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1 Introduction

Information automatically processed by applications needs to be modelled by means of appropriate representation languages able to express its meaning with formally defined semantics. The goal of such languages is to simplify machine interoperability by providing additional expressive power along with formal syntax and semantics. This is particularly relevant for the web and, in general, for any distributed environment. The *Word Wide Web Consortium* (W3C) recommends the *Web Ontology Language* (**OWL**) [55], a family of knowledge representation languages relying on *Description Logics* (DLs) [8], as a solution to this problem and indicates it as a standard for representing Semantic Web ontologies.

POC4COMMERCE exploits knowledge representation and reasoning capabilities of web ontologies to practically realize the semantic core of ONTOCHAIN and how the ONTOCHAIN ecosystem shapes up in the digital commerce vertical domain. POC4COMMERCE describes ONTOCHAIN as an interconnected and interoperable environment for digital commerce through three ontological layers modelling different degrees of knowledge: a) the ontology OC-Found modelling ONTOCHAIN participants and actors, b) the ontology OC-Commerce modelling commercial offers, products, and services, c) the ontology OC-Ethereum modelling the Ethereum blockchain, smart contracts, and digital tokens exchanged on the blockchain for commercial purposes. Such an ontological stack is then exploited to design the OC-Commerce Search Engine (in short, OC-CSE), a shared and common semantic tool to profitably find goods, products, information, and services published in the ONTOCHAIN digital market. POC4COMMERCE leverages the semantic representation of agents, blockchains, and commerce to implement an effective semantic, interoperable, and affordable marketplace aligned with, and propellent for, the ONTOCHAIN mission.

This deliverable investigates the key constituents in ontology engineering forming the state of the art for POC4COMMERCE and outlines how our project advances beyond it. The deliverable is organized as follows. Section 2 provides some preliminary knowledge, whereas Section 3 covers the main Semantic Web artifacts in support of the Semantic Web field. Section 4 concerns the best ontological practices for representing agents. Section 5 focuses on the ontological representation of digital commerce. Section 6 targets ontologies for blockchains and, in particular, for the Ethereum blockchain. Each such Section comes with an outline of the pertaining POC4COMMERCE advancements, while Section 7 demonstrates the overall vision of the project, also through an example scenario.

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2 Main languages and tools

An ontology is a formal description of a domain of interest carried out by combining three basic syntactic categories: *entities*, *expressions*, and *axioms*. These form the logical part of ontologies, namely what ontologies can express and the type of inferences that can be drawn [69, 56]. Ontologies can also be combined together in order to describe more complex domains. A specific type of ontologies, namely *upper-level* or *foundation ontologies* [69], is designed to model high-level and domain-independent categories about the real world. This provides general terms that are used to connect domain-specific ontologies (lower-level ontologies), allowing one to reach a broader semantic interoperability.

OWL, currently in version 2.1, provides users with constructs useful for designing ontologies for real-world domains that are available neither in the basic Semantic Web model *Resource Description Framework* (RDF) [65], nor in the basic Semantic Web language *RDF Schema* (RDFS) [95] — the latter being an extension of RDF admitting taxonomies and primitives to define range and domain of relations and subsumption axioms. As RDF, OWL is grounded on the idea of triples or statements, each one representing an atomic unit. Triples are ways to connect two entities or an entity and a data-value, each one represented by an *Internationalized Resource Identifier* (IRI), i.e., a sequence of characters that unambiguously identifies a resource within a specific context. Entities represent the primitive terms of an ontology and are identified in a unique way. They are *individuals* (actors), *properties* (actions), and *classes* (sets of actors with common features). Properties are of two types: object-properties and datatype-properties. Object-properties relate pairs of individuals, whereas datatype-properties relate individuals with some data type values, such as strings and numbers.

OWL expressivity can be extended by adding Horn-like rules by means of **SWRL**, the *Semantic Web Rule Language* [89]. Rules are of the form of an implication between an antecedent (body) and a consequent (head), intending that whenever the conditions specified in the antecedent hold, the conditions specified in the consequent must hold too. Details on SWRL rules can be found in [3].

To retrieve and manipulate semantic knowledge, the W3C recommends **SPARQL**, the *SPARQL Protocol and RDF Query Language* [92], as the standard query protocol for RDF. Like SQL, SPARQL is a declarative query language conceived to perform operations on data represented as a collection of RDF triples. A SPARQL query has a *head* and a *body*: the *head* comprises a modifier identifying the corresponding type of query, whereas the *body* consists of an RDF graph pattern. Most notably, SPARQL *CONSTRUCT* queries allow one to retrieve some information from a queried data-set and express it in new RDF triples. The reader is referred to [35] for a

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detailed overview of SPARQL.

3 Semantic Web Artifacts

This section introduces methods, vocabulary, and ontologies to describe and make assertions about fundamental tools for the Semantic Web. A good starting point to explore the Semantic Web realm is the definition of *Linked Open Data* [90, 15].

3.1 Resources

The term *resource* is used to indicate any physical or digital entity described via Semantic Web technologies. In the realm of the Semantic Web, every *resource* that one intends to represent must be identified by an *Internationalized Resource Identifier* (in short IRI, see [36]). The IRI standard extends *Uniform Resource Identifiers* (in short URIs, see [13]) with internalization features. In [7] some guidelines and suggestions are provided about how to choose a good IRI for a resource.

