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Ontology for Data Integration in Honeynet

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Abstract

This study presents the development of an ontology for data integration in honeynets in relation to the aspects of data collection and data mapping. The open source tool Protégé was used to develop the ontology using methontology as the methodological basis. The ontology was validated through an experiment conducted by experts, which used several indicators: necessary terms, identified concepts, relations utilised, taxonomy, properties, instances, constants, dictionary of concepts, ad hoc binary relations, instance attributes, class attributes, axioms, and rules; in addition, it identified potential errors.

Keywords: Ontology, Honeynet, Methontology, Data Integration, Ontology Validation

Introduction

An ontology defines the basic terms and relations of the vocabulary of a specific area as well as the rules for combining these terms and relations for the purpose of defining vocabulary extensions (Neches et al, 2012).

When the knowledge of a domain is represented by a declarative formalism, the set of objects that can be represented is called the universe of discourse(Lima, 2021). This set of objects and the relationships established among them are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. The definitions associate the names of entities of the universe of discourse with human-readable text that describes what the names mean and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an ontology is a logical theory (Gruber, 1993).

An ontology is "a formal and explicit specification of a shared conceptualisation" (Gruber, 1995).

Conceptualisation refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon (Studer et al, 1998).

In addition, an ontology is viewed as a particular system of categories that accounts for a certain vision of the world (Guarino, 1998), and as a representation of a conceptual system through a logical theory (Guarino et al, 1995).

The type of ontology to develop depends on the criteria of the type of knowledge content, especially the task ontologies, which establish how the domain knowledge can be used to perform certain tasks (Mizoguchi et al, 1995).

An ontology can be used in any area of knowledge, and in our case, it is a specific system to study honeynets for data integration, thus establishing a categorical structure of reality.

A honeypot is defined as a security resource whose value lies in being probed (Spitzner, 2003). A honeypot is a tool that serves as a decoy to attract attackers and deceive them into thinking that they have gained access to a real system (Franco et al, 2021). A honeynet is simply a network that contains one or more honeypots (Yang et al, 2011). A honeynet is a high-interaction honeypot that is designed to be attacked with the actual intention of providing extensive information on threats; it provides real systems, applications, and services for attackers to interact with and detects new malicious attempts (Tiwari et al, 2012)(Luna-Encalada, 2021).

Intrusions and attacks via the internet have increased substantially over the past few years; consequently, the concept of a honeypot has evolved into the idea of a honeynet, which is a network placed behind a firewall that captures all of the incoming and outgoing traffic (Levine et al, 2003)(Lozada, 2018).

A honeynet is a security tool that is designed to be probed, attacked and compromised. (Sokol et al, 2017). It consists of several monitoring mechanisms and a set of systems that are prepared to receive attacks; additionally, there are additional tools configured to capture and analyse intrusions (Kumar, 2017)(Lozada-Yánez,2022). The data is mapped with the purpose of having, in a single centralised database, all of the information for decision making in a single format(Molina-Granja, 2018); this approach allows better control over the data that is collected by various means. Data integration has been an important research area in data management (Doan et al, 2017).

There are studies on the use of ontologies for data integration such as the one by (De Giacomo et al, 2018), focused on a specific paradigm for semantic data integration, called ontology based data access (OBDA). The work of (Alizadeh et al,

2019), considers ontology as a practical tool to conceptualize the information that is expressed in computer format. (Gagnon et al, 2007) Proposes an information integration ontology with ontological mapping as an approach for the integration of heterogeneous data sources(Molina-Granja, 2022).

This heterogeneity problem can be tackled by integrating existing ontologies to build a single coherent one (Osman et al, 2019).

The main objective of this work is to develop an ontology for the integration of data in a honeynet, with the purpose of capturing intrusions from the different tools, mapping the data, in order to integrate the captured data and centralize all the data, such as shown in Fig. 1, in this way there is better administration and control over the data collected by the different tools, improving analysis time and decision making.

