Winter 2-18-2021

Measurement of Information: A Review Article

Dariush Alimohammadi
Urgench State University, Urgench, Uzbekistan, Webliographer@gmail.com

Measurement of Information: A Review Article

Dariush Alimohammadi[1]

Abstract

Purpose - Measurement of information has long been studied for many years from different perspectives. Acknowledging this diversity, the article aims at reviewing approaches to the information measurement.

Design/methodology/approach – Literature review method was used to analyze and interpret main approaches of measuring information.

Findings - Logarithm, volume, syntax, probability and entropy, quantity, impact, value, and energy of information were identified and investigated in detail as the major approaches to the information measurement.

Originality/value - Discussing strengths and weaknesses of each approach, it concludes that a multi-dimensional approach would help us measure the information more accurate.

Keywords

Information Measurement, Information, Measurement, Logarithm, Volume, Syntax, Probability, Entropy, Quantity, Impact, Value, Energy

Introduction

If information has the property of reducing the uncertainty of a situation, then measurement of information is in fact the measurement of uncertainty (Ha, 1999). The problem of measuring information is not new (Gordon and Sager, 1985). It was first in 1940s and 1950s that discussions were started to measure the information (Schroeder, 2004; Jacquet, 2009). So far, the literature has extensively been published on this subject. Taylor (2006) presented a comprehensive historical overview of the evolution of measurement concept and its application in mathematics and theoretical physics. Ozawa (2012) debated the measurement of quantum information in detail. Chatzikokolakis, Chothia and Guha (2010) did the same endeavor with a statistical viewpoint. Among the huge bulk of studies have been carried out to measure the information, a great number of works reflect the viewpoint of telecommunication engineers. As Stamper (1971) claimed, they have involved in measuring information in different ways. Gordon and Sager (1985) and Hayes (1993), for example, referred to this viewpoint as the evaluation of statistical properties of signals/messages transmitted and the capacity of channels in which signals/messages are communicated. It may be told that such an approach roots back to the *Information Theory* developed by Claude

[1]. PhD, Associate Professor, Department of Information Technology, Faculty of Physics and Mathematics, Urgench State University, Urgench, Uzbekistan.

Shannon. Another considerable viewpoint, as enumerated by Harmon (1985, 1986), is *Cybernetic* coined by Norbert Wiener. There are even minimalist researchers who believe that information may just be measureable in particular contexts (Oppenheim *et al*., 2004); and some conservative investigators that do not believe in its measurability (Shaw, 1985). The claim denoting non-measurability of information has also been stated five decades ago by Stamper (1971). He argues that to know what a measurement means, it is essential to know precisely what class of things is being measured. This is a big challenge; because information may not be defined and classified easily.

However, diversity in viewpoints confirms that different professionals have responsibility and interest in discussing the matter. Information is a multi-aspect concept and a multi-dimensional phenomenon. Each aspect of this concept brings a given profession to deal with; and each dimension reflects a given characteristic susceptible of investigation. That's why Harmon (1985) claimed that information phenomena and measurement can be studied in relation to human-generated systems and their actions, or in and among groups, organizations and societies. Accordingly, the purpose of this paper is to review approaches to the information measurement and enriching the less-discussed ones. Approaches will be compared and a new framework will be provided.

Approaches to the Measurement of Information

Logarithm of Information: From the viewpoint of developers of the information theory, information is the degree of freedom to choose between a set of messages transmitted (Miller, 1953; Cherry, 1960; Hayes, 1993; Jacquet, 2009). Calculating the logarithm to the base 2 of the number of alternative patterns, symbols and signals received would help us measure the information (Harmon, 1986; Ling-Feng and Jian-Rong, 2005). Here, bit is the unit of measurement. Typically, the amount of information conveyed by a signal is represented by the number of bits used in transmission of it. It is exactly the measure of the number of binary decisions that need to be made (Hayes, 1993). Logarithm reflects a mathematical solution; and communication engineers are too eager to this approach. There is nothing wrong with this approach as long as we are interested in engineering problem. It is an exact criterion; but at the same time, an incomplete one. The technical dimension of information transfer can be covered by the logarithm. But, semantic, social and behavioral aspects of the process could not be reflected mysteriously (Schroeder, 2004); and the meaning, significance and impact which information has for and on the recipient could not be intended (Moody and Walsh, 1999) in any approach arises from the information theory.

