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Maturity-Based Analysis of Lightweight Ontology From the Aspect of Extensibility, Reusability and Evolutionary

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Abstract

A lightweight ontology is built using classes, instances and relationships without the axiomatic definitions contained in heavyweight ontology. A lightweight ontology highlights the structure of knowledge, whereas heavyweight ontology is rich with reasoning capacities. In this study, the Herb Ontology (HO) was used. It provided an example of a lightweight ontology for herbal data. As time goes by, it is expected to extended, reused and evolved as it matures. The design of HO was inspired by two well-established full-fledged ontologies, which were Gene Ontology and OntoCAPE. The focus of this study was on the evolution of lightweight ontologies as they evolve towards becoming heavyweight ontology through maturity. Lightweight ontologies are expected to have distinct semantics, which begin to resemble heavyweight ontologies as they gradually evolve. Maturity metric principles were also proposed in this study. The metrics measured both class-levels and ontology-levels so that different aspects of ontological design could be evaluated. The results of the study pointed out the current metrics that lead to general interpretations. These metrics also indicated the complexity of maturing ontologies for lightweight and heavyweight designs.

Keywords: *Lightweight Ontology, Ontology-Level, Class-Level, Ontology Maturity, Ontology Metric.*

1 Introduction

Ontology is generally described as an explicit description of a domain of discourse. Ontologies can be modelled with different levels of internal structural complexity [1] and linearly correlated with a level of formality [2] regardless of the concepts use to represent knowledge [3]. The complexity continuum ranges from lightweight ontologies, which are typically defined as a hierarchical or taxonomy-like structure, to full-fledged ontologies where more relationships are captured. Several ontologies are classified according to its own specialized levels and including relationship between ontology formality and complexity. Such ontologies include well known, full-fledged ontologies such as Gene Ontology [4], Plant Ontology [5] and OntoCAPE [6].

The COIN Ontology [7] is classified as a lightweight ontology; this ontology however, includes high level concepts and uses formal ontology language. A summary of the structural knowledge differences between ontologies is briefly described in Table 1.

Table 1. Ontology based on the complexity of its structure.

	Concepts	Relations	Properties	Axioms	Example(s)
Heavyweight	Yes	Yes	Yes	Yes	Gene Ontology [4], OntoCAPE [6]
Lightweight	Yes	Yes	Yes	No	Herb Ontology, COIN Ontology [7]

The common complexity model designed by Obrst [8] states that ontologies migrate from the least expressive models towards real ontologies with a common understanding of the requirements needed for more complex tasks. It is a never ending question as to how lightweight ontologies would navigate the complexity/maturity dichotomy as they are simple and involve only a few relationships that do not capture many of the possible interpretations and representations of data. However, the main goal of the majority of lightweight ontologies is to represent information on a "human scale," which is recorded predominantly by domain experts, rather than highly detailed information which would be read by the computers. As a result, lightweight ontologies can be a surprisingly powerful tool for domain researchers especially when examining the connections and relationships within the ontology.

Ontologies must mature so that they can be subjected to evaluations including checks for consistency, coherence, and efficiency. Thus, discussions about the levels of ontology maturity focus on the complexity and formality of full-fledged ontologies that support the ontological development process. An evolutionary approach to ontological maturity centres on the detail descriptions of additional elements (in the form of reuse, extend and evolve) involved in the transition of lightweight ontologies as discussed by Morbach [6]. Instead creating a full-fledged ontology from scratch, the formation of an initial lightweight ontology is preferred because it can provide a general overview as to what concepts should be consider in the final model. This is very helpful because often there is only a partial awareness about the relevant domain concepts. Drawing on the descriptions provided by [6, 7, 9], discussions on issues of ontological maturity with respect to its extension, reuse and evolution, will give new insight into the possibilities of lightweight ontologies achieving an integrated maturity level.

As ontologies grow in size and number, it is important to be able to quantitatively measure their maturity. Quantitative measurements of maturity can help those who develop and maintain ontologies better understand the current status of ontology, allowing them to better evaluate its design and control its development process. Experiences from the software engineering field suggest that there are correlations between software complexity and quality (e.g. reusability and maintainability) [10-13]. In the domain of software engineering, metrics play an important role in designing, developing and maintaining software while guarding against future maintenance problems.

Initially, the concept of software metrics were used in measuring the maturity of ontology designs. However, the problem with ontology metrics is that ontologies are heterogeneous in their structure, objectives and levels of formality. As a consequence, applying different metrics to the ontologies could result in insights that could be used to determine the maturity of an ontology.

