Knowledge Representation Frameworks for Terminology Management in Cybersecurity: The OCS Project Use Case

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Abstract—Managing technical terms proper to specialized languages, represents one of the main tasks of Knowledge Organization Systems (KOSs). Cybersercurity domain contains a plethora of such terms, with a constant growth of new terms , which still need to be structured and organized from a semantic point of view. This paper aims at providing a presentation of KOSs for organizing specialized terminologies, specifically related to Cybersecurity, starting from a comparison between semantic resources presenting a higher level of semantic representation, i.e., thesauri and ontologies. To show their potentiality in the management of the Cybersecurity technical terminology, an outline of their application within a project carried out at the Institute of Informatics and Telematics of the National Research Council is described, and the distinction between them detailed in the conclusive discussion. A specific focus will be given to the more accurate description that ontologies are able to provide due to the way semantic relationships existing among terms and concepts belonging to a specific field of knowledge are formalized.

Keywords- Cybersecurity; KOS; Thesauri; Ontologies; Specialized language; Knowledge Representation.

I. INTRODUCTION

Managing technical terms proper to specialized languages, represents one of the main tasks of Knowledge Organization Systems (KOSs). In the context of KOSs, semantic resources, such as thesauri and ontologies, are useful to index documents and to help people during the information searching and retrieval from all types of information resources related to specialized domains, where semantic ambiguity between terms should be avoided. In this scenario, the paper is focused on presenting some of the main differences existing in the way of organizing and representing the information related to highly technical domains, in particular that of Cybersecurity. Amongst the KOSs [1] the comparison will focus on the two mentioned means of semantic knowledge configuration: thesauri and ontologies. The reason why these two types of resources have been selected among the others basically relies on one of the objectives of the *OCS Project* Cyber Security Observatory of the CNR Institute of Informatics and Telematics (IIT-CNR) [2], that will be presented in detail in Section IV. The project concerns the development of an Italian controlled vocabulary, in other words a thesaurus, for the Cybersecurity domain, and the enhancement of semantic connections and representation by exploiting a more interoperable

and formal language, i.e., the Web Ontology Language (OWL) [3] the recommended Semantic Web language for authoring ontologies.

Thesauri's main scope is that of structuring information and organizing it in a layered network of semantic connections, and its management and usability is piloted by KOSs functionalities [4][5]. As Soergel affirms in his work, "A thesaurus is a structured collection of concepts and terms for the purpose of improving the retrieval of information.A thesaurus should help the searcher to find good search terms, whether they be descriptors from a controlled vocabulary or the manifold terms needed for a comprehensive free-text search all the various terms that are used in texts to express the search concept" [6]. In managing information represented by terms proper to specialized language, a thesaurus should provide a reliable and a well structured semantic means to guide the understanding of technical terms representing concepts belonging to a specific field of knowledge. Its indexing function proves to be helpful in the way the users are able to analyze documents according to an informative organization of descriptors. In other words, the abstraction of knowledge occurs indirectly by exploiting terminological units that take on the status of descriptor or indexing unit. The latter is the element that language uses to describe, synthesize and extract information from documents [7].

Another relevant work to understand the aims and the methods for building a thesaurus is that of Broughton [8]. In this work, the author gives light to the main guidelines to develop a semantic tool through which technical concepts can be organized by means of hierarchical, equivalence and associative relations between the terms that represent them [9][10].

The way thesauri are structured follows standardized rules that should be respected, as the ones included in the ISO standards [11][12]. The interoperability of semantic resources, such as thesauri and ontologies, is given by the principle of linked open data [13][14][15], which guarantees a shareable knowledge organization system that can facilitate the coordination among several users for different terminological tasks. On the basis of the idea of generating a language that can guarantee a higher form of interaction between informative systems, without losing the exact meaning of the shared

information, the ontology seems to route towards a constant reuse of the managed information by providing conceptual representations of a domain [16][17]. The methods followed for building ontologies observe basic principles that can be found in the guidelines published by Noy and Mcguinness [18] or Bourigault [19].

The paper is structured as follows: Section II shortly gives an overview of main existing resources for Cybersecurity information management, both in English and Italian language. Section III includes related works focused on the construction of KOSs and on Cybersecurity. Section IV describes the construction of the Italian thesaurus for Cybersecurity and its enhancement through an ontological representation. Section V will provide a discussion about the main advantages derived from exploiting thesauri and the ontologies. Finally, Section VI sums up the key issues underlined in the paper giving some conclusions and providing some future perspectives.

