The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0368-492X.htm

What information to measure? How to measure it?

Paolo Rocchi
LUISS University, Rome, Italy

Abstract

Purpose – Thinkers are still debating about the concept of information while engineers prepare astonishing digital appliances. The purpose of this paper is to address the following questions: what concepts do experts adopt in the working environment? What information do they measure? What can be done to help them?

Design/methodology/approach – This paper offers a concise report of the researches driven on the problem of the information definition. The report consists of three principal sections. The first section is twofold. On one hand, there are comments on the various information theories; on the other hand, the semiotics concepts (that engineers and professionals use in intuitive manner) are illustrated.

Findings – In consequence of the popularity of the semiotic notions – in the second section – the authors define the concept of signifier using the mathematical language, and discuss some features of this mathematical definition.

Practical implications – The third section closes the paper with the illustration of some advantages that the mathematical definition of the signifier offers on the practical plane and from the philosophical perspective.

Social implications – The ensemble of those advantages provides a bridge between the humanist culture and digital engineering.

Originality/value – The theoretical studies on the concept of information seem to be at a standstill. This paper shows how the measurement of the items of information is handy; and various equations can be unified into a comprehensive frame that facilitates the collaboration of experts coming from different areas.

Keywords Information theory, Measurement, Philosophy, Information technology

Paper type Research paper

1. Background and motivation

The present study means to address the following issue.

Since decades thinkers are debating about the concept of information, in the meanwhile engineers have prepared and still devise astonishing digital appliances. Other scientists have discovered intriguing informational phenomena in nature. For instance biologists have decoded the DNA (deoxyribonucleic acid) typical of every living being. One can ask:

(1) What concepts of information do experts adopt in the working environment?

(2) What information do they measure?

(3) What can be done to help them?

Humanists are inclined to overlook the problem of measurement which instead has substantial value in technology and exact science. It is worth pinpointing how engineers design and build up devices on the basis of measurements. Researchers corroborate a scientific statement through test and measures. In summary, measurements are essential to science and technology. The discussion about the information measure is not a trivial argument and we mean to propose this topic to scholars versed in the humanities.

Kybernetes
Vol. 45 No. 5, 2016
pp. 718-731
© Emerald Group Publishing Limited
0368-492X
DOI 10.1108/K-06-2015-0161

The present study searches an answer for the previous queries and includes:

- a detailed inspection of the literature and the working context;
- the proposal of a novel solution; and
- the discussion of the results.

Probably, the present account will seem rather cursory to the reader but has the advantage of offering a rapid survey on the ideas developed in the research project. The recent book (Rocchi, 2012) gives a more extensive narrative to the reader.

2. A bibliographical survey

We have conducted a dedicated search around the information concept and found over 30 constructions or interpretations in the literature (see the Appendix) besides dozens of informal definitions of information. In chronological order the first theory was devised by Fisher (1922), the second was written by Hartley, the third by Shannon. The most recent information theory was put forward by Budd (2011). These constructions are so numerous and diversified that the authors of bibliographical reviews waive offer the complete illustration but tend to follow a personal criterion for selection (Flükiger, 1995; Nafría, 2010; Qvortrup, 1993). We mention some disparate aspects of theories that disagree on:

- The approach they follow, e.g. analytical (Kolmogorov), philosophical (Floridi), specialistic (Jablonka), etc.
- The opinions on information supposed to be subjective (Bar-Hillel), relational (Garfinkel and Rawls) or objective (Stonier), etc.
- The starting points of the enquiries. Some authors (Marschak, Brookes, Miller, Solomonoff, Kolmogorov and Chaitin) share Shannon's vision and attempt to improve or extend the master's work. Hofkirchner takes inspiration from Bateson. The remaining constructions begin with original and alternative ideas.
- The purposes of the authors. Some are concerned with the exhaustive interpretation of information (Burgin and Hofkirchner); others focus on somewhat special remarks pertaining to biology (Jablonka), sociology (Goguen) or anthropology (Bateson), etc.
- The relation with physical reality in the sense that someone – e.g. Wiener – presumes that information is an abstract quantity; others – such as Stonier – see information as an essential part of the physical world.
- The relation with technology. Shannon focusses on telecommunication; Derr has no concern with engineering.

There are even "negationist writers." Maturana and Varela (1980) hold "notions such as coding and transmission of information do not enter in the realization of a concrete autopoietic system." They deny the existence of information as external instruction.