This paper presents a set of ontologies metrics for evaluating the ontology design of Herb Ontology (HO), lightweight domain ontology for herbal knowledge across taxa. The HO design could aid in drug-herb and food-drug interaction studies that have been rapidly done by the researchers. This ontology could help in connecting the name of herb, with their common uses and the possible side effects or drug interactions. Such data are important in order to provide individual with a measure of the risk of interactions and a description of clinical consequences. As ontology complexity is formed by various combinations of dimensional characteristics [14], they cannot be measured directly by using a single metric. In this paper, in order to evaluate Herb Ontology using combined metrics, it is compared with another lightweight ontology which is COIN ontology. Both Herb Ontology and COIN define knowledge structure through their simple internal structure. The heavyweight ontologies (e.g Gene Ontology and OntoCAPE) are also being used in the comparison analysis. The purpose of this comparison is to discover their internal complexity and use the proposed metrics to analyse on potential maturity level of the ontologies. Following techniques proposed by Zhang et al. [15], the suite of metrics were used to evaluate on class-level and ontology-level so that different design aspects could be measured. The results of the study pointed out that the current metrics could find out how much an entity is used in an ontology. Plus, it would enable the domain and ontology experts to reflect on the lightweight ontologies and then ascertain and prioritize the pros and cons for further development.

The remainder of this paper is organized as follows: Section 2 provides a short overview on HO, covering its structure, scope, content. Section 3 presents the background of ontology metrics and is followed by Section 4, which describes the datasets, proposed metrics and its relationship to the extending, reuse and evolution of ontologies. Section 5 concludes the paper by summarizing its results and their impact to the development of maturing HO.

2 The Herb Ontology

A sound structure is vital for any ontology with a long term mission. HO aims to develop the same maturity level as most established full-fledged ontologies. One of the main goals of this paper is to improve the design of ontologies so that they will be able to manage their complexity and track changes. Another goal in this paper is to evaluate the maturity level HO. The class-level in this study refers to two distinct classes which is "*HerbBotanicalInfo*" and "*HerbUsages*". The ontology-level refers to the whole ontology structure in Fig.1. In the following section, the informal specifications of the HO structure are briefly explained and the scope and content of HO are summarized.

2.1 Scope

HO explores the holistic usage of herbs, which are based on a user's area of interest. There are two main sub-components in HO; i) "*HerbBotanicalInfo*" which provides each herb's profile and, ii) "*HerbUsages*" which specifies the uses of each herb. The class hierarchy in HO is based on a top-down approach. This approach begins with first-level compositional domain knowledge and continues to break down information into subdivisions until it is reduced to its base elements. This process is done to understand the sub-compositional knowledge without any first level knowledge being specified. Following the True Path Rule (TPR) of ontology design, the pathway from the child terms to the level of its parent term must always be true.

The inter-term relationships in HO are not fully developed, thus HO is categorised as lightweight ontology. HO provides on subsumption relationship (e.g. Is-a) which describe the immediate parent-child relationship. HO also has interterm association relationships, which adds value to this lightweight ontology by semantically connecting items. These association relationships are designed to logically relate one concept to another. However, meronym relationships (part-of) do not currently exist in HO but they will be included as it continues to mature.

The cross referencing technique and synonyms used in HO is the solution for vast herbal knowledge of redundant terms used by the different repositories. Lexical variants in HO may be broader or narrower than the term string for the following reasons: (i) it may be a related phrase; (ii) it may have alternative wording, spelling or use a different nomenclature system; or (iii) it may be a true synonym.
In a nutshell, HO was designed to establish common standards for the design and organization of herbal ontologies. HO supports long-term ontological development as it moves forward on the ontological complexity continuum. Therefore, the evolution of HO maturity takes the form of extension, reuse and evolution as it moves from a lightweight ontology to full-fledged ontology. The criteria for HO extension, reuse and evolution were adapted from several full-fledged ontologies. The HO specification is summarized in Fig. 1.

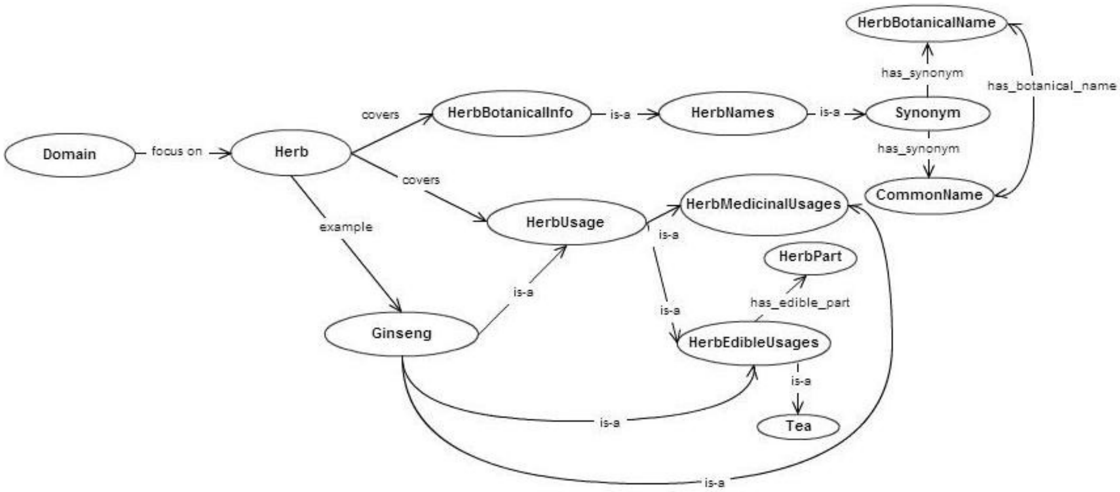

Fig. 1. HO specification.

