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ONTOMETRIC: A Method to Choose the Appropriate Ontology

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ABSTRACT

In the last years, the development of ontology-based applications has increased considerably, mainly related to the semantic web. Users currently looking for ontologies in order to incorporate them into their systems, just use their experience and intuition. This makes it difficult for them to justify their choices. Mainly, this is due to the lack of methods that help the user to determine which are the most appropriate ontologies for the new system. To solve this deficiency, the present work proposes a method, ONTOMETRIC, which allows the users to measure the suitability of existing ontologies, regarding the requirements of their systems.

Keywords: ONTOMETRIC, ontologies, metrics, selection of ontologies

THE PROBLEM OF ONTOLOGIES SELECTION

In 1991, the ARPA Knowledge Sharing Effort (Neches, 1991) revolutionized the way in which intelligent systems were built in Artificial Intelligence when proposing the construction of knowledge-based systems by means of the "assembling" of reusable components. Reusable components become the base (or skeleton) of the new system, to which are added specialized knowledge and specific reasoning methods, characteristic of the task that the system attempts to solve. This vision allows building bigger and more potent systems. The ontologies, used to represent the "static" knowledge of a domain, and the problem-solving methods used to carry out reasoning, become the key pieces that allow the reuse of knowledge and problem-solving methods (Gómez-Pérez, 1999a). The saving in costs and time that it is obtained in the software reuse (Bollinger, 1990; Poulin, 1997) is achieved in more scope in the reuse of these knowledge (ontologies and problem-solving methods), due to the enormous effort in the processes of knowledge acquisition of a domain, the conceptual model's construction, formalization and implementation of such knowledge.

At the moment, the ontologies are implemented in a great variety of languages. At the beginning of the decade of the nineties, a group of languages was designed and used for the implementation of ontologies. The most representative languages are: Ontolingua (Gruber, 1993), LOOM (McGregor, 1991), OCML (Motta, 1999), FLogic (Kifer, 1995), etc. These languages receive the name of "classic languages" (Corcho, 2000), they follow a syntax based on LISP (to exception of FLogic), and they are in a phase of stable development. Recently, XML has been adopted as a standard language to exchange information on the web. In the field of the ontologies, several languages have been created based on XML to implement ontologies. For example RDF (Lassila, 1999), RDF Schema (Brickley, 1999), XOL (Karp, 1999), SHOE (Luke, 2000), OIL (Horrocks, 2000), DAML+OIL (Horrocks, 2001) and OWL (Dean, 2003). These languages, called "web-based languages," are still in the development phase and in continuous evolution.

Equally, methodologies for building ontologies have been numerous. Already in 1990, Lenat and Guha (1990) published some methodological considerations related with the development of the CYC ontology. Some years later, in 1995, Uschold and King (1995) published the main steps in the development of the Enterprise ontology. In the same year, Grüninger and Fox (1995) showed the methodology used in the development of the TOVE ontology (Virtual Toronto Enterprise). One year later, Uschold (1996) carries out a proposal of unification of both methodologies. In the 12th European Conference for Artificial Intelligence, the methodology used to build the project Esprit KACTUS project's ontologies (Bernaras, 1996) is presented. In 1997, METHONTOLOGY appears (Fernández, 1997), which was extended later (Fernández, 1999a, 2000). It proposes the steps that should be continued to build ontologies, some guides to carry out ontologies reengineering (Gómez-Pérez, 1999b) and ontologies evaluation (Gómez-Pérez, 1999c). Also in 1997, it is presented the methodology used to build domains ontologies from the SENSUS ontology (Swartout, 1997). All these methodologies do not consider the cooperative development of ontologies. The first methodology that includes development aspects in group is Co4 (Euzenat, 1995). A comparative study of some of these methodologies appears in Fernández (1999b).