Floridi (2010) claims that the term "information" appears extremely fluid in the current literature; it has a multitude of definitions in use which often appear irreconcilable. In addition we note how many writers do not use the mathematical language but develop verbal illustrations which are inappropriate to establish a measure criterion. We also observe how those who put forward a mathematical definition for information offer a partial aid to engineers, in the sense that they qualify special forms of communication. For instance, the entropy of Shannon – the most popular measure of the group – is valid inside a transmission scheme and cannot be used everywhere. Wiener and Schrödinger redefine information as neg-entropy in view of thermodynamics notably in between a special context.

While theorists have not yet established the universal concept of information, one can find an intriguing phenomenon in the professional practice. Experts coming from various fields of study and application areas are inclined to use the semiotic notions in a pragmatic manner.

De Saussure inaugurated the structural approach to linguistics (Chapman and Routledge, 2005) and semioticians proceeded with discussing about the components of signs. Different interpretations have been put forward and have raised debates for a long while (Ogden and Richards, 1989). More recently semioticians tend to unify the various positions and converge on the view of the signifier (or information-carrier) as any material thing that signifies, while the signified is the object or concept that a signifier refers to (Eco, 1976). Today, the signifier is often assumed as something which can be seen, heard, touched, smelled or tasted (Chandler, 2007). Also signifiers enclosed in the brain – say neurons, synapses, etc. – are perceived in a way and may be associated to the same frame.

It is surprising how semiotic concepts infiltrate the digital technology where engineers calculate electrical signals which are physical quantities and reproduce music or voices, etc. That is to say signals are signifiers while the represented sound is the signified (Vaseghi, 2007). Physicists, chemists, technicians, software programmers, astronomers and many others adopt the semiotic view in the working environment; take the ensuing examples:

(1) A doctor examines the symptoms presented by a patient and diagnoses the sickness. Symptoms are – for instance – fever, vomit, a broken bone, etc. Doctors observe the symptoms that indicate a sickness thus symptoms are signifiers and the sickness plays the role of the signified (Baer, 1988).

(2) An archeologist discovers some clay pots and concludes that a certain population lived here in the past. Clay pots are material objects that covey precise meanings hence they are signifiers. The ancient population is the intended signified.

(3) A reporter is paid in function of the extent of his writings – the signifier – and the news story – the signified – that he describes.

Semiotic notions emerge also in various theoretical works which are listed in the Appendix. Shannon (1948) employs the semiotic scheme when he illustrates the Morse code in his seminal essay. He writes: "[…] by using the shortest channel symbol, a dot, for the most common English letter E; while the infrequent letters, Q, X, Z are represented by longer sequences of dots and dashes." Shannon clearly explains how dots and dashes are the signifiers that "represent" the alphabet symbols.

Professionals who are not specialized in communication frequently use the terms "form" and "content" in the place of "signifier" and "signified," respectively. They do not use the semiotic terminology nonetheless in the practice they employ the concepts emerging from the semiotic studies which prove to be in use with success.

Sometimes the relationship between the signifier and the signified is not so apparent. It turns out to be fuzzy and rises discussion but these difficulties, which may have subjective or objective origin, do not invalidate the semiotic scheme which linguists, engineers, doctors, archeologists and many others adopt in every day job.

Capurro, Fleissner and Hofkirchner give an informal proof of the so-called *Capurro Trilemma* that implies the impossibility of a unified theory of information (Capurro *et al.*, 1999). We do not mean to discuss if a definitive theory of information is achievable or not. We barely note that nowadays there is no convergence on the abstract notion of information while a large group of scholars and professionals are inclined to meet on the notions of signifier and signified which factually provide substantial support to the advance of science and technology. Those experts employ the concepts in a pragmatic manner and beyond any theoretical awareness. They seldom mention semiotics in the course of acting but measure the semiotic elements – especially the signifiers – in accurate manner. For instance, one can quote the large set of empirical equations applied in the digital and analog technologies (Manolakis and Ingle, 2011; Coughlin, 2008).

In consequence of the popularity of the semiotic notions we are personally inclined to share the reasonable approach followed by several experts. Waiting find out the abstract definition of information, we mean to accept the notions of signifier and signified and qualify them. In this way we can provide significant aid to experts who resort to semiotics in intuitive way.

