Semantic Representation as a Key Enabler for Blockchain-Based Commerce

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Abstract. Decentralized applications (in short, DApps) built on blockchains are disrupting the digital commerce foundations by pursuing new business models based on trustless, decentralized transactions, where intermediaries and central authorities are discarded. One of those emerging means are the digital tokens, certificates emitted and exchanged on the blockchain to provide digital representations of assets, which grant to the owners specific rights that are publicly verifiable by smart automatic contractual types of arrangement called smart contracts. Due to the increasing complexity of commercial mechanisms, a clear unambiguous description of commercial participants and of their in and out of blockchain activities, on top of which trustworthy and affordable ecosystems are constructed, is demanded. To face the challenges that digital commerce nowadays poses on realizing such ecosystems, the ONTOCHAIN consortium has funded a third-party research and development project named *POC4COMMERCE*. In this paper, we discuss the advancements of the project, giving insights into the approach and the best practices adopted by the developing team, to build a suite of ontologies modelling representative entities of the digital commerce ecosystem such as commercial participants and assets traded leveraging the Ethereum blockchain.

Keywords: semantic web · e-commerce · blockchain.

1 Introduction

Does today's e-commerce (that is, the technological support to commerce, including the surrounding ecosystem of assets, actors, supply chains, infrastructures, and blockchains) attain the goals of sustainability, resilience, and trustworthiness?

We contend that the present answer to this research question is not fully positive, hence the motivation that sparks off the ongoing experimental activities discussed in this paper.

The overarching assumption supporting our research and developments is that the fundamental enabler for the goals outlined above is an expressive and disambiguating semantic representation. This motivates the scientific and technical methodology taken, of making available and exploiting a hierarchy of ontologies. While these ontologies should at least represent essential features such as mechanisms to determine price or produce individual trust values, they certainly ought to cope with blockchain technology, which is increasingly being leveraged to support commerce through its inherent immutability.

Taking the semantic approach to represent real-world uses of the blockchain lies precisely at the core of ONTOCHAIN [4], which has funded a third-party research and development project named "Making ONTOCHAIN practical for e-commerce" (POC4COMMERCE, in short). The core team executing the project also authors the present paper. POC4COMMERCE aims at making ONTOCHAIN practical and, at the same time, proof of concept — specifically for the e-commerce vertical domain, though with continuous attention at desirable generalisations on other domains. This paper outlines POC4COMMERCE, with its approach and objectives, and discusses the current status of the project.

In short, the project delivers three layers of ontological description, and the design of a search engine. The scientific and technical methodology entails leveraging an ontology of agents, *OASIS*, previously published by the team [2, 3], in addition to other ontologies such as *BLONDiE* [8], for representing blockchain constitutional elements, and *GoodRelations* [5], for commercial offerings. Currently, the most two representative ontologies for blockchain, namely, the BLONDiE and Ethon [6] ontologies, provide very limited representation capabilities of blockchain smart contracts and tokens, thus preventing a deep and clear understanding of the operations carried on the blockchains. Indeed, the main progress beyond the state of the art is an ontological representation of ONTOCHAIN stakeholders up to Ethereum by the "mentalistic notion" of agent behavior [1], namely through their operational semantics, that is applied to smart contracts and tokens, delivering a clear description and, as consequence, indexing of blockchain activities, thus building a new generation of distributed applications (DApps).

The POC4COMMERCE ontological stack is populated and validated with real-world data, hence increasing overall confidence. The general impact of POC4COMMERCE on the various e-commerce stakeholders is expected to be huge thanks to the production of the foundational grounds for a marketplace and to the drastic enhancement of its interoperability, both internally, among its key components, and externally, with other marketplaces, supporting the coherent design of additional software agents in the future.

At the time of this writing, the ontological stack is completed at 95%, with the inclusion of Digital Identities, Supply Chains and Quality Valuation in the foundational level, of Auctions, Offerings and Price Determination at the commerce level, of Tokens and Smart Contract at the blockchain level. Of course, the hierarchy is mindful of the state of the art, hence appropriately leveraging the above mentioned foundational ontologies OASIS, GoodRelations, and

BLONDiE, each at the appropriate level. Consistency check of the ontologies has been carried out by exploiting the most widespread reasoners. In addition, competency questions have been defined and implemented through SPARQL queries to verify whether the ontologies are truly being developed towards the project objectives and are reaching the stated representational goals.

The working use cases concern an apple producer who wants to publish their offer of a batch of apples. The use cases also include a potential buyer who is interested in finding an offer matching her personal needs, in deciding whether to purchase it and in understanding how to carry out the entire transaction. The project is on time and is not experiencing significant risks.

