An Analysis of Ontologies for the Intellectual Property Domain

Julio Cesar Nardi [a,*], Monalessa P. Barcellos[b] and João Paulo A. Almeida [b]

[a] *Informatics Department - Research Group on Promotion and Management of Innovation (PRO-INOVA), Federal Institute of Espírito Santo (Ifes) - Campus Colatina, Espírito Santo, Brazil*
E-mail: julionardi@ifes.edu.br

[b] *Ontology and Conceptual Modeling Research Group (NEMO), Computer Science Department, Federal University of Espírito Santo (UFES), Espírito Santo, Brazil*
E-mail: monalessa@inf.ufes.br, jpalmeida@inf.ufes.br

Abstract. Intellectual Property (IP) plays a crucial role in fostering innovation and economic growth. However, the complexity of IP rights and their legal frameworks across different jurisdictions poses challenges for standardization and interoperability. Ontologies have emerged as a powerful tool to address these challenges. This study, through a literature review, aims to identify and analyze existing ontologies in the IP domain, evaluating the predominance of researchers/groups, application contexts, legal frameworks, upper-level ontologies, conceptual coverage, representation languages, and adopted formalisms. The analysis reveals core conceptual elements, including IP rights, agents, events, conditions, agreements, and works of mind, which define the dynamics of IP life cycles. We identified a greater focus of the existing ontologies on Copyright when contrasted with aspects of Industrial Property. More ontologies addressed general legal frameworks rather than country-specific regulations. Additionally, the development of IP ontologies remains concentrated in a limited number of countries and research groups, indicating the need for broader collaboration. Many ontologies prioritize implementation aspects over conceptual clarity, potentially affecting interoperability. Despite these challenges, IP ontologies play a crucial role in supporting standardization, legal compliance, and data integration. The findings emphasize, among others, the importance of refining conceptual models, promoting harmonization to enhance semantic interoperability.

Keywords: conceptual model, literature review, intellectual property, semantics, interoperability

1. Introduction

According to the World Intellectual Property Organization (WIPO), in recent years, there has been a strong growth in Intellectual Property (IP) filings, as entrepreneurship, technology, innovation, and digitalization continue to drive forward national and global growth, with the worldwide IP filings reaching an all-time high (World Intellectual Property Organization, 2022). The vast majority of countries have passed laws to protect IP, giving statutory expression to the rights of creators and innovators, as a means to promote creativity and innovation, and contribute to economic and social development (World Intellectual Property Organization, 2016a). Inventors, artists, scientists, and businesses, among others, put a lot of time, money, energy, and thought

[*]Corresponding author. E-mail: julionardi@ifes.edu.br.

into developing their innovations and creations. To encourage them, they need the opportunity to make a fair return on their investment. That means giving them the right to protect their intellectual property (World Intellectual Property Organization, 2020b).

Despite its importance and applicability, IP is far from trivial. We can find several works in the literature discussing the basis of IP as a subject area (Dratler-Jr. and McJohn, 2006; Drahos, 2016; Koepsell, 2000; Peukert, 2021; Merges, 2017; Smith, 1988). Concepts involving IP require constant revisiting due to the advancements of human society, with recent examples including (generative) artificial intelligence, genetic engineering, and new forms of content production. Moreover, many aspects of IP can be considered from different points of view, including those of lawyers, engineers, scientists, artists, and entrepreneurs, which demands an interdisciplinary analysis.

If, on the one hand, intellectual property rights arise from relations between individuals (people and organizations), like other kinds of property rights; on the other hand, unlike common property law, it posits rights in abstract objects (e.g., patents, processes, software, and trademarks) (Drahos, 2016; Dratler-Jr. and McJohn, 2006; Peukert, 2021). This particularity requires taking some domain-specific issues into account properly. For example, John owns a physical copy of "Imperfect Creation" (the book authored by Dr. Marcelo Gleiser). Dr. Gleiser, by writing the book, owns the copyright (which encompasses economic and moral rights), but he does not own John's copy of the book. Here, we have at least two aspects that need attention. The first one concerns property about a physical object, and, as a result, John may sell his book (his physical copy) to Mary, if he so desires. The second aspect concerns rights about a non-physical object (the book as an "intellectual work"): Dr. Gleiser, as the author, owns moral rights over his work (e.g., right of attribution: the right to be recognized as the author of the work), which are not transferable[1]. However, Dr. Gleiser also has economic rights over his intellectual work, which can be transferred to a third party (e.g., it can be transferred to a publisher through an assignment or licensing agreement). Thus, we can notice a complex set of agents, roles, relations, and (abstract) objects to which IP rights are related and manifested and must be considered beyond those addressed by common property law. It is crucial to make these and other IP aspects clearly stated to support smooth communication between human beings or even between computer systems. In the absence of a clear statement, misunderstandings can arise.

Furthermore, there are numerous international legal frameworks (treaties and conventions) concerning IP, with the participation of various countries that are signatories to these agreements. These countries, in turn, can define their own IP laws, which should be aligned with those international frameworks. Generally, country-based laws and regulations present specific aspects to meet a particular demand. Thus, IP legislation around the world is not completely harmonized (Dratler-Jr. and McJohn, 2006). Despite initiatives to address this issue (World Intellectual Property Organization, 2024b, 2019, 2020a), the variety in legal frameworks poses (semantic) interoperability challenges for organizations (e.g., national IP offices, innovation centers, and research labs) and individuals (e.g., IP professionals, lawyers, and applicants), as well as for information systems (e.g., IP assets databases, and innovation management systems).

Semantic technologies have been acknowledged and adopted to design solutions in several subject areas, including IP (Sarica et al., 2020; Aristodemou and Tietze, 2018). Among them, ontologies stand out. Ontologies have been acknowledged as a remarkable means for supporting

[1]Although moral rights are generally non-transferable, there may be variations in their application depending on the country.

standardization (Ruy et al., 2015; Gonzalez-Perez et al., 2016), meaning negotiation and consensus establishment among human beings and organizations (Guizzardi, 2007; Falbo et al., 2013b; Guizzardi and Guarino, 2023), as well as for information systems development, data and software application integration (Junior et al., 2021; Bernasconi et al., 2022; Pascazio et al., 2023), artificial intelligence and big data processing (Confalonieri and Guizzardi, 2023; Barba-González et al., 2024; Robson and Baek, 2023), open data and FAIRification[2] initiatives (Brewster et al., 2020; Callahan et al., 2023; Sahoo et al., 2023), among many others. In the area of IP, ontology-based solutions have also been designed and combined with other approaches (e.g., machine learning, text mining, artificial neural network, linked open data, semantic annotation, and natural language processing) for supporting several purposes, such as document classification and retrieving, legal analysis, tech-mining, trend analysis, digital rights management, checking for legal compliance, software development, domain representation, and information integration (Aristodemou and Tietze, 2018; Li et al., 2022; Trappey et al., 2023; European Patent Office, 2024; Hassan et al., 2018; Trappey et al., 2020; Delgado et al., 2003a; García and Gil, 2006; Rodríguez et al., 2007; Cevenini et al., 2008; X.M. et al., 2012; Kudumakis et al., 2019, 2020; Taduri et al., 2011, 2015; Wanner et al., 2006; Giereth et al., 2007; MKLab, 2008; Chi et al., 2016).

Therefore, considering:

(i) the complexity inherent to the representation of IP aspects, which requires approaches that bring benefits beyond those found by using textual description (e.g., international IP treaties and country IP laws), or machine-readable syntactic representations (e.g., JSON or XML-based data exchange World Intellectual Property Organization (2012));
(ii) the necessity of standardization and harmonization of the IP body of knowledge to favor (semantic) interoperability among actors of the global IP ecosystem, and the existing information systems; and
(iii) the wide adoption of ontology-based solutions in the IP area;

this work aims to identify and characterize ontologies for the IP domain available in the literature. For that, we have conducted a literature review. We have identified nine IP ontologies, identifying: those involved in their development (researchers/groups and countries); their application contexts; the addressed IP branch (copyright, industrial property, or both); the applicable legal framework, which is key to understand their generality level (e.g., international treaties or specific country laws); the upper-level ontology used in the IP ontology design (if any) and the issues regarding this usage; languages or formalisms used to represent the ontology in order to characterize concerns related to ontology design and implementation; and the ontology conceptual coverage and comprehensiveness.

To the best of our knowledge, there is no other (similar) study that explores the issues outlined in this work. Thus, from this study, we expect to bring to light the design of IP ontologies from a wide perspective. Also, considering the aforementioned interrelation between ontology and other approaches such as machine learning, text mining, artificial neural network, linked open data,

[2] Here, FAIRification initiatives refer to those ones that aim to implement FAIR principles to improve **F**indability, **A**ccessibility, **I**nteroperability, and **R**euse of digital assets. The principles emphasize machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with no or minimal human intervention), for improving the capacity to deal with the increase in volume, complexity, and creation speed of data (GO FAIR, 2023).

semantic annotation, and natural language processing, among others, the results presented in this work may draw the attention of other related research areas.

The remainder of this paper is structured as follows. Section 2 addresses the main concepts required to set the scope of our study, including the IP system, ontologies, and theoretical aspects related to the IP domain; Section 3 concerns the study design and presents the research protocol; Section 4 reports on the execution of the study and presents data synthesis and analysis; Section 5 discusses the results; Section 6 considers the study limitations; and Section 7 presents our main conclusions and identifies research opportunities.

2. Background

2.1. Intellectual Property

Intellectual property (IP) concerns the rights to abstract/intangible objects (Drahos, 2016), which are creations of the human mind (e.g., literature works, arts, inventions, computer programs, and trademarks, among others) (World Intellectual Property Organization, 2020b). From the “property” perspective, IP is generally characterized as a non-physical property of a product created from original thought (Moore and Himma, 2022). In this context, IP rights protect the interests of innovators and creators by giving them rights over their inventions/creations (World Intellectual Property Organization, 2016b).

The broad intellectual property area may be subdivided into two branches[3] (World Intellectual Property Organization, 2016a): copyright and industrial property. *Copyright*[4,5] is a legal term used to refer to the creations and rights of creators of literary, artistic, and scientific works, including performances and broadcasts (World Intellectual Property Organization, 2020b). It encompasses several kinds of productions, such as books, songs, paintings and sculptures, choreographic works, maps, plans, sketches, and three-dimensional works relative to geography, topography, architecture or science, films, and technology-based works (such as computer programs and electronic databases), among others (World Intellectual Property Organization, 2016a).

Different from copyright, *industrial property* concerns industrial application inventions and rights given to inventors and encompasses patents, utility models, industrial designs, trademarks, and geographical indications (World Intellectual Property Organization, 2020b). A *patent* is a “title of the legal protection of an invention, issued, upon application and subject to meeting legal criteria, by a government office [. . .]” (World Intellectual Property Organization, 2013) (e.g., the Thomas Edison’s patent for the light bulb). A *utility model* is a “[. . .] protective title provided for in several national laws in order to protect a minor invention, upon application, normally through mere registration, by a government office [...], in accordance with requirements somewhat

[3]We adopted this classification because it is suitable for the objectives of this work. Other classifications exist depending on the adopted legal framework, or given the necessity of a finer-grained analysis for specific purposes.

[4]In certain languages, “copyright” is also referred to as “authors’ rights”.

[5]In this work, the term “copyright” is used as encompassing “related rights” (also referred to “neighboring rights”), which protect the interests of persons and organizations that contribute to making works available to the public using sufficient creativity or technical/organizational skill to justify copyright-like property right (e.g., performers, producers of sound recordings/phonograms, and broadcasting organizations)(World Intellectual Property Organization, 2016a)

less strict than those for obtaining patent protection [. . .]" (World Intellectual Property Organization, 2013) (e.g., left-handed scissors). *Industrial design* concerns to "[...] visual aspect of an object, including its two-dimensional and three-dimensional features of shape and surface. It is protectable through registration in an industrial property office or another competent authority" (World Intellectual Property Organization, 2013) (e.g., the design of a new watch, or a new chair). A *trademark* is a "sign which serves to distinguish usually the goods (as does the "service mark" with regard to services) of an industrial or a commercial enterprise or a group of such enterprises" (World Intellectual Property Organization, 2013)(e.g., the trademarks of the Coca-Cola, and the IBM Technology Corporation). Finally, a *geographical identification* is a "sign used on goods that have a specific geographical origin and possess qualities or a reputation due to that place of origin" (e.g., Champagne) (World Intellectual Property Organization, 2016b).

Regarding IP legal/regulatory framework, there are different national and regional laws and international legal treaties and conventions around the world (World Intellectual Property Organization, 2020b). There are more than 25 international treaties on IP administered by the WIPO (World Intellectual Property Organization, 2020b). They can be classified, basically, into three types: *IP protection* (defining the basic concepts and relations concerning creations/innovations and IP rights), *global protection system* (defining aspects necessary for establishing the global system of IP protection, including procedures for the protection of creation in more than one country), and *classification systems* (defining codes of classification from different IP creations, e.g., patents and trademarks).