Moreover, every resource in the Semantic Web should be *deferenceable* (see [96]) via the *HTTP* protocol [41] using content negotiation. However, in the case of digital resources, the resource itself must be accessible via its IRI. In addition, a resource description provided using any Semantic Web languages may be accessible by content negotiation. By contrast, for any non-digital resource, the resource description should be returned anyway.

3.2 Triples

Facts and relations involving resources are stated by means of *RDF triples* [31], consisting of

- the *subject* resource
- a property, labelled by an IRI, and
- an object which may be a resource or a *concrete* datum.

RDF asserts facts about triples by means of the notion of *reification* [18, 31], which consists in using an additional resource to represent a triple, and appropriate properties to connect the triple "subject, property, object" to it. Then, information about the triple can be stated by further RDF triples involving the resource representing it. This reification mechanism is referred to as *standard reification*. This approach is quite inefficient since four triples are needed to reify every

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single triple. In addition, SPARQL queries [92] must take into account the fact that a triple may be expressed in its reified form and, as a consequence, queries may become really complex. Finally, reification lacks a formal semantics to bind the original triples with their reified forms.

During the years, other approaches to reification have been proposed.

Singleton properties reification [67] consists in creating a new property for each statement to be reified. The new property is defined as a subproperty and, in some sense, as an instance of the one in the triple we are going to reify, and can be used to annotate the triple with information. Again, the semantic relationship between triples with singleton properties and their annotations are not captured by standard semantics. In addition, it introduces a large number of properties used just once, which is untypical for RDF data and, thus, not captured by optimization heuristics used by the SPARQL engines (see [83]) and other Semantic Web machinery currently in use.

In [68] the authors propose to split a triple into two by introducing an intermediate resource to model the relation instance. In this way *n-ary relations* can be easily modelled. In addition, a relation instance can be futher characterized, for example by adding a *weight*. With this approach, OWL 2 semantics can be used to *infer* the original triple from its reified form as shown, for example, in [38]. In consequence, SPARQL queries conceived on original triples still work in presence of reified triples if an OWL 2 reasoning mechanism is in place.

*RDF**[5] (and its companion SPARQL*) is an extension of RDF which allows us to use a triple as a subject of another triple. RDF* semantics extends the standard one. However, in [51] a mapping of RDF* data and queries into the *standard* Semantic Web environment is presented. Such a mapping allows one to build a software wrapper to provide existing Semantic Web machinery with a RDF* interfaces. RDF* technology is very promising, and some wrappers are currently available.[1] However, in general, such a technology is far to be mature for an effective use.

3.3 Graphs

In [61] an *RDF graph* is defined as a set of RDF triples. A *named graph* is an RDF graph with an associated *name*, defined as an IRI. In [22] the authors propose to use these IRIs as first-class citizens of RDF graphs in such a way that statements about named graphs (for example about trust or provenance) can be asserted in the graph itself or in other graphs. OWL provides some features to reference an RDF graph by means of its IRI such as, for example, the `owl:imports` property or the so called *annotations* of `owl:Ontology` class instances (see [79] for a study of annotation framework semantics). A semantics for named graphs has been provided in [23], where also examples about using named graphs for syndication and digital signatures are provided.

[1]See `https://github.com/w3c/rdf-star` for an up-to-date list of RDF* implementations.

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Named graphs have been officially embodied in the RDF version 1.1 by introducing *N-Quads* [93]. N-Quads are RDF triples extended with a fourth component: an IRI representing the graph name the triple belongs to or, more in general, a *context* in which the fact asserted by the triple holds. In [64] a case study concerning the usage of quads to encode contexts is reported, and it is claimed that adding context information to triples does not significantly increase the storage size required for datasets, as currently most of the RDF storage systems still use a fourth context field to encode triples for internal uses. Semantics for N-Quads defined in RDF 1.1 is *minimal*, in the sense that context information does not influence reasoning activities.

3.4 Datasets

In [31] the authors define an RDF Dataset as a collection of RDF graphs with exactly one unnamed graph, called *default* graph, and zero or more named graphs. This definition has been refined and analyzed in more detail in [94]. The SPARQL query language is still equipped with features to explicitly reference graph names in queries.

Of course, RDF graphs and datasets can express information about events and about temporal aspects, for example in [74] an experiment on publishing live data about parking sites is reported. However, due to the set-theoretic definition of RDF graphs and datasets, such entities are *immutable*, i.e., adding or removing triples from an RDF graph yields a different RDF graph. OWL provides a property to annotate the ontology element with a version tag, so that the current version of the RDF graph can be embedded in the graph itself. In [31] the non-normative definition of *RDF source* is introduced to refer to a *persistent yet mutable source or container of RDF graphs*. However, the term *dataset* is widely used in literature as synonym of RDF source.

Moreover, as mentioned before, a dataset is typically accessible on the Web, for example through resolvable HTTP URIs or through a SPARQL endpoint [92].

Dataset descriptions and metadata are useful tools for dataset discovery and licensing [62]. Some experiences of publishing LOD datasets using Fusepool[2], with a particular focus on public bodies, has been reported in [60].

