Metric Evaluation in Structural Analysis of Ontologies based on Information Quantum

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ABSTRACT: *The following article attempts to clarify knowledge quanta in knowledge systems and semantic networks to propose information quanta as a novel context in the structural analysis of ontologies, which could be utilized as a basis for developing ontology evaluation metrics and measures. Identifying information quanta in ontologies could play an influential role in establishing and creating a new context in the structural analysis of ontologies by proposing, developing, and applying new metrics and criteria for measurement of the mentioned quantum elements (i.e., ontology data). Identifying information quantum in knowledge organization systems (KOS), especially ontologies, needs to rely on some theoretical foundations to facilitate the explanation of the subject. Here, two fundamental theories of the knowledge quanta, the Quantum Theory of Knowledge (QTK) created by Burgin (1995; 1997; 2004) and the Semantic Link Network Theory (SLNT) developed by Zhuge (2004; 2010; 2012), are explained to shine a light on information quantum in ontologies.*

Keywords: Quantum Theory of Knowledge (QTK), Semantic Link Network Theory (SLNT), Semantic Link Theory of Knowledge (SLTK), Knowledge Quanta, Information Quanta, Ontology evaluation; Structural Analysis

DOI: 10.6025/stm/2021/3/25-30

Received: 22 August 2021, Revised 2 October 2021, Accepted 19 October 2021

1. Introduction

Subjectivity and objectivity are two forms of perception that could be applied in various fields of science such as quantum information and information quantum. The above-mentioned scientific fields possess certain contrasting features. In the world of quantum, quantum information, as subjective information, is the information of the state of a quantum system (Nielsen, 2010) that is based on the interpretation of reality in quantum mechanics. Based on Shannon's information theory (1948), information quantum, as objective information, focuses on analyzing the source of the messages and information required to transmit messages (Gordon, 2004) and is considered with the facts that belongs to the world of information (Khrennikov, 2016). Here, the most important difference between the two-mentioned areas is their form of perception. Information quantum focuses on objective information (quantum of information) while quantum information relies on subjective information in the quantum world. Therefore, there are two different perspectives on information in the field of quantum research based on their form of perceptions.

In other words, Information quantum, as an information approach, focuses on objective Subjectivity and objectivity are two forms of perception that could be applied in various fields of science, such as quantum information and information quantum. The above-mentioned scientific fields possess certain contrasting features. In the quantum world, quantum information, as personal information, is the information of the state of a quantum system (Nielsen, 2010) based on the interpretation of reality in quantum mechanics. Based on Shannon's information theory (1948), information quantum, as objective information, focuses on analyzing the source of the messages and information required to transmit messages (Gordon, 2004) and is considered with the facts that belong to the world of information (Khrennikov, 2016). Here, the essential difference between the two-mentioned areas is their form of perception. Information quantum focuses on objective information (quantum of information), while quantum information relies on subjective information in the quantum world. In other words, Information quantum, as an information approach, focuses on objective information based on classical information theory, and quantum information relies on subjective information based on quantum mechanics. Therefore, there are two different perspectives on information in quantum research based on their form of perceptions.

The information approach in the form of information quantum plays a significant role in applications in various sciences, especially in cognitive and social sciences. Information is indeed fundamental in corresponding to the world's physical and distinctive features (Chalmers, 1995). Using the data interpretation of quantum field theory, quantum fields are determined as quantized information fields. Their quanta can be interpreted as quanta of information (i.e., information quanta) (Khrennikov, 2016). Information quanta can describe and analyze information flows and the essence of information. In other words, the pattern analysis of quanta behaviors concerning each other and their environment has a significant capability to explain the world of information (Horri, 2008). The information viewpoint can be applied in knowledge organization systems (KOSs), especially ontologies, to identify their information quantum or atoms as a basis for developing criteria, identifiers, and indices in the metric evaluation of ontology structure based on quantitative approaches. Thus, the information approach in quanta identification can be applied to recognize the information quanta in various sciences, especially in KOSs.