WIPO is an intergovernmental organization that became in 1974 one of the specialized agencies of the United Nations (World Intellectual Property Organization, 2024b). It has two main objectives (World Intellectual Property Organization, 2024b): to promote the protection of IP worldwide; and ensure administrative cooperation among the IP Unions established by the treaties administered by it. In this context, the WIPO presents a standardization strategy (World Intellectual Property Organization, 2024b) and relies on the Committee of WIPO Standards (CWS) to support communication and interoperability among actors of the global IP ecosystem (e.g., national IP offices, innovation centers, research labs, applicants, and IP professionals). This committee has discussed vocabularies and standards for providing, e.g., "recommendations on the development of APIs to facilitate the processing and exchange of IP data in a harmonized way over the Web" (World Intellectual Property Organization, 2020a). Also, the CWS has defined a task force to propose "recommendations for data exchange" to: (i) facilite the development of web services which access IP resources; (ii) provide business vocabulary and appropriate data structures; (iii) establish naming conventions for Uniform Resource Identifier (URI) of resources; and (iv) provide business cases for implementing web services (World Intellectual Property Organization, 2019).

2.2. Ontology

"Ontology" (with a capital "O") refers to the branch of Philosophy that deals with the nature and structure of "reality", and proposes formal methods, techniques, tools, as well as "theories" for clarifying conceptualizations and articulating their representations (Guizzardi, 2020). With a lowercase "o", "ontology" can be used in a philosophical perspective, referring to a system of categories or a kind of "theory" independent of language; or in an engineering perspective, referring to an artifact for a specific purpose, with constructs capturing the conceptualizations represented in a specific language (Guarino, 1998; Guizzardi, 2007, 2020).

Regarding the level of generality, ontologies can be classified according to Guarino (1998) into: (i) *foundational (or top-level) ontologies*, describing very general concepts independently of a particular problem or domain, such as object, event, action, etc. Examples are DOLCE (Masolo et al., 2003), SUMO (SUMO, 2012), YAMATO (Mizoguchi, 2009), and UFO (Guizzardi, 2005); (ii) *domain ontologies*, describing the conceptualization related to a generic domain, e.g., education or biology; (iii) *task ontologies*, describing the conceptualization related to a generic task, e.g., diagnosis or planning; and (iv) *application ontologies*, describing concepts dependent on a particular domain and/or task, but specialized in a specific application scenario. Scherp et al. (2011) extend this classification by admitting the so-called *core ontologies* with a level of generality between that of foundational and domain ontologies, providing a precise definition of structural knowledge in a specific field that spans across different application domains (e.g., a service ontology). In this work, we adopt "upper-level ontology" for referring to both foundational and core ontologies that are used in the design of domain or task ontologies.

Another ontology classification regards their usage. Thus, ontologies can be classified as *reference ontologies* or *operational ontologies* (Guizzardi, 2007; Falbo et al., 2013b). Reference ontologies are designed to be used in an offline manner to assist humans in tasks of meaning negotiation and consensus establishment (Guizzardi, 2007; Falbo et al., 2013b). Specialized versions of a reference ontology can be created for run-time use, being classified as operational ontologies. They sacrifice representation adequacy and theoretical foundation to guarantee desirable computational properties (e.g., expressiveness and tractability) (Guizzardi, 2007; Falbo et al., 2013b). Having complementary characteristics, these two types of ontologies can be used in tandem in ontological engineering approaches organized in conceptual modeling, design, and implementation phases (Guizzardi, 2007; Falbo et al., 2013b).

Ontologies can be represented using different languages and formalisms (taking into account, e.g., the trade-off between expressiveness vs. computational requirements). Ontology specification languages used for implementing (operational) ontologies tend to emphasize the inferential process, and the structure of the knowledge, being independent of the meaning of the concepts themselves (Guizzardi, 2007) (e.g., First-Order-Logics (FOL), FLogic (Frame Logic), RDF (Resource Description Framework), and OWL (Web Ontology Language)). For representing reference ontologies in a more friendly way for readers, modelers often use from free graphical representations (without formal semantics), ranging from UML(-like) diagrams, and other graphical representations (with formal semantics but without incorporating ontological aspects), to well-founded modeling languages, such as OntoUML (Guizzardi, 2005; Guizzardi et al., 2021).

We can find ontology-based solutions in the IP domain for different purposes. Li et al. (2022) designed a technology-assisted approach based on text mining and semantic analysis for trademark legal cases, taking as a basis a litigation judgment ontology. Trappey et al. (2023), in turn, developed a formal tech-mining workflow integrating semantic-based patent and non-patent literature analysis for building a B5G domain ontology to analyze the patent portfolio. The European Patent Office (EPO) presents a linked open data initiative through an API (Application Programming Interface) and semantic web technologies based on ontology (European Patent Office, 2024, 2023a,c). Hassan et al. (2018) provide semantically rich, machine-readable patents using the linked data principles, converting data of USPTO (United States Patent and Trademark Office) patents from XML to RDF, making them publicly available for re-use and integration with other data sources. Trappey et al. (2020) designed a computational intelligent method to discover topics and form an ontology representing the knowledge to support the identification of technology trends and the technology gaps. Taduri et al. (2011, 2015) developed an ontology-based solution to integrate information from the patent and court case domains, supporting information retrieval. Finally, Wanner et al. (2006); Giereth et al. (2007); MKLab (2008); Chi et al. (2016) address patent document representations to move from textual to semantic representation aiming at designing complementary techniques for retrieval, classification, extraction, summarization, visualization, and assessment of patent material.

2.3. Theoretical Concerns on Intellectual Property

The domain of Intellectual Property (IP) has attracted significant philosophical attention. It intersects multiple fields, including epistemology, metaphysics, philosophy of law, philosophy of language, social sciences, and economics. Debates on IP are rooted in theories from thinkers such as Plato, Aristotle, Marx, Hegel, and Locke (among others), whose ideas have influenced the current worldview (Koepsell, 2000; Drahos, 2016). Plato and Aristotle offered important discussions on ideas, forms/universals, and their relation to individual/concrete entities. For Plato, universals are eternal, immutable, and transcendent realities that exist independently of the sensible world. The multiplicity of sensible objects is intelligible only because each participates in its corresponding form (universal), and, therefore, genuine knowledge pertains not to the mutable and deceptive realm of appearances, but to the stable and perfect order of the forms. Aristotle, on the contrary, rejects the separation of forms from the sensible world. For him, universals are immanent within particulars rather than existing in a transcendent world. The form is instantiated in each individual, giving it structure and intelligibility (Koepsell, 2000). Locke's labor theory of property provides one of the most influential justifications for IP, suggesting that individuals acquire rights over their creations by mixing their labor with resources, even if intangible. Marx offers a critical stance, viewing private property as a mechanism of commodification and exploitation that alienates collective human creativity and restricts social access to knowledge. Hegel grounds property in the realization of individual freedom, conceiving it as an externalization of one's will and personality. From these perspectives, intellectual works embody the creator's subjectivity (resulting from, and having relation to ideas), thereby justifying strong moral and natural rights for authors, as a social construct, and as an expression of personal freedom (Drahos, 2016).

In this context, discussions on the differences between the ownership of "real property" and intellectual property arise (Peukert, 2021). Real property and intellectual property are often contrasted as two fundamental, but distinct domains of ownership. Real property refers to tangible assets such as land and buildings, where rights are typically defined in relation to physical space and permanence. The legal tradition surrounding real property is grounded in the questions of possession, transfer, and use. In contrast, intellectual property (IP) refers to intangible creations of the mind, including inventions, literary and artistic works, symbols, and designs. Unlike real property, IP rights are not naturally visible or physically bounded. They rely on legal recognition and enforcement to exist, often through systems of patents, copyrights, and trademarks (Drahos, 2016).

Also, in the IP domain, whereas "ideas" are not subject to exclusive rights, their manifestations/expressions (e.g., a book) may be the subject of property rights (Koepsell, 2000). Thus, in IP law, it is assumed that there are an infinite number of possible ways to express a single idea (Koepsell, 2000). According to Koepsell (2000), a patent in a product "[...] does not prevent the dissemination of ideas behind the product, but only its manifestation as a physical good". Moreover, Koepsell (2000) points out that the "expression" must be of an intended idea (even though an intended idea may never be expressed); "the expression of an idea is simply the making known or manifestation of that idea by way of some medium" (Koepsell, 2000). "Expressions are extensions of ideas into the physical world" (Koepsell, 2000). In this context, according to Koepsell (2000), "artifacts are expressions which have become fixed in a particular medium such that they are preserved". Thus, there is a fundamental difference between "corporeal" and "incorporeal" things, also referred to as "immaterial" and "material" objects, "abstract" and "tangible/concrete" artifacts (Koepsell, 2000; Drahos, 2016; Peukert, 2021). This duality is related to the notion of "ideas" and their "expressions" (also referred to as "manifestations") in concrete objects/artifacts (Koepsell, 2000; Peukert, 2021). Peukert (2021) highlights that, in (the traditional view of) IP law, protected objects (e.g., inventions) are simply accidentally embodied in these manifestations. In this context, immaterial objects exist as abstract types that are distinguished from their embodiments in books and products.

Peukert (2021), however, presents some criticism regarding this point of view; for him, IP objects (immaterial objects) do not exhibit characteristics of "abstract types" or "universals". Peukert (2021) discusses, therefore, a perspective founded on John R. Searle's theory of language-based and socially constructed reality. In this perspective, "immaterial objects" (as subjects of matter of IP laws) and rights belong to the category of "institutional facts". According to Searle (1998), there is a distinction between "brute facts" and "institutional facts". Brute facts exist independently of any human institution, agreement, or social convention. They are simply part of the natural world (e.g., water boils at 100°C (under standard conditions)). Institutional facts, in turn, exist only because of human agreements, rules, or institutions. They require collective recognition or acceptance to be recognized as such (e.g., the fact that a piece of paper is considered money) (Searle, 1998). According to Searle, this is better understood in terms of "constitutive rules", since institutional facts only exist within systems of such rules. Constitutive rules create/define new forms of behavior, activities, and social reality. They create the possibility of institutional facts (e.g., a piece of paper (X) counts as five dollars (Y) in the context of the monetary system (C)). Aligned to this view, Smith (1988) argues that works of art do not exist in isolation, but as part of institutional social practices, depending on rules, conventions, and social contexts that determine how objects are produced, presented, and interpreted[6]. Smith (1988) even discusses the basic structure of human work, which is seen as an intentional work produced from (human) actions and by the application of instruments and materials.

Koepsell (2000) also discusses legal objects (such as rights and obligations) and the fact that IP exists by virtue of rule-making (in a positive law view). Legal objects arise and disappear through a complex set of public and private actions. Thus, cultural objects (as IP objects) appear by virtue of agreements among a number of individuals, not appearing or existing naturally. Thus, IP rights exist only by virtue of cultural agreements. In this context, Drahos (2016) states that "Abstract objects are things that mediate property relations between individuals in the case of intellectual property". Thus, IP rights relate to the granting of property rights in something as well as constituting a set of relations between individuals (Drahos, 2016). From an "instrumental perspective" of property (in contrast to a "proprietarian perspective"), (Drahos, 2016) states that

[6]This view is, to some extent, aligned to the "Institutional Theory of Art" that argues that a work of art is defined not by its intrinsic qualities, but by its inclusion in the "artworld" and by the role of institutions (such as museums, galleries, and critics) in classifying it and granting it a special status.

the focus is more on behavioral aspects than on metaphysical, ethical, and epistemological issues of property. Thus, from an instrumentalism of property, he does not aspire to reveal the deep structure of property, but to uncover the nature of property and the point at which property is seen as an institutional mechanism. Thus, he investigates the contingent connections and processes between property and individuals and groups, property and deontic aspects, among others. Thus, we can notice that IP rights are constituted from a collective acknowledgment. These rights (and possible related obligations) inhere in intentional individuals that participate in several relations (commonly referred to as agreements). Merges (2017) highlight three key attributes of property that are applied to IP rights, as follows: (i) "it is 'good against the world' " (no prior contract or other legal relationship is required to create an acknowledgment to respect the right); (ii) "it defines uses of an asset that are under control of the owner", since it demarcates the owner's ambit of authority; and (iii) "it is broadly transferable" (despite some owner's residual rights in some cases, the owner has a special power to decide alone if and when to enforce the IP rights). In this context, Merges (2017) points out that IP rights are limited rights. Therefore, IP rights are "[...] subject to restrictions and limitations that third parties sometimes hold as rights also".

All of these theoretical considerations on Intellectual Property are fundamental when designing IP ontologies, as they allow for a clear establishment of the ontological commitments inherent to the addressed domain. This is especially important in the case of "reference ontologies", which support human communication, meaning negotiation, and consensus building, and upon which "operational ontologies" should be anchored.

3. Study Design

The research method followed in this study was inspired by the systematic literature review guidelines proposed by Kitchenham and Charters (2007). It comprises three phases: planning, conducting, and reporting. *Planning* involves the protocol definition, including the following items: study goal, research questions, inclusion and exclusion criteria, sources of publications, data extraction, and analysis procedures, among others. *Conducting* is concerned with following the research protocol to search and select publications, extract, synthesize, and analyze data. *Reporting* is the final phase and involves writing up the results and making them available to potentially interested parties. The research protocol is an important artifact in the review process. Next, we describe the main parts of the research protocol used in this work.