2.2 Structure

In order to understand the purpose of HO, a comprehensive informal structure is needed. The abstractions of HO entities are stated precisely by the manipulation of a human-readable form of the Standard Unified Modelling Language (UML). Accordingly, these representations draw upon functionality, logic, work flow, and services.

HO comes from the integration of plant species collected by domain experts such as herbalist, and turns them into specifications to finally produce the integral structure of HO. The primary structure of HO includes the class sub-components "*HerbBotanicalInfo*" and "*HerbUsages*", the primary interrelationships between classes (e.g. is-a relationship), the attributes expressed in the classes (term_name and term_ID), the format used in the ontology (OWL and RDF) and the end-user (e.g. requester). A brief description of the structure of HO can be seen in Fig. 2.

HO is designed to bridge the knowledge gap between herbalists, researchers and bioinfomaticians. HO has outlined several characteristics for its applications in terms of functionality, services offered, and procedural strategies. The HO characteristics are as follows: (i) it has up-to-date herbal knowledge; (ii) it supports cross-referencing between re-use sources; (iii) it provides reliable storage for herbal information; (iv) it is updated weekly; (v) it applies multi-layer versioning to provide distinctive versioning; (vi) it reuses potential external herb resources; and (vii) it is flexible and can be extended, reused and continue to evolve. These applications are designed based on the characteristics outlined by HO earlier to ensure that the aim of HO can be achieved. All of these applications are described by utilizing UML notations such as use case diagrams, deployment diagrams, and sequence diagrams.

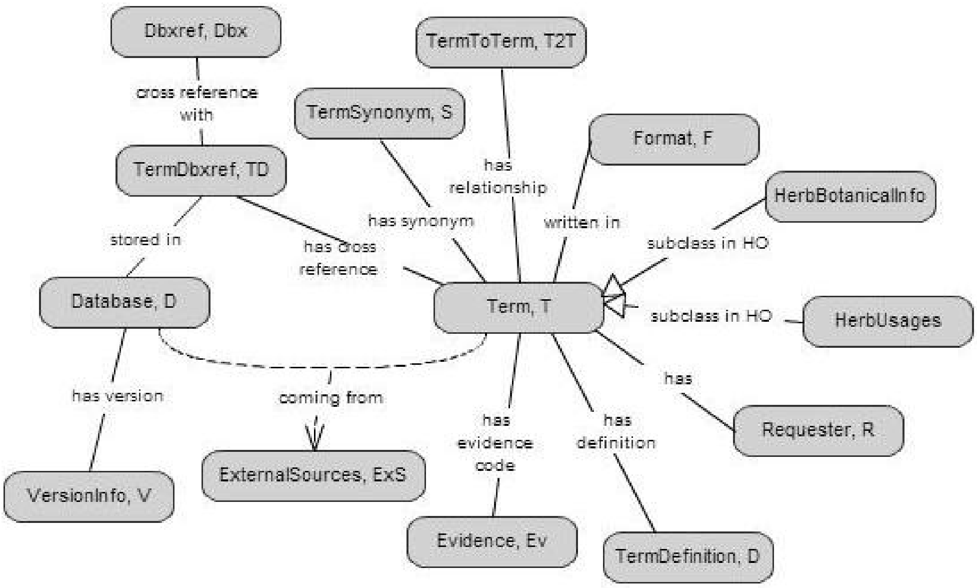

Fig. 2. HO structure

The designation of HO functionality is to define the behaviours, restrictions and interactions describing the ontology requirements in HO. HO functionality is shown by a series of use cases (*perform reasoning*, *cross resources* and *evaluate HO terms*), actors (*HO Curator*, *HO Scheduler* and *Requester*) and associations (include and exclude associations). Each of the use cases have their own HO target characteristics to be fulfilled. For example, one of the HO characteristics refers to the cross-referencing between reuse sources in the data validation process. This is made possible by the actors – *HO Curator* and *HO Database*. In deciding whether to add, delete or update new terms in HO, the *HO Curator* initiates the "*manual curations*" function. Next, the HO terms is evaluated by the "*perform reasoning*" function. The validation process is completed by *HO Database*.

The fluidity of HO is managed by the designation of HO services. The information in HO is designed to change over time according to its relevancy; this includes changes to the resources or information in the resources. The HO service consists of eight basic nodes, the *User*, *Web Interface*, *HO Curator*, *Web Server*, *Proxy Server*, *External Resources*, *Database Server*, and *HO Database Tracker,* which operate based on the characteristics of HO described earlier.

HO procedural strategies are systematically designed to cope with the advanced maturity that would gradually develop. The current design includes HO procedures involved with data access, manual curations, record keeping and weekly information updates. They are modelled using UML sequence diagrams to represent their procedural strategies.