The *Vocabulary of Interlinked Datasets* (VoID) [29] provides features to describe RDF datasets, where a dataset is intended as *a meaningful collection of triples, that deal with a certain topic, originate from a certain source or process, are hosted on a certain server, or are aggregated by a certain custodian*. Beside provenance information (among others, creation and last modification time of the graphs provided by the dataset), also information about how to access the data in the dataset can be provided, such as RDF dumps, lookup URIs, and SPARQL endpoints [87].

[2] http://fusepoolp3.github.io/

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The *Data Catalog Vocabulary* (DCAT) [4, 30] allows one to describe also non-RDF datasets, e.g. Relational Databases or CSV downloadable files. In [77] the authors present a methodology for publishing validated stable releases of datasets and corresponding DCAT records. The European Data Portal[3] is a relevant application of DCAT and its extension for governamental data DCAT-AP[59]. As of February 2019, the EDP lists provide about 900.000 datasets, consisting of about 60 million RDF triples in total and harvested from 77 data providers.

3.5 Tracking Changes in Datasets

As mentioned above, data provided by a dataset engine can change over time (see [71][64]).

In order to track changes of the underlying RDF graphs provided by a dataset, a *snapshot* of the data in a dataset can be taken periodically. This is the case of *DBPedia* [63], which makes available and downloadable versioned datasets.[4]

Another approach to keep track of changes in a dataset is to use reified statements: these can be annotated with provenance information (for example, the creation time) and, at time of deletion, instead of removing them from the dataset, they can be *marked* as deleted by recording the deletion time.

The *PROV Ontology* (PROV-O) [11] provides terms that can be used to trace the origin of a given resource, its derivation history, as well as the relationship between the resources, and the entities that contributed to the existence of the resource. Of course, it can be used to model provenance of physical and abstract resources, so that with provenance information about RDF graphs, datasets, resource description and triples can be modelled by it.

In [71] a *resource-centric* approach to track *deltas* of resource descriptions (i.e. all triples involving the resource) is presented. The authors extend PROV-O to keep track of addition and deletion of a resouce from a dataset, aside with modifications of the resource description. In more detail, for each version of a resource, an auxiliary resource, called *snapshot*, is introduced and linked with the original resource and with other snapshots related to it (usually with the one indicating the resource before it has been modified). In addition, the SPARQL query performing the update is reported.

The *Dublin Core Metadata Initiative* provides in the DCMI Metadata Terms [33] some basic properties to annotate resources with metadata, for example data about creator and versions.

The *Provenance, Authoring and Versioning Ontology* (PAV) described in [25] focuses on the provenance data of a digital resource in terms of relationships with other digital resources and

[3]European Data Portal is available at `https://www.europeandataportal.eu`.

[4]See `http://wiki.dbpedia.org/datasets` for the list of DBPedia snapshots.

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agents but abstracting away from the description of the activities (processes) that manipulate and transform the digital resources. PAV compatibility with PROV-O is guaranteed by a mapping provided by the authors. Analogously to [71], PAV uses snapshots to represent different versions of the same resources.

3.6 POC4COMMERCE advancements

In contrast with RDF sources (see Section 3.4), a blockchain is *immutable*. We observe that this can be a very useful feature in order to produce *trusted* versions and snapshots of ontologies and data provided on the Semantic Web. Likewise, immutability can be leveraged to store versions of ontologies that change over time, hence effectively tracking changes to ontologies by means of the blockchain itself. For example, we could decide to store dataset digests appropriately *on* the blockchain, which seems acceptable in terms of efficiency due to the limited size of each digest. This is the gist of one of the main ideas underlying POC4COMMERCE, that is, the use of blockchain technology in order to provide digital commerce stakeholders with tools to produce and verify *trusted* references to RDF data snapshots.

4 Ontologies for services and agents

This section presents the most relevant web ontologies and approaches for representing services and agents that are relevant for the goals of POC4COMMERCE of representing commercial parties in the ONTOCHAIN ecosystem.

4.1 Ontologies for services

The main advantage of the Semantic Web is to enable users and applications to access data-oriented web content. Additionally, users and applications should be able to discover and invoke web resources in a completely automatic way. One of the most important web resources is the one that provides access to services. Generally speaking, services are intended as artifacts that do not merely provide static information but perform actions and changes in the surrounding environment. The Semantic Web should enable users to locate, select, employ, compose, and monitor web-based services automatically. For this reason, in 2003, the *World Wide Web Consortium* (W3C) proposes OWL-S [88], an ontology for describing web services and the means by which they are accessed. OWL-S tries to enable several tasks such as automatic web services discovery, automatic web services invocation, and automatic web services composition and interoperation. In OWL-S,

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services are characterized by three organizational points of reference: a) The *service profile* used to provide the information needed for an agent to discover a service, basically what services do at a low level and described in a suitable way for service-seeking agents, including a description of what is accomplished by the service, limitations on service applicability and quality of service, and requirements that the service requester must satisfy to use the service successfully; b) the *service model*, describing how clients may use the service, the content of requests, the conditions under which particular outcomes will occur, and the step by step processes leading to those outcomes; c) *service grounding* specifying how an agent can access a service, i.e., communication protocol, message formats, and other service-specific details such as port numbers used in contacting the service. Since OWL-S is conceived to describe services, it does not adequately fit the requirements needed to described general-purpose agents operating in different types of environments, due also to the different nature distinguishing agents from services [66]. OWL-S explicitly supports the description of services as classes of activities, so that agents can decide how to use, invoke, and interpret responses from them.

