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Original research

The Identification of the Information Quanta in Semantic Network: A basis for the Structural analysis in Ontology Evaluation

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Abstract

The following article proposes a novel context by Information Quanta in the structural analysis of ontologies, which could be used to develop ontology evaluation metrics and measures. The identification of information quantum needs to clarify knowledge quanta in knowledge systems and semantic networks by considering two influential theories as Quantum Theory of Knowledge (QTK) proposed by Burgin (1995a; 1997; 2004) and the Semantic Link Theory of Knowledge (SLTK) proposed by Zhuge (2004; 2010; 2012). QTK identifies the quantum level of knowledge as knowledge quanta comprising the minimal blocks or units of knowledge in the construction of knowledge systems. In this case, knowledge quanta are primitive propositions and predicates. Elementary units of semantic networks, the triad of two nodes and a labeled semantic link between them, in SLTK based on the Semantic Link Network Theory (SLNT) could be conceptualized as knowledge quanta. Quantum units of knowledge are shared representations in the QTK and the SLTK. As a kind of semantic network, ontology also includes the triads of nodes and semantic links defined as knowledge quanta here. A semantic link as a knowledge quantum can be divided into its components, i.e., into three parts: subject, object, and relation. These separate parts can be considered as the information quantum or semantic network data. Finally, it can be said that the information quantum or data in the semantic network of ontologies that include the subject, object, and relation are derived from the fragmentation of the semantic links into their components. Identifying information quanta in ontologies could play an influential role in establishing and developing a new context in the structural analysis of ontologies through proposing, developing and applying new metrics and criteria in measurement of the mentioned quantum elements (i.e., ontology data).

Keywords: Quantum Theory of Knowledge (QTK), Semantic link network theory (SLNT), Semantic link theory of knowledge (SLTK), Semiotic, Knowledge quanta, Information quanta, Ontology evaluation, Structural analysis.

Introduction

Information is defined— in its shortest form— as processed data, with data being its smallest meaningful particle. Meaningful data is obtainable through research or cognitive processes. Data processing by the power of the mind and/or electronic processors identifies the relationship between mind and matter (Hiley, 2004), which becomes valuable information for specific purposes. The correct information at the right time for the right user constitutes the most important purposes in accessing and processing information and aiding users to achieve their goals. Therefore, the primary element and infrastructure of information are the accurate, correct, and meaningful data that takes the form of information once systematic relations and connections between data and information are established based on subjective and objective perspectives.

Discussions on Information objectivity-subjectivity, specifically in terms of human knowledge, date back to the philosophical debates in the Greek time, especially Greek philosophers such as Plato and Aristotle. However, there is no need to travel that far into the past to understand the objectivity and subjectivity of information. The modern use of the word "information" in many scientific areas dates back to the late 1940s and early 1950s (Young, 1987). Regarding the modern usage of Information objectivity-subjectivity, Mulder (2004) believed that the terms "subjectivity" and "objectivity" are closely related to a perceiving subject (usually a person) and a perceived or unperceived object, respectively (Zaliwski, 2011). Thus, the mentioned points of view culminated in grouping scientists into two schools of thought in identifying objective and subjective information.

The word "information" and its analysis, processing, and transmission have been used in various science fields, including quantum mechanics principles. "Information" from the perspective of classical information theories has specific differences as compared to the information defined by quantum information theories. One aspect of this distinction could be recognized in the objectivity and subjectivity of information. Shannon (1948) theory characterized the minimal resources required for successful communication as the sender, receiver, and the message, which exists objectively. Therefore, that information is treated objectively by the Shannon theory.

On the other hand, Donald MacCrimmon Mackay proposed that information should be defined as "the change in a receiver's mindset" in 1951 (Hayles, 1999). This demonstrates the subjective roles of information. At the turn of the 21st century, Quantum Bayesianism—as a collection of quantum mechanics interpretations by Caves, Fuchs & Schack, (2002)—regarded quantum state assignments (as an agent's degree of belief in the fields of quantum information) as subjective (Gupta, 2021). Therefore, the information approaches in quantum mechanics and information theory, similar to the mentioned perspectives in Information objectivity-subjectivity, divided researchers of various areas into two camps.

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, 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, 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 most crucial 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 information based on classical information theory, and quantum information relies on subjective information based on quantum mechanics.

The information approach in the form of information quantum plays great roles to applications in various sciences, especially in cognitive and social sciences. Information is fundamental in corresponding to the world's physical and phenomenal features (Chalmers, 1995). By using the information interpretation of quantum field theory, quantum fields are determined as quantized information fields, and 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 about each other and their environment can significantly 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 fields, especially in KOSs.

Materials and Methods

Identifying 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 major 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.