Since 1996 there is an important increase in the development of technological platforms related with the ontologies. The first ontology site was the Ontolingua Server (Farquhar, 1996) of the Knowledge Systems Laboratory (KSL) at Stanford University. In 1997, Ontosaurus appeared (Swartout, 1997), developed by the Information Sciences Institute (ISI) in the University of South California. Later, several tools have been created based on Java technology: WebOnto (Domingue, 1998) developed in the Knowledge Media Institute (KMI) of the Open University (UK); OILed (Bechhofer, 2001), developed in the IST OntoKnowledge project; OntoEdit (Staab, 2000), developed by the AIFB of the Karlsrhue University; Protégé2000 (Noy, 2001) developed by Stanford Medical Informatics (SMI) at Stanford University; and WebODE (Arpírez, 2001), developed at the Universidad Politécnica de Madrid.

In spite of the great increase that the use of ontologies has acquired, nowadays, the knowledge engineers need to look for ontologies dispersed in quite a few web servers. When they find several that can be adapted, they should examine their characteristics attentively and decide which the best are to incorporate them into their system. This election procedure usually depends on the experience and the engineer's intuition. If the system is being developed with commercial goals, it will be very difficult for them to justify the taken election.

Although most of the methodologies for building ontologies (Fernández, 1999b) propose a phase of ontology reuse, there are not works that indicate to users how to choose ontologies for a new project, and there are not methodologies that quantify the suitability of these ontologies for the system. This election problem would be palliated if a metric existed that quantified, for each one of the candidates (ontologies), how appropriate they are for a new system. The method that is described in this work (*ONTOMETRIC*) presents the set of processes that the user should carry out to obtain these measures.

This paper is organised as follows: The next section presents a set of general ontology characteristics to compare ontologies, followed by a description of the building of an ontology in the ontology domain, called *Reference Ontology*. The final section describes briefly the Analytic Hierarchy Process (AHP) in the taking of multi-criteria decisions and shows how we have adapted AHP in the choice of ontologies.

A FRAMEWORK TO COMPARE ONTOLOGIES

Existing Studies and Frameworks of Characteristics

There are different studies on identifying features for designing, comparing and classifying ontologies. The more elaborated, and also more recent proposals, tend to organize the groups of characteristics in a taxonomical fashion. A summary of the proposals, with the number of characteristics and the purpose for which were created, is shown in Table 1.

On the one hand, the five characteristics of Gruber (1995) and the three characteristics pointed out by Uschold and Grüninger (1996) are very general features and were described as fundamental properties that should be considered in the design of ontologies and that should be kept in mind in the reuse process.

The comparison framework of Noy and Hafner (1997) gathers 28 characteristics about ontologies, although the definition of some characteristics is not very precise and some features can include others. With this framework, they indicated the differences and similarities among 10 chosen ontologies. The aim of this study was to compare the different alternatives and designs of ontologies to clarify the description of a standard of ontology construction, although, some characteristics

Table 1: Summary of works related with characteristics of ontologies.

Author	Year	Number of characteristics	Purpose
Gruber	95	5	To establish design criteria
Uschold y Grüninger	96	3	To establish design criteria
Noy y Hafner	97	28	To study several ontology designs
Hovy	97	36	To compare linguistic ontologies
Uschold	98	10	To identify the ontology roles in applications

can make values quite confused. Also, this framework is not appropriate to classify ontology according to the identified characteristics.

Hovy's framework (Hovy, 1997) proposes a taxonomy of 36 characteristics about different aspects of ontologies. This framework was outlined to be able to compare ontologies for natural language processing. The study was carried out like an unfinished technical report in the ISI. For this reason, some of the characteristics are not defined, some are not clearly defined, some definitions contradict the examples, and there are several characteristics that are only relevant to natural language issues.

The 10 dimensions of characteristics indicated by Uschold (1998) were gathered from the point of view of the role that the ontologies play in an ontology-based application. The purpose of this framework was that new developers of ontology-based applications could use this information to build applications with the same requirements. The definitions of the characteristics of this framework are quite imprecise and, with the proposed framework, it is difficult to classify the ontologies appropriately.

To conclude, although there are some frameworks that identify characteristics related with the ontologies, they are only adequate to classify them partially and they are not useful to compare the suitability of several alternative ontologies with regard to the necessities of an application, because these frameworks were not conceived for this purpose. So, none of the above frameworks are appropriate for deciding which of the different ontologies is the best for using it in a system.