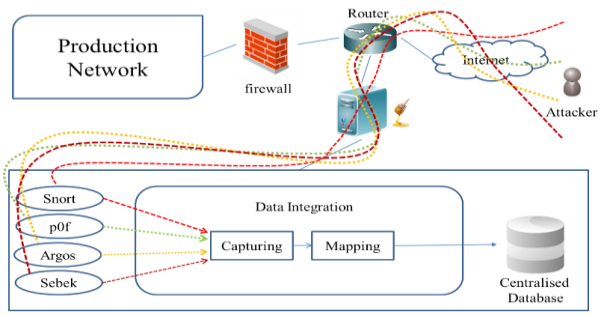

Figure 1 *Ontology Domain*

This paper is organised as follows: First, the definitions of an ontology and honeynet are provided in section 1 along with an introduction. The methodology used to elaborate the ontology is established in section 2, and the ontology for data integration in honeynets is described in section 3. The validation of the ontology is described in section 4. Finally, the conclusions of the study are discussed in section 5.

Ontology Elaboration Methodology

The most important studies that describe how to develop ontologies from a methodological perspective are, among others, those by (Uschold et al, 1995).

The ontology was developed using the methontology methodology, which was developed in the Artificial Intelligence Laboratory of the Technical University of Madrid (Fernández-López et al, 1997). It has its roots in the activities identified by the IEEE for the software development process (Corcho, 2005).

Methontology provides guidelines on how to develop ontologies through specification, conceptualisation, formalisation, implementation and maintenance activities, as shown in Figure 2.

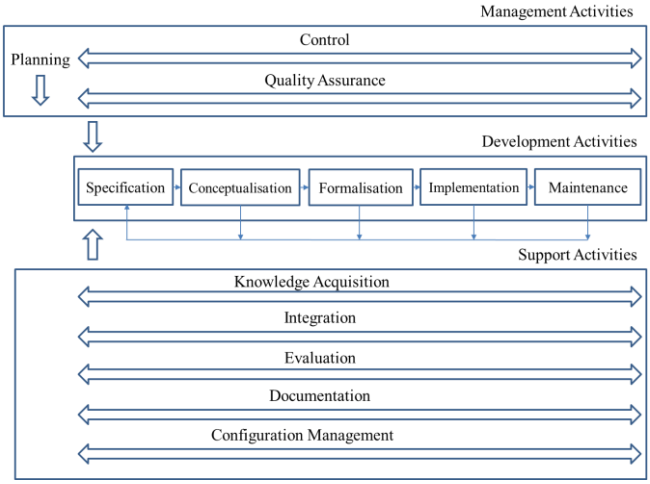

Figure 2 *Ontology development activities proposed by methontology (Corcho, 2005).*

Each of these activities is briefly described below:

The specification activity determines why the ontology is being developed, what its use will be, and who its end users are.

The conceptualisation activity organises and converts an informal perception of the domain into a semi-formal specification using a set of intermediate representations, which are based on tabular and graphical notation that can be easily understood by domain experts and ontology developers. This activity produces the conceptual model of the ontology.

The formalisation activity is responsible for the transformation of the conceptual model into a formal or semi-computable model.

The implementation activity builds computable models in an ontology language, and most ontology tools allow users to conduct this activity automatically.

The maintenance activity is responsible for updating and/or correcting the ontology, if necessary.

Methontology also identifies management activities (planning, control, and quality assurance) and support activities (knowledge acquisition, integration, evaluation, documentation, and configuration management).

Below are the conceptualisation tasks of the methontology methodology.