3. A mathematical definition for the signifier

Semiotics is called the "science of signs" though the term "science" sounds as a rather incongruous definition (Eschbach and Trabant, 1983). Semioticians rarely share the purposes and methods typical of exact sciences and a few of them argue about technology, e.g. Andersen (1990). The vast majority of authors investigate broad arguments including the relationships amongst semantics and politics, arts and sociology. They abstain from the analytical methods typical of mathematics and exact sciences thus they cannot provide the intended measures in a straightforward manner.

In our opinion, it seems necessary to fill the gap between semiotics and exact sciences. One should establish the definition of the signifier using a mathematical expression in that verbal descriptions are incompatible with the measurement process typical of science. In the first step, one should formulate the definition of the signifier in such a way to comply with the mathematical correctness and accuracy; in the second step one should derive the measure of the signifier from the previous mathematical definition.

Three remarks precede the first stage.

3.1 First remark

The material base of information may be compound or alternatively elementary. By definition, a compound signifier includes two or more elementary signifiers. For example, the ink letter A is equipped with some elementary features that are: the color black, the font Arial, the style Italics, etc.

3.2 Second remark

We mean to focus on elementary signifiers which are detected by means of a mechanical action. Elementary signifiers have the property of being perceived by biological receptors, sensors, probes, instruments, etc. which do not have any will or consciousness.

Note that the entire perception process in living beings includes several components beside the receptors. The human body is equipped with the sense organs, afferent fibers, lower and upper levels of the brain, the memory, the culture of the individual, etc.

In substance, this frame confines its attention to the initial component of the whole perception process and we shall call the elementary detector – lacking in intelligence and awareness – as “observer” or “receiver.” (Figure 1).

3.3 Third remark

The mechanical perception is the initiation step whereby a piece of information “comes to life.” As an example, take the noun *Oxford* that is a physical object made of ink. This is a perfect signifier when the contrast with the white paper page is high. The quality of this signifier diminishes when the contrast slopes down. Eventually there is no signifier with no contrast. This extreme case shows the relevance of the concrete basis of information.

The reader could have the impression that the study of signifiers is a palliative because of the inconclusive theories of information. Instead the contrary is true.

A sign or a piece of information is extant provided that it can be perceived in a way. If the observer cannot distinguish the signifier, then there is no information at all. As an example case, suppose an eminent scholar holds a lecture about a high theme. At what conditions listeners can follow him?

Somebody can quote various premises such as university studies and cultural preparation. All those are right but insufficient; the very premise is very humble and apparent. In order to follow the lecturer it is necessary that his voice is distinguishable respect to the listeners’ ears. This physical state is the basic condition to develop high intellectual considerations in second stage. When sharpness is missing, information vanishes Figure 2.

The idea of distinctness is central to Bateson (2000) who defines the elementary unit of information as a difference which makes a difference. This principle is shared by other authors such as Hofkirchner (1999).

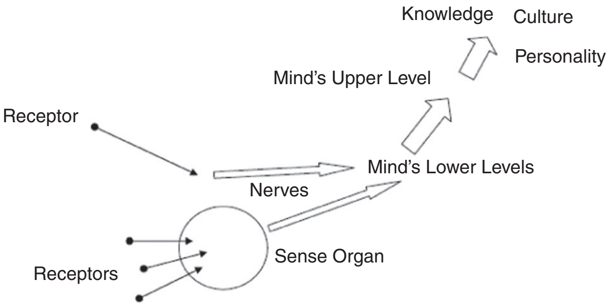

Figure 1.
The whole perception process encompasses several components in a living being

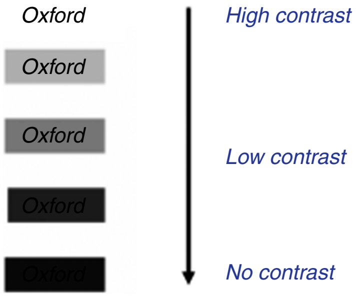

Figure 2.
The degrees of quality depending on the contrast

Experts of electronic sensors share the previous remarks. They follow a pragmatic approach and assume that a signal must be neat and different from something else in order to be detected, in consequence they have established a large group of empirical equations.