Study goal. The study aimed at identifying ontologies for the IP domain and characterizing them considering the aspects addressed in the *research questions* (RQ) presented in Table 1. It must be noted that the scope of this study is exclusively focused on *ontologies*. Therefore, studies proposing a conceptual model (in a broad sense) that is not classified as or termed an ontology fall outside the scope of this research.

Publications source and search string. In this study, we consider available evidence offered by primary studies (i.e., empirical studies that provide evidence related to specific research questions (Kitchenham and Charters, 2007)) and other types of publications (e.g., governmental websites non-published as scientific studies). The sources of publications were three electronic databases: Scopus (*http://www.scopus.com*), which is a comprehensive database that indexes publications from several other sources; IEEE Xplore (*http://ieeexplore.ieee.org*), which contains several publi-

Table 1
Research questions.

ID	Research Question	Rationale
RQ1	What ontologies have addressed IP aspects?	Identify the ontologies addressing IP aspects recorded in the literature.
RQ2	Who are the ontologies authors, and from which country are they?	Identify who is involved in the development of IP ontologies and their affiliation countries, to verify if there has been a predominance of some authors or countries addressing this subject.
RQ3	Which have been the ontologies' application contexts?	Investigate the contexts in which the ontologies have been applied (e.g., Digital Rights Management, Checking for Legal Compliance, Data Integration, and Standardization) and evaluate if any stands out.
RQ4	Which IP branches have been addressed?	Investigate if the ontologies have addressed copyright, industrial property, or both.
RQ5	On which legal or regulatory frameworks have the ontologies been based?	Identify the generality level of the legal or regulatory basis adopted in ontology design (e.g., International treaties, specific country law).
RQ6	Which languages and formalisms have been used to represent the ontologies?	Identify the predominant modeling languages used to represent graphically the ontologies concepts and relations, and the formalism applied to specify the ontologies in a machine-readable way.
RQ7	How have upper-level ontologies been used in the ontologies design?	Verify if upper-level ontologies (foundational ontologies or core ontologies) have been applied in the design of IP ontologies, identify which ones have been used, and how they have been used to support the ontological foundation.
RQ8	What has been the conceptual coverage of the ontologies concerning IP aspects?	Identify the concepts addressed by the ontologies to understand their conceptual coverage and comprehensiveness.

cations in Computer Science and some of them may not be indexed in Scopus[7]; and Google Scholar (*https://scholar.google.com*), to allows us to access publications available on organizational websites. We used an automatic search to collect publications from these sources. The search string adopted in the study contains a group of terms related to IP joined with the operator AND to a term referring to ontologies. The following string was used: *("Intellectual Property" OR "Industrial Property" OR "Copyright" OR "Patent") AND ("Ontology")*. It was reached after several tests performed in the digital libraries considering some control publications that had been previously identified and that should be retrieved.

Selection criteria. As the inclusion criterion, we considered: (IC) The publication proposes an ontology (as a conceptual model) about the intellectual property domain. In addition, we considered five exclusion criteria: (EC1) the publication was not written in English; (EC2) the publication was reported just as an abstract; (EC3) the publication is a secondary study, tertiary study, editorial, summary of keynote, tutorial or the proceedings of a scientific event; (EC4) the publication presents an ontology addressed in a more recent selected publication; and (EC5) the publication only makes available the operational ontology (e.g., an RDF file for download), without any further information (e.g., authorship, conceptual model).

[7]See (IEEE, 2021) for more information about IEEE's indexing policies.

Publications selection. Selection was performed in four steps. In *Preliminary Selection and Cataloging* (S1), the search string was applied in the search mechanism of each digital library used as a source of publications (we limited the search scope to title, abstract, and/or keywords metadata fields). In Google Scholar, we ceased our search after navigating through at least five results pages without finding any relevant records, such as scientific publications or other pertinent sources like governmental websites or webpages from recognized IP organizations. After that, we performed *Duplications Removal* (S2), i.e., publications indexed in more than one digital library were identified and duplications were removed. In *Selection of Relevant Publications – 1st filter* (S3), the abstracts of the selected publications were analyzed considering the selection criteria. Finally, in *Selection of Relevant Publications – 2nd filter*(S4), the full text of the publications selected in S3 was read and analyzed considering the selection criteria.

Data extraction. To answer RQ1 to RQ7, we extracted data from the text or metadata of each analyzed publication. For that, we carefully read the publications to identify information about the ontology design and application. To answer RQ8, we identified and extracted the concepts of each ontology from the text and/or diagrams presented in the selected publication. Extracted data was stored in a spreadsheet structured according to the RQs.

Data synthesis and analysis. The extracted data was tabulated and analyzed considering the RQs. Concerning RQ8, after identifying the concepts of each ontology, we performed the procedure described below. The main results of data synthesis and analysis are reported in Section 4.

(i) As an initial step, we built a word cloud for each ontology to highlight the most frequent terms. The words used to refer to the ontologies' concepts and relations were identified, and each was counted. Each word was considered separately. If a concept was referred to by a compound referent, e.g., "Distribution Channel", each word of this referent was counted separately (e.g., "Distribution" and "Channel"). Thus, it was possible to determine which words occur most frequently in the ontology, and, as a result, it was used to support the following steps of the analysis of the concepts and relations. We searched for the terms in the diagrams presented in each selected publication, as well as within the text itself. After that, we used the Word Art[8] tool to generate each word cloud.

(ii) We analyzed the word clouds in tandem, which allowed us to obtain a preliminary understanding of the key terms that referred to IP aspects covered by the ontologies.

(iii) Based on the world clouds, together with a preliminary analysis of ontologies' concepts, as a bottom-up approach, we defined an initial set of common aspects addressed by the ontologies, here called *"reference aspects"*[9].

(iv) We analyzed the concepts of each ontology and mapped each concept to reference aspects. When necessary, we refined the initial set of reference aspects to accommodate all the ontologies' concepts (e.g., those that did not stand out during the preliminary analysis described in step (iii)).

[8] https://wordart.com/create

[9] **Reference aspects** are (IP domain-independent) general aspects, extracted through a bottom-up analysis, that synthesize the common elements addressed by the IP ontologies and serve as a basis for mapping, comparing, and classifying the ontologies' concepts from a higher level of generality.

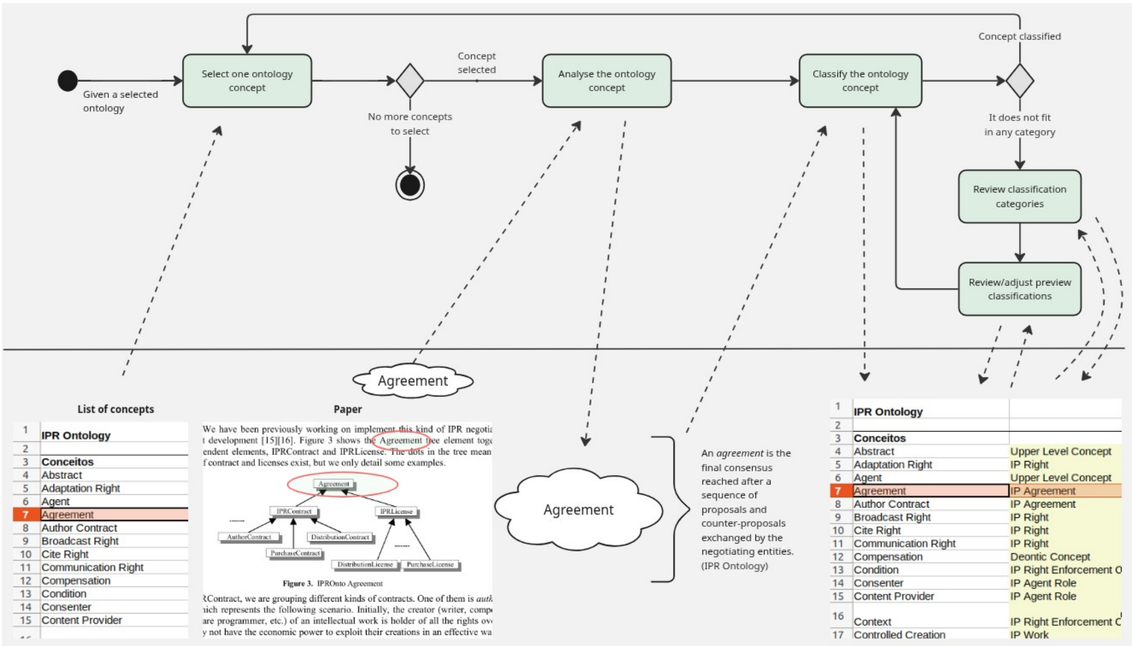

Fig. 1. Classification process of ontology concepts into IP classification categories.

(v) In sequence, we reanalyze the mapping between the concepts and the reference aspects, and then we derived (more specific) *"IP concept classification categories"*[10], and classified the ontologies' concepts into these categories. This step was important, because it allows to establish two levels of generality: the one established by the reference aspects, and that one established by the IP concept classification category. When necessary, during this process, IP concept classification categories were refined. Figure 1 illustrates this classification process and exemplifies it through a selected ontology.

Quality Assurance. The first author performed publication selection, data extraction, and preliminary data synthesis and analysis. The other two authors reviewed the results, especially concerning the study design and preliminary data synthesis and analysis. Discordances were discussed and resolved. The three authors performed together qualitative analysis considering the findings, their relation to the research questions, and the study purpose.

4. Study Execution and Data Synthesis

Searches were conducted for the last time on May 10th, 2024. As a result of the publication selection procedure, nine publications were selected.

[10]**IP concept classification categories** are more specific categories for classifying Intellectual Property concepts, derived from the reference aspects. While the reference aspects represent a more general, domain-independent level, the classification categories refine these aspects by grouping the ontologies' concepts according to more detailed characteristics that are directly related to the IP domain. They therefore constitute a second, more specialized level of generality, used to organize and compare the ontologies' concepts with greater precision.

Table 2
Selected ontologies.

Ontology	Bibliographic References	Country	Authors
IPROnto	(Delgado et al., 2003a,b)	Spain	Jaime Delgado, Isabel Gallego, Silvia Llorente, and Roberto García
Copyright Ontology	(García and Gil, 2006; García et al., 2007)	Spain	Roberto García, Rosa Gil, and Jaime Delgado
Patent Upper Level Ontology (PUMO)	(Wanner et al., 2006; Giereth et al., 2007; MK-Lab, 2008)	Spain, Germany, The Netherlands, Greece, and Italy	Barrou Diallo, Emanuele Pianta, Gautam Rao, Leo Wanner, Luciano Serafini, Mark Giereth, Pia Schoester, Sören Brügmann, Steffen Koch, Symeon Papadopoulos, Vasiliki Zervaki, and Yiannis Kompatsiaris
Intellectual Property Entity Ontology	(Rodríguez et al., 2007)	Spain	Víctor Rodríguez, Marc Gauvin, and Jaime Delgado
ALIS IP Ontology	(Cevenini et al., 2008)	Italy	Claudia Cevenini, Giuseppe Contissa, Migle Laukyte, Régis Riveret, and Rossella Rubino
Patent System Ontology	(Taduri et al., 2011, 2015)	United States	Siddharth Taduri, Gloria T. Lau, Kincho H. Law, Hang Yu, Jay P. Kesan
Ontologies for IP Rights Protection	(X.M. et al., 2012)	China, Hong Kong	Zhang X.M., Liu Q., Wang H.Q.
MPEG Intellectual Property Rights Ontologies	(ISO/IEC, 2018; ISO/IEC, 2010; ISO/IEC, 2017; Delgado et al., 2016; Rodríguez-Doncel et al., 2015; Kudumakis et al., 2019, 2020)	United Kingdom, Spain, Italy	Panos Kudumakis, Thomas Wilmering, Mark Sandler, Víctor Rodríguez-Doncel, Laurent Boch, Jaime Delgado
Patent Ontology	(European Patent Office, 2023c,a)	United Kingdom	European Patent Office

In the following, we synthesize the results of the study. Section 4.1 presents the selected ontologies and describes them in the light of RQ1 to RQ7 research questions. Section 4.2 provides information about the conceptual coverage of the ontologies, addressing the RQ8 research question.

4.1. Ontologies addressing PI

Table 2 summarizes the selected ontologies. The ontologies were developed by persons affiliated with universities or research groups from nine different countries: Spain, Italy, Germany, The Netherlands, Greece, the United States, China, Hong Kong, and the United Kingdom. Five of the nine selected ontologies were developed by authors from Spain, three involved authors from Italy, and two were created by authors from the United Kingdom. Also, authors from other countries (Germany, The Netherlands, Greece, and Hong Kong) were involved in the development of one ontology.