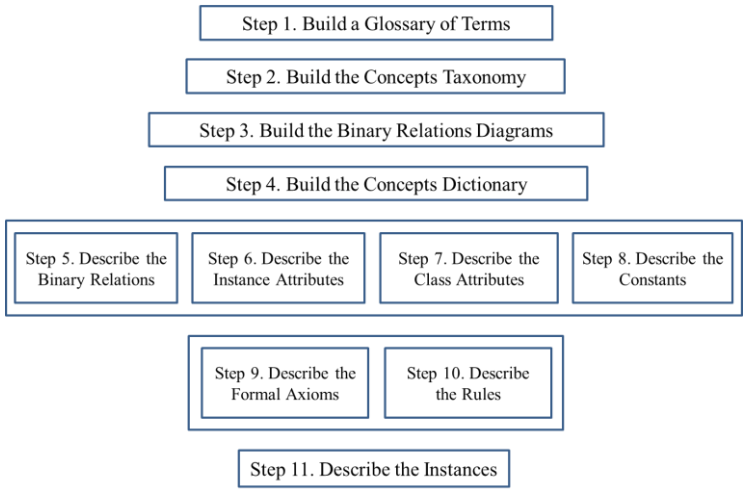

Figure 3 *Tasks of the methontology methodology (Corcho, 2005).*

Ontology for Data Integration in Honeynets

The development of the ontology for data integration in honeynets using methontology as the working methodology is described below.

Build a Glossary of Terms

All of the terms that are necessary for the construction of the ontology for data integration in honeynets are presented; these will be the basis of the technical information for the elaboration of the ontology for data integration in honeynets.

Build the Concepts Taxonomy

Once the glossary of terms has enough terms to start the ontology diagram, the taxonomies of the concepts that define their hierarchy in the construction process of the ontology for data integration in honeynets are built.

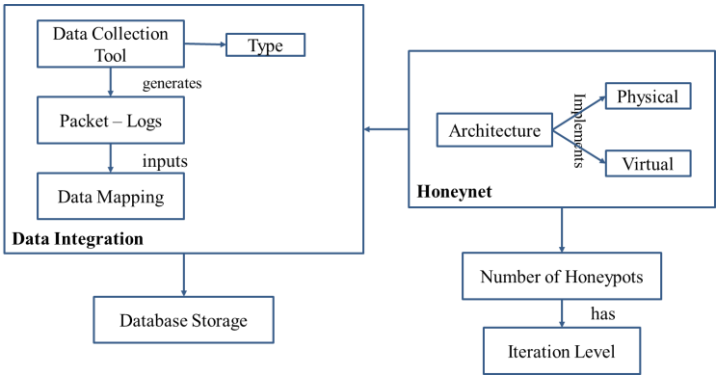

Figure 4 *Section of the Concepts Taxonomy of the ontology for data integration in honeynets.*

Build the Binary Relations Diagram

The conceptualisation activity is intended to build a diagram of ad hoc binary relations. The objective of this diagram is to establish the existing ad hoc relations between the concepts of the same taxonomy or of different concept taxonomies of the ontology for data integration.

Build the Concept Dictionary

Once the concepts taxonomies and ad hoc binary relations diagrams have been generated for the ontology for data integration, then those properties that describe each taxonomy concept, as well as the relations identified and the instances of each concept, are specified.

Table 1 *Part of the Concepts Dictionary section of the ontology for data integration in honeynet.*

Concept Name	Instances	Class Attributes	Instance Attributes	Relations
Honeynet	Design	Type of Monitoring	Number of Honeypots	contains
Architecture	Implementation	--	Generation	implements
Architecture – Physical	Implementation	--	Operating Level	establishes
Architecture – Virtual	Implementation	--	Operating Level	establishes
Honeypots	Configuration	Type of Monitoring	Iteration Level	establishes
Data Integration	--	--	Types of Data	--
Data Collection Tool	Configuration	Type of Installation	Type of Tool Name	generates
Packet – logs	Integrating	--	Type of Configuration	inputs
Data Mapping	Developer	--	Time	--
Database Storage	Administrator	--	Capacity	--

Binary Relations Description

All ad hoc binary relations identified in the binary relations diagram and included in the concepts dictionary must be described in detail.

