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POSSIBILITIES FOR STRUCTURING DATA IN THE WIKIDATA FORMAT FOR DATA STORED IN BLOCKCHAIN

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ABSTRACT

Securely storing both the data representation and the information it carries is not a simple task. The Wikidata project, since 2012, has been storing, in a format intelligible to men and machines, an infinity of informational entities cataloged by humanity. Therefore, there are initiatives to use this same standard for structuring metadata in other organizational systems outside the scope of the Wikimedia Foundation. However, for such an adoption to be made effectively, sooner or later the need to seek the guarantee of immutability of metadata stored in this format arises. Thus, this study presents a debate around the possibilities of storing metadata in Wikidata compatible format in a block chain network (Blockchain). To this end, a scope review was carried out on searches for early indications of the use of blockchain networks for storing semantic entities according to Wikidata standards. It is possible to see some promising initiatives using blockchain technologies in the search for metadata storage in the Wikidata compatible format.

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INTRODUCTION

Formal Semantics is the foundation for the generation of metadata, however, in the postmodern paradigm, the meaning – and Semantics itself – are a socio-technical phenomenon in cyberspace (Monteiro, 2018). It is not necessary to discuss the relevance of metadata in information systems […]. However, the mere establishment of metadata is not a solution (Fernando *et al*., 2020). Thus, managing metadata, linked information, intelligible to both machines and humans, and keeping it secure through a reliable and auditable persistence technology is a recent challenge. It is a horizon to be explored, since, despite the conjuncture of the internet's evolution, the efforts to achieve a homogeneous semantic "web" are (still) negligible. This means that the structuring of data consumed by machines and humans in information systems lacks standardization. In this way, the Wikidata database project, launched in 2012, has been proposing and implementing a way to store the representation of all informational entity rationalized by man. In addition, there are security challenges of ensuring the integrity of such information collected and transmitted through information systems. Some of the new solutions involve the adoption of distributed databases, among which Blockchain is becoming a promising candidate. Blockchain Technology (BCT) was first described in 2008 in an article authored under the pseudonym of Satoshi Nakamoto. Its creator defines it as a system capable of guaranteeing a decentralized ledger for storing data and transactions in a secure, persistent, transparent, auditable and immutable way. This technology was described as a cryptographically empowered, decentralized and public monetary system for carrying out monetary transactions that do not rely through a centralized financial institution (Alakananda *et al*., 2017). Since its creation, it appears that BCT has also been applied in solutions to solve problems in various scenarios (De Angelis, 2018). Currently, such technology is exploited in a wide range of application domains (Lunardi, R. C *et al*., 2019). This is the case for metadata verification initiatives through decentralized networks with BTC. Wikimedia foundation has the intention to disseminate other databases capable of storing metadata compatible with the format adopted by the Wikidata database. The Wikidata project itself is available for installation by any interested persons or associations (Wikimedia Foundation, 2012). However, it is not the design of the system that stores data from Wikidata (named Wikibase) that is priority in this context, but rather the semantic storage format, represented by LOD (Linked Open Data) based on RDF (Resource Description Framework). Its relevance is visibly perceived, as data stored and shared as LOD is discernible by intelligent machines and devices such as Alexa, Siri and others. In this way, LOD is a tangible representation of the Semantic Web, as it provides a data format capable of being interpreted by machines, so that machines can perform the related work in finding information on the web (Tharani, 2021). This means that other databases will be used to store semantic and related data, satisfying all criteria that point to a data as being Wikidata's RDF and LOD compliant format. Thus, the objective of this work is to comprehend nowadays initiatives and possibilities for using decentralized chain of blocks networks

(Blockchain) for provision of metadata in a format compatible with Wikidata. To achieve this goal, i carried out a scope review of the scientific literature that addresses the use of block chains to store structured semantic data in the Wikidata format.