A Multilevel Framework of Characteristics to Compare Ontologies

In order to solve the above problem, in this work we present a taxonomy of 160 characteristics, called also *multilevel framework of characteristics*, that provides the outline to be able to choose and to compare existing ontologies. The framework is used, on the one hand, asa representation template of the information about existing ontologies. On the other hand, it helps the user to select the necessary requirements that should complete the ontologies that will be considered as candidates. Finally, it is the skeleton used to build the multilevel tree of characteristics used in the processes of the *ONTOMETRIC* method.

Ten expert developers of ontologies (from iSOCO and Knowledge Reuse Group - AI Lab of UPM) have validated the multilevel framework of characteristics by means of questionnaires. They identified some conceptual errors and mistakes in the list of characteristics. The questionnaire and the experts' opinions appear in appendices I and III of Lozano-Tello (2002).

The multilevel framework of characteristics possesses, in the superior level of the taxonomy, five basic aspects on the ontologies that are denominated *dimensions*. These dimensions are the main aspects that the user should consider to examine an ontology for using it in his/her project. These are: the **content** of the ontology and the organization of their contents, the *language* in which it is implemented, the *methodology* that has been followed to develop it, the software **tools** used to build and edit the ontology, and the **costs** that the ontology will be necessary in a certain project. We have identified the characteristics of these dimensions from referenced papers in in this article, and from works about content of the ontologies, implementation languages, development methodologies and environments of ontologies, and costs. We have added others to complete the framework. The result of this task is a

Table 2: Characteristics relatesd to the dimension "tool".

DIMENSION: TOOLS CHARACTERISTIC	
CAPABILITIES (FACTOR)	(very_low, low, medium, high, very_high)
Local_Use	(non_supported, supported)
Network_Use	(non_supported, supported)
Internet-based_Use	(non_supported, supported)
Clarity_Of_User_Interface	(very_low, low, medium, high, very_high)
Response_Time	(very_low, low, medium, high, very_high)
Reliability	(very_low, low, medium, high, very_high)
VISUALIZATION (FACTOR)	(very_low, low, medium, high, very_high)
Browsers_Shows_Whole_Information_Of_Terms	(non_supported, supported)
Browser_Allows_Selection_Of_Detail_Level	(non_supported, supported)
Browser_Shows_Taxonomy	(non_supported, supported)
Browser_Shows_Ad-hoc_Relations	(non_supported, supported)
EDITION (FACTOR)	(very_low, low, medium, high, very_high)
Tool_Builds_The_Same_Of_Language	(non_supported, supported)
Tool_Allows_Edition_In_Any_Time	(non_supported, supported)
Tool_Shows_Taxonomy_Graphically	(non_supported, supported)
Tool_Allows_Definition_Of_New_Relations	(non_supported, supported)
INTERACTION (FACTOR)	(very_low, low, medium, high, very_high)
Tool_Allows_Independent_Use	(non_supported, supported)
Tool_Supplies_Access_Interfaces	(non_supported, supported)
Documentation_Using_Access_Interfaces	(very_low, low, medium, high, very_high)
Access_Interfaces_Are_OpenSource	(non_supported, supported)
Documentation_Programming_Access_Interfaces	(very_low, low, medium, high, very_high)
METHODOLOGICAL ASPECTS (FACTOR)	(very_low, low, medium, high, very_high)
Tool_Supports_Whole_Life_Cicle	(non_supported, supported)
Tool_Supports_Important_Development_Activities	(non_supported, supported)
Tool_Supplies_Documentation_About_Built_Products	(non_supported, supported)
Tool_Checks_Consistency	(non_supported, supported)
COOPERATIVE ASPECTS (FACTOR)	(very_low, low, medium, high, very_high)
Tool_Creates_Work_Groups	(non_supported, supported)
Tool_Allows_Simultaneous_Working	(non_supported, supported)
Tool_Looks_Edited_Ontologies	(non_supported, supported)
Tool_Looks_Edited_Terms	(non_supported, supported)
Tool_Notifies_The_Changes_To_Group	(non_supported, supported)
Tool_Identifies_The_User_Changes	(non_supported, supported)
TRANSLATION (FACTOR)	(very_low, low, medium, high, very_high)
Tool_Imports_From_Others_Langs	(non_supported, supported)
Tool_Imports_From_Markup_Langs	(non_supported, supported)
Tool_Exports_To_Langs	(non_supported, supported)
Tool_Exports_To_Markup_Langs	(non_supported, supported)
Translations_Lose_Minimun_Semantic	(non_supported, supported)
Translation_Is_Supervised	(non_supported, supported)
INTEGRATION (FACTOR)	(very_low, low, medium, high, very_high)
Ease_Of_Integration	(very_low, low, medium, high, very_high)
Difficulty_Of_Refering_New_Terms	(very_low, low, medium, high, very_high)
Tool_Allows_Selection_Of_Terms_To_Integration	(non_supported, supported)
Tool_Checks_Consistency_In_Integration_Or_Merge	(non_supported, supported)
Assistance_For_Manual_Merge	(non_supported, supported)
Semi-automatic_Merge	(non_supported, supported)