Table 2 *Part of the table of the Binary Relations section of the ontology for data integration in honeynet.*

Relationship Name	Origin Concept	Maximum Cardinality	Destination Concept	Inverse Relationship
Proposal	Honeynet	N	Data Integration	is considered
Genera	Data Collection Tool	N	Packet – Logs	are generated
Inputs	Packet – Logs	N	Data Mapping	are entered
Network environment	Architecture	N	Physical	platform
Network environment	Architecture	N	Virtual	platform
Group	Honeynet	N	Number of Honeypots	characterises
Directs	Data Integration	N	Database Storage	originates from

Describe the Instance Attributes

All of the instance attributes included in the concepts dictionary are described in detail. Each row in the table contains a detailed description of an instance attribute.

Table 3 *Part of the Instance Attributes table section of the ontology for data integration in honeynet.*

Name of the Instance Attribute	Concept	Type of Value	Value Range	Cardinality
Number of Honeypots	Honeynet	Integer	1..	(1, N)
Generation	Architecture	String of Characters	--	(1, 1)
Operation Level	Architecture – Physical	String of Characters	--	(1, 1)
Operation Level	Architecture – Virtual	String of Characters	--	(1, 1)
Iteration Level	Honeypots	String of Characters	--	(1, 1)
Type of Data	Data Integration	String of Characters	--	(1, N)
Tool Type Name	Data Collection Tool	String of Characters	--	(1, 1)
Type of Configuration	Packet – Logs	Integer	1..	(1, N)
Time	Data Mapping	String of Characters	--	(1, N)
Capacity	Database Storage		--	(1, N)
Process Monitoring Results	Agent	String of Characters	--	(1, 1) (1, N)

Describe the Class Attributes

All of the class attributes included in the concepts dictionary are described in detail. For each class attribute, the developer of the ontology must provide the following information: attribute name, name of the concept where the attribute is defined, and type of value.

Table 4 *Section of the Class Attributes table of the ontology for data integration in honeynet.*

Class Attribute Name	Concept	Type of Value
Type of Monitoring	Honeynet	String of Characters
Type of Installation	Data Collection Tool	String of Characters
Type of Control	Intrusion	String of Characters
Type of Blocking	Firewall	String of Characters

Describe the Constants

The objective of this task is to describe in detail each of the constants identified in the glossary of terms.

Table 5 *Section of the Constants table of the ontology for data integration in honeynet.*

Name	Value Type	Value	Unit of Measure
Bandwidth	Numeric	320 Mbps	Bps
Firewall outside address	32 bit binary	190.15.135.2	
Channel capacity	Numeric	1000 MHz	Hz

Describe the Formal Axioms

The formal axioms that are required in the ontology for data integration are identified and described with precision. For each formal axiom definition, the methontology approach suggests specifying information such as the following: the name, description in natural language, Boolean expression that formally defines the axiom using first-order logic, and the concepts, attributes, and ad hoc relations used in the axiom as well as the variables used.

Table 6 *Section of the Formal Axioms table of the ontology for data integration in honeynet.*

Axiom Name	Description	Expression	Concepts	Relations	Variables
Log generation	All data collection tools generate packet – log	(exists(?X,?Y) (data collection tool?X) and generates (packet_log?Y)	Data collection tool packet – logs	Generates inputs	?X ?Y
Log storage	Logs are stored in a database	(stores(?Y, ?Z) (packet_log?Y) and stores(database ?Z)	Packet – logs database storage	Inputs	?Y ?Z
Data integration using the logs collected	Data integration is performed on all packet – logs stored in the database	(exists(?Y,?Z,?I) (packet_logs?Y) and stores(database?Z) and integrates(data integration?I)	Data integration packet – logs	Integrates	?Y ?Z ?I

Describe the Rules

Here, the rules that are required in the ontology for data integration that will be described in the rules table are identified. For each rule, the methontology suggests the following information: the name, description in natural language, expression that formally describes the rule, and concepts, attributes, and ad hoc relations used in the rule as well as the variables used. The expressions of the rules are specified using the format if < conditions > then < consequence >. The left side of the rule is a combination of simple conditions, while the right side is a simple expression of a value of the ontology.