SCOPE REVIEW AND METHODOLOGY

The present work approached a methodology like a systematic review, known as Scope Review. Such review is important as a beacon that will guide deeper future work and research. According to Petticrew *et al*, (2018), such methodology involves a research and evaluation of the existing literature to determine which categories of studies can be considered as a way of refining the research question. This opens the way for the possibility of carrying out a future systematic review. This research involves knowing where such records are published and in which scientific databases they are located. According to the same author, this research typically receives restriction of studies by language and publication date of the researched records. On the other hand, it is important to highlight that a typical systematic review work is guided by some steps for its execution, according to the publication of the Cochrane Handbook (Higgins *et al*, 2022). These steps are alike the following: a) Formulation of the Research Question; b) Location of studies; c) Critical evaluation of studies, d) Data collection; e) Groupings and presentation of data; f) Interpretation of data.

Definition of inclusion and exclusion criteria: To determine the validity of the selected studies, the following inclusion and exclusion criteria were used:

Inclusion Criteria (CI)

CI1 - The record must be related to information technology.
CI2 - The record must be related to data storage in the Wikidata format in a network based on blockchain technology.
CI3 - The record must be in English or Portuguese.
CI4 - The record should come since 2017 (about five years after the launch of the Wikidata project) until 2021.

Exclusion Criteria (EC)

CE1 - Records prior to 2017.
CE2 - Repeated records.
CE3 - Records unavailable or inaccessible electronically.
CE4 - Records that are not scientific articles or theses.
CE5 - Records in a language other than English and Portuguese.
CE6 - Proceedings of congresses, conferences, and the like.

Search and exclusions based on criteria and scope analysis: By carrying out the search for studies in the databases and by the keywords, I obtained the results of 156 preliminary studies. These were then filtered by the exclusion criteria, which resulted in 69 remaining studies.

Table1. Scope Analysis Flow: Search Results by Keywords with application of filters based on exclusion and inclusion criteria

1 - Searches in databases using keywords		2 - Exclusion of studies based on exclusion criteria	3 - Exclusion of studies based on reading the title and abstract		4 - Inclusion of studies based on reading the abstract filtering texts by the criteria
Database	Keywords Used	Number of Returned Studies	Number of Excluded Studies	Number of Excluded Studies	Number of *Included* Studies
ACM	"blockchain" and "Wikidata"	6	2	1	3
ACM	"smart contracts" and "Wikidata"	2	2	0	0
EMERALD	"blockchain" and "Wikidata"	2	0	2	0
EMERALD	"smart contracts" and "Wikidata"	0	0	0	0
IEEE Xplore	"blockchain" and "Wikidata"	0	0	0	0
IEEE Xplore	"smart contracts" and "Wikidata"	0	0	0	0
ScienceDirect Elsevier	"blockchain" and "Wikidata"	3	1	2	0
ScienceDirect Elsevier	"smart contracts" and "Wikidata"	0	0	0	0
Google Scholar	"blockchain" and "Wikidata"	112	53	52	7
Google Scholar	"smart contracts" and "Wikidata"	31	29	2	0
Total Returned Studies	*BOTH KEYWORDS*	*156*	*87*	*59*	*10*

The steps of this scope review adopted in this project were inferred from the explanations of both authors mentioned above. These are:

- Choice of relevant scientific literature databases.
- Definition of search keywords.
- Definition of inclusion and exclusion criteria.
- Search and exclusions based on criteria and scope analysis.
- In-depth analysis of the studies included and tabulation of what was learned.

Choice of relevant scientific literature databases: The selection of studies was performed by consulting the following databases:

- ACM Digital Library (http://portal.acm.org);
- Emerald (http://www.emeraldinsight.com/search.htm);
- Google Scholar (http://scholar.google.com.br);
- IEEE Xplore (http://ieeexplore.ieee.org/Xplore/home.jsp);
- ScienceDirect Elsevier (http://www.elsevier.com).