comparison framework of ontologies that serves as baseline work for the proposed method.

Tables 2, 3, 4, 5 and 6 show the identified characteristics for the dimensions: "tools", "language", "content", "methodology", and "costs". Detailed definitions and justifications of these characteristics can be found in Lozano-Tello (2002).

The dimensions are defined through a set of factors, as shown in above-mentioned tables. The factors are the fundamental elements that should be analyzed to obtain the value of the dimensions. These factors are defined through a group of characteristics that allow calculating the value of their suitability. These characteristics can be defined, recurrently, by means of other characteristics, or more specific subcharacteristics, so that they describe them with more detail. It allows analyzing the criteria with more depth. Thus, the multilevel framework of characteristics is organized taxonomically, in which the dimensions are described by factors, the factors by characteristic, and these by other more specific subcharacteristics. It will use the term *criterion* to refer indistinctly to any element of the multilevel framework, that is: dimensions, factors, characteristics and subcharacteristics of the taxonomy.

The multilevel framework of char-

Table 3: Characteristics related to the dimension "language".

Dimension: Language	
Charteristic	Type
Domain Knowledge (Factor)	(very_low, low, medium, high, very_high)
CONCEPTS/ INSTANCES/ FACTS/ CLAIMS	(very_low, low, medium, high, very_high)
Allows_Instances_Of_Class	(non_supported, supported)
Has_Metaclasses	(non_supported, supported)
Can_Define_Classes_Without_Metaclasses	(non_supported, supported)
Allows_Facts	(non_supported, supported)
Allows_Claims	(non_supported, supported)
ATTRIBUTES	(very_low, low, medium, high, very_high)
Can_Define_Class_Attributes	(non_supported, supported)
Can_Define_Instance_Attributes	(non_supported, supported)
Can_Define_Local_Attributes	(non_supported, supported)
Can_Define_Global_Attributes	(non_supported, supported)
Can_Define_Polymorph_Attributes	(non_supported, supported)
Can_Define_Exceptions_In_Attributes	(non_supported, supported)
FACETS	(very_low, low, medium, high, very_high)
Has_Default_Attribute_Values	(non_supported, supported)
Has_Attribute_Types	(non_supported, supported)
Can_Define_Cardinality_Of_Attributes	(non_supported, supported)
Allows_Define_Procedural_Knowledge	(non_supported, supported)
Allows_New_Facets	(non_supported, supported)
RELATIONS	(very_low, low, medium, high, very_high)
Allows_Definition_Of_Functions	(non_supported, supported)
Arbitrary_N-ary_Relations	(non_supported, supported)
Allows_Define_Ad-hoc_Relations	(non_supported, supported)
Can_Constrain_The_Type_In_Relations	(non_supported, supported)
Can_Constrain_The_Value_In_Relations	(non_supported, supported)
Has_Operational_Definition	(non_supported, supported)
Can_Declare_Properties_In_Relations	(non_supported, supported)
TAXONOMIES	(very_low, low, medium, high, very_high)
Contain_-SubclassOf-_Relation	(non_supported, supported)
Contain_-NotSubclassOf-_Relation	(non_supported, supported)
Can_Define_Exhaustive_Decomposition	(non_supported, supported)
Can_Define_Disjoint_ Decomposition	(non_supported, supported)
Multiple-Subclass-of_In_Classes	(non_supported, supported)
Multiple-Instance-of_In_Instances	(non_supported, supported)
AXIOMS	(very_low, low, medium, high, very_high)
Allows_Axioms_Embedded_In Terms	(non_supported, supported)
Allows_Independent_Axioms	(non_supported, supported)
Allows_Axioms_In_First_Order_Logic	(non_supported, supported)
Allows_Axioms_In_Second_Order_Logic	(non_supported, supported)
PRODUCTION RULES	(very_low, low, medium, high, very_high)
Allows_Disjuntives_In_PRs	(non_supported, supported)
Allows_Conjuntives_In_PRs	(non_supported, supported)
Each_Rule_Has_Defined_A_Chaining_Mechanism	(non_supported, supported)
Each_Rule_Has_Defined_A_Priority	(non_supported, supported)
Procedures_In_The_Consequent_In_PRs	(non_supported, supported)