This paper is structured as follows. Section 2 reports the main concepts and goals behind POC4COMMERCE; Section 3 presents our solution and Section 4 discusses it over a real-world use case. Then, Section 5 outlines the impact that comes from the adoption of POC4COMMERCE, and Section 6 draws some concluding remarks.

2 Concept and objectives of POC4COMMERCE

In order to promote a sustainable, resilient, and trustworthy e-commerce by defining it over the ONTOCHAIN ecosystem, the POC4COMMERCE project leverages an ontological approach consisting in a hierarchical semantic modelling towards the effective and efficient interoperability of blockchain technology with the e-commerce domain, enforcing the contribute of blockchain technology to a sustainable, resilient, and trustworthy e-commerce. The POC4COMMERCE project aims to address the challenge of developing a consistent, unambiguous, and shared semantic model supporting the interoperability of the heterogeneous stakeholders, ranging from the blockchain ledger elements to the relevant software agents and, ultimately, people. The project moves towards four main steps. The first step consists in deploying an ontology, namely the ontology "OC-Found", covering all relevant stakeholders in the ONTOCHAIN ecosystem and offering a base-level support to their interoperability. These comprise, but are not limited to, the blockchain ledger, including constitutive elements such as accounts, nodes, blocks, transactions, fungible, non-fungible, and semi-fungible tokens, smart contracts, services, and actual end-users, that is, people and organizations. The second step involves the construction of the ontology "OC-Commerce", specialising OC-Found on the e-commerce vertical domain. OC-Commerce exploits the OC-Found definitions to represent the specific stakeholders of the business and e-commerce activities carried out on the ONTOCHAIN ecosystem. Then, the ontology "OC-Ethereum", specialising OC-Commerce on the Ethereum blockchain environment, is defined. OC-Ethereum exploits the OC-Commerce definitions to represent the specific stakeholders of the Ethereum blockchain, in particular smart contracts and token representations compliant with standards ERC721, ERC20, and ERC1155. Finally, on top of the ontological stack, POC4COMMERCE designs a commercial software API, namely "OC-Commerce Search Engine" (OC-CSE, in brief) implementing a search ser-

vice that enables end-users to conveniently find goods, products, and services in a semantic-enabled marketplace. It stands on the solid grounds provided by the full underlying ontology, thus leveraging the semantic interoperability of all involved stakeholders. During the developing of the ontological stack, the most widespread ontology metric criteria [7] have been adopted, which are necessary to evaluate ontologies both during the design and implementation phase, thus allowing for fast and simple assessment of ontologies while ensuring the suitability of the ontologies. Appropriate competency questions are defined and applied side by side with the development of the ontological stack: competency questions constitute questionnaires in natural language and are implemented in the SPARQL [9] query language, which helps to clarify the context and the scope of ontologies. Finally, OWL 2 compliant reasoners are executed on the ontologies, to verify their consistency, and real-world datasets provided by partners are used to validate them.

3 The POC4COMMERCE solution

POC4COMMERCE describes an interconnected and interoperable digital commerce through three ontological layers modelling different degrees of knowledge. POC4COMMERCE is fully aware of the modern literature and embraces it in an ontological engineering process to promote an interoperable and sustainable shared e-commerce in the ONTOCHAIN ecosystem. The project takes a hierarchical ontology approach to deliver an ontological stack with three distinct building-blocks that practically port ONTOCHAIN to the e-commerce vertical domain. The first ontological layer provides a formal description of all ONTOCHAIN ecosystem stakeholders through the OWL 2 ontology OC-Found. Although ontologies for representing agents have been available since 2008, they are strictly focused on specific contexts, such as the Internet of Things, or tied to application domains, such as economy or health-care. OC-Found also provides a formal specification of how participants interact, exchange information, take decisions, and establish plans, provisions, and obligations. Therefore, OC-Found provides a high-level, consistent, broad representation of ONTOCHAIN stakeholders, in particular of ONTOCHAIN agents and their functionalities, which are described through the mentalistic notion of agent behavior implemented by the ontology OASIS. OC-Found provides a "semantic glue" for unifying the diversity of development technologies and communication standards, the large availability of architecture, hardware, software, and technologies of different types underlying the ONTOCHAIN ecosystem, hence favouring their interoperability.

The second ontological layer, that is, the OWL 2 ontology OC-Commerce, provides a full and comprehensive model of commercial agents and activities, goods, products, offerings, and services related with business and commerce. OC-Commerce describes how market activities are carried out by absorbing and extending the ontology for commerce GoodRelations by the general characterization of stakeholders introduced by OC-Found. OC-Commerce represents a

unifying level for all the commercial activities carried out in the ONTOCHAIN ecosystem, regardless of the vendor and buyer sale channels.