4.2 Ontologies for agents

Describing agents as they coincide with services, although of a limited kind, may lead to an inaccurate and ambiguous depiction of them, also because services capabilities need to be semantically described both at high and low level. Hence, one of the most prominent visions of the relationships between agents and services consists in a perspective where agents exploit, use, are composed of, or are deployed as and extended by services [66], which remain relatively simple. For instance, *Google Maps* or *GeoSPARQL* may be conceived as agents for retrieving driving directions and described as actors able to compute the best path (in terms of time or distance) from a geographical amenity to another that is realized through the related end-points. Whereas *GeoSPARQL* is free to use, *Google Maps* requires an API-KEY that can be obtained free for a limited use or on payment. The requirement of owning an API-KEY is a low level mechanism related to the service, whereas the needed authorization is a high-level constraint of the agent. For these reasons, research communities have investigated several representation systems for agents.

As from 2000, many results concerning how agents enter and leave different interaction systems have been provided both by exploiting *commitment objects* [43] and *virtual institutions* [39]. Commitment objects are unambiguous, objective, and independent of the agent mental states concepts describing the effects that sending a message has on the social relationship between the sender and the receiver of the message, whereas virtual institutions describe systems that regulate the behavior of agents in a multi-agent system or in multi-agent society, in particular their interaction,

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in compliance with the norms in force in that society.

Integration of agent systems and Semantic Web technologies has been analyzed in the last decade in several contexts [52, 50, 46] and the manifest advantages of ontology-based applications have been recognized in the analysis and development of MAS [82], especially in the context of a) agents matching, i.e., the capability of finding agents satisfying specific requirements and automatically engaging them; b) in the context of developing agents with standard features exploiting shared common semantic tools, or c) as decision support for supply chains.

Approaches analogous to those of *Agent-Oriented Software Engineering* (AOSE) [32, 28], a software engineering paradigm for the development of complex MAS based on the abstraction of agent roles and on their organizations, have been applied to model ontologies for MAS. Other approaches inspired by *belief-desire-intention* (BDI) [73] agent architectures are proposed in [17] and [40]. Inspired by Bratman's theory of human practical reasoning [16], BDI systems are based on the concept that an agent has certain goals (desires) and a set of plans to achieve them; plans are selected, thus becoming intentions, depending on the agent's perception of the circumstances (represented by a set of beliefs). Beliefs, desires, and intentions are specified at a high level, often using a powerful logic/declarative approach: this enables complex behaviors to be implemented, still keeping code transparent and readable.

The AOSE approach is intended to support all analysis and design activities in the software development process, whereas the BDI approach provides a flexible environment offering both traditional object-oriented imperative and declarative constructs, enabling the definition of a robot's high-level behavior in a simple, natural way. In [44], an ontology for agent-oriented software engineering is proposed together with a tool that uses the ontology to generate programming code for MAS, but without examining agents and their interactions in great enough detail. Moreover, an appropriate modelling of agent communication is missing.

Much effort have been made to bring uniformity and coherence to the increasing volume and diversity of information in specific domain. In [47], the authors propose an ontology-based framework for seamlessly integrating agents and Semantic Web Services, focusing on biomedical information. In [45], an infrastructure to allow agent-oriented platforms to access and query domain-specific OWL ontologies is presented. In [26], the authors introduce an approach to design scalable and flexible agent-based manufacturing systems that integrates automated planning with multi-agent oriented programming for the *Web of Things* (WoT), where autonomous agents synthesize production plans using semantic descriptions of web-based artifacts and coordinate with one another via multi-agent organizations.

Concerning *Internet of Things* (IoT), ontological approaches have focused mainly on the description of sensors, with the purpose of collecting data associated with them for generating percep-

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tions and abstractions of the observed world [9]. In [86], a comprehensive ontology for representing IoT services is presented, together with a discussion on how it can be used to support tasks such as service discovery, testing, and dynamic composition, taking into account also parameters such as *Quality of Services* (QoS), *Quality of Information* (QoI), and IoT service tests. A unified semantic knowledge base for IoT, capturing the complete dynamics of IoT entities and where their heterogeneity is hidden and semantic searching and querying capabilities are enabled, is proposed in [2].

Unification of the state-of-the-art architectures, as put forward by the scientific community of the *Semantic Web of Things* (SWoT), by means of an architecture based on different abstraction levels, namely *Lower*, *Middle* and *Upper Node* (LMU-N), is described in [76]. The LMU-N architecture provides a reading grid used to classify processes, to which the SWoT community contributes, and to describe how the Semantic Web impacts the IoT. In [12], the authors propose a lightweight and scalable model, called *IoT-lite*, to describe key IoT concepts allowing interoperability and the discovery of sensory data in heterogeneous IoT platforms.