acteristics can be represented like a hierarchical tree, so that the criteria placed in son-nodes describe and represent the father-node's properties. Thus, the users will be able to extend or to prune the criterion that they considers opportune, so that the new tree depends on the particularities of the project, the business and the organization that will reuse the ontology. This tree is called *multilevel tree of characteristics* (abbreviated as MTC), and it can be represented in a graphic form as appears in Figure 1.

It should be kept in mind that the framework is subject to the conceptual and technological novelties that will appear in the future in the ontology field. In this sense, the MTC constitutes a set of "living" criteria that should be actualized according to the produced changes.

Table 4: Characteristics related to the dimension "content"

DIMENSION: CONTENT *CHARACTERISTIC*	
CONCEPTS (FACTOR)	(very_low, low, medium, high, very_high)
Essential_Concepts	(very_low, low, medium, high, very_high)
Essential_Concepts_In_Superior_Levels	(very_low, low, medium, high, very_high)
Concepts_Properly_described_In_NL	(very_low, low, medium, high, very_high)
Formal_Specification_Of_Concepts_Coincides_With_NL	(very_low, low, medium, high, very_high)
Attributes_Describe_Concepts	(very_low, low, medium, high, very_high)
Number_Of_Concepts	(very_low, low, medium, high, very_high)
RELATIONS (FACTOR)	(very_low, low, medium, high, very_high)
Essential_Relations	(very_low, low, medium, high, very_high)
Relations_Relate_Appropriate_Concepts	(very_low, low, medium, high, very_high)
Formal_Specification_Of_Relations_Coincides_With_NL	(very_low, low, medium, high, very_high)
Arity_Specified	(very_low, low, medium, high, very_high)
Formal_Properties_Of_Relations	(very_low, low, medium, high, very_high)
Number_Of_Relations	(very_low, low, medium, high, very_high)
TAXONOMY (FACTOR)	(very_low, low, medium, high, very_high)
Several_Perspectives	(very_low, low, medium, high, very_high)
Appropriate_Not-Subclass-Of	(very_low, low, medium, high, very_high)
Appropriate_Exhaustive-partitions	(very_low, low, medium, high, very_high)
Appropriate_Disjoint-partitions	(very_low, low, medium, high, very_high)
Maximum_Depth	(very_low, low, medium, high, very_high)
Average_Of_Subclasses	(very_low, low, medium, high, very_high)
AXIOMS (FACTOR)	(very_low, low, medium, high, very_high)
Axioms_Solve_Queries	(very_low, low, medium, high, very_high)
Axioms_Infer_Knowledge	(very_low, low, medium, high, very_high)
Axioms_Verify_Consistency	(very_low, low, medium, high, very_high)
Axioms_Not_Linked_To_Concepts	(very_low, low, medium, high, very_high)
Number_Of_Axioms	(very_low, low, medium, high, very_high)

