer is an explicit defender of this position when he claims that "[i]*nformation is not a disembodied abstract entity; it is always tied to a physical representation. It is represented by engraving on a stone tablet, a spin, a charge, a hole in a punched card, a mark on a paper, or some other equivalent*." (1996, p. 188). According to this view, it is precisely because of the physical nature of information that the dynamics of its flow is constrained by physical laws and facts: "*Information handling is limited by the laws of physics and the number of parts available in the universe*" (Landauer 1991, 29; see also Bennett and Landauer 1985). When appealing to the concept of information to elucidate the notion of scientific observation, Peter Kosso states that "*information is transferred between states through interaction.*" (1989, p. 37). The need of a carrier signal sounds natural in the light of the generic idea that physical influences can only be transferred through interactions.

From this physical perspective, the relation between information and knowledge is not essential, since the transmission of information can be used only for control purposes, such as operating a device at the destination end by modifying the state of the source. Of course, this does not mean that information conceived as a physical magnitude cannot supply knowledge; it can, but it is not defined in terms of knowledge.

The physical interpretation is the usual view in communication engineering: traditionally, the main interest of engineers is to optimize the transmission of information by means of physical signals, whose energy and bandwidth is constrained by technological and economic limitations. And the channels have to be designed in such a way that they can transfer the required amount of information; the capacity of a channel is measured in bits per second. To the extent that the unity of measurement of information is involved in the calculations side by side with the unities of traditional physical magnitudes, it is not easy to resist the temptation of conceiving information also as a physical magnitude. In turn, in the field of physics, the attempts to construct an objective interpretation of quantum mechanics on the basis of informational constraints (e.g. Clifton, Bub and Halvorson 2003, Bub 2005) may find conceptual support in the physical interpretation of information.

By adopting the physical view, some authors conceive information as a physical entity with the same ontological status as energy (Stonier 1990, 1996). Others, more cautiously, consider the analogy between the historical emergence of the concept of information and that of the concept of energy (Rovelli, personal communication). In fact, in the context of strict Newtonian mechanics, the concept of energy is subsidiary to the dynamical description of a system; it is a sort of "adventitious" concept designed to measure the capacity of a system to perform a certain task –work–. However, the concept was gradually acquiring its own, not merely adventitious, meaning, and became one of the fundamental concepts of physics. The words of William Thomson in the nineteenth century already express clearly this transformation: "*The very name energy, though first used in its present sense by Dr. Thomas Young about the beginning of this century, has only come into use practically after the doctrine which defines it had* [...] *been raised from a mere formula of mathematical dynamics to the position it now holds of a principle pervading all nature and guiding the investigator in every field of science*" (Thomson 1881, p. 475). At present, energy, although not material, has acquired a substantial nature –in the Aristotelian sense– in some physical domains, and plays a central unifying role in physics: energy is a magnitude essentially present in absolutely all contemporary physical theories; it is conceived as something that can be generated, accumulated, stored, processed, converted from one form to another, and transmitted from one place to another. Mutatis mutandis, in the light of the relevant role played by the concept of information in present-day physics, it is not difficult to suppose that it is following a historical trajectory analogous to that followed by the concept of energy in the nineteenth century physics: from initially being a tool designed to describe what we can do with material systems, the concept of information is progressively acquiring an independent and unifying physical content.

4.- Epistemic interpretation versus physical interpretation

The difference between these two interpretations of information is clear: if there is no interaction or physical signal between source and destination, from the physical view there is no transmission of information between them, whereas the epistemic view does not prevent such a transmission (see Lombardi, Fortin and Vanni 2015). In turn, this difference is not a mere irrelevant detail, but has important consequences regarding the view of certain traditional philosophical problems. Let us consider the case of the characterization of scientific observation.