II. STATE OF THE ART

One of the main purposes of this research activity is related to the creation of a semantic resource, a thesaurus, that can be considered as a reliable knowledge organization system that structures the information related to Cybersecurity in Italian language. Indeed, the basis from which the activity has taken inspiration was connected to the absence in Italian language of a highly semantically structured way to manage the terminology of this field of study. Some of the resources that have been taken into account to build a source corpus to be processed in order to obtain a list of representative terms are hereafter summarized.These terms synthesize the concepts belonging to a specific domain and they represented the starting model to realize the ontology for Cybersecurity based on the structure created for the Italian thesaurus. The ontology has been developed with the goal of representing the classes linked to each other through more precise properties that could, at times, specify the interconnections between them better than a flat visualization that belongs to a thesaural organization of terms.

Among the examples of Cybersecurity glossaries and vocabularies, of great importance are: for English, the ones contained in the NIST 7298 [20] and ISO 27000:2016 [21] standards for Information and Communication Technologies (ICT) security, and, for Italian, the Italian book ”*Libro Bianco*” (White Book for Cybersecurity) realized by the National Laboratory of Cybersecurity of the Consorzio Interuniversitario Nazionale per l'Informatica (CINI) [22], which thoroughly sheds light on the key issues related to Cybersecurity guidelines and on the latest related episodes that have changed the mode of conduct to defend informative systems and to conceive some specific concepts proper to Cybersecurity. Another relevant existing resource for Italian is the Italian ”Glossario Intelligence” [23], a technical glossary published by the Presidency of the Council of Ministers, which contains several terms belonging to the Cybersecurity domain and which has been used as basis for the creation of the Italian thesaurus and the ontology for Cybersecurity under investigation.

With respect to ontologies, it is worth mentioning the works targeted at the creation of ontology models for Cybersecurity, i.e., [24][25][26][27], and the studies focused on the approaches for developing an architecture for Cybesecurity standards [28] and enterprise's Cybersecurity metrics [29]. In particular, in [25] an ontology has been presented, which has been designed to integrate data from different heterogeneous sources, in the absence of a common terminology, offering a sufficiently complete knowledge on the possible threats, thus allowing Organizations to perform reasoning and support decision-making processes related to security.

III. RELATED WORKS

Processing the information belonging to specific domains of interest involves the analysis of those documents which semantically tend to represent concepts through a technical language [30]. The creation of terminological databases [30] follows some given criteria linked to gathering the related documents that have to constitute the reference corpus from which terms can be retrieved. To achieve this first informative structure, the corpus firstly aims at including documents that can represent the domain in an official way [31], i.e., the gold standards, [32] collecting a terminological standardized repository made up of terms that are meant to be closely specific to the technical field of knowledge under review [33]. To obtain a matching system between the terminology shared by a community of experts from a particular domain and the terms contained in a list derived from the processing of a reference corpus, the documents gathered in the corpus undergo a process of terminology extraction, which shall compare the equivalence between the representative terms of a domain with the ones of the gold standards [34].

This last step is usually implemented by exploiting semi-automatic term extraction tools. Nazarenko *et al.* [35] and Loginova [36] gave in their works detailed lists of several tools for extracting terminologies from texts. With regards to the Cybersecurity domain and the research activity treated in this paper, various existing sources, both in English and in Italian, have been analyzed in order to retrieve an accurate terminological basis from which to build a more sophisticated semantic resource to guide the knowledge representation process. The intent of this project task, as aforementioned, is to provide an Italian structure, firstly conceived as a thesaurus, to configure the terminology of Cybersecurity in a network of semantic relations that can better orientate to a lexical understanding of specialized concepts represented by terms belonging to this field. The goal of this research activity is also based on the reuse of the terms contained in the thesaurus to realize in a consequential way an ontology system that could support the inclusion of customized properties between classes and more comprehensively clarify the associative relationships of the thesaurus. This represents the reason why ontologies can be usually considered as resources that can provide a more exhaustive and explicit frame for knowledge representation.

IV. THE OCS PROJECT

In this Section the project case will be presented. The activity regarded the creation of a thesaurus in Italian language as a semantic tool to organize the terminology on the Cybersecurity domain. The thesaurus has been inserted amongst the services of the online platform Cyber Security Observatory (OCS) [37].

A. The Cybersecurity context

As previously mentioned, the Cybersecurity domain is mainly characterized by a technical terminology. Given that Cybersecurity is a synergy of different sub-fields, the schematising of this specialized field reflected this high level of heterogeneity. Cybersecurity is permeated by its multidisciplinary nature that involves Information and Communication Technologies (ICT) and its sub-areas, such as, audiovisual techniques, computer software, electronics, by its specificity with respect to technical and standardized terms, and by its cross-fielding thematic coverage, i.e., computer science field, legislative systems, regulations. Given these premises, the treatment of its internal language, that derives from the textual content extracted from the source corpus documents, is meant to be managed by formal semantic systems in order to obtain shareable standardized lists of the domain's representative terms organized according to their semantic relations, which, in turn, will orientate the understanding of the conceptual model of the domain [38].