The W3C advance a formal model and a common representation for WoT things description based on a small vocabulary that makes it possible both to integrate diverse devices and to allow diverse applications to interoperate [97]. The representation system provides a way to expose the state of a thing and to invoke functions that however must be known in advance, thus making difficult the task of invoking agents that join the environment in a plug-and-play manner. Moreover, the schema provided does not allow agents to interact according to the roles they play.

Finally, in [21] the authors propose a first version of OASIS - An Ontology for Agent, Systems, and Integration of Services, a ontology for representing agents and their interactions by exploiting the mentalistic notion of agent behaviors [17], i.e., goals and tasks they are able to perform, and of a domotic assistant based on it, called PROF-ONTO. OASIS is an OWL 2 ontology providing a semantic representation of agents abstracting from their implementation details and configurations, for integrating, uniforming, and activating agents, and a representation system for their behaviors, interactions, and world observed. The approach adopted in [21] also represents a first, foundational attempt at using Semantic Web technologies for defining a transparent communication protocol among agents founded on the exchange of fragments of OASIS, each consisting of a description of a request that is checked, by means of ad-hoc constructed queries, against the description of the behavior of the agent selected to satisfy it.

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4.3 POC4COMMERCE advancements

To build a semantic digital commerce for ONTOCHAIN, POC4COMMERCE requires a representation system able to describe commercial partners, such as products and service providers, in each phase of the supply chain. Indeed, a digital interconnected marketplace not only requires a complete description of all stakeholders such as providers and goods, but also of supply and selling mechanism, such as offers, auctions, payment tools, transportation, and other related services and activities.

For this reason, POC4COMMERCE aims to apply the OASIS ontology to the realm of digital commerce related to blockchains. However, OASIS only provides the essential elements to describe agents in terms of their capabilities of contributing to a shared system, including responsibilities and constraints on their interactions. Therefore, to represent ONTOCHAIN participants in the vertical domain of digital commerce, POC4COMMERCE foresees to extend OASIS as to include the descriptions of commercial parties involved in the ONTOCHAIN ecosystem, including blockchain smart contracts, thus delivering the ontology OC-Found, which stands at layer I in the ontological stack we aim to build. In this sense, the representation model provided by OC-Found gives a novel conceiving of digital commerce, where actors are described through their roles in each step of the supply chain.

5 E-Commerce

E-commerce (electronic commerce) is the activity of electronically buying or selling of products on online services or over the web [48]. The term was first used in the California's Electronic Commerce Act, enacted in 1984.

In [57] the authors identify six challenges facing the e-commerce ecosystem: existing product data are not suitable for automated processing; product data often lack interoperability; insufficient use of unique product identifiers; heterogeneity of product category taxonomies; incomplete, inconsistent, or outdated product descriptions; weakness of current product recommender systems. Then, they propose a technological stack, based on Semantic Web, which would allow the creation of *intelligent* e-commerce applications.

Resource Description Framework in Attributes (in short RDfa, see [91]) is a format to embed RDF descriptions in HTML pages. Several search engines use RDFa to enhance the appearance of individual search results with a structured description [14].

In [85] the authors suggest that Semantic descriptions of products enable the implementation of *semantic search engines* [49] to find out items in a very specific range. Creating shared or, at

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least, interoperable vocabularies for product descriptions have been recognized as a crucial task for e-commerce [78]. As so, during the years, several industry *Products and Services Categorization Standards* (in short PSCS) has been proposed and adopted, see [54] for a comparative analysis. Among others:

- the *United Nations Standard Products and Services Code*[5] (in short, UNSPSC) is a taxonomy of products and services for use in e-commerce;
- *eCl@ss*[6] was designed to create a standard classification of material and services for information exchange between suppliers and their customers;
- the *ECCMA Open Technical Dictionary*[7] (in short eODT) contains terms, definitions and images linked to concept identifiers used to create unambiguous descriptions of individuals, organizations, locations, goods, services, processes, rules and regulations;
- the *RosettaNet Technical Dictionary* (in short, RNTD) is the reference model for products in the supply chains that use RosettaNet for their interactions.

Most of them converged into the *GS1* initiative,[8] an organization that develops and maintains global standards for business communication such as, for example, barcodes and Electronic Product Codes [1]. Notice that the Electronic Product Codes standard provide a *Pure Identity URI* to denote a specific physical object, which can be easily integrated in Semantic Web tools. Then, *eClassOWL*[53] is the OWL counterpart of eCl@ass. In general, these classification systems consist of taxonomies for grouping similar products. In addition, the most sophisticated ones include a dictionary of properties that can be used to describe product instances.

The proliferation of PSCS reveals that e-commerce stakeholders have not reached a consensus on product and service description representation systems, which is an obstacle for the interoperability of applications following different standards. Of course, as proposed in [27], Semantic Web technologies may help to overcome this issue by enabling *Ontological Mapping* between different systems.

GoodRelations is an OWL vocabulary to describe offerings of tangible goods and commodity services. Its descriptive features are broad enough to cover both product and service instance descriptions. In addition, a wide range of offerings and pricing can be modelled via GoodRelations.