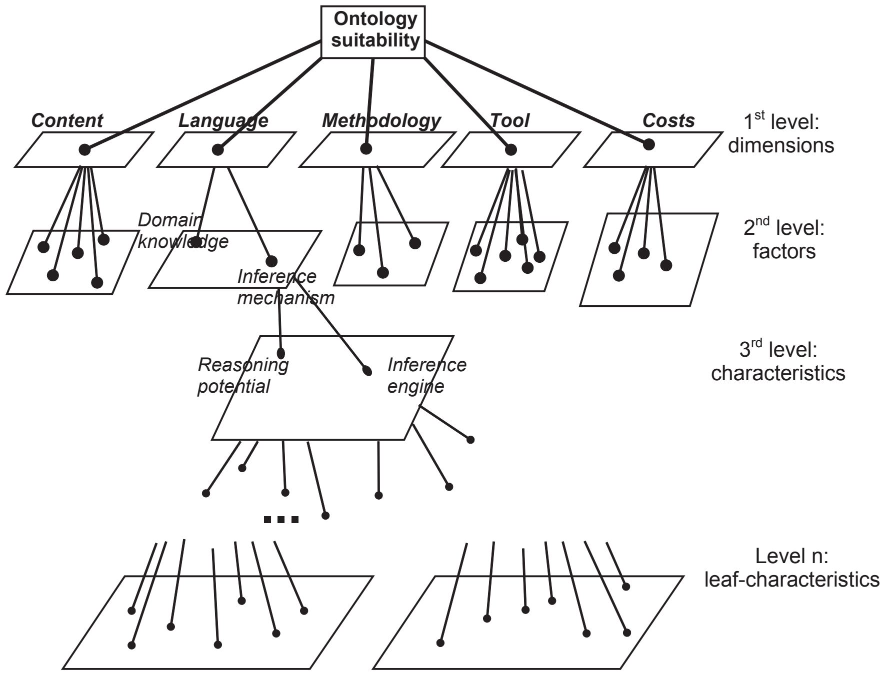
Table 5: Characteristics related to the dimension "methodology"

DIMENSION: METHODOLOGY CHARACTERISTIC	
PRECISION (FACTOR)	(very_low, low, medium, high, very_high)
Delimitation_Of_Phases	(very_low, low, medium, high, very_high)
Specification_Of_Activities_By_Phases	(very_low, low, medium, high, very_high)
Specification_Of_Personnel_By_Phases	(very_low, low, medium, high, very_high)
Specification_Of_Techiques_By_Phases	(very_low, low, medium, high, very_high)
Specification_Of_Finished_Products_By_Phases	(very_low, low, medium, high, very_high)
USABILITY (FACTOR)	(very_low, low, medium, high, very_high)
Clarity_Of_Activities_and_ Techniques _Description	(very_low, low, medium, high, very_high)
Quality_Of_Manuals	(very_low, low, medium, high, very_high)
Manuals_With_Complete_Examples	(very_low, low, medium, high, very_high)
MATURITY (FACTOR)	(very_low, low, medium, high, very_high)
Number_Of_Developed_Ontologies	(very_low, low, medium, high, very_high)
Number_Of_Different_Domains	(very_low, low, medium, high, very_high)
Importance_Of_Developed_Ontologies	(very_low, low, medium, high, very_high)

Table 6: Characteristics related to the dimension "costs"

DIMENSION: COSTS *CHARACTERISTIC*	
Use_Licences_of_the_Ontology (FACTOR)	(very_low, low, medium, high, very_high)
Estimated_costs_of_hw_and_sw (FACTOR)	(very_low, low, medium, high, very_high)
Costs_of_access_interfaces (FACTOR)	(very_low, low, medium, high, very_high)
Use_Licences_of_the_ontology_tools (FACTOR)	(very_low, low, medium, high, very_high)