2.3 Content

A dramatic increase of interest in the use of herbs is due to critical scientific analysis of their therapeutic potential and quality control to ensure their safety. Currently, there are thousands of herbal information resources created by wide range of information providers including herbalist, government agencies, charitable organizations, and non-profits. An herb information resource can be the website of a plants research group that publishes its research details as webpages. It can be a database of herbs that allows customer to navigate through to choose their own herbs and spices and it can also be a profile of herbs, collected by herbalist and documented as a public reference.

The primary focus of HO is on the holistic usage of herbs and a few points must be clarified. The reason for focusing on the holistic use of herbs is two-fold. Firstly, since the early development of herbal repositories was guided by herbalists and alternative practitioners, it is believed to be based on symptomatological and introspective deductions without modern insights especially in the case of medical herbs. However, the pharmacological compounds in traditional herbs are recognized if they are compared with modern medicines. Secondly, the naming given to an herb varies according to across different countries and different cultures. For example, there seems to be various common names for *Panax ginseng* as it is known with different names in different countries such as Japanese ginseng (Japan), renshen (China) and Korean ginseng (Korea). Integrating heterogeneous sources of herbal knowledge may help remedy any gap in knowledge between herbalist and researchers, and traditional and modern results by explicitly setting out the interrelation of their various concepts.

In order to focus on the holistic use of herbs, the data sources in HO consist of a combination of ontological and non-ontological (e.g. classification schemes, thesauri and lexicons) data sources. The potential data sources are analysed before being added to the terms in HO. These various data sources need to be reviewed over the time, and they may undergo changes that affect the relevance of herbal knowledge they provide. Current data sources used in HO are shown Fig. 3.

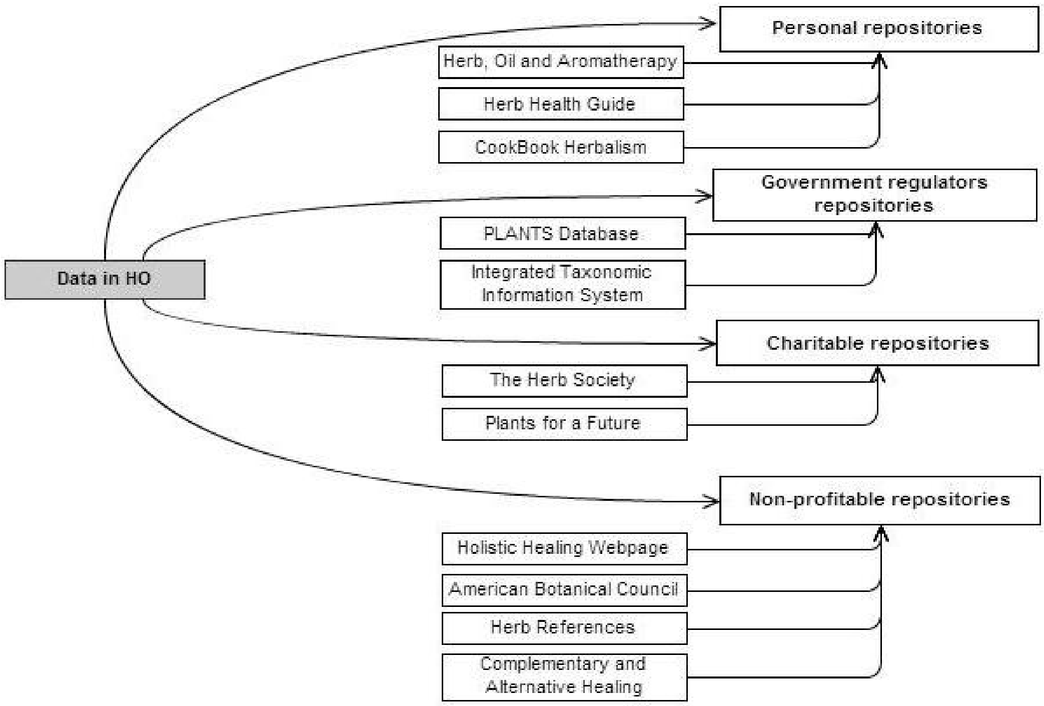

Fig. 3. HO data source

3 Ontology Maturity Metrics

The OWL ontologies shared elements that are common when constructing an ontology which lead to the proposals of ontology metrics by several authors. Ontology metrics are adapted from the field of software engineering and they represent an important approach for evaluating and assessing ontologies. By recognizing the quality of an ontology, the ontology developers can specify which parts of an ontology might cause problems. Most of the authors however, argued about the quality of ontology could be justified by using a single metric. Their arguments led to various set of metrics proposed to create a better way to measure ontologies.

In this paper, eleven metrics proposed by several authors were collected and then divided into three categories depending on their maturity principles. The categories were: i) reuse, ii) extend and iii) evolve. In order for lightweight ontologies to mature, they need to be on the same level as established full-fledged ontologies.

Table 1. Ontology maturity metrics summary.