Results

Knowledge Quantum

Identifying information quantum needs to clarify concepts such as knowledge item, knowledge system, knowledge unit or knowledge quantum and, knowledge element. Burgin (2017a) believed that knowledge item is a system contemplated separately from other knowledge systems. Moreover, knowledge unit is a knowledge item that is used for constructing other knowledge systems and treated as a unified entity. Furthermore, Knowledge quantum is a minimal, in some sense, knowledge unit. Additionally, knowledge element is an element of a knowledge system. For instance, considering that a physical body "A" is apple and red (i.e., "an apple" is a knowledge element), the knowledge quantum or knowledge unit would be that "it is a red apple". Moreover, the mentioned knowledge quantum belongs to a knowledge system or knowledge item entitled "Red apple, called Red Deliciou or Hawkeye, originated in Iowa, USA in 1892". The concept of knowledge quantum can be recognized in two influential theories, Quantum Theory of Knowledge (QTK) and the Semantic Link Network Theory (SLNT), to identify the information quantum.

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 constructed 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: "The Identification of the Information Quanta in Semantic Network: A basis for the Structural analysis in Ontology Evaluation, it has some pages, it has three main sections". The knowledge unit or knowledge quantum of the above statement is this proposition: "This article is about information quantum." (Burgin, 2017a). Burgin (2017) proposed various kinds of knowledge quantum, and he states:

"At first, let us consider descriptive knowledge as the most typical category of knowledge. In this case, the simplest knowledge about an object gives some property of this object. The simplest property is existence of the object in question. However, speaking about properties, we have to discern intrinsic and ascribed properties of objects. 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".

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

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 such 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)." According to the contemporary understanding of reality, people do not have direct access to intrinsic properties of natural objects (Frieden, 1998; Burgin, 2010; 2012) and it is only possible to receive information about intrinsic properties (Burgin, 2010).

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 & Shi, 2003; 2004; Zhuge & Sun, 2010; Zhuge & Xu, 2011; Zhuge & 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 α = (X, α, Y) where X and Y are called semantic nodes and can be any objects, e.g., texts, people, computers, semantic links, etc., while α 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)

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

Knowledge Quanta in Ontologies

Ontology is a discipline that has originated from philosophical theories whose name and practice dates back to Aristotle. Ontology has focused on the existence and nature of things (Welty & Guarino, 2001) or the study of beings (Simperl, 2009). By the early 1980s, researchers had identified that ontology applications were relevant to describing intelligent systems (Welty & Guarino, 2001). 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) to 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, Catenacci, Ciaramita & Lehmann, 2005). Ontological relations generally consist of three main elements: subject, object, and property to make a relationship between concepts (Amirhosseini, 2016).

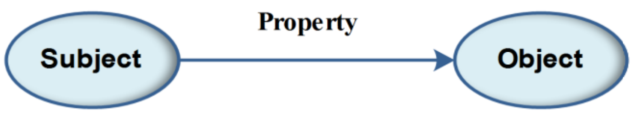

Figure 3: The main elements to make a relation between concepts in ontological relations

As stated previously, subject, object, and relation are the three elements in semantic relations in ontologies. In fact, these three basic elements are a fundamental semantic link that is used to construct complex semantic relations in the semantic network of ontologies, for instance, "Cat is a species of Feloidea (cat-like)". In this semantic relation, the subject is "cat" and "a species of cat-like" is its predicate, which can be represented as a proposition. The following figure identifies the three elements clearly:

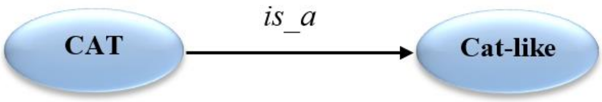

Figure 4: The tree elements of semantic relation, example: "Cat is a species of Feloidea (cat-like)"

The above figure demonstrates that "cat" plays a role as subject, "cat-like" as an attribute (intrinsic property) that is in the role of the object, and the subject and object which are the two semantic nodes, and *is_a* is the connection (link) between two semantic nodes. Moreover, a labeled arrow with the symbol of "*is_a*" is an arrow semantic link for the inner semantic link between subject and object. It is essential to say that 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 considered a knowledge unit or knowledge quanta of the semantic network in ontologies.

Discussion

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 that comprise the minimal blocks or units of knowledge in constructing 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. Elementary units of complex semantic networks in the before-mentioned theories could be conceptualized as knowledge quanta. These elementary units essentially include 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 knowledge representation method representing semantic relations between concepts (Chung, 2010) that have been applied in ontologies. There is a minimal structure in the semantic network of ontologies with the three basic elements of the subject, object, and relation known as a semantic link. This elementary unit, as a triad, is a complete semantic link, considered the minimal blocks and bricks of a complex semantic network. Concepts, signs and symbols play an essential role in the formation and representation of the elementary units of the semantic link. From another point of view, propositions and predicates as symbolic knowledge units can define and represent the three basic elements in the semantic link. In other words, the semantic link can be described as a proposition, mainly when the predicate is ascribed to the subject. Thus, it can be said that the knowledge unit in ontologies as a minimal structure, as mentioned 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.