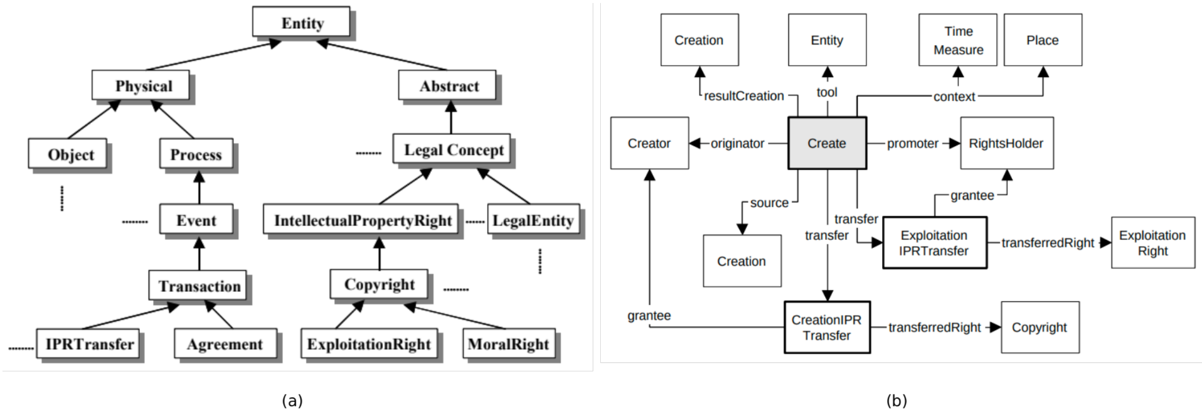

Fig. 2. IPROnto: fragment (a) illustrates the static view, and fragment (b) shows the creation event diagram from the dynamic view (Delgado et al., 2003b)

The Intellectual Property Rights Ontology (IPROnto). IPROnto aims to model intellectual property rights for Digital Rights Management (DRM) (Delgado et al., 2003a,b). This work was developed in the context of MPEG-21 standardization towards developing applications that follow the DRM MPEG-21 standards in a machine-readable form, such as Rights Expression Language (REL) and Rights Data Dictionary (RDD). IPROnto is specified in OWL, and its specification can be found in (Delgado and García, 2003). The ontology is structured in static and dynamic views. The first one addresses the key concept "Entity", which is specialized in "Physical" and "Abstract" concepts, and their correspondent hierarchies of concepts (Object, Process, Legal Concept, Legal Entity), as illustrated by Figure 2 (a). The dynamic view addresses some related events, such as the creation event, the agreement event, the distribution event, and the purchase license event, among others. Figure 2 (b) illustrates the intellectual property creation event, which starts the IP life-cycle and is related to correspondent roles and associated rights. The ontology is grounded in SUMO (Suggested Upper Merged Ontology) (SUMO, 2012), which, according to the authors, provides a robust basis for interoperability. Also, IPROnto is based on the Berne Convention and WIPO-administered treaties as a legal framework for intellectual property domain aspects.

The Copyright Ontology (CopyrightOnto). CopyrightOnto was built based on the conceptualization provided by IPROnto. It is applied in Copyright-Aware Copyright Management Systems (García and Gil, 2006; García et al., 2007; Garcia, 2022) to address Digital Rights Management (DRM). This ontology aims to formalize the copyright domain to facilitate automated (or computer-supported) copyright management and interoperability throughout the entire content value chain. The ontology is structured in three models. The Creation Model defines the core concepts of the ontology by considering the notion of creation from three distinct points of view: Abstraction, Objects, and Processes, as illustrated by Figure 3 (a). The Rights Model constrains which actions are favored or restricted based on different legal regimes. Finally, the Action Model, as illustrated in Figure 3 (b), corresponds to the actions that can be performed on the concepts defined in the Creation Model, which are regulated by the rights defined in the Right Model (García and Gil, 2006). The Copyright Ontology was not bound to any upper-level ontology. This was a design choice for being agnostic concerning more general concepts. Anyway, according to the authors, they "[. . .] keep in mind some top ontologies in order to make our model [...] easy to align with as many upper ontologies as possible". According to the authors, the ontology is enriched with

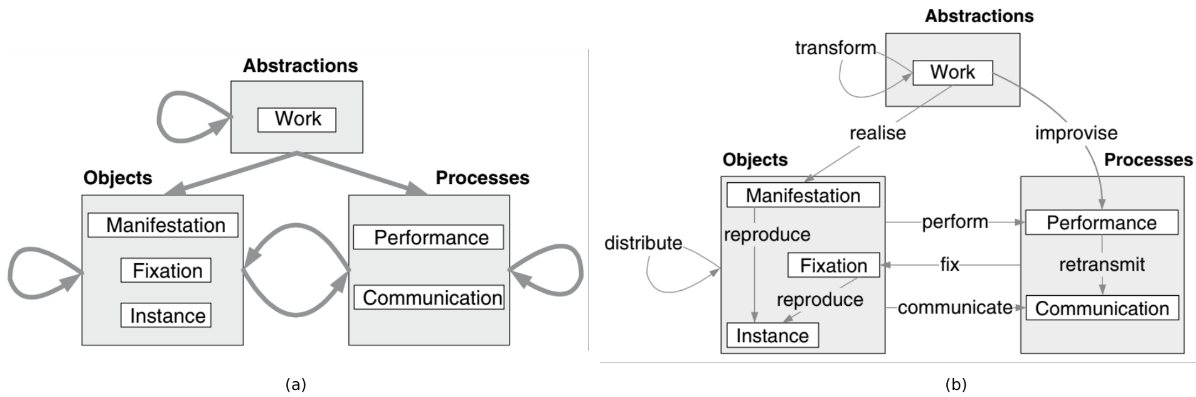

Fig. 3. CopyrightOnto: fragment (a) presents the Creation Model, and fragment (b) presents the actions in the creation life-cycle (García et al., 2007).

general concepts for time, space, tools, parthood, etc, which are taken from upper-level ontologies such as IEEE SUMO (Pease et al., 2002), DOLCE (Gangemi et al., 2002), and LRI-Core (Breuker, 2004). The ontology adopts the generic thematic/case roles (Sowa, 2000; Judith, 1991), and then represents elements such as "agent", "effector", "recipient", "patient", "result", etc. The ontology is based on WIPO recommendations, which offer, according to authors, a common worldwide legal framework that can be specialized in particular law systems. Finally, the ontology specification OWL is available in (Garcia, 2022).

Patent Upper-Level Ontology (PULO). PULO addresses the patent terminology and acts to bridge the gap between the higher-level concepts of SUMO and the domain ontologies (Wanner et al., 2006). PULO is part of an ontological framework of the PATExpert project (MKLab, 2008) that aims at representing information of patent documents by using semantic web formalism to support retrieval, classification, extraction, summarization, visualization, and assessment of patent material (Giereth et al., 2007). The ontological framework is divided into three major blocks (Giereth et al., 2007): (i) common sense knowledge (addressed by SUMO using concepts such as rights, obligations, and individuals), (ii) patent genre-specific knowledge (addressed by PULO), and (iii) domain-specific knowledge (encompassing the Patent Classification Ontology (PCO), and domain ontologies of interest, e.g., optical recording devices, and mechanical engineering tools). PULO subsumes three other ontologies (Giereth et al., 2007): the Patent Metadata Ontology (PMO), the Patent Structure Ontology (PSO), and the Patent Drawings Ontology (PDO). PMO describes patent documents or related data, such as bibliographic data, priority date, references to other related patent documents, patent family, and legal status information. PSO aims to capture the structural decomposition of a patent document, in which the central concept is PatentApplication, but there are others, such as PatentSupplement, Non-PatentSupplement, PatentPublication. PDO intends to provide a taxonomy for patent drawing types (e.g., circuits, waveform, flowchart, etc.). PUMO is based on WIPO standards and regulations (which are aligned with international treaties, such as the Paris Convention). Also, PUMO is specified using OWL (Giereth et al., 2007). Figure 4 presents a diagram of the Patent Metadata Ontology.

Intellectual Property Entity Ontology. The Intellectual Property Entity Ontology addresses intellectual creations and their manifestations, adaptations, and subsequent stylistic instantiations (Rodríguez et al., 2007). It is applied in the context of the Digital Media project in a Digital

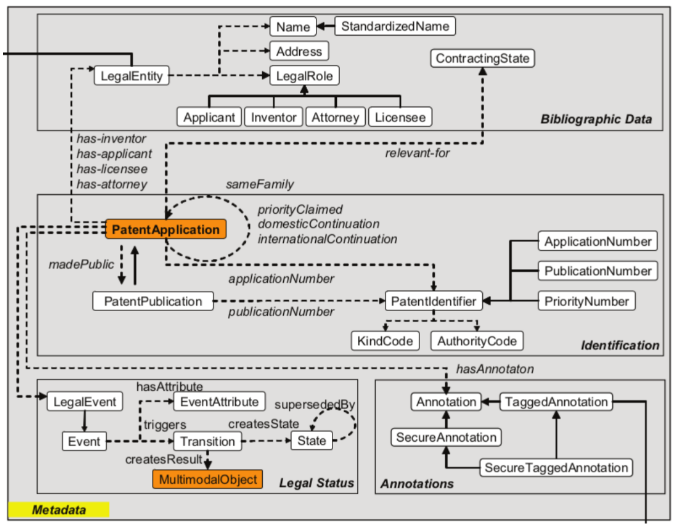

Fig. 4. PULO: a diagram of the Patent Metadata Ontology (Giereth et al., 2007).

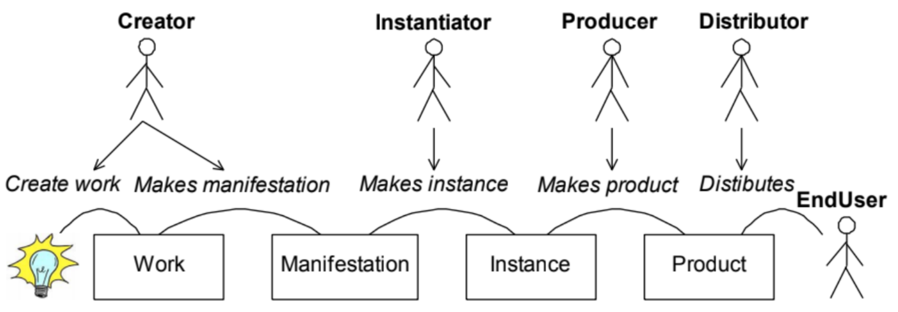

Fig. 5. Intellectual Property Entity Ontology: IP entity value chain and related roles (Rodríguez et al., 2007)

Rights Management (DRM) platform. The authors advocate that a formalized semantic expression provides a solid and common basis for computer-based inferring and reasoning. The ontology aims to be general enough to be independent of specific country laws, being "[. . .] extendable to and interoperable with different specializations of IP Entity systems [...]". The ontology addresses three aspects: (i) IP entities (work, adaptation, manifestation, instance, copy, and product), (ii) individuals/roles that act on these entities (creator, adaptor, instantiator, producer, distributor, and end-user), and (iii) the actions performed by actors on or with the IP entities (create, adapt, make instantiation, etc.). The ontology is not grounded on an upper-level ontology. The authors state that this is a design choice for minimizing the complexity of the ontology. Finally, the ontology is specified using the OWL. Figure 5 presents some roles, actions, and IP entities along the value chain addressed by the ontology.

The ALIS Intellectual Property Ontology. The ALIS Intellectual Property Ontology was designed in the context of the ALIS project, an initiative that stands for Automated Legal Intelligent System (Cevenini et al., 2008). This project aimed at "[. . .] modeling a legal system for IP law and providing citizens, public and private organizations with fast and reliable access to the European IP law [...]" (Cevenini et al., 2008). Thus, it fits in the Artificial Intelligence area ranging from

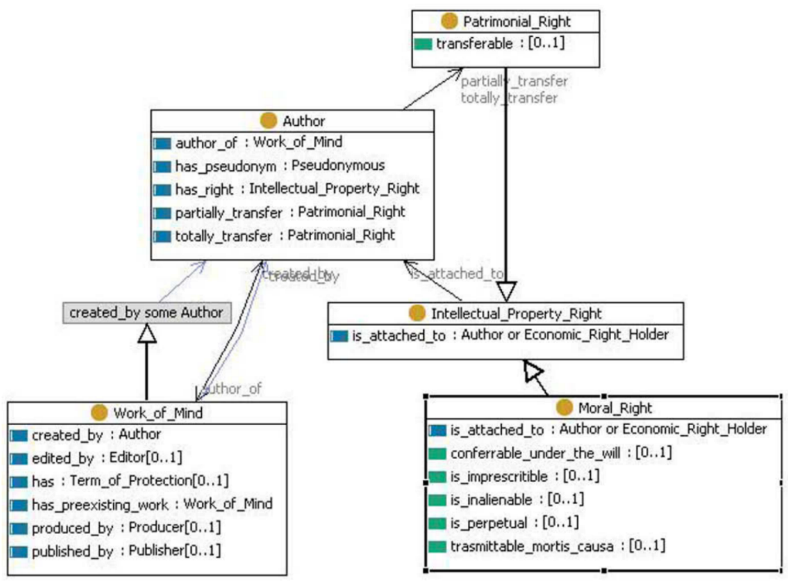

Fig. 6. ALIS Intellectual Property Ontology: UML diagram laying out its main IP concepts (Cevenini et al., 2008)

knowledge representation to reasoning. This ontology was designed as a kind of "[. . .] agreement between lawyers and software engineers who have to work together in this initiative [...]" from an interdisciplinary approach (Cevenini et al., 2008). From the legal perspective, the ontology was designed taking as a basis the French IP law, in which the concepts of "author", "work of mind", and "intellectual-property rights" are of fundamental importance to this legal framework. The IP life-cycle model addressed by the ontology was inspired in IPROnto's, and presents five stages, as follows: organize, create, assert, transfer, and use. The ALIS Intellectual Property Ontology uses the LKIF-Core Ontology (Hoekstra et al., 2007, 2009) as an upper-level ontology, which embeds the concepts of "manifestation" and "expression". The ALIS ontology is specified in OWL. Figure 6 presents the main concepts addressed by it.