B. The Italian thesaurus for Cybersecurity

The main focus of this paper is the creation of a semantic tool for the Italian project *Cyber Security Observatory* (OCS) [37], carried out in collaboration with the Institute of Informatics and Telematics of the National Research Council. During this task, while seeking a resource that could represent the Cybersecurity terminological framework and could be used as a service for experts and common users, some of the key differences between thesauri and ontologies in the management and organization of highly technical information and language arose.

Firstly, the choice to privilege a thesaurus structure instead of other semantic resources, such as glossaries or taxonomies, relies on its peculiarity of managing the representative terms of a specific domain as an entangled network of semantic relations that guide the comprehension of a conceptual model proper of a field of knowledge to be studied [8]. In order to obtain the knowledge organization with respect to a structuring system as provided by a controlled vocabulary, i.e., a thesaurus, several guidelines need to be observed [11][12]. These aforementioned standards depict the way the terms, that represent the concepts of a specialized domain, should indicate a unique and an unambiguous meaning (through the use of scope note, SN) and should be connected to each other. As mentioned in Section I, three main basic forms of connections are generated for structuring the information under the basis of thesaurus's modelling [39]:

1) Equivalence relation, marked with the tags *Used (USE)* and *Used For (UF)*

2) Hierarchical relation, marked with the tags *Broader Term (BT)* and *Narrower Term (NT)*;

3) Associative relation, marked with the tag *Related Term (RT)*.

The methodology followed for the realization of the Italian thesaurus for Cybersecurity covered classical sequences. As primary step, the terminology contained in the thesaurus has been extracted from reliable sources which made up the corpus characterized by documents distinctively selected for their content oriented to Cybersecuritity issues [31]. This collection of texts made the information retrieval highly oriented to the domain to be represented [40], and covered different types of documents, such as standards and laws [41], Cybersecurity-related magazines or guidelines and certifications. The conceptual content of these documents was meant to be processed to obtain lists of terms (a glossary) sorted according to statistical measurements able to provide a first semantic schematization [42]. Indeed, the second phase concerned the semi-automatic processing of the information included in the source corpus by exploiting a term extractor software [36] (more specifically the Italian native tool, Text to Knowledge (T2K)) [43] that provided, as outputs, lists of terms ranked according to their occurrence's value in the texts.

Only once having received the validation by the experts of the domain, i.e., the third phase of the methodology, the terms have been selected as candidate terms to be integrated in the thesaurus and their semantic relations with other terms belonging to the domain and deriving from the corpus have been created. The current thesaurus in Italian language contains 245 candidate terms, already validated and mapped to the taxonomies contained in the main gold standards for Cybersecurity, i.e., NIST 7298 [20] and ISO 27000:2016 [21] together with domain experts collaborating on the project. The alignment with the terms contained in the standards for ICT security granted a coordination between the knowledge shared by an international Cybersecurity community of experts and the one represented in the structured thesaurus, which are preferred terms selected amongst those extracted by T2K as the most frequent. In order to carry out a matching configuration with the standards as predictable and stable as possible, the terms included in the standards, and selected with the support of domain experts as key elements representing the domain, have been translated using the Interactive Terminology for Europe (IATE) term banks [44]. This is considered an important step given the instructive purposes of the application that the thesaurus would have had in the web portal of the Cybersecurity Observatory. The first main entries in the Italian thesaurus for Cybersecurity are four categories finely selected from the glossary including the frequency of terms and from the mapping with the standards alongside the approval by the domain experts. These macro categories are:

- Cybersecurity;
- Cyberdefence;
- Cyberbullism;
- Cybercriminality.

Almost each of the candidate terms included in the thesaurus network, generated by the semantic relations among the terms, are accompanied by their definitions, i.e., *Scope Note (SN)*, which helps in understanding the terms in their specific contexts giving their definition taken from the source documents [45].