Table 7 *Section of the Rules table of the ontology for data integration in honeynet.*

Name of the Rule	Descriptions	Expression	Concepts	Attributes	Relations	Variables
Automatic negotiation	The speed of the port between the device and the host is negotiated and at the lowest speed	If [port speed](?X) and device speed (?Y) and ?X > ?Y then negotiate [device speed] (?Y) otherwise negotiate [port speed] (?X)	Port of the unit Device	Speed	Negotiate	?X ?Y
Protection web server enables port 80	Only port 80 is enabled for security in a web server	If [web server](?A) and port(?B) and ?A => 80 then protected [web server](?A)	Web server Port	Port number	Enable	?A ?B=80
TCP attack (connection)	Establish a threshold for SYN attack protection	If [protection threshold] (?U) and Connections TCP(?C) and ?U > 200 connections per second then an attack has occurred	Threshold connections TCP attack	Number of connections	Define	?U ?C=200 connections per second
Jumbo frames	Discard packets larger than the allowed frames	If [packet size](?P) and Frame size allowed (?T) and ?P > 1500 bytes then Jumbo Frames are enabled, and the packet is discarded	Allowed frame data packet jumbo frames	Packet size Frame size	Allow	?P ?T=1500 bytes

Describe the Instances

Once the conceptual model of the ontology for data integration is created, the instances that appear in the concepts dictionary can be defined.

A preliminary set of classes developed for the representation of data integration in the honeynet corresponds to those seen in the Protégé editor in Figure 5.

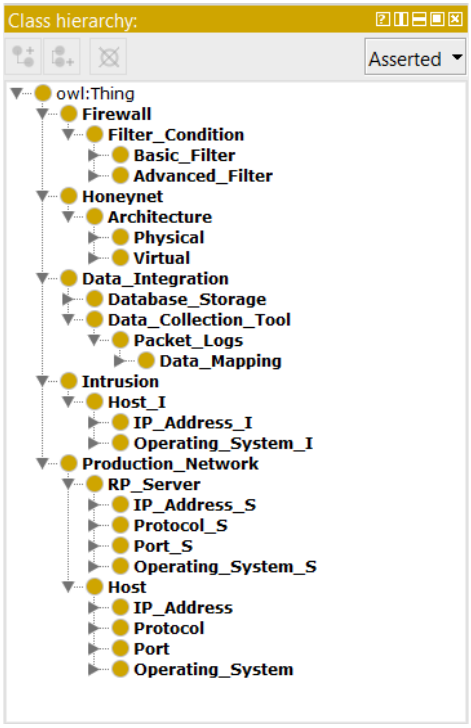

Figure 5 *Classes and sub-classes of the ontology for data integration in honeynet*

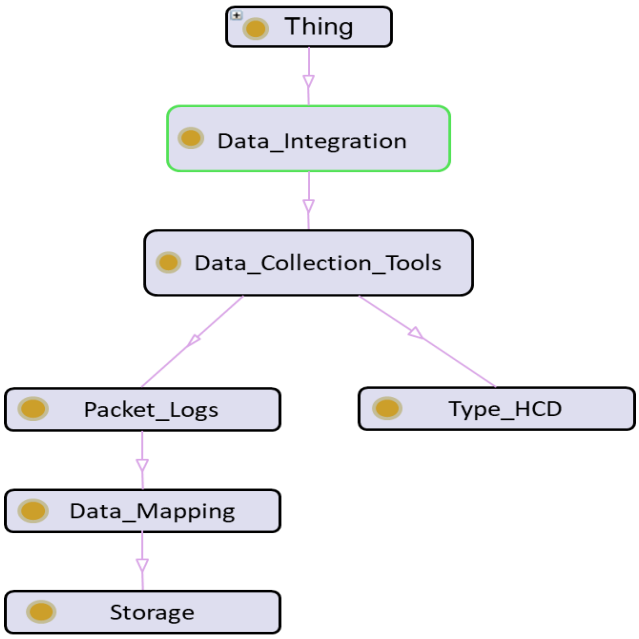

Figure 6 *Fragment of the data integration hierarchy*

The main classes of the ontology for data integration in honeynets are described below:

One of the issues encountered in the honeynet is the integration of data from the different tools that were configured since each tool generates its own logs, which must be interpreted individually by the network administrator. The goal is to have a single centralised log that collects the data generated from the tools to enable decision making.