The identification of information quantum in KOS needs to rely on some theoretical foundations to facilitate the explanation of the subject. Here, two fundamental theories of the knowledge quanta, the Quantum Theory of Knowledge (QTK) created by Burgin (1995; 1997; 2004) and the Semantic Link Network Theory (SLNT) developed by Zhuge (2004; 2010; 2012), are explained to shine a light on information quantum in KOSs. The relations between the two theories comprise a significant role in identifying information quantum in KOS. In this case, we attempt to describe knowledge quantum in knowledge systems by explaining the Quantum Theory of Knowledge (QTK). Moreover, the Semantic Link Network Theory (SLNT) will be discussed to recognize knowledge quantum in semantic networks. Finally, the article's discussion focuses on identifying information quanta in KOSs by explaining knowledge quanta in knowledge systems and semantic networks based on the distinction between data and information.

2. The Quantum Theory of Knowledge (QTK)

The quantum level of knowledge contains "quantum bricks" and "quantum blocks" of knowledge as knowledge units used to construct knowledge systems. Knowledge systems are built using quantum elements, such as propositions and predicates (Burgin, 2017). For instance, an example of a knowledge item or system regarding the title and features of the present article would be the following proposition: "Information Quanta: A Basis for Metric Evaluation in Structural Analysis of Ontologies. It has some pages, it has five main sections". The above statement's knowledge unit or knowledge quantum is this proposition: "This article is about information quantum." (Burgin, 2017a). Burgin (2017) proposed various kinds of knowledge quantum, and he states that:

"At first, let us consider descriptive knowledge as the most specific category of knowledge. In this case, the simplest knowledge about an object gives some property to this object. The simplest property is the existence of the object in question. However, speaking about properties, we have to discern objects' intrinsic and ascribed properties. In this, we are following the longstanding tradition of attributive realism, in which it is assumed that objects have intrinsic properties. Taking an object A and its feature (intrinsic property) QA, we come to an inherent descriptive quantum (IKQ) of knowledge K = (A, q, QA), the graphical form of which is represented by the following diagram".

$$A \xrightarrow{\;q\;} Q_A.$$

Figure 1. The graphical representation of the inherent descriptive quantum (IKQ), (Burgin, 2017)

"For example, taking a physical body (object), we know that it can have an intrinsic property as 10 kg of mass. At the same time, it can have such an intrinsic property as "being a rigid object" (an attribute), as well as intrinsic property mass (a natural property)." Burgin (2017) explains that "When the object A and the property QA are indecomposable, the inherent quantum of knowledge is called an elementary inherent descriptive knowledge unit (EIKU)."

2. The Semantic Link Network Theory (SLNT)

Another representation of quantum knowledge is developed in the semantic link theory of knowledge (SLTK) based on semantic link network theory (SLNT) elaborated by Hai Zhuge and his collaborators (Zhuge, 2004; 2010; 2012; Zhuge and Shi, 2003; 2004; Zhuge and Sun, 2010; Zhuge and Xu, 2011; Zhuge and Zhang, 2010). The goal of SLNT is to create a semantic map of the Web, representing complex systems as semantic networks (Burgin, 2017). Elementary units of semantic networks in SLNT could be conceptualized as knowledge quanta. Burgin (2017) stated that: "The SLNT elementary unit is called a semantic link, which is a triad $\alpha = (X, \alpha, Y)$ where X and Y are called semantic nodes and can be any objects, e.g., texts, people, computers, semantic links, etc., while á is the connection (link) between X and Y, which indicates a relation between these semantic nodes. The graphical representation of the semantic link α has the following form:”

$$X \xrightarrow{\alpha} Y \, .$$

Figure 2. The graphical representation of the semantic link, (Burgin, 2017)

Semantic links can construct semantic networks and build the networks in which semantic relations connect physical objects. Here, the elementary unit of knowledge is a knowledge link that includes X and Y called knowledge nodes that can be names of any symbolic things, such as words and symbols. Moreover, there is a connection (α or link) between the knowledge nodes. Zhuge (2012) demonstrated a labeled arrow á as an arrow semantic link for inner semantic link $\alpha = (X, \alpha, Y)$. A knowledge link is a kind of a complete semantic link (Burgin, 2017) that could be called knowledge quanta in a semantic network.