Volume of Information: One could measure the amounts of information in terms of numbers of bits, characters, words and records (Harmon, 1984). This approach can especially be followed when the potential hardware's bulk of an information system is supposed to be estimated (Stamper, 1971). Information systems, regardless of type and size, should have some prerequisites. In the information age, with tremendous volumes of data that should be stored on a tiny digital chip, calculating the bulk of existed data and the ratio of their increase is necessary. Adopting such a strategy helps the administrator to have an approximate estimation of the future requirements of the system. It is not absolute, because the same number of signs does not necessarily carry the same amount of information. Volume covers the technical dimension too.

Syntax of Information: Theoretically, messages convey information. But, the information is manifested with different scales. Sometimes, we just receive one word. For example, a friend says *Hi*; which is a welcoming message and conveys a good starting point for a given conversation. Some other times, we receive a sentence. For instance, someone asks us about the availability of information on a given subject or informs us about the cost of shipping of an information resource. We make different decisions and follow diverse procedures in each case. The reason behind this diversity is the quantity of information we receive. A *Hi* is enough to establish a relationship between two persons; but it never holds added meaning to direct the addresser to select from a wide range of potential options or to give a piece of information to the speaker. However, when the conversation is continued and sentences are communicated one after another, both persons would be able to better understand purposes, decrease the ambiguity, and advance the process. Stamper (1971) discussed the lingual characteristics and claimed that usual messages convey less information than unusual ones. Information tends to increase as the surprising value of the statement increases. Gordon and Sager (1985) made a progress for such an idea and developed some quantitative measures of the information content of textual material through analysis of the linguistic structure of sentences in the text. The manipulated texts were divided into two categories including *theory* and *report*. Their counts and calculations were based on the number of words in each sentence, the number of operators in each sentence, the ratio of the number of words to the number of operators, and so on. There were also distinctions among nouns, verbs, adverbs, adjectives, and etc. Stamper (1971) remarks that adjectives have more capacity for information transfer. Measuring information gain from discourse has also been investigated. Mosberg (1970) differentiates factual information from relational information; and believes that the factual information has more chance to be measured and to be competent of increasing performance. After Mosberg, Stamper (1971) wrote that logical precision of the message indicates the degree of its effect. We may be able to associate Mosberg's factual information with Stamper's conception of precise message; because they both tend to prioritize the scarcity of information as the desirable situation in the measurement process. Miller, on the contrary, has a different viewpoint; a negentropic one. He has claimed anything that increases the variance through observation, also increases the amount of information (Schroeder, 2004). Kondraske and Vasta (2000) stated another claim about simple and complex information and envisioned the chance of better measurement for complex information. Hayes (1993) also contributed in the syntax of information. The syntax approach mainly explains lingual aspect of the information transfer process.

Probability and Entropy of Information: This approach has yet broadly been followed (Miller, 1953; *Solomon Kullback* in Cherry, 1960; Gorbatenko, 1971; Harmon, 1984 and 1986; Hayes, 1993; Schroeder, 2004). Stamper (1971) believes that the concept of measurement can only be understood if we discuss the concept of probability. On one hand, probability implies that an event may or may not be occurred. The equal probability is always 50/50; i.e. occurrence or nonoccurrence has an equal chance. The equal chance can be translated into 1 or 0. We replace 1 with the information; because we overwhelm the lack of knowledge or 0 when the information is received and understood. On the other hand, probability is opposite to the certainty. When we have more probabilities, we have less certainty about the condition encircled us. Therefore, information is the absence or reduction of probability and the presence of certainty; and inversely, uncertainty is a probabilistic and entropic situation in which there is no or less/deficient information (Schroeder, 2004). Regarding this statement, one can measure the information if and only if s/he would be able to calculate the probability of occurrence of an event. Stamper (1971) proceeds and argues that relative frequency probability is the best-known information measure. Relative frequency probabilities can only be assigned to a limited class of statements; those which refer to classes of events (not isolated events) which display a stable statistical pattern of behavior over the relevant period of time. The probabilistic and computational approaches to the measurement of information have further been discussed (Buehler, 1971a, 1971b; Good, 1971; Lindley, 1971; Williams, 1971; Kitchin, 1997; Titchener, 2008).