The following keywords were used to perform the search for studies. Initially, such words were selected and modified in such a way as to restrict the resulting number of scientific records without correlation with those of resulting studies that had no connection with the objectives of this work.

Definition of search keywords

- "blockchain" AND "Wikidata";
- "smart contracts" AND "Wikidata".

Then, these were organized in an intermediate table containing their respective titles and abstracts, for which, one by one, they were analyzed based on the inclusion criteria. Finally, 10 scopes of studies met the inclusion criteria and were included. The table abow illustrates the dynamics of the scope analysis flow performed as well as the quantitative studies filtered in each step.

RESULTS

In this section, the results of the analysis of the scope of the 10 studies that were included are shown. It is noteworthy that of these 10, none was excluded after in-depth analysis, that is, all were considered to stay in the results table.

Studies Included based on the criteria: 10 of the 156 studies found in the searches performed were included, after analysis of titles and abstracts, with application of inclusion and exclusion criteria. The included records after applying these criteria are listed below.

1) Domingue, J., Third, A., & Ramachandran, M. (2019, May). The FAIR TRADE framework for assessing decentralised data solutions.

Abstract: Decentralized data solutions bring their own sets of capabilities, requirements and issues not necessarily present in centralized solutions. In order to compare the properties of different approaches or tools for management of decentralized data, it is important to have a common evaluation framework. We present a set

of dimensions relevant to data management in decentralized contexts and use them to define principles extending the FAIR framework, initially developed for open research data. By characterizing a range of different data solutions or approaches by how Trusted, Autonomous, Distributed and Decentralized, in addition to how Findable, Accessible, Interoperable and Reusable, they are, we show that our FAIR TRADE framework is useful for describing and evaluating the management of decentralized data solutions, and aim to contribute to the development of best practice in a developing field.

2) Beris, T., Angelidis, I., Chalkidis, I., Nikolaou, C., Papaloukas, C., Soursos, P., & Koubarakis, M. (2019, May). Towards a decentralized, trusted, intelligent and linked public sector: A report from the Greek trenches

Abstract: This paper is a progress report on our recent work on two applications that use Linked Data and Distributed Ledger technologies and aim to transform the Greek public sector into a decentralized, trusted, intelligent and linked organization. The first application is a re-engineering of Diavgeia, the Greek government portal for open and transparent public administration. The second application is Nomothesia, a new portal that we have built, which makes Greek legislation available on the Web as linked data to enable its effective use by citizens, legal professionals and software developers who would like to build new applications that utilize Greek legislation. The presented applications have been implemented without funding from any source and are available for free to any part of the Greek public sector that may want to use them. An important goal of this paper is to present the lessons learned from this effort.

3) Leal, F., Veloso, B., Malheiro, B., González-Vélez, H., & Burguillo, J. C. (2020). A 2020 perspective on "scalable modelling and recommendation using wiki-based crowdsourced repositories:" fairness, scalability, and real-time recommendation.

Abstract: Wiki-based crowdsourced data sources generally lack reliability, as their provenance is not intrinsically marshalled. By using recommendation, one may arguably assess the reliability of wiki-based repositories in order to identify the most interesting articles for a given domain. In this commentary, we explore current trends in scalable modelling and recommendation methods based on side information such as the quality and popularity of wiki articles. The systematic parallelization of such profiling and recommendation algorithms allows the concurrent processing of distributed crowdsourced Wikidata repositories. These algorithms, which perform incremental updating, need further research to improve the performance and generate up-to-date high-quality recommendations. This article builds upon our previous work (Leal *et al*., 2019) by extending the literature review and identifying important trends and challenges pertaining to crowdsourcing platforms, particularly those of Wikidata provenance.

4) Shrestha, A. K., & Vassileva, J. (2018, June). Blockchain-based research data sharing framework for incentivizing the data owners.