Patent System Ontology. The Patent System Ontology aims to standardize the patent system representation towards integrating heterogeneous data sources, such as patent documents, court cases, and file wrapper domains (Taduri et al., 2011). From this, the authors aim to build a knowledge base to answer queries spanning these different domains (Taduri et al., 2015). The patent document domain addresses elements such as title, citation, classification, inventor, etc. The court case domain encompasses information contained within the text body which includes the claims under concern, the patents involved, and the analysis. The file wrappers domain includes details of every communication between the patent office and the applicant (e.g., initial application, applicant's amendments, examiner's response, rejection, or approval) (Taduri et al., 2011). The structure of the Patent System Ontology is based on the US patent system, more specifically, on the USPTO patent document structure and court cases from the LexisNexis database. The ontology is specified using OWL (Taduri et al., 2011). Figure 7 presents a fragment of the class hierarchy of the ontology.

Ontologies for IP Rights Protection. These ontologies address intellectual property rights (IPR) (X.M. et al., 2012) and are used as a means to provide a formal description of objects and relations (a shared terminology) and a formal basis for domain knowledge reasoning. From the ontologies,

Fig. 7. Patent System Ontology: fragment of the class hierarchy (Taduri et al., 2011)

the authors aim at establishing a comprehensive understanding of the domain and supporting the design and development of IPR protection systems. The authors define two ontologies: static ontology and dynamic ontology. The former addresses the static aspects of IPR protection and defines the basic concepts, e.g.: IP Works, Participants, and Activities. The latter addresses changing aspects of the world by means of states, transitions, and processes in the context of the IP domain. According to Guarino's classification (Guarino, 1998), the static ontology appears to be a domain ontology, whereas the dynamic ontology seems to be a task ontology, since it defines concepts related to the IP life-cycle represented through UML-like activity diagrams. The authors point out some concerns in defining general concepts (such as Things, IP works, Participants, and Activities). Although the term "top-level ontology" is used widely adopted top-level ontologies such as DOLCE (Masolo et al., 2003), SUMO (SUMO, 2012), YAMATO (Mizoguchi, 2009), and UFO (Guizzardi, 2005) are not employed. The ontologies are specified in OWL. Figure 8 (a) presents the basic concepts of the static ontology, and Figure 8 (b) illustrates the dynamic ontology by presenting a pirate process in the creation stage.

MPEG Intellectual Property Rights Ontologies. The MPEG working group of ISO/IEC organizations developed media coding standards (Kudumakis et al., 2019, 2020). The initiative includes three ontologies for the codification of intellectual property rights (IPR) information, such as (Rodríguez-Doncel et al., 2015; Kudumakis et al., 2019, 2020): the Media Value Chain Ontology (MVCO), the Audio Value Chain Ontology (AVCO), and the Media Contract Ontology (MCO). The MVCO (ISO/IEC 21000-19) (ISO/IEC, 2010; ISO/IEC, 2018) favors rights tracking for fair, timely, and transparent royalties payment by capturing user roles and their permissible actions on a particular IP Entity, as illustrated by Figure 9 (a). The AVCO (ISO/IEC 21000-19/AMD1) (ISO/IEC, 2018)extends MVCO and addresses the description of composite IP entities in the audio domain (e.g., multi-track audio and time segments). The MCO (ISO/IEC 21000-21) (ISO/IEC, 2017; Rodríguez-Doncel et al., 2015; Delgado et al., 2016; Kudumakis et al., 2019, 2020) facilitates the conversion of narrative contracts to the audio-visual domain, and it permits the creation of

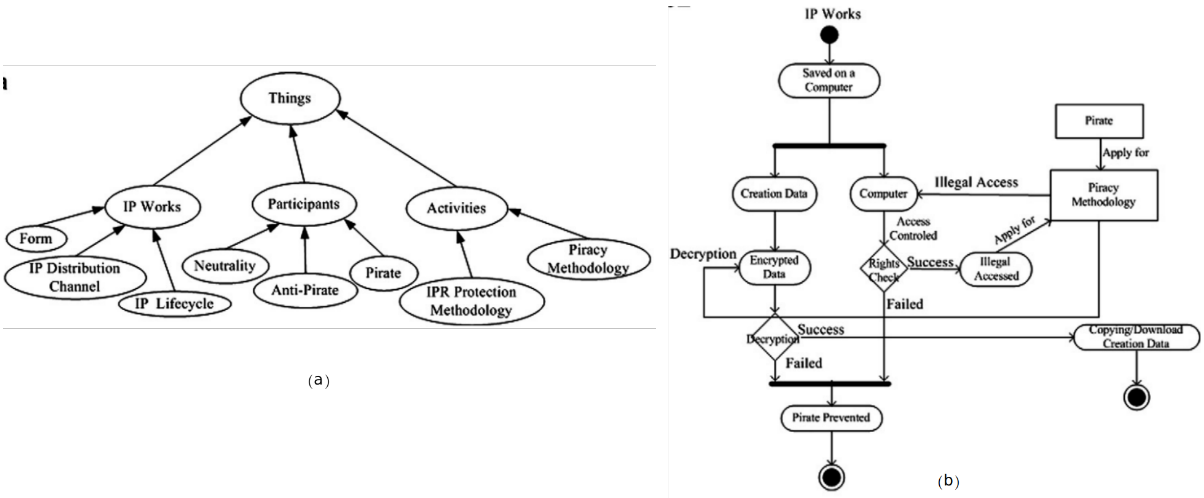

Fig. 8. Ontologies for IP Rights Protection: fragment (a) presents the basic concepts of the static ontology, and fragment (b) presents the pirate process in the creation stage of the dynamic ontology (X.M. et al., 2012)

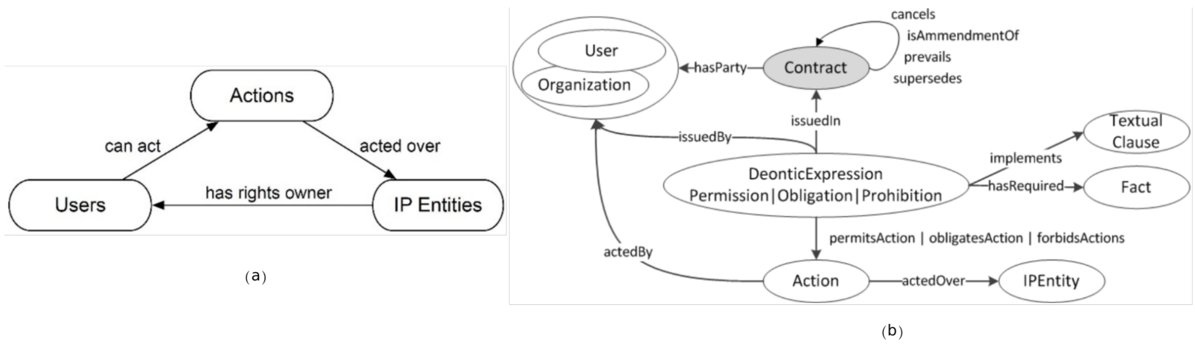

Fig. 9. MPEG Intellectual Property Rights Ontologies: fragment (a) presents the basic concepts and relations in MVCO, and fragment (b) presents the main elements of MCO (Kudumakis et al., 2019, 2020)

new contracts in machine-readable electronic format. Figure 9 (b) presents the main concepts and relations of MCO. The ontologies support the creation of generic deontic statements encompassing permission, prohibition, and obligation, being also applicable to smart contracts. Finally, they are specified in OWL.

The Patent Ontology. The Patent is used as a conceptual model of patents and patent data (European Patent Office, 2023b,c). The ontology's main concepts are Application and Publication. Application regards an application for a patent or other intellectual property right. Publication, in turn, refers to the publication of a patent document, being a result of a formal process of application analysis (European Patent Office, 2023b). This ontology is specified in OWL and is used in the context of the Linked Open European Patent Data Service of the European Patent Office. This service supports a web interface that can be used by developers to query patent data and retrieve it in a format of their choice (European Patent Office, 2023a). This interface conforms to the Linked Data API Specification. Developers can query the data using SPARQL. Queries can be entered into a web form by users or be sent by a computer program directly to the database. Figure 10 presents the main classes and relations of the ontology.

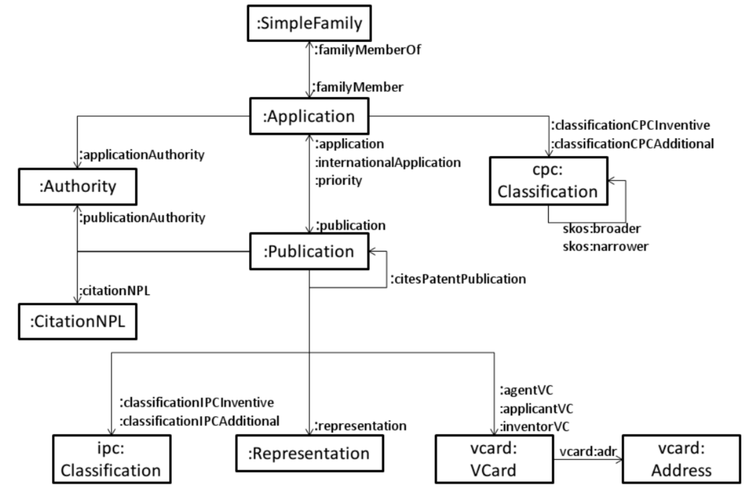

Fig. 10. Patent Ontology: main classes and relationships (European Patent Office, 2023b)

Table 3 summarizes data concerning the investigated ontologies.

4.2. Conceptual Coverage

As explained in Section 3, we used word clouds to support a preliminary analysis of conceptual coverage. It served as an initial strategy to understand the focus of the ontology, which was later complemented by an analysis of the concepts in each ontology. Figure 11 presents the word cloud of each ontology.

For both IPROnto and the Copyright Ontology, we can observe that the term “right” stands out (i.e., it has more occurrences than the others). The word clouds of the Ontologies for IP Rights Protection and the MPEG Ontologies, in turn, highlight the terms “stage” and “action”, respectively, which are related to the notion of the “events” performed by agents/roles during the IP life-cycle (e.g., since creation to exploitation and usage). In the word cloud of the Intellectual Property Entity Ontology, the term “make” has the highest occurrence. This is because the ontology represents various actions using this and other action verbs (e.g., “make instance”, “make a copy”, along with “adapt,” and “consume”). Similar to Ontologies for IP Rights Protection and the MPEG Ontologies, the Intellectual Property Entity Ontology presents a clear concern on addressing the notion of “event” during IP life-cycle. The ALIS Ontology, by being based on the French IP law, brings an extensive classification of “works of mind”, which explains the high number of occurrences of the term “work”. Finally, the Patent Ontology, the Patent System Ontology, and the Patent Upper-Level Ontology (PULO) focus on describing a particular type of intellectual work: a patent. This is reflected in the used terms, which refer to several concepts that characterize the informational structure of a patent (e.g., “Application”, “Family Member”, “Classification”, and “Citation”).

Taking as a basis the word clouds, together with a preliminary analysis of the ontologies’ concepts, we identified common aspects across the ontologies, here referred to as “reference aspects”,

Table 3
Summarization of the analyzed aspects.

Ontology	Application context	IP branch	IP legal frameworks	Languages and Formalisms	Upper-level ontology [a]
IPROnto	To address intellectual property rights for Digital Rights Management (DRM)	Copyright	WIPO-administered regulations	OWL graphical representation, and own representation. It is also specified in OWL	SUMO
Copyright Ontology	To address Digital Rights Management (DRM) through the whole content value chain	Copyright	WIPO-administered regulations	Own representation. It is also specified in OWL	It does not use **a specific**[b] upper-level ontology.
Patent Upper-Level Ontology (PULO)	To describe patent structure favoring data integration and usage	Industrial Property	WIPO-administered regulations	Own representation. It is also specified in OWL	SUMO
Intellectual Property Entities Ontology	To address Digital Rights Management (DRM) in a digital media project	Copyright	Not identified	Own representation. It is also specified in OWL	It does not use upper-level ontology
ALIS IP Ontology	It is applied in an intelligent system to support document annotation, reasoning, checking for legal compliance, etc.	Copyright	French IP law	UML-like diagram. It is specified in OWL	LKIF-core
Patent System Ontology	To standardize and integrate (heterogeneous) data sources for supporting information retrieval	Industrial Property	USPTO / US patent system data structure	UML-like diagram, and OWL graphical representation. It is also specified in OWL	Not identified
Ontologies for IP Rights Protection	To protect IP works against pirating by providing an understanding of the domain, and supporting systems development.	Copyright	Not identified	UML-like diagram, and own representation. It is also specified in OWL	General concepts proposed by the authors (e.g., Things, IP Work, Participants) were considered top-level ontology
MPEG Intellectual Property Rights Ontologies	To provide standardization of IP information in multimedia domain	Copyright	Not identified	OWL graphical representation. It is also specified in OWL	Not identified
Patent Ontology	To describe patents structure favoring data access (by human users and web services)	Industrial Property	Not identified	UML-like diagram. It is also specified in OWL	Not identified

[a] "Not identified" indicates that upon analyzing the selected publications, the authors did not find any reference to the use of upper-level ontologies.