[5] `https://www.unspsc.org/`, `https://en.wikipedia.org/wiki/UNSPSC`
[6] `https://www.eclass.eu`
[7] `https://eccma.org/resources/`
[8] `https://www.gs1.org`

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Offerings described using the GoodRelations vocabulary are recognized by major search engines such as Google,[9] Yahoo,[10] and Bing.[11] Also, well-known content management tools as Joomla!,[12] osCommerce,[13] and Drupal,[14] support publishing data with the GoodRelations ontology. In [6], the adoption and usage of Good Relations has been reported and analyzed. In addition, GoodRelations has been integrated in *schema.org* [70],[15] a general purpose vocabulary largely used in tagging web page contents.

Of course, trading activities other than offerings are of some interest. In [81] the authors show that ownership information may be used for personalized recommendations.

5.1 POC4COMMERCE advancements

In order to fully describe commercial offers and provide product descriptions, POC4COMMERCE aims to absorb the GoodRelations ontology, which represents a landmark in the domain. However, our project seeks out to integrate GoodRelations with OASIS, which is our previously published ontological representation of agents. It is clear that the full commerce experience cannot do without a complete mentalistic representation of who does what. In brief, the integrated version of GoodRelations with OASIS constitutes our planned ontology named OC-Commerce, which stands at layer II in the ontological stack anticipated in the POC4COMMERCE proposal. Notably, POC4COMMERCE aims at a specific extension of GoodRelations in support for the linking of offerings and product descriptions, on one side, with the related items on the blockchain. No full-fledged blockchain-enabled marketplace will get established without the feature to associate *tokens* with product instances as well as with *smart contracts* that were used to generate, trade, and manipulate those tokens in the first place (see Section 6).

6 Ontologies for blockchains

This section describes how blockchains are conceived and represented in and through the Semantic Web realm.

[9] http://www.google.com
[10] www.yahoo.com
[11] www.bing.com
[12] https://www.joomla.org/
[13] http://www.oscommerce.com/
[14] https://www.drupal.org/
[15] http://blog.schema.org/2012/11/good-relations-and-schemaorg.html, https://schema.org/

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The *blockchain* [24] is a peer-to-peer public ledger maintained by a distributed network of computational nodes allowing for the interaction of digital parties in a distributed manner without the requirement of trusted entities. Blockchains provide several benefits since they guarantee the ownership, transparency, traceability, public availability, continuity, and immutability of digital assets, in an efficient and trust-less environment where censorship is not achievable. One of the most popular applications of the blockchain is a self-executable contract, also called *smart contract* (SC) [80], a way of representing contracts into lines of immutable program codes which are allowed to be self-run on a public ledger.

Only recently have researchers focused on conjoining the blockchain with ontologies [37, 19]. One of the areas of investigation has concentrated in developing a characterization of blockchain concepts and technologies through ontologies. In [34], a theoretical contribution looking at the blockchain with an ontological approach has been provided. In [75], the authors propose a blockchain framework for SWoT contexts settled as a *Service-Oriented Architecture* (SOA), where nodes can exploit smart contracts for registration, discovery, and selection of annotated services and resources.

Other works aim to represent ontologies within a blockchain context. In [58], ontologies are used as common data format for blockchain-based application such as the proposed provenance traceability ontology, but are limited to describe implementation aspects of the blockchain.

The *Blockchain Ontology with Dynamic Extensibility* (BLONDiE) [84] project would provide a comprehensive vocabulary that covers the structure of different components (wallets, transactions blocks, accounts, etc.) of blockchain platforms (Bitcoin and Ethereum) and that can be easily extended to other alternative systems.

In [42], the authors propose a discussion of the blockchain applied for tracking the provenance of knowledge, for establishing delegation schemes, and for ensuring the existence of patterns in formal conceptualizations using zero-knowledge proofs.

In [10], the authors propose a semantic interpretation of smart contracts as services bases on the *Ethon ontology* [72]. The main limitation of the approach consists in a poor semantic description of the smart contracts that precludes the discovering of unknown smart contracts and of the operations that they have fulfilled during their life-span.

In [20], the authors extend the ontology OASIS with conditionals and *ontological smart contracts* (in short, OSCs). OSCs are ontological representations of smart contracts that allow to establish responsibilities and authorizations among agents and set agreements, whereas conditionals allow one to restrict and limit agent interactions, to define activation mechanisms that trigger agent actions, and to define constraints and contract terms on OSCs. Conditionals and OSCs are applied to extend with ontological capabilities digital public ledgers such as the blockchain and smart contracts implemented on it. The authors also sketch the architecture of a framework based on OSCs that exploits the *Ethereum* platform and the *Interplanetary File System*.

6.1 POC4COMMERCE advancements

It can be observed that the literature lacks a detailed description of smart contracts and their functionalities, including descriptions of digital tokens, and in particular of *non-fungible tokens* (NFTs), unique, irreplaceable, and traceable digital certificates of property released on the Ethereum blockchain. However, NFTs are crucial for the digital marketplace conceived by ONTOCHAIN, since they carry all the guarantees provided by blockchains. For this reason, POC4COMMERCE aims to fill the gap left by the missing representation of blockchain applications by extending the OASIS ontology to describe smart contracts as agents participating to the ONTOCHAIN ecosystem. The project also aims to include a full description of NFTs, in particular of those related to (physical) products or services involved in commercial exchanges, along with the smart contracts responsible for managing them.