Abstract: Data sharing practices are much needed to maximize knowledge gain by researchers. However, when and what data should be shared with whom, and how credit should be awarded to the data owner needs to be clearly addressed to create an individual incentive for data owners to share their data. A platform that allows owners to control and get rewards from sharing their data would be an important enabler of research data-sharing, since presently, such incentives for researchers to share their data are largely missing. Our approach delivers a usable blockchain based model for a collection of researchers' data, providing accountability of access, maintaining the complete and updated information, and a verifiable record of the provenance, including all accesses/sharing/usages of the data. Data owners will not only enjoy increased transparency and protection of data from falling into the wrong hands, but they will also be incentivized with digital tokens, acknowledgment, or both to share their data with the interested data seekers, thus becoming active participants that stand to benefit from the research data economy.

Rojas, Remy. "RDF management založený na technologii Blockchain." (2019).

Abstract: As Structured open data sees a growth in popularity evidenced by the size of networks such as the Linked Open Data LOD cloud, aspects of its lifecycle management and scalability have yet to be addressed. At the time of writing, implementations of change tracking and provenance do not guarantee integrity and availability and depend upon individual domain owners to be deployed and maintained. This represents a threat to the stability of a system in which data is composed of cross-domain URI references such as the Semantic Web's de-facto model: RDF. In this paper we explore the advantages and capabilities a solution based on Blockchain can provide when used as a support for RDF. We provide the design, implementation, testing, and evaluation of a Proof of Concept Distributed Ledger which addresses the use-cases of Create, Read, Update, Delete (CRUD) operations, Linked Data Notifications, and Publish/Subscribe Observer pattern. Our solution provides mutually distrusting parties a support for traceability and provenance of versioned RDF statements, leveraging integrity and availability with decentralization.

Kirstein, F. (2019). A Decentralized Provenance Network for Linked Open Data.

Abstract: With the growing availability of Linked Open Data (LOD) and the consequential generation of derived and aggregated data, the need for trustworthy, reproducible and accessible provenance information has increased. Yet, no consistent mechanism has been established to manage provenance data of LOD on a global dataset-level. Decentralized networks and peer-to-peer mechanisms have made their revival in the last years with blockchain and similar distributed ledger technologies. We propose a novel approach to track and store provenance information for LOD on a dataset-level by sharing an immutable, common state between data providers. The basic architecture will not disrupt existing methodologies and standards for publishing LOD, but will be transparently integrated into existing ecosystems as an additional layer to foster broad acceptance. We will investigate the application of emerging blockchain technologies and established Linked Data specifications for building this decentralized anchor of truth. We are actively involved in the design and implementation of LOD and Open Data platforms and will evaluate our approach in real-world scenarios regarding feasibility, governance, scalability and usability.

Brutzman, D. P., Blais, C. L., & Wu, H. F. (2020). Ethical Control of Unmanned Systems: Lifesaving/Lethal Scenarios for Naval Operations.

Abstract: This research in Ethical Control of Unmanned Systems applies precepts of Network Optional Warfare NOW to develop a three-step Mission Execution Ontology MEO methodology for validating, simulating, and implementing mission orders for unmanned systems. First, mission orders are represented in ontologies that are understandable by humans and readable by machines. Next, the MEO is validated and tested for logical coherence using Semantic Web standards. The validated MEO is refined for implementation in simulation and visualization. This process is iterated until the MEO is ready for implementation. This methodology is applied to four Naval scenarios in order of increasing challenges that the operational environment and the adversary impose on the Human-Machine Team. The extent of challenge to Ethical Control in the scenarios is used to refine the MEO for the unmanned system. The research also considers Data-Centric Security and blockchain distributed ledger as enabling technologies for Ethical Control. Data-Centric Security is a combination of structured messaging, efficient compression, digital signature, and document encryption, in correct order, for round-trip messaging.

Aebeloe, C., Montoya, G., & Hose, K. (2021, April). ColChain: Collaborative linked data networks.