By rejecting causal and anthropocentric approaches to observation in science, an important philosophical tradition explains scientific observation in informational terms. In order to elucidate the notion of observation without resorting to perceptual matters, Dudley Shapere proposes the following characterization: "*x is directly observed (observable) if: (i) information is received (can be received) by an appropriate receptor; and (ii) that information is (can be) transmitted directly, i.e., without interference, to the receptor from the entity x (which is the source of information)*" (Shapere 1982, p. 492). From a similar perspective, Harold Brown says: "*To observe an item I is to gain information about I from the examination of another item I*, where I* is an item that we (epistemically) see and I is a member of the causal chain that produced I**" (Brown 1987, p. 93). With a terminology more familiar to physicists, Kosso appeals to the concept of interaction: "*The ordered pair <object x, property P> is observable to the extent that there can be an interaction (or a chain of interactions) between x and an observing apparatus such that the information 'that x is P' is transmitted to the apparatus and eventually conveyed to a human scientist*" (Kosso 1989, p. 32). By contrast with the causal account of observation, this view makes it possible to recognize situations observationally equivalent but causally different, and situations causally identical but informationally different which, for this reason, represent different cases of observation. It is quite clear that, given this view of scientific observation, much burden falls on how the concept of information is interpreted, and this becomes particularly evident in the case of negative experiments.

Negative experiments were originally proposed in the context of the problem of measurement in quantum mechanics (Jammer 1974, pp. 495-496). In a negative experiment, an event is supposedly observed by noting the absence of some other event. The typical example is the case of neutral weak currents, which are observed by noticing the absence of charged muons (see discussion in Brown, 1987, pp. 70–75). Nevertheless, negative experiments can be analyzed independently of quantum physics. Let us consider a tube in whose middle point a classical particle is emitted towards one of the ends of the tube; a detection device is placed at one of the ends, say the right end *A*, in order to know in which direction the particle was emitted. Since there is a perfect anticorrelation between both ends of the tube, by looking at the right end *A*, we can know the state at the left end *B*. Nevertheless, the instantaneous propagation of a signal between *A* and *B* is physically impossible. Let us now suppose that, after a sufficient time the device at *A* indicates no detection: immediately we can conclude that the particle was emitted toward the left end *B*. But the question is: have we *observed* the emitted particle? The answer given from an informational approach to scientific observation depends on the interpretation of the concept of information adopted. Since there is a perfect anticorrelation between the two ends of the tube, by looking at the state –presence or absence of the particle– at the right end *A*, one can *know* the state –absence or presence, respectively– at the left end *B*. Therefore, according to the epistemic interpretation, there is an informational channel between the two ends of the tube, which allows us to *observe* the presence of the particle at *B*, even though there is no signal between *B* to *A*. The physical view, by contrast, leads us to a concept of observation narrower than the previous one: since there is no physical interaction between the ends *A* and *B*, by looking at the detector we observe the state at *A*, but we do not observe the state at *B*; such a state is *inferred*.

Given that the difference between the epistemic and the physical interpretations of the concept of information is not merely nominal, it is necessary to consider the difficulties that they have to face when conceptually analyzed.

5.- Epistemic and physical interpretations: difficulties

The appeal of the epistemic interpretation lies in its resonance with the everyday use of the word 'information', commonly linked with knowledge. However, conceptual difficulties arise in the technical domain. In fact, mutual information $I(S; D)$ can be easily interpreted in epistemic terms, as a measure of the knowledge about the source obtained at the destination end. However, it is difficult to conceive the noise N and the equivocation E as measures of knowledge, since they are precisely obstacles to knowledge acquisition. In particular, noise can be generated outside of the communication arrangement and has no relation with the source of information (think, for instance, in white noise in a radio receiver); therefore, it sounds conceptually dissonant to view it as carrying or yielding knowledge. A way out of this problem might be to consider that only the information $I(S)$ produced by source, the information $I(D)$ received at the destination, and the mutual information $I(S; D)$ have to be conceived as measures of knowledge, but not noise and equivocation. But this answer would lead to admit the possibility of adding and subtracting variables referring to different kinds of items, in this case knowledge –or something that measures knowledge– and something different from knowledge (see, e.g., eq. (1)), a practice not allowed in mathematized sciences.