3.4 Formal description of the signifier

On the basis of the previous three points one can reasonably conclude that any real object or event *E* is an elementary signifier if it differs from an adjacent entity *E** with respect to the observer or receiver R. This definition may be expressed by the following mathematical expression that literally says: the entity *E* is a signifier when it is not equal to *E** in relation to R. In fact, we use the symbol "NOT $=_{\mathrm{R}}$" to signify "not equal respect to R":

$$E\ \mathrm{NOT}{=}_R\ E^* \tag{1}$$

This expression is an inequality and can be taken as the formal or mathematical definition for the signifier. Inequality (1) can be used as the starting point to measure the signifier.

As an example of the inequality, suppose you have an apple in hand which you like to eat. The apple is a fruit and at the same time the apple *E* is distinct respect to your hand *E** and thus it is a signifier. You can satisfy hunger thanks to the capability of the apple of contrasting with the surrounding objects. Equation (1) is true and *E* conveys information. When (1) is false – namely, *E* and *E** are equal – there is no signifier and in turn there is no information (as an example see the bottom case in (Figure 1).

Shannon inquires the interference of the noise on the receiver R and assumes that "[…] the actual message is one selected from a set of possible message […] in other words he assumes that the transmitted signifiers are distinct (Rocchi, 2012). The present frame fits with the Shannon theoretical scheme and we examine closely the preliminary condition to transmission that is the sharpness of signifiers Figure 3.

Inequality (1) can be applied in technology when R is man-made; (1) is valid for living beings when R is biological. The benefits offered by definition (1) are worthy of discussion. We sum up this rather extensive argument in a few points.

4. Fall-out

4.1 Mathematical developments

Using (1) one can unify various forms of measure which technicians devised by trial and error. The present frame offers the theoretical justification and the comprehensive frame to results achieved following empirical methods so far (Rocchi, 2012). The case of discrete signals will be expanded in the next section. In addition we can quote:

- the measures used in ICT (information and communication technology) such as the luminance contrast, the factor of contrast and others;
- the statistical methods to qualify a set of data;
- the algorithms to establish the dissimilarity of images, symbols, objects, etc.; and
- the equations to calculate the quality of analog signals.

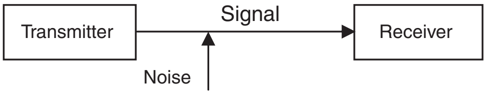

Figure 3.
Detection with noise

From the inequality (1) one can deduce more general equations than the equations used so far. As an example, it is worthy of mention the complete measure of redundancy. Factually a single system may include multiple forms of redundancy – redundancy of circuits, of information and mechanical components – designers are required to relate and balance various redundant components in order to optimize the overall systems, but a rigorous method is missing so far. The present frame yields a simplified mode to calculate heterogeneous redundant resources which is consistent with the calculus of redundancy devised by Shannon, the proof is in Rocchi (2007).

The mathematical description (1) also suggests the answers to some vexed issues raised by thinkers. Let us argue over those philosophical topics of discussion.

4.2 The problem of digital vs analog

Some commentators claim that analog signals are close to Nature and more appropriate. Digital signals deviate from the shape typical of inanimate and animate bodies. Digital appears less authentic and forced in a way (Watzlawick *et al.*, 1967; MacLennan, 1993; Fischer, 2011).

This debated topic turns out to be rather complex and here we can but sum up a few tenets.

Suppose to calculate the inequality (1) using the electrical signals $V_1 = E$ and $V_2 = E^*$. These values imply that the expression (1) has to be rewritten this way:

$$V_1 \neq V_2$$

Using mathematical rules one obtains the following equation which in substance imposes the signals to lie apart from each other:

$$s = |V_2 - V_1| \neq 0 \tag{2}$$

Equation (2) shows how to measure discrete signals and this conclusion matches with current professional criteria. Second, (2) shows how discretization meets the needs of sharpness and binary bits are optimal because distinct. From this basic feature derives all the virtues of the digital technology (Rocchi, 2012). By way of illustration, the signals of an analog computer usually distort and technicians develop additional circuits to handle them. In practice, they insert various filters and amplifiers into an analog device in order to correct distorted signifiers (Rybin, 2011). This heavy work is unnecessary in the digital realm.

Concluding, Equation (2) proves that discrete signals are perfect and the supposed superiority of the analog paradigm has not ground.