The third ontological layer is the OWL 2 ontology OC-Ethereum specializing OC-Commerce and, hence, OC-Found. OC-Ethereum continues the mentalistic approach innovatively on Ethereum, thus it fully specifies the building blocks of the Ethereum blockchain such as accounts, nodes, blocks, transactions, fungible, non-fungible, and semi-fungible tokens compliant with standards ERC20, ERC721, ERC1155, respectively, as well as smart contracts, the latter being defined through the guidelines drawn by the conceptualization of agents in OC-Found. OC-Ethereum is exploited to share knowledge and services over Ethereum in a coherent, consistent, and fully interoperable way, thanks to the full definition of the semantics at ontological level.

This ontological core of POC4COMMERCE is exploited to design the OC-Commerce Search Engine (in short, OC-CSE), explaining how an ONTOCHAIN digital platform for commerce works by providing a shared and common semantic tool to profitably find goods, products, information, and services, meeting the end user requirements and published by the wide array of ONTOCHAIN commercial participants in the provided ontological knowledge base. OC-CSE enables the interoperability of commercial parties whose businesses would have been disconnected otherwise, favouring the spread of products and services through the ONTOCHAIN ecosystem and reducing economic inefficiencies.

4 Use cases

A classical POC4COMMERCE use case is illustrated in Figure 1, which depicts a green apples vendor, *AppleBay*, who wants to sell her assets by granting to the buyer *Bob* an Ethereum ERC721 compliant non-fungible token (NFT), which assigns ownership rights of the specific batch of apples purchased. A suitable Ethereum smart contract is published to mint and transfer ERC721 compliant tokens of apple batches. The user Bob would purchase apples using FIAT currency through a digital payment platform such as PayPal. To complete the purchase, the token corresponding to the apples batch bought by Bob is minted and transferred to the buyer's Ethereum wallet as a proof of quality and quantity of the product purchased and of the payment received by the seller. Then, the product shipment process is finalized through the shipment service chosen by the seller.

Initially, to join the commercial ecosystem, both the participants AppleBay and Bob publish the OC-Found-compliant ontological representation of their digital identities in the semantic knowledge base.

Next, AppleBay publishes the ontological representation of the service to be deployed by generating a fragment of OC-Found, representing the green apple selling service and a fragment of OC-Ethereum describing the smart contract releasing NFTs of apple batches. In this phase, specific APIs may assist AppleBay to semi-automatically build the required ontological representations. From now on, the supply chain of AppleBay is semantically described and publicly available

through the ecosystem, and offerings concerning the marketable assets can be generated on request. The seller generates an ontological representation of the offering concerning the asset as a fragment of OC-Commerce, connecting it with the related supply chain constituted by the payment agent, the smart contract releasing the NFT, and the shipping courier. Such a representation depicts the distribution mechanisms provided by AppleBay, which are finally searchable by potential clients such as Bob. Above them, the apple seller manifests the promise that each time an offering is accepted and the related payment is completed, the seller mints and transfers to the buyer the related NFT.

Bob can rely on the OC-CSE search engine to find the desired product. For instance, Bob would search for a service realising NFTs, corresponding to apples batches as a proof of purchase. The search engine generates the SPARQL query describing Bob's requirements and submits it to one of the triple stores available so as to probe the repository for the desired results. Since AppleBay is a vendor corresponding to Bob's requirements, the available offerings produced by AppleBay are then presented to Bob by means of one of the standard RDF serializations. Bob now has the required information to complete the purchase or, alternatively, he may invoke a quality valuer to estimate the reputation of AppleBay, the number of NFTs already sold, or the age of the service. Once the purchase is completed, Bob can assess his experience by evaluating the offering, the asset, or the agents involved in the transaction, thus contributing to the trustworthiness of the ecosystem.