Figure 1: Representation of the multilevel tree of characteristics



AN ONTOLOGY IN ONTOLOGY DOMAIN: THE *REFERENCE ONTOLOGY*

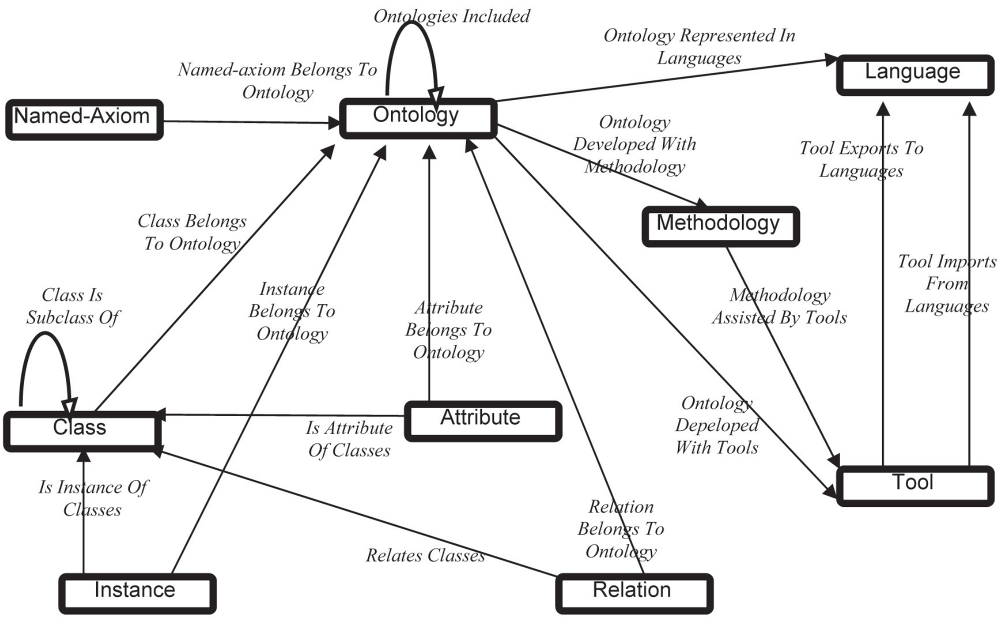
The multilevel framework of characteristics is the base to build an ontology in the ontology domain, called ***Reference Ontology***. The conceptual model of this ontology gathers the characteristics of the framework exposed in the previous section. A direct relationship exists among all the descriptive characteristics identified in the dimensions, and the instance attributes specified in the *Reference Ontology*.

The development methodology of ontologies, METHONTOLOGY (Fernández, 1997; Gómez-Pérez, 1998), and the development environment of ontologies (that follows METHONTOLOGY) WebODE (Arpírez, 2001), were used to build the *Reference Ontology*.

In the *Reference Ontology* are defined, among other, the concepts: *Language*, *Methodology* and *Tool*, whose instance attributes are related to the criteria identified in the multilevel framework of characteristics on languages, methodologies and tools, respectively.

Also, in the *Reference Ontology* are defined the concepts: *Ontology*, *Class*, *Attribute*, *Instance*, *Relation* and *Axiom*. The Reference Ontology gathers information of these concepts from 160 existing ontologies. The instance attributes of these concepts are not directly related to (like in *Language*, *Methodology* and *Tool*) the characteristics identified in the multilevel framework of characteristics in the dimensions "content" and "costs". In this case, the user must determine the values in the characteristics indicated in the framework, from the knowledge included in the *Refer-*

Figure 2: Diagram with direct relationships among the concepts in the reference ontology.



ence Ontology.

Figure 2 shows the direct relationships among the concepts: *Ontology, Class, Attribute, Instance, Relation, Axiom, Language, Methodology* and *Tool* defined in the *Reference Ontology*.

ONTOMETRIC: A METHOD TO CHOOSE ONTOLOGIES

In this section we describe the *ONTOMETRIC* method. This method is based in AHP, adapting some processes for the reuse of ontologies. Next, we describe the steps of the AHP method, and later we explain the adaptation for the method *ONTOMETRIC*.

The Analytic Hierarchy Process

There are several methods and tools available to aid decision making (Triantaphyllou, 2002), some of them used in software projects (Fenton, 1996). The multi-criteria decision methods are useful in comparing several alternatives when, at the same time, several objectives need to be borne in mind. In these methods, the evaluator can directly assign a normalized weight to a criterion that will indicate the importance which that criterion has for the final objective. But the normalization and composition of weights, with regard to more than one criterion, obtains erroneous numbers; this is because the use of normalized groups of separate numbers destroys the lineal relationship among them (Fenton, 1996). To avoid this, the AHP method compares, firstly, the relative importance that each criterion has with regard to all the others; this assessment enables the relative weights of the criteria to be calculated, and finally the method normalizes the weights in order to obtain the measures for the existing alternatives (Saaty, 1977); for this reason, AHP constitutes one of the best options to aid multi-criteria decision making.