The above difficulty is not the main trouble of the epistemic interpretation in the communicational context. Let us consider a TV transmitter T that broadcasts an electromagnetic signal to two television sets TV_A and TV_B. In this case, the correlations between the states of the two TV sets are not accidental, but they are the result of the physical dependence of the states of TV_A and TV_B on the states of T. However, there is no physical interaction between the two TV sets. Nevertheless, if the epistemic view is consistently adopted, it leads to admit the existence of an informational link between the two TV sets to the extent that it is possible to learn something about TV_B by looking at TV_A and vice versa: "*If the statistical relations defining equivocation and noise between S and R are appropriate, then there is a channel between these two points, and information passes between them, even if there is no direct physical link joining S with R.*" (Dretske 1981, p. 38). The set TV_B may even be farther from the transmitter T than TV_A, so that the states of TV_B are later than those of TV_A. Nonetheless, this is irrelevant from the epistemic perspective: despite the fact that the events at TV_B occur later, TV_A carries information about what will happen at TV_B.

This conceptualization of the above case sounds rather odd, and not because considerations about knowledge, but due to the communicational context in which the discussion is framed. In fact, whereas in communication the relationship between source and destination is asymmetric, the situation just described is completely symmetric: both TV_A and TV_B can indistinctly play the role of the source of information. This symmetry is a manifestation of the fact that nothing can be done, say, at the TV_A end that will affect what happens at the TV_B end. In other words, the change of the state of TV_A cannot be used to control or modify the state of TV_B. Communication, on the contrary, establishes an asymmetric relationship between two systems: one is the source and the other is the destination, and communication implies that someone does something at the source that has consequences at the destination. Therefore, the epistemic approach to information misses something essential of the usual conception of communication.

The case of the two TV sets is informationally analogous to the case of the EPR-type experiments, characterized by theoretically well-founded correlations between two spatially separated particles (Einstein, Podolsky and Rosen 1935). In fact, here there is also an epistemic link between the two particles: measurements on one particle can be used, by means of the quantum correlations resulting from the original interaction, to generate predictions about the other. However, as it has been often repeated, information cannot be sent from one of the particles to the other because the propagation of a superluminal signal between them is impossible: there is no information-bearing signal that can be modified at one point of space in order to carry information to the other spatially separated point. These cases act as a silver bullet for the epistemic view, since they make clear that merely epistemic relations are not sufficient for communication. In other words, the epistemic interpretation of information, although based on a natural conception of information as linked to knowledge, loses its reference to the communicational context in which the information is defined.

For the defender of the physical interpretation of information, on the contrary, the example of the TV sets and the EPR-type experiment support his position: both cases seem to make clear the need of a physical carrier of information between source and destination; it is this physical signal that allows us to say that what happens at the destination is the consequence of what happens at the source. This seems to tip the balance in favor of a physical interpretation of the concept of information. However, as always, matters are not so easy when quantum mechanics enters the scene.

The paradigmatic and conceptually conflictive situation in the field of quantum information is the case of teleportation. Broadly speaking, an unknown quantum state $|\chi\rangle$ is transferred from Alice to Bob with the assistance of a shared pair of particles prepared in an entangled state and of two classical bits sent from Alice to Bob (the description of the protocol can be found in any textbook on the matter; see, e.g., Nielsen and Chuang 2010). In general, the idea is that a very large (strictly infinite) amount of information is transferred from Alice to Bob by sending only two bits through a classical channel. The question is: "*how does the information get from Alice to Bob?*" (Timpson 2006, p. 596). It is quite clear that there is no physical signal by means of which the information contained in the quantum state can be transmitted. But it is also clear that what Alice does on his particle has consequences on what happens to Bob in another place.

In order to give a physical answer to the question, Richard Jozsa (1998, 2004) conceives quantum information as a new kind of information, which has an amazing non-classical property: it may flow backwards in time. A similar opinion is expressed by Roger Penrose: "*How is it that the continuous 'information' of the spin direction of the state that she wishes to transmit* […] *can be transmitted to Bob when she actually sends him only two bits of discrete information? The only other link between Alice and Bob is the quantum link that the entangled pair provides. In spacetime terms this link extends back into the past from Alice to the event at which the entangled pair was produced, and then it extends forward into the future to the event where Bob performs his*." (Penrose 1998, p. 1928). A different explanation is given by David Deutsch and Patrick Hayden (2000), who consider that the quantum information travels hidden in the classical bits sent by Alice to Bob. These rather bizarre answers to the question are implicitly tied to a physical interpretation of information: they insist on the search for a physical link, the signal that carries the information from Alice to Bob. Jozsa and Penrose think in a quantum channel. But since there is no quantum signal between Alice to Bob, then the channel extends towards the past up to the event at which the entangled pair was produced, and then towards the future. For Deutsch and Hayden, by contrast, the two classical systems that travel from Alice to Bob are the physical carriers of the information of the quantum state.