4.3 The problem of perception fallacy

For millennia scholars have been aware of the fallacy of the senses. An assortment of phenomena, typically known as illusions, false impressions and hallucinations, yields untrustworthy sense data and in turn the erroneous consciousness of things external to us (Fish, 2009). Thinkers raise the epistemological problem of perception that is how beliefs about the physical world generally can be justified or warranted on the basis of sensory or perceptual experience. Philosophers reasonably wonder whether the human knowledge has solid basis or derives from unreliable sensations (Avant and Helson, 1973).

The present frame is confined to the elementary perception process that is purely mechanical. It describes the behavior of R that is a biological receptor – say the cone or the rod of the eyes – or an artificial sensor or any entity without self-awareness. The observer R does not recognize or understand things; R merely emits a signal or changes its status as soon as it comes into contact with *E*.

By contrast, philosophers investigate the perception argument in all its parts and from various perspectives. They link perception to the cognitive processes and human consciousness. The overall perception process includes billions components including receptors, nerves, neurons and synapses (Figure 1). We observe how several factors can interfere within this large network and results in a broad variety of fallacies; therefore the perception problem – posed as an "all-inclusive" argument – appears an ill-posed question from the present stance. By definition, an ill-posed problem has more than one solution and cannot be solved in a definitive way. The disjunctive theory of perception, the sense-datum theory, the intentionalist theory, the adverbial theory and other constructions that provide various and somehow contradictory answers to the perception argument bring evidence that the conclusions of the present conceptual frame are true.

4.4 The problem of uniformity

Information treated by equipment, which is alien to cognition and other dimensions of the human soul, does not share the nature of information exchanged by men. This difference fires a non-trivial debate amongst scientists (McDowell, 1994).

The present theoretical frame circumvents the problem of uniformity between the biological and artificial spheres because it focusses on the initial action of perception. The receptor R does not have any self-awareness; it is an appliance or a neural receptor, an electronic sensor or a cell which recognizes the DNA code. Inequality (1) applies to signals in a wireless system and to the signals moving along the nerves alike. The mathematical definition of signifier (1) crosses the biological and the technical realms since it is based on essential operational properties. It deals with living and lifeless bodies.

4.5 The problem of information physicism

The following three paradoxical phenomena deal with the physical origin of information.

First paradox. We bring this example case to introduce the problem.

The Allies sealed several documents at the end of the Second World War. Information disappeared for decades. When the Cold War finished, those secret documents became available and information came into existence once again. Those military papers died for four decades and then were resurrected. The fact that information ceases to exist and in turn comes "back to life" seems to disprove the physical nature of information in evident terms.

The inequality (1) includes two terms: R and E^* besides *E*. The present frame shows how the perception process, although elementary, depends on the observer and the element of comparison E^*. To exemplify, the observer A sees *E*, whereas the observer B does not detect *E*. In short, the signifier *E* is not an absolute quantity but depends on R and E^*. The signifier is a relativistic entity and in turn information is a relativistic concept. The argument of relativism does not disprove the material nature of phenomena in physics (Phillips, 2011) and the same should be said in ICT. The documents that come back to life – because the observers changed – do not disprove the material essence of signifiers.

Moreover the information relativism is consistent with the large number of diverging theories of information that derive from the different viewpoints assumed by the authors as we recall in the first section.

Second paradox. Let us examine this pair of cases:

- during a conversation, people sometimes communicate using a silent pause; and
- the blank space between two lines in a text means to separate the subject contents notably it expresses a distinctive message.

The silence, the blank and the void prove to be vehicles of information. The lack of matter can be used as signifier and this openly seems to rebut the physical origin of information.

The present frame provides an answer with the mathematical language.

As first we invert the position of the two terms in (1):

$$E^* \text{ NOT}{=_R}\, E$$

This means that also E^* is a signifier and can convey information. By definition E^* is any and we select the null value:

$$E^* = 0$$

We obtain that the null element can inform people as long as this special signifier contrasts with E:

$$0 \text{ NOT}{=_R}\, E$$

The symbol zero demonstrates on the theoretical plane that "nothing" is a potential vehicle of information. Note that the symbol zero does not denote an ethereal entity. As a matter of facts, the pause silence is real and not abstract in a conversation. The blank space can be touched by the fingers in a book page. In conclusion a bodiless signifier has to be classified as an element extant in the physical world.