The resulting ontology is called OC-Ethereum and stands at layer III of the ontological stack that is aimed at. It will also feature a detailed description of the transactions consolidated on the Ethereum blockchain by conjoining the representations provided by the ontologies BLOONDiE and Ethon.

7 The POC4COMMERCE vision

POC4COMMERCE innovates the ontological representation of Ethereum blockchain-oriented digital commerce by integrating and extending the most representative ontologies for modelling commercial actors, offers, and products. In order to promote sustainable, resilient, and trustworthy digital commerce, an ecosystem of modular ontologies describing each semantic compartment of ecommerce is necessary. We believe that commerce on or through the blockchain is a novel business opportunity that is gaining momentum mainly thanks to the exchange mechanisms of NFTs. However, probing the (Ethereum) blockchain for identifying the desired NFT, the associated features and products, or the smart contract trading it and the conditions of trading is often hard even though the source code of the related smart contracts is publicly available together with the transactions storing them, mainly hard-coded. This is due at least to two reasons. On one hand, the nature of the blockchain requires preexisting knowledge of the address of the trading smart contract. On the other hand, the monetary cost of the transactions is not irrelevant, and this

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forces NFT developers to divert the information associated with the NFT to external off-chain storing systems.

To provide semantic descriptions of Ethereum smart contracts and related transactions, particularly of smart contracts related to NFT trading and associated with commercial means, lies at the core of POC4COMMERCE's vision. Implementing such a vision requires a deep level of interoperability of well-founded ontologies for commercial participants, blockchains, and commercial offers. To reach the desired level of interoperability, POC4COMMERCE reuses and extends the most relevant ontologies in the area, namely: a) OASIS [21] for the representation of commercial participants and smart contracts; b) GoodRelations for representing commercial offers and c) BLONDiE [84] and Ethon [72] for describing Ethereum blockchain transactions.

Specifically, POC4COMMERCE re-adapts and extends OASIS to define the ontology OC-FOUND, thus describing the ONTOCHAIN participants, their roles and capabilities related (not only) with the commercial domain, ranging from service and product providers to clients. In particular for commercial participants, the POC4COMMERCE ontological stack describes how they are supposed to provide goods and selling conditions. There is no reference in the literature concerning the description of the mechanisms for providing goods and services in commerce, neither concerning the application of OASIS to the commercial vertical domain, hence our approach is original.

Commercial offers are integrated in the ontological stack provided by POC4COMMERCE in the OC-Commerce ontology by redesigning GoodRelations in such a way as to include the description of commercial agents in the OASIS fashion. The progress beyond the state of the art is clear because trading offers related with affordable semantic marketplaces where sellers and buyers may freely choose the services associated with their business activities may be effectively built. Such a marketplace also requires tools allowing final users to transparently access data provided by sellers and to probe desired goods and services in full alignment with user requirements.

OASIS is also exploited to define the OC-Ethereum ontology, describing smart contracts and, in particular, smart contracts for exchanging NFTs, by integrating blockchain transaction information provided by BLOONDiE and Ethon. The latter ontologies are indeed limited to descriptions of satellite information concerning transactions, such as gas spent, transaction hash and block miner, but do not provide any data about the type and content of the NFT exchanged or of the trading smart contract.

POC4COMMERCE designs the OC-Commerce Search Engine (OC-CSE in short) on top of the ontological stack. OC-CSE exploits the novel semantic representation provided by the three ontologies to build a tool enabling users to profitably find goods, products, resources, and services published by ONTOCHAIN parties. OC-CSE is constructed by means of a combination of

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Semantic Web API, reasoning services, and ad-hoc constructed SPARQL queries to define a software interface for the ONTOCHAIN digital market. The novel ontological representation of the ONTOCHAIN ecosystem pursued by POC4COMMERCE requires innovative tools to access the rich and diverse knowledge base built on that ecosystem. Indeed, existing tools for e-commerce do not fit the defined ontological framework, since they tightly depend on the semantic structure underneath and hence suffer in model overfitting. POC4COMMERCE fills such a gap by leveraging best practices and open standards in software engineering to construct the fundamentals of the ONTOCHAIN-enabled marketplace.

All this can be exemplified through the example scenario depicted in Figure 1. The main actors are identified as: i) final users, products and services providers; ii) the ONTOCHAIN web service that serves as a conjunction point for the parties; iii) the POC4COMMERCE knowledge base storing the dataset provided by the ontological stack; iv) the Ethereum blockchain storing smart contracts and NFTs exchanged, and v) the OC-CSE search engine.

In this scenario, we identify four main steps a) registration; b) product and service publishing; c) product and service selection; d) purchase.

The registration phase allows participants to join the ecosystem and identify themselves. Tools and technologies for authorization and identity verification may be provided by the *HIBI.Human Identity Blockchain Initiative: Trustworthy*[16] and *Solid Verif*[17] projects. Subsequently, representations of agents describing the commercial activities are added to the POC4COMMERCE knowledge base. Notably, POC4COMMECE might leverage the GraphChain[18] project to store ontological data and the *A Low Code Development Platform (LCDP)*[19] to semi-automatically generate it.

In the second step, products and service providers publish offers, release new NFTs, or notify ONTOCHAIN of already existing NFTs. Offers and ontological description of NFTs are stored by the OC-Commerce and OC-Ethereum ontologies to be exploited by the OC-CSE search engine.