In short, the physical interpretation faces conceptual difficulties in the case of teleportation. However, this does not imply a return to the epistemic interpretation, which could account for communication in teleportation but not in much simpler cases. Christopher Timpson cuts the Gordian knot of teleportation by adopting a deflationary view of information, according to which 'information' is an abstract noun and hence does not refer to a spatio-temporal particular, to an entity or a substance (Timpson 2004, 2013; see also Duwell 2008). As a consequence, "*there is not a question of information being a substance or entity that is transported, nor of 'the information' being a referring term*." (Timpson 2006, p. 599). From this viewpoint, asking for how information gets from Alice to Bob makes no sense: the only meaningful issue in teleportation is about the physical processes involved in the protocol.

Timpson's stance dissolves the problem of the interpretation of the concept of information, rather than solving it. This view may sound strange to the physicists' and engineers' ears, since it forces them to admit that, in a situation of communication, there is nothing transmitted from source and destination, and that what is measured in bits/sec is not something physical. Then, it is worthwhile to consider whether the deflationist view is the only way out to the problem, in particular, whether there is a way of preserving a physical interpretation with no need of a physical carrier that travels through space. Perhaps the clue lies in the concept of causation: independently of the nature of the channel, communication would require that what happens at the source in a certain way produces, *causes* what happens at the destination. Moreover, the causal connection between source and destination would recover the asymmetry of the communication process. The main challenge of this strategy is the elucidation of the very concept of causation.

6.- What causation?

Although causation may offer a way out to the problem of interpreting the concept of information, the risk is to elucidate an obscure concept –information– by means of another even more obscure –causation–. In fact, the concept of causation is one of the most discussed topics in the history of philosophy; the difficulties that surround it have lead many authors to follow Humean ideas and to advocate for the "the complete extrusion" of the word 'cause' from physics (Russell 1912). Of course, we will not follow this path.

Despite the long tradition of the counterfactual approaches to causation, if the purpose is to support a physical view of information, it seems reasonable to appeal to a physical conception of causation. From the physical perspective, causation has been conceived in terms of energy flow (Fair 1979, Castañeda 1984), physical processes (Russell 1948, Dowe 1992), or property transference (Ehring 1997, Kistler 1998). However, all these views involve physical signals or space-time connections and, as a consequence, they are not adequate to elucidate a concept of information that does not require a physical interaction between source and destination.

On the other hand, independently of any philosophical discussion, both in the everyday life as in science people act as if there were real causal links, without considering if there is a space-time connection between the cause and its effect or not. Regarding causes, anyone distinguishes the case of pain on a finger due to a hammer blow from the appearance of the paperboy when the sun rises. Similarly, a chemist clearly distinguishes the causal action of a catalyst in increasing the rate of a reaction from the mere correlation between the melting point and the color of an element.

The *manipulability accounts of causation* intend to capture this intuitive distinction. Their basic idea is that it is possible to draw the distinction between cause-effect relationships and mere correlations by means of the notions of manipulation and control. Nancy Cartwright (1979) stresses this central feature of causation: causal relationships are needed to ground the distinction between effective and ineffective strategies; an effective strategy proceeds by intervening at a cause in order to obtain a desired outcome. In a similar vein, Thomas Cook and Donald Campell hold: "*The paradigmatic assertion in causal relationships is that manipulation of a cause will result in the manipulation of an effect*" (1979, p. 36). In other words, only causal relationships but not mere correlations are exploitable by us in order to bring about a certain outcome (Frisch 2014).