Third paradox. Wiener (1961) writes: "If people always get the same signal, this becomes inessential and nothing may be transmitted with the same result." Wiener concludes that information is neither matter nor energy and discards the physicism of information.

The answer offered by the present theory appears rather easy.

De Saussure claims there is not any necessary relationship between the signifier and the signified; he emphasizes the importance of the Arbitrariness Principle. Factually, those who use the object E to represent X, can substitute E with the smaller or more manageable signifier F. When one transmits the same signal for a long time, obviously he selects a bodiless signifier. The silence proves to be the cheapest signifier to represent a repeated message. The silence conveys information but a bodiless sign does not deny the physical origin of information – as we have seen above – and the conclusion of Wiener has not ground.

5. Conclusion

This work begins by noting that thinkers are discussing the concept of information while experts coming from several fields exploit the semiotic notions with success. This infiltration is particularly fruitful in ICT where engineers employ discrete signals beyond special studies on semiotics. In this way we answered queries A and B. In order to help researchers coming from various sectors (query C) we put forward a simple mathematical definition of the signifier which brings about various outcomes.

The comments on the outcomes of the present research can be arranged at three levels which we call: operational, strategic and political:

1. At the operational level:
   - the mathematical definition of signifier unifies various measurements used with occasional criteria so far; and
   - it provides new equations for ICT engineering.

     The present theoretical frame yields the following answers to philosophical questions about information:
     - discrete signals are optimal and not unnatural;
     - the perception fallacy conundrum is an ill-posed argument and therefore has many solutions;
     - information is a relativistic concept; and
     - “nothing” is a potential vehicle of information and does not deny the information physicism.
2. At the strategic level, the previous outcomes enhance the effectiveness of engineers and improve the comprehension of what information is.
3. At the political level, this work suggests a new vein of research and shows how one could go down this road. The mathematical definition of the signifier proves to be simple and manageable, and these virtues contribute to fill the gap extant between thinkers and engineers, between philosophy and technology.

This paper means to offer a concise and handy summary of the achievements which (Rocchi, 2012) illustrates in a more extensive way.

References

Andersen, P.B. (1990), *A Theory of Computer Semiotics. Semiotic Approaches to Construction and Assessment of Computer Systems*, Cambridge University Press, Cambridge, MA.

Avant, L. and Helson, H. (1973), “Theories of perception”, in Wolman, B.B. (Ed.), *Handbook of General Psychology*, Prentice Hall, Englewood Cliffs, NJ, pp. 419-448.

Baer, E. (1988), *Medical Semiotics*, University Press of America, Lanham, MD.

Bateson, G. (2000), *Steps to an Ecology of Mind*, University of Chicago Press, Chicago, IL.

Brookes, B.C. (1980), "The foundations of information science, Part I, philosophical aspects", *Journal of Information Science*, Vol. 2 Nos 3-4, pp. 125-133.

Budd, J.M. (2011), "Meaning, truth, and information: prolegomena to a theory", *Journal of Documentation*, Vol. 67 No. 1, pp. 56-74.

Burgin, M. (2009), *Theory of Information: Fundamentality, Diversity and Unification*, World Scientific Publishing Co., Singapore.

Capurro, R., Fleissner, P. and Hofkirchner, W. (1999), "Is a unified theory of information feasible?", *Proc. 2nd Intl. Conf. on the Foundations of Information Science*, pp. 9-30.

Carnap, R. and Bar-Hillel, Y. (1953), "An outline of a theory of semantic information", in Bar-Hillel (Ed.), *Language and Information: Selected Essays on Their Theory and Application (1964)*, Addison Wesley, Reading, MA, pp. 221-274.

Chaitin, G.J. (1977), "Algorithmic information theory", *IBM Journal of Research and Development*, Vol. 4 No. 21, pp. 350-359.

Chandler, D. (2007), *Semiotics: The Basics*, Routledge, London.

Chapman, S. and Routledge, C. (Eds) (2005), *Key Thinkers in Linguistics and the Philosophy of Language*, Edinburgh University Press, Edinburgh.

Chernavsky, D.S. (1990), *Synergetics and Information*, Znaniye, Moscow (in Russian).

Coughlin, T.M. (2008), *Digital Storage in Consumer Electronics: The Essential Guide*, Elsevier, Burlinghton, MA.