3. Knowledge Quanta in Ontologies

The term ‘‘ontology” entered computer science to formalize the kinds of things relating to a system or a context (Simperl 2009) as well as the identification of concepts and their relations in knowledge management operations (De Silva 2008). In our context, ontologies are explicit formal specifications of the terms in a domain and the links among them, which include concepts, roles (i.e., properties or slots) between concepts’ instances, and restrictions (i.e., facets) that define a knowledge base in knowledge representation (Lu 2006). Structurally, an ontology represented as a graph includes nodes and arcs, which regard conceptualizations in formal semantics (Gangemi et al., 2005). Ontological relations, in general, consist of the three main elements: subject, object, and property, to make a relation between concepts (Amirhosseini, 2016).

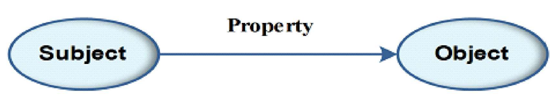

Figure 4. The main elements to make relation between concepts in ontological relations

The subject, object, and relation are the three elements in semantic relations in ontologies. These are fundamental semantic links used to construct complex semantic relations in the semantic network ontologies. This semantic link can be matched with the semantic link in the Semantic Link Network Theory (SLNT). Therefore, this minimal semantic link structure can be a knowledge unit or quantum of the semantic network in ontologies.

4. Discussion

4.1 Shared representation of quantum units of knowledge

Burgin (1995; 1997; 2004) proposed the Quantum Theory of Knowledge (QTK) and identified the quantum level of knowledge as knowledge quanta comprising the minimal blocks or units of knowledge in the construction of knowledge systems. Knowledge quanta are primitive propositions and predicates. Zhuge (2004; 2010; 2012) proposed the semantic link theory of knowledge (SLTK) based on the semantic link network theory (SLNT) to build a semantic map of the Web in the form of a semantic network that provides a basis for knowledge representation. In the before-mentioned theories, elementary units of complex semantic networks could be conceptualized as knowledge quanta. These elementary units include, essentially, the triad of two nodes and a labeled semantic link between them. However, knowledge systems and complex semantic networks reside in the knowledge stage of cognition states. A semantic network is a method of knowledge representation that represents semantic relations between concepts (Chung, 2010) applied in ontologies. There is a minimal structure in the semantic network of ontologies with the three essential elements of the subject, object, and relation known as a semantic link. This elementary unit, as a triad, is a complete semantic link, which is considered the minimal blocks and bricks of a complex semantic network. Thus, it can be said that the knowledge unit in ontologies as a minimal structure, in the same way as expressed in the discussion of QTK and SLNT, can appear in the role of knowledge quantum. Consequently, Quantum units of knowledge are shared representations in the quantum theory of knowledge, the semantic link network theory, and the semantic network of ontologies, which coincides with the fact that they are in the knowledge stage of the cognition states.

4.2 Information Quanta in Ontologies

In this context, propositions and predicates have two characteristics: they provide us with information, and the other is that the building blocks of their structure are concepts, objects, and properties. In natural languages, the predicate provides information about the subject in the form of a proposition, such as what the subject is, what the issue is doing, what the subject is feeling, and what the subject is like (Burridge and Stebbins, 2020). The theories of information structure assume that the ordinary meaning of the whole sentence must be composed of the two informational units in a subject-predicate manner, i.e., proposition (Von Heusinger, 2002; Sasse, 1987; Jacobs, 2001; Kuroda, 2005). Moreover, as knowledge units, propositions and predicates play the primary role in determining the knowledge quantum in knowledge systems and in semantic networks. Russell (1903) ascribed deûnite structures to propositions, regarding concepts, objects, and properties as constituents of propositions (Burgin, 2017b). Therefore, including subjects and predicates in a structured proposition, including concepts, objects, and properties as structural elements of knowledge, quanta recognizes such quanta as information.

Concepts, Signs, and Symbols are considered elementary units or knowledge quanta of propositions and predicates in natural language in the realm of semiotics (Burgin, 2017). However, the determination of elementary units in various structures is done differently. For example, the minimal structure or quantum units of society are humans as “social atoms” in social sciences (Khrennikov, 2016). On the other hand, in human physiology, the cells are considered quantum units of humans and “human atoms.” Thus, a semantic link described through a proposition and a predicate is regarded as a knowledge quantum in a complex semantic network. This is while semantic link and its propositional description reside in the information stage of cognition states due to its nature and essence.