For a better understanding of the terms in the Italian Thesaurus for Cybersecurity, Table I gives a metrics of the numbers of terms, as well as of the semantic relations:

TABLE I. FEATURES OF THE ITALIAN THESAURUS FOR CYBESECURITY

	Terms	Semantic Relations	Non-preferred Terms	Scope Notes
Total	246	280	33	74

C. Ontology enhancement

Another activity of the OCS project has also been focused on the migration of the thesaurus into a more formal semantic resource, i.e., an ontology, to better organize and represent the information about Cybesecurity and addressed to users who want to get closer to this field of knowledge. The formalization of a thesaurus into an ontology is a task that in the last ten years has attracted much interest. In fact, in the literature different approaches are proposed for reusing thesaurus semantic content to build ontology meta-models and to populate knowledge bases in different domains, see for example [46][47][48].

The need for migrating the content included in the thesaurus to an ontology lies in the decision to better clarify the associative relationships between the terms of the thesaurus. In particular, the flat modality in which associative relationship between terms is represented in the thesaurus, i.e., via the RT relation, turned out to be not fully satisfactory in the seek of getting a complete terminological outline for Cybersecurity.

As shown in Figure 1 and Figure 2, there is a clear distinction between the two systems used to organize and represent the terminology belonging to the Cybersecurity domain. The example taken into account to represent the differences is referred to the semantic relationship linked to the idea of opposition, i.e., *Spoof* and *Antispoof*: in the thesaurus, even though a definition is present (within the black square), which corresponds to the *SN*, proper to thesauri, giving many details on the context from which terms come from, the "opposition" is not so well represented because it is only shown through the associative relation (*RT*) between these aforementioned terms without giving other explications on the way the two terms are related as the OWL language does.
the other hand, in the ontology, these two concepts are connected through the *ObjectProperty* "HasAsContrary" that helps in considering the *Domain* and the *Range* as linked by a precise relationship. 38304480

Another representative case is depicted by Figure 3 and Figure 4 that show how a thesaurus sometimes gives a weak

Fig. 1. Thesaurus representation of the semantic relationship that describes opposition
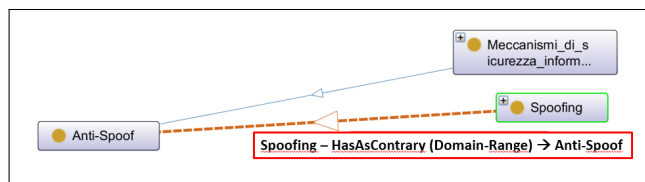

Fig. 2. Protégé representation of the semantic relationship that describes opposition

visualization of some attributes associated to a concept.

In the following case, the relation that had to be provided was related to several attributes that security properties proper to informative systems own. For this specific purpose, the ontology resource gives more advantages in the visualization of the informative structure allowing a higher accurate organization and representation of the attributes related to the concepts. In detail, the main difference that makes ontologies a good semantic means to represent the conceptual model connected to certain semantic classes is related to the fact that, in this case, the security properties, i.e., integrity, authenticity, confidentiality, availability, reliability, non-repudiation, and privacy, are represented as *Data Properties* and are conceived as attributes. In the thesaurus, as shown in Figure 4, they are related to the *BT* "Data" and are represented as its specific terms, i.e., the *NT* [11].

To give an idea of the content of the ontology derived from the Italian Cybersecuirty Thesaurus, Table II above shows some metrics and highlights the changes in the number of the relationships and concepts and the number of axioms with respect to the results shown for the thesaurus in Table I.

V. DISCUSSION

Although thesauri and ontologies belong to the same family of knowledge organization systems and some of their functionalities are the same (e.g., their use for improving information retrieval, indexing, and knowledge organization) they are built for different purposes. In fact, it has been demonstrated in this contribution that ontologies allow for a more formal representation of knowledge for a given domain, by providing explicit relationships between concepts, disjunctions, applying data properties for each concept or instance and by providing
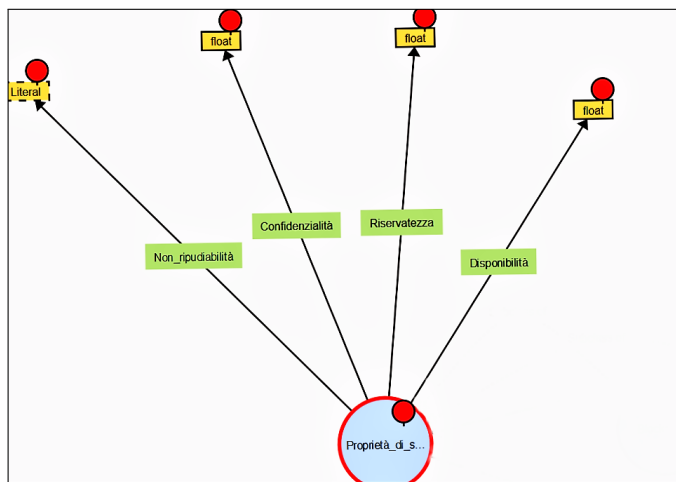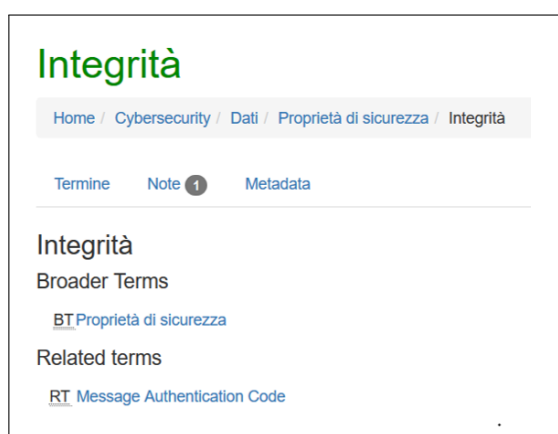
Fig. 3. WebVOWL representation of Security properties as *Data Properties*