There are different manipulability accounts of causation. According to the early versions, causal terms need to be reduced to non-causal terms, such as free agency. For instance, Georg von Wright states that "*to think of a relation between events as causal is to think of it under the aspect of (possible) action. It is therefore true, but at the same time a little misleading to say that if p is a (sufficient) cause of q, then if I could produce p, I could bring about q. For that p is the cause of q.*" (von Wright 1971, p. 74). A more recent version of a manipulability account of causation is presented by Huw Price (1991) and Peter Menzies and Price (1993), who attempt to develop an "agency" theory of causation: "*an event A is a cause of a distinct event B just in case bringing about the occurrence of A would be an effective means by which a free agent could bring about the occurrence of B.*" (Menzies and Price 1993, p. 187). The basic premise of this approach is that, from an early age, we have direct experience not merely of Humean succession of events, but mainly of acting as agents. Therefore, the notion of causation has to be tied to our "*personal experience of doing one thing and hence achieving another*" (Menzies and Price 1993, p. 194).

These first manipulability versions received several criticisms. On the one hand, they were charged of circularity: "doing" and "producing" are already causal notions, which, therefore, cannot be legitimately used to define the notion of causation. On the other hand, manipulability is an anthropocentric notion; then, the resulting concept of causation is not sufficiently general since linked to human manipulation power. For instance, this account would not be able to identify the relationship between the gravitational attraction of the moon and the motion of the tides on the earth as a causal relation. In other words, the agent-based account of causation is inapplicable to causal relationships in which the manipulation of the cause by human beings is not practically possible.

The interventionist version of the manipulability account of causation, developed by James Woodward (2003, 2007; see also Pearl 2000), comes to solve those criticisms. Woodward notices that the accounts of causation common among non-philosophers, statisticians and theorists of experimental design have no reductionist aspirations: causation is a primitive notion that cannot be reduced to simpler and more basic concepts (Woodward 2013). Moreover, the author points out that causal attributions were traditionally made even before the advent of the Galilean idea of natural law (Woodward 2003, p. 171). On this basis, the interventionist approach does not intend to define causation in terms of non-causal notions, but to delimitate the domain of causation by means of the possibility of control or manipulation: the response to interventions is used as a probe to know whether a certain relation is causal or not (Woodward 2003, p. 21). As Mathias Frisch puts it, "*the results of interventions into a system are a guide to the causal structure exhibited by the system*" (Frisch 2014, p. 78).

Woodward's interventionist proposal "*focuses on the purposes or goals behind our practices involving causal and explanatory claims; it is concerned with the underlying point of our practices*" (2003, p. 7). Two elements are central in the proposal: the characterization of causal relationships as relating *variables*, and the notion of "*intervention*" as an action that produces a change in the value of a variable. The former makes possible to identify with precision the relata of the relation under scrutiny, and to conceptualize the changes introduced by manipulation as changes in the values of the variables (2003, p. 39). In this way, Woodward intends to capture, in non-anthropocentric language, the idea of determining whether *X* causes *Y* by means of an ideal experimental manipulation of the value of *X*.

Informally, regarding the relationship between *X* and *Y*, an *intervention* is a causal and exogenous process that modifies the value of *X* in a specific way: "*the intuitive idea is that an intervention on X with respect to Y changes the value of X in such a way that if any change occurs in Y, it occurs only as a result of change in the value of X and not from some other source*" (Woodward 2003, p. 14; for a detailed definition, see p. 98). In this case, it can be said that the relationship between *X* and *Y* is a genuine case of causation. Let us consider the following example: in May 22nd, 1960, a very strong earthquake destroyed the city of Valdivia, in Chile, where the seismograph recorded 9.5 on its scale. Three two-value variables can be defined: *E*, *D* and *S*, whose values 1 represent the occurrence of the earthquake, the destruction of Valdivia, and the reading of 9.5 in the seismograph, respectively. If an intervention on *E* changed its value from 1 to 0 (by inhibiting the occurrence of the earthquake) without changing other environmental variables, then *D* and *S* would also change their values from 1 to 0 (the destruction of Valdivia would not occur and the seismograph reading would not be of 9.5, respectively); therefore, the relationships between *E* and *D*, and between *E* and *S* are causal. On the contrary, the value of *D* would not change at all if an intervention on *S* changed its value from 1 to 0: regrettably, the destruction of Valdivia could not have been prevented by an exogenous modification of the reading of the seismograph, and this is the indication that the relation between *D* and *S* is not causal but a mere correlation due to a common cause.