Abstract: One of the major obstacles that currently prevents the Semantic Web from exploiting its full potential is that the data it provides access to is sometimes not available or outdated. The reason is rooted deep within its architecture that relies on data providers to keep the data available, queryable, and up to date at all times – an expectation that many data providers in reality cannot live up to for an extended (or infinite) period of time. Hence, decentralized architectures have recently been proposed that use replication to keep the data available in case the data provider fails. Although this increases availability, it does not help keeping the data up to date or allow users to query and access previous versions of a dataset. In this paper, we therefore propose ColChain (Collaborative knowledge CHAINs), a novel decentralized architecture based on blockchains that not only lowers the burden for the data providers but at the same time also allows users to propose updates to faulty or outdated data, trace updates back to their origin, and query older versions of the data. Our extensive experiments show that ColChain reaches these goals while achieving query processing performance comparable to the state of the art.

Abbas, N., Alghamdi, K., Alinam, M., Alloatti, F., Amaral, G., d'Amato, C., ... & Xu, W. (2020). Knowledge Graphs Evolution and Preservation

Abstract: One of the grand challenges discussed during the Dagstuhl Seminar "Knowledge Graphs: New Directions for Knowledge Representation on the Semantic Web" and described in its report is that of a:

"Public FAIR Knowledge Graph of Everything: We increasingly see the creation of knowledge graphs that capture information about the entirety of a class of entities. [...] This grand challenge extends this further by asking if we can create a knowledge graph of "everything" ranging from common sense concepts to location based entities. This knowledge graph should be "open to the public" in a FAIR manner democratizing this mass amount of knowledge."

Although linked open data (LOD) is one knowledge graph, it is the closest realization (and probably the only one) to a public FAIR Knowledge Graph (KG) of everything. Surely, LOD provides a unique testbed for experimenting and evaluating research hypotheses on open and FAIR KG. One of the most neglected FAIR issues about KGs is their ongoing evolution and long term preservation. We want to investigate this problem, that is to understand what preserving and supporting the evolution of KGs means and how these problems can be addressed. Clearly, the problem can be approached from different perspectives and may require the development of different approaches, including new theories, ontologies, metrics, strategies, procedures, etc. This document reports a collaborative effort performed by 9 teams of students, each guided by a senior researcher as their mentor, attending the International Semantic Web Research School (ISWS 2019). Each team provides a different perspective to the problem of knowledge graph evolution substantiated by a set of research questions as the main subject of their investigation. In addition, they provide their working definition for KG preservation and evolution.

Bucur, C. I., Ciroku, F., Makhalova, T., Rizza, E., Thanapalasingam, T., Varanka, D., Wolowyk, M. & Domingue, J. (2019). A decentralized approach to validating personal data using a combination of blockchains and linked data.

Abstract: Linked Open Data (LOD) is the publicly available RDF data in the Web. Each LOD entity is identified by a URI and accessible via HTTP. LOD encodes global scale knowledge potentially available to any human as well as artificial intelligence that may want to benefit from it as background knowledge for supporting their tasks. LOD has emerged as the backbone of applications in diverse fields such as Natural Language Processing, Information Retrieval, Computer Vision, Speech Recognition, and many more. Nevertheless, regardless of the specific tasks that LOD-based tools aim to address, the reuse of such knowledge may be challenging for diverse reasons, e.g. semantic heterogeneity, provenance, and data quality. As aptly stated by Heath *et al*. Linked Data might be outdated, imprecise, or simply wrong": there arouses a necessity to investigate the problem of linked data validity. This work reports a collaborative effort performed by nine teams of students, guided by an equal number of senior researchers, attending the International Semantic Web Research School (ISWS 2018) towards addressing such investigation from different perspectives coupled with different approaches to tackle the issue.

Positioning bias of studies on blockchain use with Wikidata.