[b] Despite not bounding to any upper-level ontology, the Copyright Ontology is enriched with general concepts (e.g., time, space, tools, and parthood), which are based on different upper-level ontologies such as IEEE SUMO (Pease et al., 2002), DOLCE (Gangemi et al., 2002), and LRI-Core (Breuker, 2004).

Fig. 11. Word clouds of the selected ontologies.

such as: "right", "event"[11], and "work" (i.e., "work of mind"). These reference aspects are independent of a specific type of intellectual work (e.g., patent, software, or a book).

In the sequence, we analyzed each concept of the ontologies and tried to classify them into the reference aspects ("right", "event", and "work of mind"). Some concepts could be directly classified, but others could not. So, we noticed the lack of some aspects (not identified in preliminary analysis), such as: "to whom the rights are applicable", "in which conditions the rights are applicable", and "the relations in which the rights are established/bounded". Thus, we considered three new reference aspects termed "agent", "condition", and "agreement". These aspects can also be found in the literature that addresses theoretical issues of IP, as we described in Section 3.

Also, during our analysis, we identified that the reference aspects ("right", "event", "work of mind", "condition", "agreement", and "agent") do not present themselves in isolation. They have relations among them that characterize the dynamics of the IP life-cycle. Figure 12 presents these aspects and their relations. For example, an *agent* (e.g., "John") can *participate in* certain kinds of *events* (e.g., "adapt") *performed over* certain *works of mind* (e.g., "a novel written by John") as long as these *events* are *guided* by *rights* that this *agent is the subject of* (e.g., "the right of John to adapt his novel") by being *involved with* these *works of mind* (e.g., "John as the author of the novel"). Furthermore, this is possible under certain *conditions* (e.g., "John can adapt his novel since it was not licensed to a third party"). These dynamics involving rights, events, and works of mind may be governed by *agreements* established between (intentional) agents (e.g., "a licensing contract between John and the XPTO publisher"). In our view, these aspects and their

[11]We have chosen to use the term "event" to encompass the notions of "stage", and "action" presented in the analyzed ontologies.

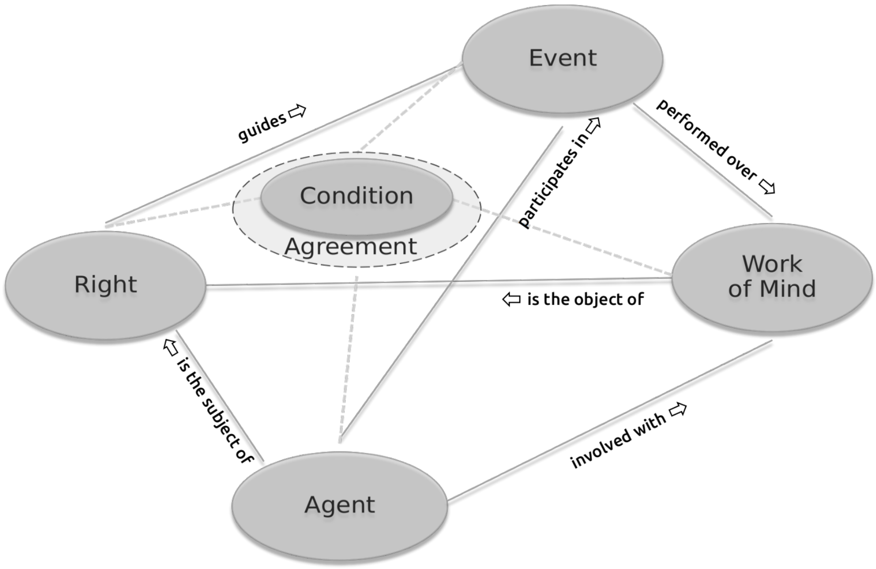

Fig. 12. Reference aspects identified from the selected ontologies and their relations: a conceptual framework.

corresponding relations constitute a conceptual framework[12] that provides the starting point for designing any intellectual property ontology.

Following the conceptual coverage analysis, we used the six reference aspects as a starting point to define (more specific) IP classification categories. This was important because it allowed us to establish two levels of generality: that one offered by the reference aspects (independent of the IP domain), and that one provided by the IP concept classification categories (dependent on the IP domain).

Thus, we took each concept and fitted it into one of the IP concept classification categories. We have classified approximately 503 (five hundred-three) concepts. During this process, we specialized/subdivided certain reference aspects into more detailed categories in order to highlight some particularities of the analyzed ontologies. The “right” reference aspect was decomposed into “IP Right” and “Deontic Concept”, whereas the “agent” aspect was subdivided into “IP Agent” (intentional individual) and “IP Agent Role” (roles played by IP agents). Moreover, considering that some ontologies present application-specific concepts (e.g., piracy), we defined an ancillary category, “application-specific concepts”, to address this kind of concept. Table 4 details the classification categories relating them to their corresponding reference aspects.

After defining the categories, we classified the ontologies’ concepts according to them. The results are shown in Table 5[13].

[12]For the sake of simplification, we have made no distinction between individuals and types in the definition of the conceptual framework

[13]For the sake of space and layout, for some classification categories, it was not possible to present all the concepts of some ontologies. However, the concepts covered in the Table 5 are sufficient to provide a good understanding of the conceptual coverage of each ontology.

Table 4
IP Classification Categories of the Ontologies' Concepts.

Reference Aspects	(IP) Classification Categories	Description
—	Upper-Level Concept	Concepts that refer to upper-level aspects necessary to design the IP ontologies. Some of these concepts were imported from the adopted top-level ontologies, while others were defined as part of a generalization strategy. These concepts serve as a foundation for the more specific ones. E.g.: Thing, Right, Situation, and Action.
Right	IP Right	Concepts that address kinds of IP rights. E.g.: Moral Right and Reproduction Right.
	Deontic Concept	Concepts that address deontic aspects inherent to the dynamics of IP rights. E.g.: Obligation, Permission, and Prohibition.
Event	IP Life-cycle Event	Concepts that address events of the IP life-cycle. E.g.: Create, Transform, Distribute, and Use.
Work of Mind	IP Entity	Concepts that address types of creative work / invention and expressions thereof. E.g.: graphical work, literary writing, manifestation, and instance.
Agent	IP Agent	Encompasses types of intentional agents that can have IP rights. E.g.: Corporate Person and Individual Person.
	IP Agent Role	Encompasses roles played by agents along the IP life-cycle. E.g.: Author, Editor, and User.
Condition	(IP Right) Enforcement Condition	Concepts that refer to conditions necessary to the validity/existence of IP rights. E.g.: Access Policies, Context, Terms of Protection.
Agreement	IP Agreement	Concepts that refer to kinds of agreements possible along the IP life-cycle. E.g.: Author Contract, Authorisation, Distribution Contract, IPR License, and IPR Transfer.
—	Application-Specific Concept	Concepts - not fitting into the previous categories - that refer to aspects related to an application context. E.g.: IPC Classification, (Patent) Family, Piracy, Citation, and Digital Certificate.

Table 5: A Panorama of the Analyzed Ontology Concepts.

Category	IPR Ontology	Copyright Ontology	PULO	Intelectual Property Entity Ontology	ALIS Ontology	Patent System Ontology	Patent Ontology	Ontologies for IP Rights Protection	MPEG IP Ontologies
Upper-Level Concept	Abstract, Agent, Entity, Legal Entity, Natural Legal Entity, Corporate Legal Entity, Event, Legal Concept, Object, Input, Result, Tool, Source, Resource, Physical, Process, Right Holder, Situation, Transaction	Abstract, Agent, Effector, Recipient, Experimenter, Patient, Object, Process, Right	Artifact, Certificate, Content Bearing Object, Human, Organization, Event, Event Attribute, Legal Entity, Legal Event, Legal Role, Linguistic Expression, Multimodal Object, Object, State, Patent, Text, Transition	Agent, Action	Natural Person, Legal Person, Right Holder	Event, Information	Agent	Things, Activities, Individual, Corporate	Action, Right, Role, Individual, Organization
IP Agent	Legal Entity, Natural Legal Entity, Corporate Legal Entity	Agent	Human, Organization	Agent	Natural Person, Legal Person	–	Agent	Individual, Corporate	Individual, Organization
IP Agent Role	Consenter, Content Provider, Creator, Customer, Disseminator, Grantee, Granter, Licensee, Licenser, Media Distributor, Originator, Patient, Promoter, Recipient	Effector, Recipient, Experimenter, Patient	Applicant, Inventor, Attorney, Licensee	Adaptor, Creator, Distributor, End User, Instantiator, Producer	Author, Editor, Producer, Publisher	Assignee, Examiner, Inventor, Issuing Authority	Applicant, Application Authority, Authority, Inventor, Publication Authority	Anti-Pirate, Creator, Neutrality, Participants, Pirate	Adaptor, Creator, Distributor, End User, Producer, User

Table 5 continues on next page.

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Concepts	IPR Ontology	Copyright Ontology	PULO	Intelectual Property Entity Ontology	ALIS Ontology	Patent System Ontology	Patent Ontology	Ontologies for IP Rights Protection	MPEG IP Ontologies
IP Right	Adaptation Right, Broadcast Right, Cite Right, Communication Right, Copyright, Dissemination Right, Distribution Right, Exception Right, Exclusive Right, Exploitation Right, Intellectual Property Right, Intellectual Right, Libraries Right, Moral Right, Neighbouring Right, Paternity Right, Private Copyright, Public Performance Right, Rental Right, Reproduction Right, etc.	Adaptation Right, Attribution Right, Broadcasting Right, Communication Right, Copyright Exception, Disclosure Right, Distribution Right, Economic Right, Fixation Right, Importation Right, Integrity Right, Making Available Right, Moral Rights, Motion Picture Right, Neighbouring Rights, Private Copy, Public Performance Right, Quotation Right, etc.	–	–	Economic Right, Incorporeal property rights, Intellectual Property Right, Moral Right, Patrimonial Right, Right of disclose under the name, Right of disclose under to direction, Right of divulge work, Right of make a collection, Right of performance, Right of reconsider assignment of exploitation, Right of reproduction, Right of respect for authorship, etc.	–	–	Copyright	–
IP Agreement	Agreement, Author Contract, Distribution Contract, Distribution License, Distribution IPRTransfer, IPR Contract, IPR License, Purchase Contract, Purchase License	–	–	Authorization	–	–	–	–	Contract

Table 5 continues on next page.

Table 5 continues on next page.

Concepts	IPR Ontology	Copyright Ontology	PULO	Intelectual Property Entity Ontology	ALIS Ontology	Patent System Ontology	Patent Ontology	Ontologies for IP Rights Protection	MPEG IP Ontologies
IP Entity	Controlled Creation, Creation, Manifestation	Fixation, Instance, Manifestation, Work	Patent	Adaptation, Copy, Instance, IP Entity, Manifestation, Product, Work	Anonymous Work, Applied art work, Architectural work, Artistic writing, Audiovisual work, Book, Choreographic work, Cinematographic work, Circus act, Collaborative Work, etc.	Patent	(Patent) Publication	Designs, Form, IP Works, Multimedia, Software	Copy, Instance, IP Entities, Manifestation, Product, Work
IP Lifecycle Event	Create Event, Disseminate, Distribution Contract Event, Distribution License Event, Expression, IPR Agreement Event, Purchase License Event, Transfer, Transform, Use	Adapt, Agree, Broadcast, Communicate, Copy, Counteroffer, Derive, Disagree, Distribute, Fix, Lend, Make Available, Offer Action, Perform, Performance, Communication, Record, Rent, Reproduce, Retransmit, Sell, Transfer, Transform, Translate	–	Adapt, Consume, Create, Make Instance, Make Manifestation, Make Product, Play, Transforming	Assert Stage, Create Stage, Organize Stage, Transfer Stage, Use Stage	Applicant Event, Application Event	–	Assertion Stage, Creation Stage, Distribution Stage, IP Lifecycle, Usage Stage	Create, Distribute, End-user Action, Make Adaptation, Produce, Public Communication, Public Performance, Fixation, Reuse, Synchronize
Deontic Concept	Compensation, Obligation, Permission.	Obligation, Permission, Prohibition.	–	–	–	–	–	–	Obligation, Permission, Prohibition.
Enforcement Condition	Condition, Context.	Condition.	–	–	Term of Protection.	–	–	–	Access Policies, Condition, Fact, Modalities.