The tools used for data collection are snort, P0f, Argos, and Sebek. These tools are used for monitoring the access to the network with the purpose of capturing the behaviour of the intruder within the honeynet.

The packet logs are the result of each data collection tool; their header information was analysed to integrate each of those log files into a centralised log.

The purpose of data mapping is to match a couple of entities to transform data from one format to another. (De Giacomo et al, 2018).

Data storage consists of having all of the information collected from the honeynet in a centralised database to manage the network adequately and make decisions.

Validation

The ontology for data integration in honeynet was validated with the assistance of 12 experts who participated in the experiment and are specialists in the field of network security with expertise in ontology development. These experts were surveyed after they reviewed and used the ontology for data integration in honeynet. The survey had two groups of questions. The first group of questions aims at complying with the aspects that methontology determines in the ontology for data integration in honeynet: the terms required, identified concepts, relations used, taxonomy, properties, instances, constants, concepts dictionary, ad hoc binary relations, instance attributes, class attributes, axioms, and rules.

The second group of questions is intended to identify potential errors that will be detected after the evaluation of the ontology with regard to the location error, distribution error, semantic inconsistency error, class and incomplete classifications error, disjoint knowledge omission error, exhaustive knowledge omission error, redundancy error, error due to poor specification or delimitation of properties of the system components, error due to incompleteness in the declaration of labels, and error due to incorrect knowledge description.

The statistical method used to validate the ontology is Kendall's coefficient of concordance (W), which measures the degree of concordance or association that individuals have in relation to k variables and has values between 0 and 1. W values that are close to 0 indicate total disagreement between individuals, while values close to 1 indicate total agreement. If the experts were fully in agreement, then the range assigned to the values of one of the key characteristics would systematically be equal to 1, and the range assigned to a second characteristic would systematically be equal to 2, and so on. Consequently, the averages of the ranges of the n key characteristics would be equal to 1, 2, …, n. Conversely, if the experts were completely discordant, then the averages of the ranges of the n key characteristics would be approximately equal to one another.

The proposed hypothesis is the following:

H_0: There is no agreement among experts
H_1: There is agreement among experts

Despite the Kendall's W statistic, the significance of this statistic determines whether the null hypothesis is rejected or not. If the significance of the statistic is greater than the pre-set alpha level of 0.05, then the null hypothesis is accepted, and it will be rejected if the significance is less than or equal to the alpha level.

The analysis of the statistical results of the first group of questions shows that the question with more disagreement is number 5 (The taxonomic system used for the development of the ontology is clear, consistent, flexible, comprehensive and practical), since its average is

2.58, and consequently, based on the recommendations of the experts, appropriate measures were taken to improve this parameter.