Consequently, the quantum element of a semantic link or a proposition can be considered as the concepts, signs, and symbols of the semantic link or proposition. These concepts, signs, and symbols are, in fact, the essential components of a semantic link, which are: the subject, object, and relation. For example, a semantic link as a knowledge quantum can be divided into its components, i.e., into three parts: subject, object, and relation. In this case, these separate parts can be considered the information quantum or data of the semantic network. Finally, it can be said that the information quantum in the semantic network of ontologies that include the concepts, signs, and symbols or the subject, object, and relation are derived from broken propositions or fragmentation of the semantic links into their components, which results in placing the said quanta in the data stage of cognition states.

5. Conclusion

Information quanta could be used to describe and interpret the information flow and the essence of information by analyzing their behavior with respect to each other and their surroundings in explaining the world of information (Horri, 2008). Information quantum can play a significant role in analyzing various fields of sciences, primarily cognitive and social sciences. The information viewpoint can be applied in knowledge organization systems (KOSs), especially ontologies, to identify their information quanta or atoms. Information quanta are the data in the complex semantic network of ontology. According to the Holism idea, the whole has more things than the sum of its components (Smuts, 1926). However, the perception and recognition of the whole do not eliminate the need to understand its components (Horri, 2008). There is a considerable amount of data, including concepts and semantic relations in the structure of the semantic network of ontologies that could be measured by analyzing their behavior concerning each other and the environment around them to percept the domain, structure, and flow of information in recognizing the world of information. In the core literature in ontology evaluation, structural evaluations have focused on the semantic link or knowledge quantum (i.e., information) in ontologies rather than the information quantum (Amirhosseini, 2016). However, information quantum (i.e., data) can be involved in measuring the structure of ontologies (Amirhosseini & Salim, 2019) in analyzing the behavior of data in ontology structure. This involvement can be realized by developing criteria, identifiers, and indices in the metric-based evaluation of ontology structure based on a quantitative approach. Consequently, the information approach in quanta identification can be applied to recognize information quanta in various fields of sciences, especially in KOSs, to recognize their atoms or quanta, specifically to achieve the goals of ontology evaluation by proposing novel metrics.

References

[1] Amirhosseini, Maziar. (2016). Analysis of concept structure and semantic relations based on graph-independent structural analysis, Ph. D. Dissertation. Faculty of Information Sciences and Technology, Universiti Kebangsaan Malaysia, 388

[2] Amirhosseini, Maziar., Salim, Juhana. (2019). A Synthesis Survey of Ontology Evaluation Tools, Applications and Methods to Propose a Novel Branch in Evaluating the Structure of Ontologies: Graph-independent Approach. *International Journal of Computer* (IJC), 33 (1) 46-68.

[3] Burgin, M. (1995). The phenomenon of knowledge, Philosophical and Sociological Thought, No. 3–4, 41–63.

[4] Burgin, M. (1997). Fundamental Structures of Knowledge and Information, Ukrainian Academy of Information Sciences, Kiev (in Russian). Structures and Processes. New Jersey: World Scientific Series in Information Studies, p 45-168.

[5] Burgin, M. (2004). *Data, information, and knowledge, Information*, 7 (1) 47–57.

[6] Burgin, Mark (2017) Chapter 4: Knowledge Structure and Functioning: Microlevel or Quantum Theory of Knowledge, In Theory of Knowledge Structures and Processes. *New Jersey: World Scientific Series in Information Studies*, 307-394.

[7] Burgin, Mark (2017a) Chapter 2: Knowledge Characteristics and Typology, In Theory of Knowledge Structures and Processes. New Jersey: World Scientific Series in Information Studies, pp. 45-168.

[8] Burgin, Mark (2017b) Chapter 5: Knowledge Structure and Functioning: Macrolevel or Theory of Average Knowledge, In Theory of Knowledge Structures and Processes. New Jersey: World Scientific Series in Information Studies, pp. 395-592.
Burridge, Kate and Stebbins, Tonya N. (2020) For the Love of Language: An Introduction to Linguistics. London: Cambridge University press.

[9] Chalmers, D. J. (1995). Facing up to the hard problem of consciousness. *Journal of Consciousness Studies* 2 (3) 200-219.