Derr, R.L. (1985), "The concept of information in ordinary discourse", *Information Processing & Management*, Vol. 21 No. 6, pp. 489-499.

Eco, U. (1976), *A Theory of Semiotics*, Indiana University Press, Bloomington, IN.

Eschbach, A. and Trabant, J. (Eds) (1983), *History of Semiotics*, John Bebjamins Publ. Comp, Amsterdam.

Fischer, T. (2011), "When is analog? When is digital?", *Kybernetes*, Vol. 40 Nos 7/8, pp. 1004-1014.

Fish, W. (2009), *Perception, Hallucination, and Illusion*, Oxford University Press, Oxford.

Fisher, R.A. (1922), "On the mathematical foundations of theoretical statistics", *Philosophical Transactions of the Royal Society*, Ser. AA222, pp. 309-368.

Floridi, L. (2010), *Information: A Very Short Introduction*, Oxford University Press, Oxford.

Flükiger, D.F. (1995), "Contributions towards a unified concept of information", doctoral thesis, University of Berne.

Garfinkel, H. and Rawls, A. (2008), *Toward a Sociological Theory of Information*, Paradigm Publishers, London.

Goguen, J. (1997), "Towards a social, ethical theory of information", in Bowker, G., *et al.* (Eds), *Social Science, Technical Systems and Cooperative Work: Beyond the Great Divide*, Erlbaum, Mahwah, NJ, pp. 27-56.

Hartley, R.V.L. (1928), "Transmission of information", *Bell System Technical Journal*, Vol. 7 No. 3, pp. 535-563.

Hofkirchner, W. (1999), "Towards a unified theory of information. The merging of second-order cybernetics and semiotics into a single and comprehensive information science", *Actes 15e Congrès International de Cybernétique*, pp. 175-180.

Jablonka, E. (2002), "Information: its interpretation, its inheritance and its sharing", *Philosophy of Science*, Vol. 69 No. 4, pp. 578-605.

Janich, P. (1998), “Informationsbegriff und methodisch-kulturalistische Philosophie (the concept of information and methodologic-culturalist philosophy)”, *Ethik und Sozialwissenschaften*, Vol. 9 No. 2, pp. 169-182.

Kåhre, J. (2002), *The Mathematical Theory of Information*, Kluwer Academic Publishers, New York, NY.

Karpatschof, B. (2000), *Human Activity. Contributions to the Anthropological Sciences from a Perspective of Activity Theory*, Dansk Psykologisk Forlag, Copenhagen.

Kharkevich, A. (1973), *Information Theory*, Nauka, Moscow (in Russian).

Klir, G. (1991), *Facets of System Science*, Plenum Press, New York, NY.

Kolmogorov, A.N. (1965), “Three approaches to the definition of the quantity of information”, *Problems of Information Transmission*, Vol. 1, pp. 3-11.

Levitin, L.B. (1992), “Physical information theory Part I”, *Proc. Workshop on Physics and Computation*, pp. 210-214.

Losee, R.M. (1997), “A discipline independent definition of information”, *Journal of the American Society for Information Science*, Vol. 48 No. 3, pp. 254-269.

Luhmann, N. (1990), *Essays on Self-Reference*, Columbia University Press, New York, NY.

Lyre, H. (1995), “Quantum theory of Ur-objects as a theory of information”, *International Journal of Theoretical Physics*, Vol. 34 No. 8, pp. 1541-1552.

McDowell, J. (1994), *Mind and World*, Harvard University Press, Cambridge, MA.

MacKay, D.M. (1969), *Information, Mechanism and Meaning*, MIT Press, Cambridge, MA.

MacLennan, B.J. (1993), “Grounding analog computers”, *Philosophical Explorations*, Vol. 2, pp. 8-51.

Manolakis, D.G. and Ingle, V.K. (2011), *Applied Digital Signal Processing: Theory and Practice*, Cambridge Univ. Press, Cambridge, MA.

Marschak, J. (1971), “Economics of information systems”, *Journal of the American Statistical Association*, Vol. 66, pp. 192-219.

Maturana, H. and Varela, F. (1980), *Autopoiesis and Cognition: the Realization of the Living*, D. Reidel Publishing, Boston, MA.

Mazur, M. (1974), *Kachestvennaja Teorija Informazii (Qualitative Theory of Information)*, Mir Publ., Moscow (in Russian).