Maturity / Metrics	Acronym	Level	Reuse	Extend	Evolve
Size of vocabulary	SOV	Ontology level		√	
Edge node ratio	ENR	Ontology level			√
Tree impurity	TIP	Ontology level		√	
No of classes	NOC	Class level			√
No of inheritance	NOI	Class level			√
No of properties	NOP	Class level			√
No of root classes	NORC	Class level		√	
Average population	AP	Class level		√	
Class richness	CR	Class level		√	
Inheritance richness	IR	Class level	√		
Relationship richness	RR	Class level		√	

This maturity principle allows lightweight ontologies to be measured so that they can be enriched and progress over time. The summary of the metrics used in this paper is shown in Table 1. This study followed a technique proposed by Zhang et al. [15], which relied on evaluations based on ontology-level and class-level. The goal of this study was to holistically evaluate the ontology by using different points of view to analyse each ontology.

3.1 Reuse metric

The reuse metric used in this paper was Inheritance Richness (IR), and it was used to measure the distribution of information across different level of ontology inheritance.

3.1.1 Inheritance richness, IR (Tartir et al., 2005)

Definition: IR defines the average number of subclasses per class. Formally, IR is defined as:

$$IR = \frac{\sum_{C_i \in C} |H^C(C_1, C_i)|}{|C|}, \qquad (1)$$

Where $|H^C(C_1, C_i)|$ is the number of subclasses (C_1) for a class (C_i) and the divisor $(|C|)$ is the total number of class.
Rationale: As defined by Tartir et al. [16], this metric serves as an indicator of how well knowledge is grouped into different classes and subclasses. A value close to zero would indicate that the ontology contains more general knowledge. On the other hand, large values show that detailed domain knowledge was used by an ontology. In this paper, IR acted as an indicator that showed if an ontology was more reusable or usable, or if it fell in middle of the reusable-usable scale.

3.2 Extension metrics

The proposed extend metrics in this paper were Size of Vocabulary (SOV), Tree Impurity (TIP), Number of Root Classes (NORC), Average Population (AP), Class Richness (CR), and Relationship Richness (RR). These metrics are a collection of the works of several authors that attempt to measure the level to which an ontology could be extended.

3.2.1 Size of vocabulary, SOV (Weyuker, 1998)

Definition: SOV measures the complexity of an ontology by counting the total number of named entities. As described by Zhang et al. [17], an ontology represented by a graph is $G = < N, P, E >$. Hence, SOV is defined as the cardinality of the named entities N_n, and P_n in G:

$$SOV = |N_n| + |P_n| \, . \qquad (2)$$

Rationale: In ontology graph G, SOV is the total number of N_n and P_n defined by the ontology. The size of ontology is proportional to the value of SOV. The greater the SOV value, the larger the size of the ontology. This metric helps to indicate the potential of expanding the ontology domain.

3.2.2 Tree impurity, TIP (Weyuker, 1998)

Definition: TIP measures how far an ontology's inheritance hierarchy $G' = < N', P', E' >$ deviates from its initial tree structure. It is defined as:

$$TIP = |E'| - |N'| + 1, \quad (3)$$

Where $|E'|$ is the number of subclass edges and $|N'|$ is the number of nodes in an ontology inheritance.

Rationale: The more an ontology's inheritance hierarchy deviates from a pure tree structure, the greater the complexity of the ontology. This metric serves as an indicator as whether there is enough deviation (more deviation, more complex, harder to handle), or if it needs to extend its deviation away from its current tree structure.

3.2.3 Number of root classess, NORC (Yao et al., 2005)

Definition: NORC is the number of root classes (without superclasses). Let C be the class in ontology:

$$NORC = |C_i|, \neg \exists\, C_j | C_j \nsubseteq C_i. \quad (4)$$

Rationale: The range of this metric is from 1 to $|C|$. There is at least one root and the larger the number of root classes, the more diverse the ontology will be. However, the diversity of ontology is dependent on the domain it explores. Extension in terms of root classes requires a closer look by ontology engineers.

3.2.4 Average population, AP (Tartir et al., 2005)

Definition: AP measures the average distribution of instances across all classes. Explicitly, it is defined as:

$$AP = \frac{|I|}{|C|}. \quad (5)$$

Rationale: The AP metric is used with the CR metric to indicate if the information regarding a domain is sufficient in the ontology. The AP metric helps ontology developers ensure the numbers of instances extracted are enough compared to the number of classes.

3.2.5 Class richness, CR (Tartir et al., 2005)

Definition: CR is the result of the numbers of classes that have instances ($|C'|$) divided by the total number of classes. The formal definition of CR is:

$$CR = \frac{|C'|}{|C|}. \quad (6)$$

Rationale: The CR metric measures how many instances are related to the classes that define them. The extensions in ontological insertion depend on this measurement.

3.2.6 Relationship richness, RR (Tartir et al., 2005)

Definition: RR is defined as the result of the number of relationships divided by the sum of the number of subclasses plus the number of relationships:

$$RR = \frac{|P|}{|SC| + |P|}, \quad (7)$$

Where $|P|$ is the number of relationships and SC is the number of subclasses (or the number of inheritance relationships).