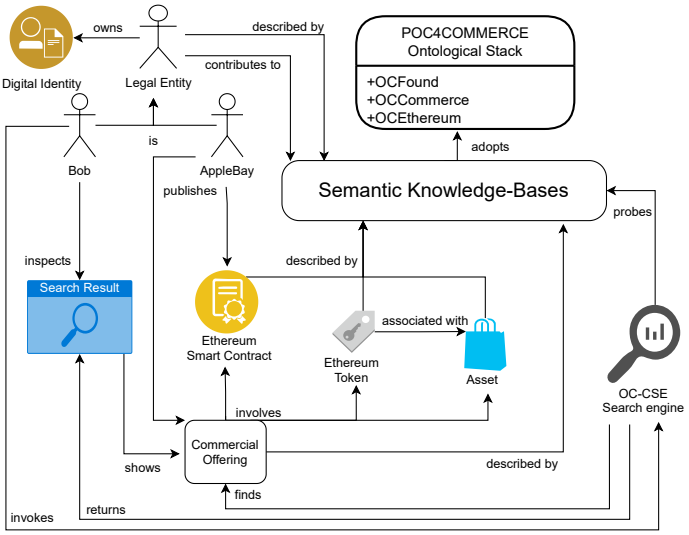

Fig. 1. A typical POC4COMMERCE use case

5 POC4COMMERCE impact

POC4COMMERCE contributes to many aspects of the ONTOCHAIN ecosystem. The POC4COMMERCE ontologies make the ONTOCHAIN ecosystem

readily functioning to build a sustainable, interoperable, and trustworthy e-commerce environment for people and software to work together. The ontology OC-Found provides a unifying canvas for all ONTOCHAIN participants and relationships among them, a substrate describing and connecting what really exists, with the relevant stakeholders interoperating coherently in a heterogeneous context. OC-Found also lays the grounds for the semantic interoperability of potentially innumerable domain-specific ontologies for the ONTOCHAIN ecosystem, such as those for eScience, eEducation, eHealth, eGovernment, e-commerce, eTourism, and eInfrastructures. OC-Commerce impacts on how digital commerce is carried out in the Web 3.0 and beyond. Commerce on the digital representation of products requires affordable marketplaces, where sellers and buyers may freely choose the services associated with their business activities. There are significant costs to select the required features of goods, e.g., where they are produced and stored, and how they can be moved to the consumer: inevitably, such costs concur to the business costs, namely to the final price paid by consumers. Therefore, the results of POC4COMMERCE contribute to a shift towards a novel micro-economic model, where individuals and companies cooperate and coordinate, by deciding the allocation and utilization of resources, and the subsequent effect on price, demand, and supply merely upon the basis of personal choices and without the intermediation of third-parties. It opens up new business opportunities for companies of any size because the absence of price profiteers reinstates the equilibrium of the relation of demand and supply that determines the competitive capability of any organization — thus re-establishing their decision power in setting the price of goods and services. Such principle is strengthened by decentralized marketplaces that directly connect consumers and sellers. For this reason, OC-Ethereum promotes the concept of a semantic blockchain that conjoins the high level of trustworthiness and transparency of a decentralized public ledger, where economic parties interact with their own rules: no restrictions imposed by third parties and a machine interpretable representation of the knowledge is retrieved by meanings and not just by spellings. A semantic blockchain implies that smart contracts can be referenced without pre-existing knowledge of their deployment and of the underlying programming code: their functionalities are fully specified by formal and machine-understandable representations, thus realizing an interoperable environment, where off-chain services interact with applications lying potentially on any blockchains such as Hyperedger Fabric, NEO, ONTology. POC4COMMERCE is a success story about the application of ontologies to huge-scale business applications such as e-commerce, boosting the practical impact of the ONTOCHAIN ecosystem in this domain.

6 Conclusions

We presented the advancements and the general solution provided by the project POC4COMMERCE, funded by the ONTOCHAIN consortium, which was launched in 2020 by the European Commission's Next Generation Internet initiative. The POC4COMMERCE project leverages a hierarchical ontological

stack in order to semantically represent and conjoin blockchain technologies with the e-commerce domain. The POC4COMMERCE stack is constituted by three ontologies, a) the ontology OC-Found, describing participants, digital identities, and valuation mechanisms that exploit the agent-behavior oriented representation mechanisms provided by the ontology OASIS; b) the ontology OC-Commerce, inheriting OC-Found and adopting and extending GoodRelations to provide supply chains associated with offerings, auctions, and price determination mechanisms; c) the ontology OC-Ethereum, inheriting OC-Commerce and hence OC-Found, and extending BLONDiE to define Ethereum tokens and smart contracts, in particular the ones associated with commercial transactions.

At the time of this writing, the ontological stack is almost fully implemented, whereas tests on real-word data are going to be developed. The next step will consist in designing on top of the ontological stack the search engine OC-CSE, a common semantic tool enabling ONTOCHAIN users to profitably find goods, products, information, and services, meeting their requirements.

Acknowledgements The work of POC4Commerce has been supported by the ONTOCHAIN NGI European project grant agreement no. 957338. We are thankful to the ONTOCHAIN Consortium who mentored and assisted the research.

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