Information quanta in ontologies

In this context, propositions and predicates have two characteristics: one is that they provide us with information, and the other is that the building blocks of their structure are concepts, objects, and properties. Zeno of Citium and his followers, in the third century B.C., believed that it is possible to find the first employment of the notion of proposition, in the roughly modern sense, as the informational content of sentences (Burgin, 2017b). In natural languages, the predicate provides information about the subject in the form of a proposition: for example, what the subject is, what the subject is doing, or what the subject is feeling, and what the subject is like (Burridge & 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 main role in determining the knowledge quantum both in knowledge systems and in semantic networks. Aristotelian logic treats a proposition as a sentence that affirms or denies a predicate of the subject of a sentence. For instance, "The Sun is a star" is a proposition with "The Sun" as its subject and "is a star" as the predicate. Recently, logicians started to study structured propositions (King, 1995). Russell (1903) ascribed definite structures to propositions, regarding concepts, objects, and properties as constituents of propositions (Burgin, 2017b). Therefore, the inclusion of subjects and predicates in the form of a structured proposition including concepts, objects, and properties as structural elements of knowledge quanta, recognizes such quanta as information.

In natural languages, concepts as kind of symbols and symbols as type of signs, are treated as the quantum units of knowledge which is the subject of discussion in the semiotic realm. Semiotic is a linguistics discipline that focuses on the theoretical models of the structure of conceptual signs and symbols. The term semiotics comes from a Greek word that means "a sign or a mark". John Locke (1690) used the concept in the form semeiotike as "the doctrine of signs". Stubbes (1670) used this concept for the first time in English, entitled "semeiotics" denoting the branch of medical science related to the interpretation of signs (Burgin, 2017). Two influential theories in contemporary semiotics were proposed by the American logician and philosopher Charles Sanders Peirce (1839–1914) and by French linguist Ferdinand de Saussure (1857–1913), who originally called it semeiotic and semiology, respectively. Saussure (1916) proposed the first theoretical approach to the concept sign. He believed that "the basic property of a sign is that it points to something different from itself, transcendent to it". This property can be represented in the form of a structural model of sign, including a fundamental triad in the following figure:

Figure 5: The structural model of sign

With regard to a word, a signifier may be understood as the sound or written pattern of the word and a signified may be treated as the conception or meaning of the signifier. Saussure (1916) emphasized that signs can exist only about other signs. Thus, a linguistic sign is not a link between a thing and a word, but between a concept and a sound/written pattern. In this context, concepts (signified) as a kind of symbols and symbols as a type of signs are treated as quantum units of knowledge in natural languages.

Concepts, Signs, and Symbols are considered elementary units or knowledge quanta of propositions and predicates in natural language in 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 the field of 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 that can be described through a proposition and a predicate is considered as a knowledge quantum in a complex semantic network. This is while semantic link and its propositional description, due to its nature and essence, reside in the information stage of cognition states.

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 basic components of a semantic link: 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 as the information quantum or semantic network data. Finally, it can be concluded that the information quantum in the semantic network of ontologies (including the concepts, signs, and symbols or the subject, object, and relation) is derived from broken propositions or fragmentation of the semantic links into their components. It results in placing the said quanta in the data stage of cognition states.

Conclusion

Information is fundamental in corresponding to the world's physical and phenomenal features (Chalmers, 1995). Quantum fields can be determined as quantized information fields and their quanta can be interpreted as information quanta (Khrennikov, 2016). Information quanta could be used to describe and interpret information flow and the essence of information by analyzing their behavior concerning each other and their surroundings in explaining the world of information (Horri, 2008). Information quantum can greatly analyze various sciences fields, especially in 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. Data is valuable only when it can be understood, perceived, interpreted, and ultimately have its value extracted (David, 2020). 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 huge 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. Structural analyses have been involved in evaluating ontologies when researchers focus on graph representations (Gangemi, Catenacci, Ciaramita & Lehmann, 2006) based on Conceptual Graph (CG) (Sowa, 2008) to identify that two nodes in a graph are related (Obrst, Ashpole, Ceusters, Mani, Steve & Smith, 2007), such as root, leaf, sibling, etc. (Gangemi et al., 2005). In other words, structural evaluations have focused on the semantic link or knowledge quantum (i.e., information) in ontologies rather than the information quantum. However, information quantum (i.e., data) can be involved in measuring the structure of ontologies based on a graph-independent approach (Amirhosseini & Salim,

2019) in analyzing the behavior of data in ontology structure. This involvement can be realized through 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.

Endnote

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