Rationale: The RR metric reflects the diversity of relations and the placement of relationships in the ontology. The RR metric appears as an extend metric in this paper and it signifies if relationships in an ontology was extended.

3.3 Evolution metrics

The proposed evolutions metrics used in this study were ENR (Edge Node Ratio), NOC (Number of Classes), NOI (Number of Instances), and NOP (Number of Properties). Evolution, according to Morbach [6] changes the ontology with respect to granularity, scope, conceptualizations, and the specifications that occur while leaving the ontology intact. Examples of evolutionary changes that contribute to this maturity metric include: (i) new conceptual understandings; (ii) new task and/or application areas; and (iii) new representation language. The NOC, NOI and NOP metrics help to indirectly specify the maturity status of an ontology. Any extension of OWL ontology elements (e.g. class, instance and property) will lead to the evolution of the ontology.

3.3.1 Edge node ratio, ENR (Weyuker, 1998)

Definition: When using $G = < N, P, E >$ to define an ontology graph the ENR is defined as:

$$ENR = \frac{|E|}{|N|}, \quad (8)$$

Where $(|E|)$ the number of edges divided by the number of nodes $(|N|)$ in G.

Rationale**:** ENR measures the density of connectivity which increases as more edges are added between nodes (classes and individuals). A high ENR value indicates that further modularization is needed to ease the effort required for understanding and maintenance. The ENR metric acts as an indicator as whether an ontologies need to expand its connectivity over time, and evolve its simple internal design towards modularization.

3.3.2 Number of classes, NOC

Definition: The NOC metric is simply a count of the named classes $(|C|)$ in the ontology.

Rationale: This metric indicated if there was any growth in number of classes in the ontology.

3.3.3 Number of instances, NOI

Definition: The NOI metric is a tally of the instances $(|I|)$ in the ontology.

Rationale: The NOI points out any growth in the number of instances in the ontology.

3.3.4 Number of properties, NOP

Definition: This metric is a simple count of instances $(|P|)$ in an ontology.

Rationale: This metric indicates the growth of number of properties in the ontology.

4 Result and Analysis

In this section, the metrics were evaluated based on ontology-levels and class-levels following the technique proposed by Zhang et al. [15]. This was done to ensure a holistic evaluation of the ontology from different perspectives. Results from these evaluations were analysed based on the maturity metrics used to classify them. This study relate with the evaluations of maturity principles so that ontology developers will be able to determine any weaknesses in their ontologies that require improvement.

4.1 Dataset

In order to analyse the relationships between the previously defined metrics, four ontologies were used. The famous full-fledged ontologies, Gene Ontology and OntoCAPE were compared to lightweight ontologies (HO and COIN ontology). The complexity and its relationship to the maturing design of the full-fledged ontologies were compared to the lightweight ontologies. Table 2 describes the ontologies used in this study.

4.2 Ontology Level Evaluation

Table 3 shows the measurement values collected ontology for the ontology-level evaluation. The numbers marked with (*) indicate the largest values. The SOV values ranged from 32 (COIN ontology) to 134K (the GO_daily-termdb ontology), indicating that different sized vocabularies were used. However, after considering the ENR value, OntoCAPE had the highest ENR value (3.15) showing that this full-fledged ontology was more complex than the GO_daily-termdb ontology, which ranked last for this metric. HO ranked second in terms of its ENR value, providing a surprising performance in ontology complexity despite its lack of vocabulary. This was due to the fact that there were more than 3 edges associated with each node in HO, thus creating a denser network compared to GO. However, higher ENR values indicated that further modularization is needed to support understanding and maintenance efforts. HO would benefit from having a modularization technique inserted in future.

Table 2. List of ontologies.

Ontology	Description	Version	Size (KB)	URL
Go_daily-termdb	Gene ontologies, definitions and mappings to other databases	2012-09-08	94291	http://archive.geneontology.org/lite/2012-09-08/
OntoCAPE	Large-scale ontology for the domain of Computer Aided Process Engineering (CAPE).	2011-12-23	4	http://www.ontocape.org/2011/12/23/new-ontocape-version/
COIN	COntext INterchange (COIN) lightweight ontology project for semantic data interoperation purposes which provides the structure for organizing context descriptions to account for the subtleties of the concepts in the ontology.	1.0	-	http://ontoware.org/swrc/coin/COINOntology-Initialversion/COIN.owl
HO	Specializing in herb domain, HO explores on the holistic usages of herb based on its profile species.	1.0	207	-

Table 3. Ontology-level results.

	Go_daily-termdb	OntoCAPE	COIN	HO
SOV	134142*	1047	32	322
ENR	1.13	3.15*	1.77	1.84
TIP	13981*	980	11	1

The empirical results also showed that none of the ontologies had a strict single inheritance (with TIP = 0). All of them adopted multiple inheritances and the least inheritance deviation went to HO (with TIP = 1). On the other hand, GO_daily-termdb deviated heavily from a pure tree structure, with TIP = 13981. The OntoCAPE and COIN ontologies placed second (TIP = 980) and third (TIP = 11), respectively, in their TIP metric values.