Study 1: Positive: The article discusses several common principles for evaluating decentralized data platforms. This approach includes platforms that store, through blockchain networks, metadata based on RDF (Resource Description Framework) with communication via query in the SPARQL Language (SPARQL Protocol and RDF Query Language). These standards are also used by Wikidata and are therefore perfectly compatible with it. Although the article does not literally mention the term "Wikidata", it does consider, with great emphasis, compatibility with information stored in this format.

Study 2: Positive: Blockchain usage to provide immutability for public sector documents encoded in RDF. Wikidata Interconnection for sophisticated searches and knowledge trees generation in the context of government data.

Study 3: Positive: As a future trend, these authors' research aims to use emerging technologies such as blockchain, taking advantage of their characteristics of immutability, transparency and traceability, to seek data accuracy in Wikidata repositories, generated and maintained by crowds.

Study 4: Neutral: Sharing personal data via blockchain. Although this article proposes the sharing of personal data in a blockchain network, the storage form was not made explicit and Wikidata was cited as a related solution with a different architecture.

Study 5: Positive: There is growing popularity in the provenance of data of type LOD, which means: Linked Open Data. The article is written within the need of integrity and availability guarantee during the registration of changes, as well as other steps within the provenance of these data (Data provenance). Thus, they propose "A system that responds to the needs for monitoring changes and provenance in the Semantic Web with a guarantee of availability and integrity. For this guarantee, the system is inspired by trends in Blockchain technology and by the parallels between decentralized applications and the Semantic Web ."

Study 6: Positive: A decentralized network, using blockchain, specifically, Hyperledger Fabric, to the provenance of LOD-type data and RDF standards and modeling. The work recognizes the impacts that the adoption of LOD represents on the internet, pointing to Wikidata as a popular publisher.

Study 7: Neutral: Work involving ethical mission control (military) in unmanned systems. It proposes a format for storing military mission order data, called MEO - Mission Execution Ontology. This described storage should occur ethically, taking value of the advantages arising from the blockchain principles. Despite not mentioning the term "Wikidata", the proposed work presents wide compatibility for supporting metadata based on RDF (Resource Description Framework) with communication via queries in the SPARQL language for querying metadata in the tests of MEO concepts.

Study 8: Positive: Knowledge Graphs (KG) reliably storage through blockchain networks, having RDF encoding. Allows the user community to retrieve and change information similarly to Wikidata users.

Study 9: Positive: It is a set of studies that involve problems addressed in dealing with knowledge graphs and their forms of preservation. Chapter six specifically dealt about using a blockchain platform for SPARQL-compatible data preservation, which deduces automatic relationship with Wikidata; it's called VAD2ER (Volunteer Anonymous Decentralized Data to Empower Research), an architecture for preserving, evolving, and sharing knowledge graphs of confidential and private information, based on decentralized technologies such as blockchain and Solid.

Study 10: Neutral: Set of articles dealing with relationships with LOD and RDF. Chapter nine specifically addresses a personal data validation model that combines LOD with blockchain to do this. Although Wikidata is not mentioned, the linked data format is strongly correlated to that database.

CONCLUSION

To the best of our knowledge, as it can be seen from the table presented: among the 10 studies, none was classified as negative in relation to the bias of the positioning on blockchain metadata storage in the format (compatible with) Wikidata; 7 studies presented a favorable bias; and 3 studies with a neutral bias. It is important to note that the issue of bias reflects the current situation of metadata provisioning technologies and processes through blockchain networks. As this work found, studies are beginning to emerge, proposing the combination of the immutability guarantee provided by blockchain networks with the storage of LOD metadata based on RDF. This storage format is intelligible to both humans and machines, intercommunicable on Wikidata. This semantic data storage format provides a pattern that is apparently being followed as a target horizon for cataloging informational objects within the scope of human knowledge. This can mean the secure and interchangeable representation of any information objects within a society made up of both intelligent men and machines. It is perceived that blockchain technologies, in P2P networks, have been used as an object of study in academia, public and private environments to search for storage of metadata compatible with Wikidata in a transparent, auditable and immutable way.

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