Table 5 continues on next page.

Table 5 continues on next page.

Concepts	IPR Ontology	Copyright Ontology	PULO	Intelectual Property Entity Ontology	ALIS Ontology	Patent System Ontology	Patent Ontology	Ontologies for IP Rights Protection	MPEG IP Ontologies
Application-Specific Concept	–	–	Abstract, Address, Annotation, Application Number, Authority Code, Citation, Citation Relevance, Claim, Claim Reference, Classification Entity, Classification Schema, Contracting State, Description, Description of Drawings, Description of Invention, Description of Technical Field, Drawing Reference, etc.	–	–	Application, Application Number, Backward Citation, Classification, Content, Date, Document, Forward Citation, International Classification, IPC Sub Class, Location, Metadata, Patent Document, Patent Number, Text, Title, US Classification, US Sub Class	Address, Application, Application Kind, Citation, Classification, Classification CPC, Classification IPC, Country Code, Family, Family Member, Filing Language, International Application, Priority, Procedural Language Publication, Publication Kind, Record, Representation, Representation Format, etc.	Channel, Copying, Crack, Digital Certificate, Digital Signature, Digital Watermarking, Dishonest Claim, Downloading, Encryption, IP Distribution Channel, IPR Protection Methodology, Metadata, Online Shop, Physical, Piracy Methodology, Rerecord, Reuse, Superdistribution	Interval, Segment, Timeline, Track

End of Table 5˙

	Upper Level Concept	IP Agent	IP Agent Role	IP Right	IP Agreement	IP Entity	IP Life cycle Event	Deontic Aspects	Enforcement Condition	Application Specific Concept
IPR Ontology	19	3	14	27	9	3	10	3	2	0
Copyright Ontology	9	1	4	32	0	4	24	3	1	0
PULO	14	2	4	0	0	1	0	0	0	45
Intelectual Property Entity Ontology	2	1	6	0	1	7	8	0	0	0
ALIS Ontology	3	2	4	16	0	44	5	0	1	0
Patent System Ontology	2	0	4	0	0	1	2	0	0	18
Patent Ontology	1	1	5	0	0	1	0	0	0	20
Ontologies for IP Rights Protection	4	2	5	1	0	5	5	0	0	18
MPEG Ontologies	5	2	6	0	1	6	10	3	4	4

Fig. 13. Heat map of the number of concepts of each ontology by the classification's categories.

Figure 13 presents a heat map that summarizes the data of Table 5. This heat map is based on the number of concepts of each ontology by classification category. With this, we aim to remark which categories of concepts stand out in each ontology, providing valuable insights into the conceptual coverage analysis. The IPR Ontology points out into several categories (such as "Upper-level Concept", "IP Agent Role", "IP Right", "IP Agreement", and "IP Life-Cycle Event") followed by Copyright Ontology, PULO, and ALIS Ontology. The IPR Ontology provides the most comprehensive classification of IP agent roles, and IP agreements, whereas Copyright Ontology stands out by the number of concepts for addressing IP rights and IP life-cycle events. PULO, Patent System Ontology, Patent Ontology, and Ontologies for IP Rights Protection are distinguished by their application-specific concepts: the first thee present several concepts related the patent structure (e.g., "Classification CPC", "Classification IPC", "Family", "Priority", "Citation", and "Description"), whereas the latter provides a comprehensive understanding of the anti-piracy domain. The Intelectual Property Entity Ontology, and the MPEG Ontologies, despite of addressing several categories ("IP Agent Role", "IP Entity", and "IP Life-Cycle Event"), are not the most representative in each category. The ALIS Ontology points out into the "IP Entity" category, as it introduces a comprehensive set of intellectual works based on French IP law. Finally, regarding the use of upper-level concepts, IPR Ontology and PULO stands out. Not by chance, these two ontologies explicitly report the use of a top-level ontology (SUMO) to ground the ontology conceptualization. A further discussion about these data are conducted in the next section.

5. Discussion

In this section, we discuss the findings related to each research question.

Provenance (RQ1 and RQ2). Considering the authorship of the nine analyzed ontologies, it involves 37 (thirty-seven) different persons from nine countries. Interestingly, some people act as authors of more than one ontology, which indicates some level of shared conceptualization among them (this is addressed in the following items). Jaime Delgado and Roberto Garcia participated in the development of IPROnto and Copyright Ontology. Besides that, Jaime Delgado and Victor Rodriguez have also worked on the Intellectual Property Entity Ontology and MPEG Intellectual Property Rights Ontologies. Thus, Jaime Delgado has contributed to developing four of the nine analyzed ontologies, whereas Roberto Garcia and Victor Rodriguez contributed to developing two of the nine ontologies. In this regard, it is important to notice that Jaime Delgado and Victor

Rodriguez have contributed to the design of the MPEG Intellectual Property Rights Ontologies, which are related to the standardization efforts of ISO/IEC 21000-19, ISO/IEC 21000-19/AMD1, and ISO/IEC 21000-21. As previously mentioned, the two authors have also been involved in the development of the IPROnto, the Copyright Ontology, and the Intellectual Property Entity Ontology. Therefore, although beyond the scope of this study, it is worth highlighting — and could merit further investigation — the extent to which these four IP ontologies, developed by authors in common, have contributed to the standardization process aimed at interoperability. There is a predominant participation of Spanish and Italian authors/institutions, with little representativeness of other countries. In addition, as aforementioned, the development of different ontologies has involved researchers in common, indicating some level of collaboration. However, the number of countries, people, and organizations around the world involved in the development of IP ontologies remains limited. This indicates the necessity to expand the discussion and collaboration towards other frontiers and research groups.

Application context (RQ3). IPROnto, Copyright Ontology, and Intellectual Property Entity Ontology share, basically, the same application context: intellectual property rights for Digital Rights Management (DRM) and, not by chance, these ontologies also share authors. The ALIS IP Ontology, in turn, is applied in the context of intelligent systems to support reasoning and legal compliance checking, document-retrieval, information exchange through web services, and design of GUI (Graphical User Interface). The Ontologies for IP Rights Protection are applied in the design of systems against pirating, being also applicable to Digital Rights Management (DRM). The MPEG Intellectual Property Rights Ontologies focus on standardization of the multimedia domain, becoming ISO/IEC standards, and supporting several initiatives in this domain. The Patent Upper-level Ontology, the Patent System Ontology, and The Patent Ontology are applied to describing and structuring patent information supporting data access, and data integration. In summary, we can notice a predominance of the DRM/multimedia application context (five of the nine analyzed ontologies), followed by the description and structuring of patent information (three ontologies). In these application contexts, the ontologies were used to support standardization, data access, data integration, (intelligent) system design, and legal compliance, among others. We believe that there is still much to explore in several other application contexts, such as innovation management, intellectual property asset management, teaching IP, and IP data/system integration/access (especially guided by FAIR principles), among others.

IP branches (RQ4). We can observe that the Copyright branch stands out, comprising six ontologies (IPROnto, Copyright Ontology, Intellectual Property Entities Ontology, ALIS IP Ontology, Ontologies for IP Rights Protection, and MPEG Intellectual Property Rights Ontologies). The Industrial Property branch, in turn, includes three ontologies (Patent Upper-level Ontology, Patent System Ontology, and The Patent Ontology). It is important to say, however, that although some ontologies are presented as addressing IP in general (such as IPROnto, ALIS IP Ontology, and Ontologies for IP Rights Protection), their presentation, as well as the concepts and relations they describe, suggest—according to our analysis—that they are, in fact, more closely aligned with the Copyright domain. Regarding the ontologies of the Industrial Property branch, they address only patent issues, more specifically, the patent document structure. Therefore, considering the analyzed ontologies, the Copyright branch stands out, with other ontologies addressing a limited part of the Industrial Property branch. Consequently, we consider that several aspects of the IP domain deserve further attention, especially those related to Industrial Property. Also, there is a lack of a wide and integrated conceptualization that explicitly addresses the Copyright and Industrial Property branches together.

IP legal/regulatory frameworks (RQ5). Three of the analyzed ontologies (IPROnto, Copyright Ontology, and MPEG Intellectual Property Rights Ontologies) are based on general IP legal/regulatory frameworks (e.g., Berne Convention, and Paris Convention). According to the ontologies' authors, this is a design choice for broadening international applicability. In the remaining ontologies, one (ALIS IP Ontology) is specifically based on French IP law, another is based on USPTO/US patent data structure (Patent System Ontology), and for the other four ontologies, it was not possible to identify the used IP legal/regulatory framework (it is not explicitly mentioned in the paper). In one of these four ontologies (Intellectual Property Entities Ontology), however, the authors mentioned that it is "independent of specific country law". Overall, we can notice that there is a tendency to favor generality when designing the ontologies, taking into account general IP legal/regulatory frameworks. We understand that there is a trade-off in that choice: while more general IP legal/regulatory frameworks may favor generality and interoperability (e.g., between systems and organizations from different countries), specific IP legal/regulatory frameworks may be required for supporting initiatives based on specific country laws (which is the case of the ALIS IP Ontology, and Patent System Ontology). We believe this trade-off could be addressed with a layered design strategy, with ontologies based on general IP legal/regulations being specialized in lower layers by ontologies dedicated to specific country laws/regulations. This was not attempted in the ontologies we have identified in the literature.

Languages/formalisms (RQ6). Regarding languages/formalisms, we consider two aspects: (i) graphical representation of conceptual models, and (ii) ontology specification in a machine-readable formalism (e.g., OWL specification language). Concerning the first one, we can notice three kinds of graphical representations: "OWL graphical representation" (with a focus on representing OWL class hierarchy with ad hoc diagrams), "own representation" (other kinds of ad hoc representations proposed by the authors to illustrate the concepts and their relations), and "UML-like diagrams" (representations whose syntactic and semantic aspects are largely based on the OMG Unified Modeling Language (UML)). Some studies have used more than one type of representation in a combined way. In this context, "UML-like diagrams" were used in four ontologies (ALIS IP Ontology, Patent System Ontology, Ontologies for IP Right Protection, and Patent Ontology), "own representation" was used in five ontologies (IPROnto, Copyright Ontology, Patent Upper-level Ontology, Intellectual Property Entities Ontology, and Ontologies for IP Rights Protection), and "OWL graphical representation" in three ontologies (IPROnto, Patent System Ontology, and MPEG Ontologies). Despite the importance of using the aforementioned graphical representations, they present some important limitations. "Own representations" do not offer a shared (or widely accepted) syntactic and/or semantics. "OWL graphical representations" (while also not standard) are not designed to address important features of conceptual models, e.g., "cardinalities", and whole-part relations. "UML-like diagrams", despite incorporating additional modeling support, still present limitations, especially for representing ontological models, since this kind of diagram does not incorporate ontological distinctions. Regarding the ontology specification in a machine-readable formalism, all the analyzed ontologies were specified in OWL. OWL is one of the most used ontology specification languages (Nardi et al., 2013), especially for semantic web applications, whose focus is on ontologies applied at run-time (so-called "operational ontologies"). In summary, according to our analysis, there is a tendency to focus on implementation aspects at the expense of representativeness, clarity, and soundness of the graphical representation of conceptual models. Neglecting the graphical representation of conceptual models may cause semantic conflicts/misunderstandings. Thus, we advocate that there must be a sound balance between the use of well-founded ontology modeling languages (for graphical representation), and machine-readable formalisms. (Well-founded) Graphical representations and machine-readable formalisms present different concerns and are applied during different phases of the ontology engineering process for building different artifacts. This requires a clear understanding of the purpose of each ontology ("reference ontologies" vs. "operational ontologies"; from analysis to implementation phases; from well-founded graphical models to code).

Usage of upper-level ontology (RQ7). In terms of Guarino's ontology classification (Guarino, 1998), only the IPROnto and the Patent Upper-level Ontology were designed using a specific top-level/foundational ontology (the SUMO) as a basis. According to their authors, this was a design choice looking for robustness and interoperability. The ALIS IP Ontology was based on the LKIF Core Ontology (Hoekstra et al., 2007, 2009), a legal ontology that embeds the concepts of "manifestation" and "expression", among others. As a "core ontology" (in terms of (Scherp et al., 2011)), it tends to be more specific than a foundational ontology, but still addresses concepts that span various domains (e.g., legal concepts applicable to IP, and insurance service, among other domains). The authors of the Ontologies for IP Rights Protection, in turn, present general concepts (e.g., Things, IP Work, Participants), which are considered by them as a top-level ontology. Despite the general characteristics of these concepts, we do not consider them as a top-level ontology (in terms of Guarino's classification). The Copyright Ontology's authors stated that they tried to be "agnostic in relation to more general concepts", as a justification for not adopting any specific upper-level ontology. However, they have mentioned their intention to make their model easy to align with as many upper ontologies as possible. Thus, they brought to the ontology some general concepts (e.g., time, space, and tools) from different upper-level ontologies (such as IEEE SUMO (Pease et al., 2002), DOLCE (Gangemi et al., 2002), and LRI-Core (Breuker, 2004)). The Intellectual Property Entities Ontology's authors justified their design choice by stating that "[...] overly complex Ontologies are difficult to manage in terms of maintaining both consistency as per available machine-based reasoners and corresponding human understanding of the relationships between concepts". For the remaining three ontologies (Patent System Ontology, MPEG Intellectual Property Rights Ontologies, and Patent Ontology) it was not possible to identify an explicit mention of the usage of upper-level ontologies. Considering the aforementioned, we highlight the usage of SUMO, as a foundational ontology. SUMO offers several fundamental ontological distinctions (e.g., process vs. object, and qualities, among others) that are useful to support the design of (IP) domain models. By analyzing Table 5, concerning the usage of upper-level concepts, IPR Ontology and PULO stand out, not by chance. These ontologies incorporate several concepts and relations from SUMO, which allows to model lower-level concepts.