Overall, the HO performance was lacking in terms of the size of the vocabulary used and the least amount of inheritance deviation. However, the dense network demonstrated that this lightweight ontology has the potential to expand. The evaluation values in Table 3 show that ontologies may be "more complex" in one aspect but "less complex" in another aspect. These ontologies are becoming more understandable in terms of their complexity levels. An obvious comparison can be made between Go_daily-termdb and OntoCAPE. The former is larger in size but OntoCAPE had the largest ENR values from among all of the ontologies evaluated. This showed that the size of and ontology does not reflect its overall complexity.

4.3 Class Level Evaluation

Table 4 summarized the result of the class-level evaluation and ontologies involved. NOC, NOI and NOP are simple counts of the classes, individuals and properties involved in an ontology. Not surprisingly, the largest value went to the largest ontology. Among all of the four ontologies studied, Go_daily-termdb was the largest and the value of the NOC and NOI metrics for Go_daily-termdb were the highest at 38097 and 276890, respectively. However, the highest NOP metric went to OntoCAPE (244), indicating that OntoCAPE was a sound and useful reasoning system. The modularization technique used in OntoCAPE was perhaps a contributing factor to the high usage of restrictions in ontology.

The NORC metric measured the number of root classes in an ontology. There was at least one root class in each ontology. The higher the NORC value, more diverse is the ontology. The COIN ontology had the highest value (10), followed by OntoCAPE (6), Go_daily-termdb (3) and finally the HO ontology (2). As COIN ontology is a lightweight ontology, having 10 root classes in the ontology is quite large. The COIN ontology focused on a taxonomy-based semantic data interoperation, resulting in the large number of root classes involved. This example illustrates that the diversity of an ontology is subject to the domain and purpose of the ontology itself.

The AP metric determines average distribution of instances across all classes. The ontology with the highest AP value is the one with the most sufficient information distributed in the ontology. Go_daily-termdb ranked first in the AP metric evaluation, which was an indication that the populations in the ontology were diverse. On the other hand, the CR metric in Go_daily-termdb was the lowest value. As both AP and CR were correlated, Go_daily-termdb achieved only 0.00010 for this metric. CR metric evaluate how the instances were actually related to the classes defined.

The IR metric represents the different levels of inheritance as a tree and serves as an indicator of how well knowledge is grouped into different classes and subclasses in the ontology. Values closer to zero indicate a flat ontology while large values represent vertical ontologies. In this study, HO ontology had the smallest value (IR = 0.99301), indicating that the knowledge contained in the ontology was general. OntoCAPE, on the other hand, had the largest value (IR = 2.39761), indicating that it contained detailed knowledge.

The reflection of the diversity of relationships and the placement of relationships was evaluated using the RR metric. An ontology that contains many relationships other than class-subclass relationships (values close to 1) is richer than the taxonomies with only class-subclass relationships (value close to zero). In this study, the COIN ontology was found to be richer in content (RR = 0.41026) compared to the heavyweight Go_daily-termdb (RR = 0.00011). This was perhaps due to the purpose of the domain itself, and the scope of the content that particular ontology covered.

In terms of a class-evaluation summary of HO performance, HO had the least amount of classes and properties. However, HO ranked third in a simple count of individuals, which meant that HO had more individuals that were connected to a class compared to COIN, the other lightweight ontology. HO ranked last in both of the evaluation metrics AP (0.11189) and CR (0.24825), indicating that much improvement is required in terms of managing related instances to the classes in ontology. The IR metrics that HO possessed showed that the knowledge about its domain remains general. Therefore, it is easier for HO to be reused, but harder for the domain user to use HO as a source of herbal knowledge. HO must strike a balanced between its domain knowledge and a need to fill existing gaps.

Table 4. Results summary on class-level evaluation.

	Go_daily-termdb	OntoCAPE	COIN	HO
NOC	38097*	503	13	286
NOI	276890*	300	3	32
NOP	8	244*	16	4
NORC	3	6	10*	2
AP	7.26803*	0.59642	0.23077	0.11189
CR	0.00010*	0.10735	0.07692	0.24825
IR	1.84461	2.39761*	1.76923	0.99301*
RR	0.00011	0.16828	0.41026*	0.01389

4.4 Reuse Maturity Principle

The metric related to the principle of reuse is the IR metric. Based on the results in Table 4, the HO ontology had a value closer to zero (IR = 0.99301), which indicated that the knowledge it covered was general. This indicated that HO was easier to reused and share across software systems and between different groups of users. OntoCAPE, on the other hand, had the largest IR value (IR = 2.39761), representing that the knowledge it covered was more detailed. This meant that OntoCAPE was easier to use.

The concepts of usable and reusable are in conflict: Usability implies specialization, whereas reusability requires generalization in order to be applicable to different contexts. Consequently, it is difficult to simultaneously achieve high degrees of usability and reusability. In order to be efficient, an ontology must have a reasonable usable-reusable balance. Despite being reusable, HO needs to improve its usability if it is to provide effective search help in the domain of herbal knowledge.