Quantity of Information: A measure of information I can be defined as the amount of information which, when acted upon, results in one joule of work (Harmon, 1984; 1985; 1986). According to this definition, a given unit of information I equals one joule of work J. Thus:

$$1I = 1J$$

For example, an information officer is responsible for providing a (right) answer A for every query Q submitted to the *Ask the Librarian* system in 15 minutes. The system lets the user give a feedback through filling a checkbox. The officer should at least procure 75 percent of the user satisfaction. This means that if he works 8 hours H a day, 24 questions should at least be answered correctly. Thus:

$$1Q = 1A$$

$$1Q = 15m$$

$$15m = 1A$$

$$1Q = 1A = 15m \text{ OR } 15m = 1AQ$$ [2]

$$1H = 15m \times 4 \text{ OR } 1H = 4AQ$$

$$8H = 32\ (15m) \text{ OR } 8H = 32AQ$$

$$8H = 32AQ = 100\%$$

$$75\% = 32\ (15m) / 4 \times 3 = 24\ (15m) = 24AQ$$

[2]. AQ = Answered Question

$$24AQ = 24J$$

$$24J = 24I$$

Impact of Information: Investigating the impact of information has suffered from lack of standardized definitions which are necessary for the exchange of information among those doing research or analysis in the field (Meadow and Yuan, 1997). However, information impact Ii, as defined by Harmon (1984), is the number of joules J a system S uses to do the right work without information A minus the number of joules the system uses to do the same work with information B. Thus:

$$Ii = SAJ - SBJ$$

Therefore, information impact equals the joules that a system in state A uses minus the joules the system uses in state B. As an example, the supposed information officer receives a query about the economic crisis in the United States of America and its impact on the commercial balance between Kyrgyzstan and Russia. He may have enough information on the economic crisis; while he doesn't know anything about the commercial balance. Under such a condition, if he searches the database *1000J* will be consumed; and finally no relevant record may be retrieved. However, he can analyze the query, detect the facets, control the concepts against a given thesaurus, search the database, and then consumes just *200J*. Thus:

$$Ii = 1000J – 200J$$

$$Ii = 800J$$

The equation proves that the right answer saves *800J* for the information system.

Value of Information: Measurement of information value is based on the measurement of information quantity (Hilbert, 2012). Discussions of information value have normally been related to management's use of and acquisition of information. Information has no value in itself. The only value is the result of the decision based on the information, contrary to results achieved without information (Sepstrup, 1972). In other words, the value of information is dependent on the context and use (Oppenheim *et al*., 2004); or it is an outcome of the choice in uncertain situations an individual may follow (Mughele and Abayomi, 2013). Generally, it is aligned with quantity and impact of information.

Information value Iv can be expressed in terms of money M or time T (Harmon, 1984). The monetary value of information to a system S can be defined as the net amount of money that a system gains or losses in doing the right work *with* information B minus the gain or loss in doing the same work *without* information A. Thus:

$$Iv = SBM - SAM$$

The time T value of information to a system S can also be defined as the amount of time that a system uses in doing the right work *without* information A minus the time it uses *with* information B. Thus:

$$Iv = SAT - SBT$$

These formulae seem instrumental. But, there are researchers that address *Iv* cautiously. Sepstrup (1972) believes that using economic units for evaluation of the expected results of information is much more difficult. Mughele and Abayomi (2013), observe information as an economic commodity; and assert that considering information as an asset, makes sense that it should be valued using the same methods used to value other assets. The value of an asset may come from *use* and *sale*. Benefits of information generally arise from use; rather than sale (exchange). In most cases, there are no buyers of information. Therefore, its value in exchange could predominantly be zero.

Energy of Information: A broad diversity of information phenomena can be studied at the cellular and genetic levels. Biologically, cells became so organized to conduct and integrate information (Harmon, 1975). Nucleotide bases are always combined to produce deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) molecules (Harmon, 1985; 1986). A basic genetic message unit is the codon *C*, a code word made up of three adjunct nucleotides *N*, also known as amino acids. Since each nucleotide carries about two bits of data *2I*, a codon or triplet carries about six bits (Miller, 1978; Jacquet, 2009). Thus:

$$1C = 3N$$

$$1N = 2I$$

$$1C = 6I$$

A gene, for example, consists of 200 amino acids; and hence 600 bits of information. Genes convey the energy; and foods also give the energy. Therefore, if we accept that foodstuffs energize the human, there would be an immediate impact of energy on the physical and behavioral systems of human beings. Comparing and evaluating someone's behavior before and after launch, for example, shows how many bits of information the person has absorbed. Empirical and experimental investigations have provided a clearer notion of and tool for energy-information conversion (Harmon, 1975; Ida, 2009).

Conclusion

Approaches to the measurement of information were discussed in this article. Computational and statistical approaches have unconsciously been adopted by most of the researchers involved in information measurement. For example, measuring informational content of the opportunity sets has been investigated (Bossert, 1998). There also exist researchers that derive information measures from the broad range of physical, biological, lingual and social phenomena. Kvålseth (1989) introduced a potentially useful measure in behavioral research. Gordon and Sager (1985) argued that the number of operators in each sentence would be one measure of the information amount of a sentence. Quantitative amounts of information that a neuron delivers to its targets has also been measured (Crumiller *et al*., 2013).