Table 8 *Descriptive statistics – Methontology aspects*

	N	Average	Standard deviation	Minimum	Maximum	Range
All terms necessary for the construction of the ontology are present.	12	2.67	.492	2	3	6.29
The (identified) concepts used in the ontology are adequate.	12	3.00	.000	3	3	8.79
The relations used in the ontology represent a type of association between concepts of the domain.	12	3.00	.000	3	3	8.79
The taxonomies used in the ontology construction process establish the concepts that define their hierarchy.	12	2.83	.389	2	3	7.54
The taxonomic system used to develop the ontology is clear, consistent, flexible, comprehensive and practical.	12	2.58	.515	2	3	5.67
The properties that describe each concept of the taxonomy are specified in the development of the ontology.	12	3.00	.000	3	3	8.79
All instances are identified in the ontology.	12	2.83	.389	2	3	7.54
Do you agree with the constants (numerical values that do not change over a prolonged period of time) used in the ontology?	12	3.00	.000	3	3	8.79
All concepts of the domain, its relations, instances and class and instance attributes are included in the dictionary of concepts.	12	3.00	0.00	3	3	8.79
All ad hoc binary relations are described in detail in the binary relations diagram and included in the dictionary of concepts.	12	2.92	.289	2	3	8.17
All instance attributes included in the dictionary of concepts are described in detail.	12	2.92	.289	2	3	8.17
All class attributes included in the dictionary of concepts are described in detail.	12	3.00	0.00	3	3	8.79
The formal axioms used in the ontology are Boolean expressions that are always true to define constraints in the ontology.	12	3.00	0.00	3	3	8.79
The rules used in the ontology are used to infer knowledge.	12	2.67	.492	2	3	6.29

The fact that the significance of Kendall's W (0.001) is less than or equal to the pre-set alpha level is evidence in favour of the alternative hypothesis, and therefore, there is agreement among the experts.

Table 9 *Test statistics – Methontology aspects*

N	12
Kendall's W[a]	.218
Chi-square	36.650
Degrees of freedom	14
Asymptotic sig.	.001

With regard to the second group of questions, the question that has more disagreement is number 2 (distribution error) since it has an average of 2.67; this finding suggests that this average could be improved to avoid the distribution error.

Kendall's coefficient of concordance

Table 10 *Descriptive statistics – Identification of potential errors*

Do you consider the following errors to be discarded?	N	Mean	Standard deviation	Minimum	Maximum	Range
Location error	12	3.00	.000	3	3	5.92
Distribution error	12	2.67	.492	2	3	4.25
Semantic inconsistency error	12	2.83	.389	2	3	5.08
Class and incomplete classification error	12	3.00	.000	3	3	5.92
Disjoint knowledge omission error	12	2.92	.289	2	3	5.50
Exhaustive knowledge omission error	12	3.00	.000	3	3	5.92
Redundancy error	12	2.75	.452	2	3	4.67
Error due to poor specification or delimitation of properties of the components of the system	12	3.00	.000	3	3	5.92
Error due to incompleteness in the declaration of labels	12	3.00	.000	3	3	5.92
Error due to incorrect knowledge description	12	3.00	.000	3	3	5.92

The fact that the significance of Kendall's W (0.018) is less than or equal to the pre-set alpha level is evidence in favour of the alternative hypothesis, and therefore, there is agreement among the experts.

Table 11 *Test statistics – Potential errors identification*

N	12
Kendall's W[a]	.185
Chi-square	20.000
Degrees of freedom	9
Asymptotic sig.	.0018

Kendall's coefficient of concordance

Conclusions

Ontologies are the basis of the Semantic Web and provide the possibility of offering a system that allows "smart" recovery of information.

The development of an ontology initially requires identifying the context, conceptualising the knowledge and representing it, in addition to the construction and validation of the ontology. The acquisition of knowledge is one of the most complex processes in the development of ontologies; in this step, a variety of information sources must be consulted to identify the main aspects related to the subject domain and, thus, to obtain an effective knowledge that allows determining the classes, instances, relations, and attributes that represent its knowledge.

In the first group of questions that relate to the aspects considered in the ontology for data integration in honeynet, the significance of the value of Kendall's W (0.001) that was obtained was less than or equal to the pre-set alpha level, and therefore, there is agreement between the experts that the aspects considered by methontology are adequate.

In the second group of questions that relate to the potential errors to consider in the construction of the ontology for data integration in honeynet, the significance of the value of Kendall's W (0.018) that was obtained was less than or equal to the pre-set alpha level, and therefore, there is agreement among the experts.

The use of the Ontology for Data Integration in Honeynet is proposed as the basis for future work on the implementation of an Architecture of Honeynet with Data Integration for the analysis of digital evidence that would allow network administrators to manage decision making better with timely and faster decisions.

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