[10] Chung, Wingyan (2010) Web Searching and Browsing: A Multilingual Perspective. *In*: Advances in Computers V. 78, 2010, p 41-69.

[11] De Silva, Sisira T. (2008). An ontology to medel time in clinical practice guideline. Master of Health Informatics, Dalhousie University.
[12] Gangemi, A., Catenacci, C., Ciaramita, M., Lehmann, J. (2005). A theoretical framework for ontology evaluation and validation. Proceedings of SWAP2005.

[13] Gordon, Timpson Christopher (2004) Quantum Information Theory and the Foundations of Quantum Mechanics. Thesis or the degree of Doctor of Philosophy. Oxford:University of Oxford

[14] Horri, Abbas (2008). An Introduction to informology: Functions and Applications. Tehran: Dama; Ketabdar.

[15] Jacobs, Joachim (2001). The dimensions of topic–comment. In: Linguistics 39: 641–81.

[16] Khrennikov, A. (2016). Social Laser': action amplification by stimulated emission of social energy', Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374: 20150094.

[17] Kuroda, Shige-yuki (2005). Focusing on the matter of topic: A study of wa and ga in Japanese. In: *Journal of East Asian Linguistics,* 14 : 1–58.

[18] Lu, Q. 2006. OntoKBEval: A Support Tool for OWL Ontology evaluation. Master of computer science, Concordia University.
Nielsen, Michael A. (2010). Quantum computation and quantum information. Chuang, Isaac L. (10th anniversary ed.). Cambridge: Cambridge University Press.

[19] Russell, B. (1903) Principles of Mathematics, Cambridge University Press, Cambridge.

[20] Sasse, Hans-Jürgen (1987). The thetic/categorical distinction revisited. In: Linguistics 25 : 511–80.

[21] Shannon, C. E. (1948). A mathematical theory of communication. The Bell System Technical Journal, 27, 379-423, 623-656. Retrieved from http://cm.bell-labs.com/cm/ms/what/shannonday/shannon1948.pdf

[22] Simperl, E. 2009. Reusing ontologies on the Semantic Web: A feasibility study. Data & Knowledge Engineering 68: 905–925. [Online] http://www.sti-innsbruck.at/fileadmin/documents/articles/reusing_ontologies.pdf

[23] Smuts, Jan Christiaan (1926) Holism and evolution. New York: The Macmillan company, 362 p.

[24] Sowa, J. F. 2008. Conceptual Graphs. Handbook of Knowledge Representation edited by F. van Harmelen, V. Lifschitz and B. Porter. London: Elsevier.

[25] Von Heusinger, Klaus (2002)Information structure and the partition of sentence meaning. Prague Linguistic Circle Papers, E. Hajicová, P. Sgall, T. Hoskovec & P. Sgall (eds.). Amsterdam: Philadelphia: Benjamins, 275-305

[33] Zhuge, H. and Zhang, J. (2010) Topological centrality and its applications, *Journal of the American Society for Information* Science and Technology, v. 61, No. 9, 1824–1841.

[26] Zhuge, H. (2004) China's e-science knowledge grid environment, *IEEE Intelligent Systems*, 19, No. 1, pp. 13–17.

[27] Zhuge, H. (2010) Interactive semantics, Artiûcial Intelligence, v. 174, pp. 190–204.

[28] Zhuge, H. (2012) The Knowledge Grid: Toward Cyber-Physical Society, World Scientiûc Publishing Co.

[29] Zhuge, H., Shi, X. (2003) Fighting epidemics in the information and knowledge age, *IEEE Computer*, v. 36, No. 10, pp. 114–116.

[30] Zhuge, H. and Shi, X. (2004). Toward the eco-grid: A harmoniously evolved interconnection environment, *Communications of the ACM*, 47 (9) 78–83.

[31] Zhuge, H., Sun, Y. (2010). The schema theory for semantic link network, *Future Generation Computer Systems*, 26 (3) 408–420.

[32] Zhuge, H., Xu, B. (2011). Basic operations, completeness and dynamicity of cyber physical socio semantic link network CPSocio-SLN, Concurrency and Computation: Practice and Experience, 23 (9) 924–939.