4.5 Extend Maturity Principle

The six metrics proposed that were associated with the principle of extension and maturity, were SOV, TIP, NORC, AP, CR and RR. The extension and maturity principle metric helps to detect the potential of a particular ontology to be extended.

The SOV metric measured the size of the vocabulary used by ontology studied. As Go_daily-termdb was the largest ontology studied, it had the highest SOV metric value, followed by OntoCAPE. Both Go_daily-termdb and OntoCAPE are well-established ontologies and they have undergone a few changes over time resulting in an impressive expansion of each of these ontologies. On the other hand, the SOV metric revealed that COIN and HO had much smaller vocabularies.

Go_daily-termdb also ranked first in the TIP metric, which recognized its heavy inheritance hierarchy that deviated from a pure tree structure. The smallest value went to HO, which reflected the simplicity of its internal complexity. HO lacked the extra edges that allow an inheritance hierarchy to move away from a tree structure. In terms of the NORC metric, COIN was a more diverse ontology compared to HO, even though both were considered to be lightweight ontologies. However, the level of diversity is subject to the domain of ontology.

The highest AP values define the most well informed ontologies. AP is correlated to the CR metric which uses the smallest values to define instances related to the classes defined. Go_daily-term ranked first in terms of the AP and CR metrics, indicating the diversity and how well the information was stored in this ontology. The COIN ontology surpassed the well-established OntoCAPE in the CR metric, indicating that this lightweight ontology had more instances that were related to the classes defined. HO ranked last in terms of both metrics (AP = 0.11189 and CR = 0.24825) indicating that much of improvement need in terms of managing the related instances to the classes in this ontology. However, HO has the potential for expansion based on further reviews in its maintenance processes.
The RR metric evaluated the relationships in the ontologies and their placements. The evaluation of an ontology using this metric represents the richness of the ontology axioms-wise. This metric depends on the aim of the ontology in its particular domain, and the scope of the content covered by the ontology. In this study, the COIN ontology was evaluated as being richer in axioms (RR = 0.41026) compared to the heavyweight Go_daily-termdb (RR = 0.00011). The small scope of COIN affected the results compared to the wider range of knowledge covered by Go_daily-termdb.

An evaluation of HO performance in terms of extend maturity principles revealed that the HO ontology is still lacking in vocabulary which must be expanded and reviewed over time based on what needs must be fulfilled in its domain. In order to accommodate more herbal knowledge, HO needs to have a more complex internal structure. HO also needs to expand its domain knowledge by adding more herbal species to the ontology. Plus, HO must also add more on relationships to be on par with heavyweight ontologies. Richer axioms would contribute to its maturity as it evolves towards becoming heavyweight ontology. However, HO has the potential of extending after further analysis and reviews.

4.6 Evolve Maturity Principle

To investigate the evolve maturity principle, the use of four metrics was proposed. The four metrics were ENR, NOC, NOI and NOP.

OntoCAPE received the highest ENR values (ENR = 3.15), indicating that the connectivity in the ontology was quite dense. Furthermore, OntoCAPE used modularization technique to maintain its complexity over the time. HO ranked second (ENR = 1.84), and hopes to add modularization technique in future.

Go_daily-termdb was the largest and most complex ontology based on its NOC and NOI values. This ontology, however, had one of the lowest NOP scores which contrasted with its NOC and NOI values. Like Go_daily-termdb, HO has also had higher NOC and NOI values, and a low NOP value. As the NOC, NOI and NOP metrics were simple counts of classes, individuals and properties of the ontologies, they are considered to be descriptive metrics. These metrics help to review the status of the ontology over the time to determine their potential for evolution.

The performance of HO in terms of the evolve maturity principle was demonstrated by its second place ENR ranking. This metric indicated the dense network in the HO ontology. HO must consider including modularization technique in the future in maintaining its complex connectivity. However, to be on par with Go_daily-termdb, HO must add to its number of class and individuals. These additions will allow HO to accommodate the needs of herbal users by having more information available.

5 Conclusion

We have presented eleven combinations of metrics, which were used to examine the maturity principles of reuse, extend and evolve. The significance of these principles to the overall objectives of maturity-based analysis was addressed. The maturity-based ontology metric has been introduced to measure the ontology complexity which is formed by various combinations of dimensional characteristics. An evaluation by a single metric would not cover the overall insights of ontologies explored. Hence, the maturity metric consists of different sets of ontology metrics in order to achieve better results in interpreting the ontology insights in terms of ontology maturity. The maturity-based ontology metric is specifically developed to address the complexity of ontology and its relation to maturity principles in extending, evolving and take control of reusability issue in lightweight ontology design. These metrics were aimed at the betterment of lightweight ontologies, specifically HO. Through these metrics, the potential of HO to mature was validated. Comparing HO with other well-established full-fledged ontologies made the validation more reliable. This study could be expanded by adding in on human assessment method to add value to the ontology metrics by including both ontology and domain expert.

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