In addition to the above-mentioned approaches, there is *Semantic Information Theory* that authenticates the recipient as the only person who is deserved to do a measurement. According to this theory, information can just be measured when it is received and understood. Subjectivity of this approach has specifically been stressed (Sepstrup, 1972). This testimony is as Stamper's idea (1971) where he claims that measurement would be possible through invoking the judgment of the user, someone whose action or decision will be affected by the message; Sepstrup's statement (1972) that encourages communicators to explicitly concentrate on the value of information as seen from the recipient's point of view; and Belzer's (1973) and Miller's (1978) notions on the need to measure the *meaning* rather than *information*. The last cited researchers formulated that no matter how much *information* we receive; what is important is that how much *meaning* we understand. However, Harmon (1986) has pointed out that information measures should be compatible with other sets of scientific and socioeconomic measures. The textbook of Solomon Kullback (Cherry, 1960) reflects the same approach. The systems philosopher, David Easton, once stated that concepts are neither true nor false; they are more or less useful (Harmon, 1985). Finally, it seems that a multi-dimensional approach would help us measure the information more accurate.

References

- Belzer, J. (1973), "Information Theory as a Measure of Information Content", *Journal of the American Society for Information Science*, Vol. 24, No. 4, pp. 300-304.
- Bossert, W. (1998), *Opportunity Sets and the Measurement of Information*, Department of Economics, University of Nottingham, Nottingham.
- Buehler, R. J. (1971a), "Measuring Information and Uncertainty", in Godambe, V. P. and Sprott, D. A. (Eds.), *Foundations of Statistical Inference*, Rinehart & Winston, Toronto: Holt, pp. 330-337.
- Buehler, R. J. (1971b), "Reply to the discussions of Measuring Information and Uncertainty" by R. J. Buehler", in Godambe, V. P. and Sprott, D. A. (Eds.), *Foundations of Statistical Inference*, Rinehart & Winston, Toronto: Holt, pp. 340-341.
- Chatzikokolakis, K., Chothia, T. and Guha, A. (2010), "Statistical Measurement of Information Leakage", in *International Conference on Tools and Algorithms for the Construction and Analysis of Systems (TACAS 2010)*.
- Cherry, C. (1960), "The Measurement of Information", *Nature*, Vol. 186, No. 4724, p. 506.
- Crumiller, M., Knight, B. and Kaplan, E. (2013), "The Measurement of Information Transmitted by a Neural Population: Promises and Challenges", *Entropy*, Vol. 15, pp. 3507-3527.
- Good, I. J. (1971), "Discussion of "Measuring Information and Uncertainty" by R. J. Buehler", in Godambe, V. P. and Sprott, D. A. (Eds.), *Foundations of Statistical Inference*, Rinehart & Winston, Toronto: Holt, pp. 337-339.

- Gorbatenko, V. V. (1971), "K voprosu o mere kolichestva informatsii = the measurement of information", *Nauchno Tekhnicheskaya Informatsiya Series*, Vol. 2 No. 2, pp. 5-8.
- Gordon, D. B. and Sager, N. (1985), "A method of measuring information in language, applied to medical texts", *Information Processing and Management*, Vol. 21, No. 4, pp. 269-289.
- Jacquet, P. (2009), "*The Birth of Information Theory*", available at: http://www.bibnum.education.fr/sites/default/files/Brillouin-analyse-english.pdf (accessed 18 February 2021).
- Ha, K. V. (1999), "*Information Measurement*", available at: https://www.hiof.no/ia/prosjekter/hoit/html/nr1_99/im.html (accessed 25 September 2018).
- Harmon, G. (1975), "Information and Metaenergy", in Debons, A. and Cameron, W. J. (Eds.), in *Proceedings of the NATO Advanced Study Institute on Perspectives in Information Science held in Aberrystwyth, Wales, UK, August 13-24, 1973,* Noordhoff, Leyden, pp. 93-99.
- Harmon, G. (1984), "The measurement of information", *Information Processing and Management*, Vol. 20, No. ½, pp. 193-198.
- Harmon, G. (1985), "Information Measurement in Natural and Artificial Systems", in Agrawal, J. C. and Zunde, P. (Eds.), *Empirical Foundations of Information and Software Science*, Plenum Press, New York, pp. 303-309.
- Harmon, G. (1986), "Information Measurement: Approaches, Problems, Prospects", in *Proceedings of the American Society for Information Science,* Knowledge Industry Publications, Inc., New York, Vol. 23, pp. 3-15.
- Hayes, R. M. (1993), "Measurement of information", *Information Processing and Management*, Vol. 29, No. 1, pp. 1-11.
- Hilbert, M. (2012), "How to Measure "How Much Information"? Theoretical, Methodological and Statistical Challenges for the Social Sciences", *International Journal of Communication*, Vol. 6, pp. 1042-1055.
- Ida, I. (2009), *Biological Information Measurement Apparatus and Method*, European Patent Office.
- Kitchin, P. L. (1997), "*A New Method for Comparing Experiments and Measuring Information*", PhD Dissertation, Virginia Polytechnic Institute and State University, Virginia.
- Kondraske, G. V. and Vasta, P. J. (2000), "Measurement of Information-Processing Performance Capacities", in Bronzino, J. D. (Ed.), *The Biomedical Engineering Handbook*, CRC Press LLC, Boca Raton.
- Kvålseth, T. O. (1989), "Note on information measurement", *Bulletin of the Psychonomic Society*, Vol. 27, No. 2, pp. 181-183.
- Lindley, D. V. (1971), "Discussion of "Measuring Information and Uncertainty" by R. J. Buehler", in Godambe, V. P. and Sprott, D. A. (Eds.), *Foundations of Statistical Inference*, Rinehart & Winston, Toronto: Holt, pp. 339-340.