Fig. 4. Thesaurus representation of Security properties as hierarchical relations

TABLE II. CYBERSECURITY ONTOLOGY METRICS

Metric	Total
Axiom	640
Logical axiom count	316
Declaration axioms count	233
Class count	157
Object property count	37
Data property count	7
Individual count	31
Annotation Property count	5
CLASS AXIOMS	
SubClassOf	58
EquivalentClasses	0
DisjointClasses	24
OBJECT PROPERTY AXIOMS	
SubObjectPropertyOf	7
InverseObjectProperties	1
FunctionalObjectProperty	1
TransitiveObjectProperty	0
SymmetricObjectProperty	1
AsymmetricObjectProperty	0
ObjectPropertyDomain	40
ObjectPropertyRange	39
DATA PROPERTY AXIOMS	
SubDataPropertyOf	1
DataPropertyDomain	8
DataPropertyRange	5
INDIVIDUAL AND ANNOTATION AXIOMS	
ClassAssertion	31
AnnotationAssertion	89

restrictions that avoid ambiguity in the representation of the meaning and the context of use of a concept and their terms in the domain of reference. Nevertheless, the two semantic resources can be used together or, as widely demonstrated both in this paper and in the literature, one can be reused to build or populate the other, thus they complement each other, improving the end user's search experience.

The natural structural rigidity of thesauri, given by the use of *a priori* defined semantic relationships (hierarchical, associative and equivalence), seems to be a point against these type of controlled vocabularies; by contrast, such weakness seems to be overcome by the flexibility, scalability and reusability of ontologies that, as stressed by the semantic staircase of Blumauer and Pellegrini [49], compared to other KOSs, bring to a highest level of semantic richness thanks to an internal formal description of concepts. This latter combines a system of relations and properties of the concepts themselves.

Despite this, one of the strengths of the thesaurus compared to the ontology, when used in a specialized domain, is its greater capacity to eliminate ambiguity between the terms through the use of synonymy control [1] and the choice of pre-

ferred terms, compared to non-preferred terms for representing the concepts. This guarantees a standardization of technical terms in specialized domains, which can help in the process of unifying, and thus sharing, a specific field of knowledge's terminology.

VI. CONCLUSION

This paper aimed at presenting two different types of KOSs, i.e., thesauri and ontologies, exploiting their use and feasibility to organize and manage the specialized terminology proper to the Cybersecurity domain. Beginning from a general overview of Knowledge organization and representation systems, the analysis focused on the way the thesaurus, in particular, has proved to be a reliable system to structure the information derived from heterogenous sources belonging to the Cybersecurity domain, which is full of technical terms. Concurrently, attention has also been given to the comparison between the modality of representing in the thesaurus some of the relationships existing among terms, that represent the relevant concepts of the domain, with the ones proper to ontologies and the OWL language. The perspective has been oriented to provide a demonstrative outline of ontology peculiarities and advantages when using an existing thesaurus, like the one created in the Italian OCS project framework, as a basis for building the meta-model and populating the knowledge base. Being the presented activity a work in progress, in the near

future both the thesaurus and the knowledge base in OWL will be extended with more terms, relationships and restrictions where needed, and a new evaluation will be executed. Among the future works there will be a translation in another language (firstly English) to allow, within the OCS project team, the recognition of threats even from non-Italian sources and improve the thesaurus/ontology usability and sharing also at an international level. Moreover, the remainder of this work targets also at taking into account the insertion of several other types of documents to be part of the source corpus. In particular, following the perspective of getting updated on the changes related to the Cybersecurity domain, documents shall be taken from the social media world, adjusting all the analysis related to the processing of information to the treatment of texts written in a specialized form.

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