The interventionist approach to causation explicitly faces the criticisms to the previous manipulability views (see Woodward 2013). On the one hand, the circularity criticism does not apply. In deciding whether *X* is a cause of *Y*, we can use assumptions about the causal relationship between *other* pairs of variables: for instance, the causal relationship between the intervention *I* and the variable *X*. Of course, this would be unacceptably circular if the aim were to define causation by reducing the concept to non-causal notions. But since this is not the purpose of the interventionist approach, there is no vicious circularity: the causal assumptions are not about the very relationship whose causal nature we are examining. On the other hand, the interventionist approach also eludes the charge of anthropocentrism, because the concept of intervention should be understood without reference to human action. The consideration of *possible* interventions admits a counterfactual formulation, which makes sense of causal claims in situations where interventions do not occur and even in cases in which they are impossible in practice.

Besides the traditional charges of circularity and anthropocentrism, other criticisms have been directed toward the interventionist approach to causation (see Woodward 2013). One of them is related with the use of counterfactuals: since the truth conditions for counterfactuals can be explained in terms of laws, the appeal to interventions is not necessary (Hiddleston 2005). In turn, Nancy Cartwright characterizes the interventionist approach as "operationalist": it admits a single criterion to test causation, and leads to "*withhold the concept* [of cause] *from situations that seem the same in all other aspects relevant to its application just because our test cannot be applied in those situations*" (Cartwright 2002, p. 422). Independently of how appropriate these criticisms are, they are directed toward an approach that intends to elucidate the very concept of causation. But since our concerns about causation are more modest, we will not address these objections: we are not interested in supplying a characterization of causation applicable in every circumstance in which the causal talk makes sense. Our only aim here is to explore the possibility of appealing to interventionist causation to characterize the informational relation between source and destination in a communicational context

7.- Information, causation and manipulability

Let us recall that the concept of causation was appealed to with the purpose of preserving a physical interpretation of information that does not need a physical interaction or a physical carrier that travels through space from source to destination. To this end, the manipulability conception of causation, in particular in its interventionist version, seems appropriate. For instance, if an argument analogous to that of the Valdivia earthquake is applied to the case of the two TV sets considered above, the interventionist perspective will identify as causal precisely those relationships in which there is communication (from the transmitter T to TV_A and to TV_B), and will regard the relation between the two TV sets, which cannot be used to communication, as a mere correlation. But the main challenge is to apply this approach to teleportation, where there seems to be a communicational channel with no physical interaction.

The first obstacle to be overcome is related with the application of the interventionist version of causation to quantum mechanics, which was explicitly impugned by Woodward: "*The notion of an intervention with respect to one of the measurement events is not well defined in the EPR phenomena, because the distinction between intervening with respect to X and acting directly on both X and Y cannot be drawn*." (Hausman and Woodward 1999, p. 566; see also 2004). Here the issue concerns the ontological interpretation of entangled systems in EPR-type experiments: Daniel Hausman and Woodward presuppose ontological holism, according to which the two particles of the entangled pair constitute a single composite whole. It is quite clear that, from this ontological perspective, there cannot be an intervention upon, say, the spin value *a* of particle *A* without intervening the spin value *b* of particle *B*. In his discussion with the authors, Mauricio Suárez proposes to distinguish between the non-separable state of the entangled particles and the non-separability of the events involved in the experiment. On this basis, he concludes that "*whether interventions are available in EPR (and quantum mechanics in general) is a complex and contextual question that does not have a unique or uniform answer*" and that "*different combinations of causal hypotheses under test and interpretations of quantum mechanics yield different answers to the question*." (2013, p. 199).

The discussion about the ontology of EPR is highly relevant in the context of the interpretation of quantum mechanics. However, although teleportation is based on EPR correlations, it is not an EPR-experiment. In fact, Alice not only counts with a particle of the entangled pair, but has access also to the state $|\chi\rangle$ to be teleported, and to the two two-state classical systems needed to send the two bits of information through the classical channel. Since communication requires those three elements, the intervention does not need to act on the entangled pair, but it can operate on the other two elements. For instance, the intervention on Alice's end may change the state to be teleported, from $|\chi\rangle$ to $|\varphi\rangle$: as a consequence, something changes in Bob's end, since he will recover $|\varphi\rangle$ and not $|\chi\rangle$. Or the intervention might block one of the classical systems that Alice sends to Bob: in this case, Bob would be unable to recover the teleported state. It is worth stressing that we can be sure about the consequences of these interventions independently of whether the entangled pair is interpreted as a single holistic system or not.