- Ling-Feng, L. and Jian-Rong, T. (2005), "Quantitative Information Measurement and Application for Machine Component Classification Codes", *Journal of Zhejiang University Science*, Vol. 6A (Suppl. 1), pp. 35-40.
- Meadow, C. T. and Yuan, W. (1997), "Measuring the Impact of Information: Defining the Concepts", *Information Processing and Management*, Vol. 33, No. 6, pp. 697-714.
- Miller, G. A. (1953), "What is information measurement?", *American Psychologist*, Vol. 8, No. 1, pp. 3-11.
- Miller, J. G. (1978), *Living Systems*, McGraw-Hill, New York.
- Moody, D. and Walsh, P. (1999), "Measuring the Value of Information: an Asset Valuation Approach", Paper presented at the *Seventh European Conference on Information Systems (ECIS 99)*, Copenhagen Business School, Frederiksberg, Denmark, 23-25 June, 1999.
- Mosberg, L. (1970), "*Measurement of Information Gain from Written Discourse*", working paper, Southwest Regional Laboratory for Educational Research and Development, Washington, D. C.
- Mughele, E. S. and Abayomi, D. (2013), "Quantitative and Financial Measurement of the Value of Information", *Information Systems, Development Informatics and Business Management*, Vol. 4, No. 2, pp. 1-4.
- Oppenheim, C., Stenson, J. and Wilson, R. M. S. (2004), "*Views of Information Professionals on Information as an Asset*", Loughborough University Institutional Repository, Loughborough.
- Ozawa, M. (2012), "*Mathematical Foundations of Quantum Information: Measurement and Foundations*", available at: https://arxiv.org/abs/1201.5334 (accessed 18 February 2021).
- Schroeder, M. J. (2004), "An Alternative to Entropy in the Measurement of Information", *Entropy*, Vol. 6, No. 5, pp. 388-412.
- Sepstrup, P. (1972), "*Measurement of Information Value*", available at: https://tidsskrift.dk/ledelseogerhvervsoekonomi/article/view/34726/34901 (accessed 18 February 2021).
- Shaw, R. E. (1985), "Measuring information", in Warren, Jr., W. H. and Shaw, R. E. (Eds.), *Persistence and Change*, Lawrence Erlbaum and Associates, Hillsdale, NJ, pp. 327-343.
- Stamper, R. K. (1971), "Some Ways of Measuring Information", *Computer Bulletin*, Vol. 15, No. 12, pp. 432-436.
- Taylor, R. D. (2006), "The nature and measurement of information: Two "grand challenges" for the field", *16th Biennial Conference of the International Telecommunications Society*, Beijing, China.
- Titchener, M. R. (2008), "Towards Real-Time Measurement of Information in a Scientific Setting", *6th International Symposium on Communications Systems, Networks and Digital Signal Processing (CNSDSP 2008)*.

- Williams, J. S. (1971), “Discussion of "Measuring Information and Uncertainty" by R. J. Buehler, in Godambe, V. P. and Sprott, D. A. (Eds.), *Foundations of Statistical Inference*, Rinehart & Winston, Toronto: Holt, p. 340.