Miller, J.G. (1978), *Living Systems*, McGraw-Hill, New York, NY.

Nafría, J.M.D. (2010), “What is information? A multidimensional concern”, *TripleC*, Vol. 8 No. 1, pp. 77-108.

Nauta, D. Jr (1970), *The Meaning of Information*, Mouton, Paris.

Ogden, C.K. and Richards, I.A. (1989), *The Meaning of Meaning*, Harcourt Brace, New York, NY.

Phillips, P.J.J. (2011), *The Challenge of Relativism: Its Nature and Limits*, Continuum Intl. Publ. Group, London.

Qvortrup, L. (1993), “The controversy over the concept of information”, *Cybernetics & Human Knowing*, Vol. 1 No. 4, pp. 3-24.

Rocchi, P. (2007), “How ‘unused’ codewords make a redundant code”, *Proc. 45th ACM Southeast Conference*, pp. 407-412.

Rocchi, P. (2012), *Logic of Analog and Digital Machines*, 2nd revised ed., Nova Science Publishers, Huntington, New York, NY.

Rybin, Y.K. (2011), *Electronic Devices for Analog Signal Processing*, Springer, New York, NY.

Shannon, C.E. (1948), “A mathematical theory of communication”, *The Bell System Technical Journal*, Vol. 27, pp. 379-423.

Stonier, T. (1994), *Information and the Internal Structure of the Universe: An Exploration into Information Physics*, Springer-Verlag, London.

Vaseghi, S.V. (2007), *Multimedia Signal Processing: Theory and Applications in Speech, Music and Communications*, John Wiley & Sons, New York, NY.

von Weizsäcker, E. (1974), "Erstmaligkeit und Bestatigung als Komponenten der Pragmatischen Information (first-time and confirmation as components of pragmatic information)", in von Weizsäcker, E. (Ed.), *Offene Systeme I*, Ernst Klett Verlag, pp. 82-113.

Watzlawick, P., Beavin, J.H. and Jackson, D.D. (1967), "Some tentative axioms of communication", in Watzlawick, P., Beavin, J.H. and Jackson, D.D. (Eds), *Pragmatics of Human Communication: A Study of Interactional Patterns, Pathologies, and Paradoxes*, W.W. Norton & Company, New York, NY, pp. 48-71.

Wiener, N. (1961), *Cybernetics: Or the Control and Communication in the Animal and the Machine*, 2nd ed., MIT Press, Cambridge, MA.

Appendix. Theoretical interpretations of the concept of information since the early twentieth century

- the statistical theory of information by Fisher (1922);
- the transmission theory of information by Hartley (1928);
- the communication theory of information by Shannon (1949);
- the semantic theory of information by Carnap and Bar-Hillel (1953);
- the cybernetic theory of information by Wiener (1961);
- the algorithmic theory of information by Solomonoff, Kolmogorov (1965), and Chaitin (1977);
- the descriptive information theory by MacKay (1969);
- the semiotic/cybernetic theory of information by Nauta (1970);
- the economic theory of information by Marschak (1971);
- the utility theory of information by Kharkevich (1973);
- the pragmatic theory of information by von Weizsäcker (1974);
- the qualitative theory of information by Mazur (1974);
- the living system information theory by Miller (1978);
- the autopoietic theory on information by Maturana and Varela (1980);
- the hierarchical information theory by Brookes (1980);
- the common-sense information theory by Derr (1985);
- the dynamic theory of information by Chernavsky (1990);
- the systemic theory of information by Luhmann (1990);
- the general information theory by Klir (1991);
- the physical theory of information by Levitin (1992);
- the organizational information theory by Stonier (1994);
- the quantum theory of information by Lyre (1995);
- the independent theory of information by Losee (1997);
- the social theory of information by Goguen (1997);

- the purpose-oriented theory of information by Janich (1998);
- the unified theory of information by Hofkirchner (1999);
- the anthropological information theory by Bateson (2000);
- the activity-based information theory by Karpatschof (2000);
- the biological information theory by Jablonka (2002);
- the mathematical theory of information by Kåhre (2002);
- the sociological theory of information by Garfinkel and Rawls (2008);
- the general theory of information by Burgin (2009);
- the philosophy of information by Floridi (2010); and
- the communicative information theory by Budd (2011).

Corresponding author
Paolo Rocchi can be contacted at: procchi@luiss.it