Although interventionism gives a clear answer to the charge of anthropocentrism, in the application of this approach to interpreting the concept of information, anthropocentrism is not an issue: here we are not interested in the moon causing tides or in the motion of tectonic plates causing earthquakes. Our context of interest is very limited, since confined to cases of communication, in which there is always a deliberate intervention on the source of information with the purpose to change the state of the destination. Moreover, Cartwright's worries are beyond our limited scope: the fact that the interventionist concept of cause cannot be applied in certain relevant causal situations is not a problem if those situations do not involve communication. In our case, causation is used only as a probe tool to know whether there is transmission of information or not in the communicational context, independently of signals and interactions between source and destination.

Regarding the objection to the use of counterfactuals, it is also innocuous in our context of interest. In fact, counterfactuals are introduced in the interventionist approach to deal with cases where the intervention on the cause is physically or practically impossible. But in situations of transmission of information the interventions on the source are always physically and practically possible. Even more, since the messages to be transmitted are embodied in sequences of the states of the source, the possibility of controlling the state of the source is an essential requirement for communication: the nature of communication itself includes that possibility; it makes no sense to conceive a source of information whose states cannot be modified.

It is worth emphasizing again that here it is not argued that the manipulability approach is the right or the best theory of causation, which accounts for all conceivable cases of causation. The discussion of this point is not relevant for our argumentation, since our aim is more limited: we appeal to a manipulability view of causation only to disentangle the problems related with the interpretation of the concept of information in the communicational context.

Summing up, the interventionist version of the manipulability approach to causation seems to be a productive resource to preserve a physical interpretation of information in the communicational context in the face of the difficulties introduced by quantum-assisted communication. In particular, it eludes the bizarre answers given by those who try to retain for teleportation an explanation in terms of physical interactions or signals travelling through space and time. Moreover, it agrees with the intuitive idea that communication not only involves correlations, but also essentially requires the possibility of changing the state of the destination by manipulating the state of the source.

8.- Conclusions

Among the many different discursive domains in which the concept of information plays a significant role, this work has focused on the communicational context, perhaps the traditional context to talk about information, where two interpretations of the concept were distinguished. It has been shown that the epistemic interpretation of information, although possibly useful in scientific or philosophical studies about human knowledge, does not incorporate the essential asymmetric feature of communication: what happens in the source of information must produce modifications on what happens in the destination. The physical interpretation does not suffer of this shortcoming, to the extent it that conceives information as something physical, that can be generated at one point of the physical space and transmitted to another point, that can be accumulated, stored and converted from one form to another. From this traditional viewpoint, information is always transferred by means of a physical mean: source and destination must be linked through a physical signal that carries the information. However, this interpretation faces serious difficulties to deal with teleportation, the typical case studied in the field of quantum-assisted communication: although Alice succeeds in the transmission of the information corresponding to the teleported state, there is no carrier of that information that travels from the source to the destination following a continuous space-time path. For this reason, some authors decided to reject the physical interpretation and to adopt a deflationist view of information, which dissolves the problem of the interpretation of the concept.

The challenge of this work has been to retain the view of information as a physical magnitude, but dispensing with the requirement of a physical carrier for its transmission. It has been argued that a way to reach this purpose is to exploit a basic and intuitive idea behind the concept of communication: the idea of causation, the intuition that a change in the state of the source must produce a change in the destination. Of course, no concept of causation based on physical interactions is useful to that purpose, since it would amount to come back to the traditional physical interpretation of information. By contrast, the manipulability approach to causation, in its interventionist version, seems to be the appropriate conceptual resource to deal with the problem. From this perspective, the essential feature of causation is the capability of controlling the effect by manipulating the cause, independently of whether there is a physical interaction between the cause and the effect. A physical interpretation of information tied to this view of causation seems to be the suitable tool for picking up all the cases usually conceived as communication situations and only them.

In short, if it is accepted that "no information without causation", and causation is conceived in manipulabilist terms, the slogan becomes "*no information without manipulation*."

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