Conceptual Coverage (RQ8). Regarding "IP Agent" category, five ontologies (IPR Ontology, PULO, ALIS Ontology, Ontologies for IP Rights Protection, and MPEG IP Ontologies) address it by making a basic distinction between "human being" and "organization". Other three (Copyright, Intelectual Property Entity Ontology, and Patent Ontology) only present the concept "Agent" (not specializing it). Only the Patent System Ontology does not address a specific concept for IP agents. On the contrary, it addresses only the roles played by these agents, without making a distinction between agent and roles thereof. Concerning "IP Agent Role", the IPR Ontology presents the widest set of roles, being these roles related to the DRM domain. PULO, Patent

System Ontology, and Patent Ontology stand out by presenting roles related to the patent domain. The Copyright Ontology presents some roles ("Effector", "Recipient", "Experimenter", and "Patient"), however, they are generic (based on (Sowa, 2000)), not being related specifically to the IP domain. The "IP Right" category is widely addressed by IPR Ontology, Copyright Ontology, and ALIS Ontology. Specifically, IPR Ontology and Copyright Ontology present great similarities, since Copyright Ontology was built based on the IPROnto. They also incorporate deontic aspects relating to IP rights. The other ontologies do not detail the IP rights, focusing on other aspects of IP life-cycle (such as events, agents, and roles). In most ontologies, we can find a concern in addressing IP live-cycle events, with special attention to Copyright Ontology, closely followed by IPR Ontology. These ontologies address the events especially related to IP Entities (creation, modification, use, etc.), and IP agreements (license event, transfer, disagree, offer, etc.). PULO and Patent Ontology do not address this aspect, since it focus on the informational aspects of patent structure. "IP Agreement" coverage is noteworthy in the IPR Ontology. The other ontologies (except Intellectual Property Entity Ontology, and MPEG IP Ontologies) do not present explicitly concepts for this. These ontologies focus on the events realized along IP life-cycle and not on the relation among intentional agents created (or modified) by these events (here in reference to the concept of "relator" by (Guarino and Guizzardi, 2015)). The ALIS Ontology addresses a wide "IP Entity" classification, which is useful for characterizing "works of mind". PULO, Patent System Ontology, Patent Ontology, and Ontologies for IP Rights Protection stand out in application-specific concepts. These ontologies detail the structure of a patent document (the first three ontologies) and concepts related to piracy in the DRM domain (the last one).

In the context of this section, it is important to extend the discussion on the role of the (IP) ontologies and their inherent design aspects. In the literature and industry practice, we have seen different usages of ontologies from different perspectives, which influence the design choices on theoretical foundations, logical consistency, degree of formalization, and computational concerns. In fact, depending on the purpose of usage, some ontology requirements may conflict. Guizzardi (2007) and Falbo et al. (2013b,a) address these issues by discussing ontology generality levels, and by examining the trade-offs involved in the design of "reference ontologies" and "operational ontologies". Aligned to this view, we understand that, even though there may be ontologies for different purposes (e.g., for human being communication, or machine processing), there are fundamental aspects to the domain of study that need to be clearly stated in order to establish the inherent ontological commitments (see Section 2.3 for a discussion of these fundamental aspects of the IP domain.). Even operational ontologies that prioritize computational requirements should be grounded in a well-founded conceptualization — such as those provided by reference ontologies — otherwise, there is a risk of ending up with an ordinary (conceptual) model that lacks a clearly delineated ontological foundation. Guizzardi and Halpin (2008) state that in the "[...] conceptual modeling phase in ontology engineering, the main requirements for the resultant models [...] is domain appropriateness and comprehensibility appropriateness", to make the models truthful to the phenomena being represented, and that "[...] as important as sponsoring a well-founded philosophical position is to be explicit about which commitments are implied by this position". The authors reinforce that in this phase, ontology engineering is permeated by ontological questions that should be made by the ontology designer. In this way, (Koepsell, 2000) highlights that an IP ontology "[...] involves more than simply resolving the terms we use to classify objects". It "[...] must be something more than looking for a consensus regarding the usages of words". "Ontology may be useful for discovering the bases for categorizations such as those embodied by or undertaken in the law" (Koepsell, 2000).

Considering the analyzed ontologies, we observe that, despite their significant contributions, certain ontological aspects could be more clearly articulated or described. For instance, the Copyright Ontology provides a list of rights regulating actions over intellectual works; however, the nature of these (IP) rights is not explicitly defined. The Ontologies for IP Rights Protection include an interesting description of causal relations, represented through a UML-like activity diagram. Nevertheless, this ontology lacks a sufficiently rigorous definition of the concepts it addresses, which may lead to confusion. For example, "form" and "IP Lifecycle" are both represented as types of "IP Works": while the former suggests being an object, the latter denotes a process (that encompasses the following stages: creation, assertion, distribution, and usage). The ALIS IP Ontology offers a comprehensive list of types of works of mind. However, based on the analyzed text, we could not identify the aspects that differentiate one type of work from another. The authors also mention the use of LKIF Core (as a form of upper-level ontology), which incorporates the notions of "manifestation" and "expression". But these notions are not further elaborated in the analyzed study. The Intellectual Property Entities Ontology is described by the authors as being "[...] less elaborate than IPROnto in that it does not intend to express several related fields at once, such as both genesis and legal treatment of IP Entities". Consequently, this ontology does not offer ontological discussions of some IP concepts, appearing instead to focus mainly on implementation aspects. The Patent System Ontology focuses on the concepts and relations within the domains of patent documents and court cases. However, it does not provide a well-founded analysis of these concepts and relations. Instead, the resulting model resembles an informational model upon which some inference can be performed. Similarly, we have the Patent Ontology, whose focus is on implementation aspects for supporting interlinked patent data by means of standardized web technologies (e.g., RDF and SPARQL). The MPEG Intellectual Property Rights Ontologies introduce interesting aspects — for example, with respect to contracts. Nevertheless, in the analyzed texts, the emphasis lies more on presenting the concepts and relations of the ontologies and their formalization in OWL, rather than on discussing their ontological foundations. In particular, in the case of contracts, some ontological aspects could be explored in depth, especially due to their relation to rights over IP entities and to the (intentional) agents bound by contractual relations. We observed that the ontologies grounded on an upper-level ontology - Patent Upper Level Ontology, and IPR Ontology - provided a more detailed and structured foundation in the definition of concepts and relations, even though some aspects of these ontologies could require further in-depth analysis.

We naturally understand that the way ontologies were designed and presented in the analyzed texts also depends on their purpose of use, as well as their intended audience. In any case, it seems that by using upper-level ontologies, the ontology designer is confronted with a range of ontological aspects that would otherwise remain implicit or overlooked. Thus, we understand that using upper-level ontologies can serve as a way to bring foundational aspects to light. Nevertheless, we argue that beyond adopting upper-level ontologies as foundational theories, what matters most is asking the right ontological questions and making explicit the ontological commitments underlying the intended conceptualization. This can be achieved not only by reusing upper-level ontologies, but also by ensuring that the proposed concepts and relations are well-defined and consistently formalized (especially by using a consistent theoretical apparatus). Some authors of the analyzed ontologies (e.g., of the Intellectual Property Entities Ontology), however, point out that the choice of not using an upper-level ontology stems from the fact that it may increase the complexity of IP ontologies and make their management more challenging (e.g., maintaining logical consistency for machine-based reasoners while also ensuring comprehensibility for humans). We consider, however, that this is a design choice that favors operational aspects instead of "domain appropriateness" and "comprehensibility appropriateness" (using the terms of Guizzardi and Halpin (2008)). Refraining from addressing a well-founded ontology, albeit complex, may jeopardize clear communication among ontology users and hamper interoperability initiatives. Finally, the lack of explicit foundations hinders comparative analysis of (IP) ontologies.

6. Limitations of this study

Like any study, the study presented in this paper has some limitations, which must be considered together with the results. Some limitations are related to challenges we faced during the study, such as how to select a comprehensive and relevant source of publications, how to consistently apply the inclusion/exclusion criteria, how to classify data, and how to interpret them. Next, we discuss the main limitations of our study. When possible, we carried out actions aiming at minimizing their influence on the results. Publication selection and data extraction were initially performed by one of the authors. To minimize possible biases, data analysis and discussion involved the three authors, and potential discrepancies were discussed and solved among them.

Despite the rigor of this research, we must clarify that we do not consider it a systematic literature review (in terms of Kitchenham and Charters (2007)) because the search and selection activities are not entirely repeatable or auditable. We did not strictly control the publications excluded in each step. Instead, we have focused on the selected publications.

Although we have performed simulations in the digital libraries engine for defining the search string, terminological issues in the used search strings may have led to missing some studies. Thus, we cannot rule out that some valuable studies or newer versions of the analyzed ontologies may have been excluded from our analysis. Moreover, the sources used to collect publications can also affect the study's comprehensiveness. To minimize this threat, we used Scopus, which is a comprehensive digital library that indexes publications from several other sources, and we complemented it by using IEEE Xplore. To increase coverage and include publications from non-academic sources (e.g., organizations' websites), we also used Google Scholar. On one hand, this contributes to the study's coverage. On the other hand, the defined "stopping point" (i.e., the number of pages considered) may have caused us to miss relevant publications.

Another limitation is related to the classifications we made for categorizing data. Some categories were based on classifications proposed in the literature (e.g., IP branches). Others were established during data extraction, based on data provided by the analyzed publications (e.g., categories used in RQ8). Classification schemas and data categorization were done by the first author and reviewed by the other two authors. These categorization schemes are naturally subjective. Thus, different results could be obtained by other researchers.

7. Conclusions

This work presents an analysis and discussion of ontologies for the Intellectual Property (IP) domain. We have analyzed nine ontologies in the light of eight research questions, addressing who was involved in their development; the IP ontology application contexts; the addressed IP branch (copyright, industrial property, or both); the legal framework or jurisdiction adopted; the upper-level ontology used in the IP ontology design (if any); languages or formalisms used to represent the ontology; and the conceptual coverage of each ontology.

The main results of this study are summarized as follows: (i) the number of countries and researchers/organizations involved in the design of the ontologies is limited (nine countries), with the predominant participation of Spain and Italy; (ii) there has been a predominance of the DRM/multimedia application context, followed by the description of patent (document) information. Also, the ontologies were used for supporting standardization, data access and integration, system design, and legal compliance, among others; (iii) IP ontologies have focused on the Copyright branch, with 3 (three) ontologies addressing a limited part of the Industrial Property branch; (iv) there is a tendency in adopting general IP legal/regulatory frameworks at the expense of specific country laws/regulations; (v) there is also a tendency to focus on implementation aspects in the designing of ontologies, at the expense of a deep ontological analysis (and a clear ontological commitment establishment), representativeness and clarity of the (graphical) representation of conceptual models; (vi) only 2 (two) ontologies made usage of a top-level ontology explicitly (according Guarino's classification), despite we noticed in all ontologies some attention to general concepts typically found in upper-level ontologies (e.g., Agent, Object, Event, Legal Entity, etc.); and, finally, (vii) regarding conceptual coverage, the categories "IP Agent", "IP Right", "IP Entity", and "IP Life-Cycle Event" stand out as most frequently addressed. The IPR Ontology covers several categories, followed by the Copyright Ontology, PULO, and ALIS Ontology. Some ontologies (namely, PULO, Patent System Ontology, Patent Ontology, and Ontologies for IP Rights Protection) stand out by providing several application-specific concepts related to patent document description, and anti-piracy in the DRM domain. We can also highlight the ALIS Ontology, by its extensive set of "IP Entity" types, which, besides being based on a specific country law (IP French law), offers a valuable view on possible "works of mind."

Considering the study results, we identified as main opportunities: (i) to involve authors from a more varied set of countries in the development of IP ontologies, which should foster their universal application; (ii) to explore the usage of IP ontologies in several different application contexts, beyond those few ones identified in this work (e.g., in innovation management, teaching, system integration); (iii) to give further attention to the IP aspects related to Industrial Property; this includes the need to develop integrated conceptualizations that explicitly address both Copyright and Industrial Property branches together; (iv) to leverage foundational ontologies in the design of IP ontologies to support the investigation on the ontological nature of the elements in the intellectual property domain; and, finally, (v) to improve their representation and formalization, particularly, we believe the use of well-founded ontology modeling languages would be beneficial. These opportunities are part of our future research agenda.

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