OC-CSE is the main actor of the next step. OC-CSE is exploited by the ONTOCHAIN web service to enable users to search products and services fitting their needs. Controlled vocabularies provided by the POC4COMMERCE knowledge base are exploited to build ad-hoc SPARQL queries that are executed on it: search results are then showed to final users that can choose the product or service desired. In this phase, a cooperation between POC4COMMERCE and the *TENACIOUS - Trustworthy sEmaNtic Aware marketplaCe for Interoperable clOUd Services*[20] project will be

[16] https://ontochain.ngi.eu/content/hibi
[17] https://ontochain.ngi.eu/content/solid-verif
[18] https://ontochain.ngi.eu/content/graphchain
[19] https://ontochain.ngi.eu/content/lcdp-ont-app
[20] https://ontochain.ngi.eu/content/tenacious

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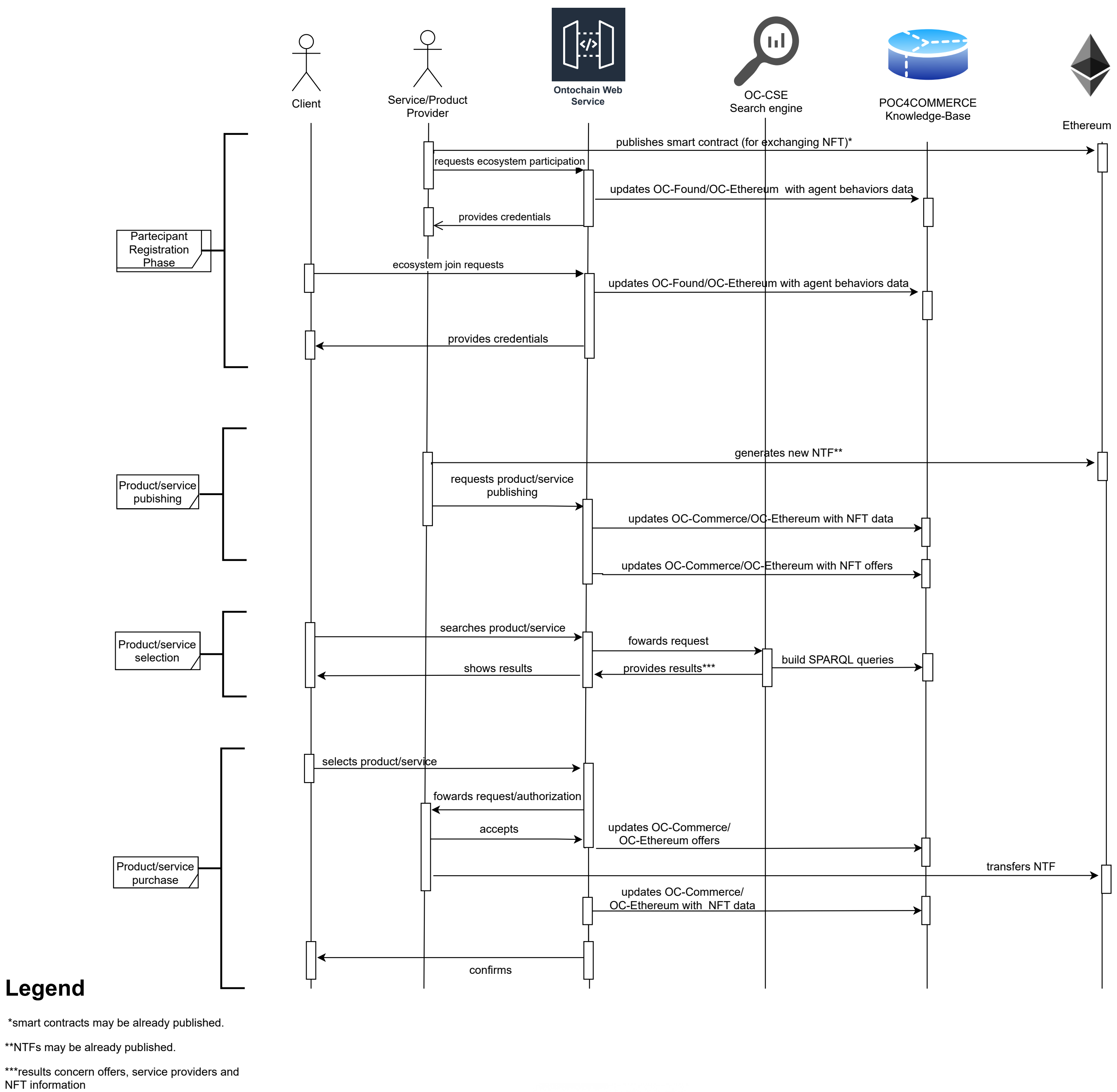

Figure 1: An example scenario underlying the POC4COMMERCE vision

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evaluated. Finally, selected results enable users to perform the purchase either directly through the ONTOCHAIN platform or by redirecting on the web service of the product or service provider. As consequence, the NFTs corresponding to sold products or services are exchanged on the Ethereum blockchain.

POC4COMMERCE has only just started, and... the best is yet to come!

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