The Analytic Hierarchy Process was

devised by Thomas L. Saaty (1977) in the early seventies. It is a powerful and flexible tool for decision-making in complex multi-criteria problems. This method allows people to gather knowledge about a particular problem, to quantify subjective opinions and to force the comparison of alternatives in relation to established criteria. The method consists of the following steps:

STEP 1: Define the problem and the main objective to make the decision.

STEP 2: Build a hierarchy tree (as shown in Figure 3) in this way: The root node is the objective of the problem, the intermediate levels are the criteria, and the lowest level contains the alternatives. This hierarchical organisation is used to obtain a general overview of the criteria and their relations.

STEP 3: For each level, build a pairwise comparison matrix with the brothers (sons of the same node). The matrix contains the weights of pairwise comparisons between brother nodes. This provides us with a pairwise comparison matrix (for exampleTable 7) for each father node.

The user considers "Consumption" six times less important than "Price", twice as important as "Security", etc.

For each comparison matrix, an *eigenvector* must be calculated, using the equation: $|A - \lambda I| = 0$, where A is the comparison matrix, I is the identity matrix and λ is the *eigenvector*. This calculus must be performed for each level of the tree. The entire process can be studied in Saaty (1990).

STEP 4: Value each alternative (leaf nodes) with a fixed scale previously. The scales for rating characteristics should be established and described in a precise way.

STEP 5: Determine the value of each criterion using a weighted addition formula, with the weights from Step 3 and the values from Step 4. These results ascend up the tree to calculate the final value of the objective (root). This final value is used to make a decision about the objective.

ONTOMETRIC: APPLYING THE ANALYTIC HIERARCHY PROCESS IN THE ONTOLOGIES CHOICE

The AHP model can be applied to decide whether or not to reuse ontologies. This method is called *ONTOMETRIC*. In order to decide the reuse in a new software project, *ONTOMETRIC* can be used to: 1) select the most appropriate ontology among various alternatives, or 2) decide the suitability of a particular ontology for the project. For example, *ONTOMETRIC* can be applied to the evaluation of ontologies in order to be used on business systems analy-

Figure 3: Hierarchical structure of the AHP method and example of the objective "Buy a car"

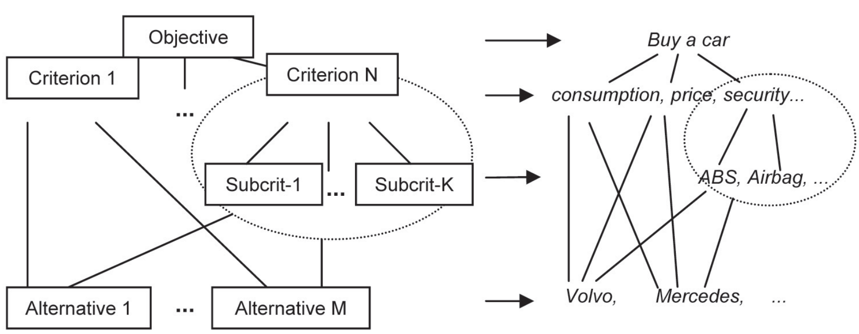


Table 7: Example of comparison matrix for the first level to "Buy a car"

	Consumption	Price	Security	...
Consumption	1	1/6	2	
Price	6	1	3	
Security	1/2	1/3	1	

sis. Thus, the users can evaluate several existing ontologies for their analysis.

In this section, we describe the *ONTOMETRIC* method using the software tool, *OntoMetric Tool*, to assist the user in applying the method. We have used the tool to evaluate two ontologies: Chisholm's ontology (Chisholm, 1996) and BWW-ontology (Weber, 1997), in order to decide on the most appropriate ontology to be used in business systems analysis. The values used in the weights and the characteristics of the example (shown in the figures below) have been assigned for a hypothetical evaluation project. The real users that need to evaluate these ontologies will have to assign the weights and values depending on the objectives of their evaluation (precision, reliability, time, etc.).

Taking into account the general steps of AHP, previously described, we have adapted the method to be used in the reuse of ontologies:

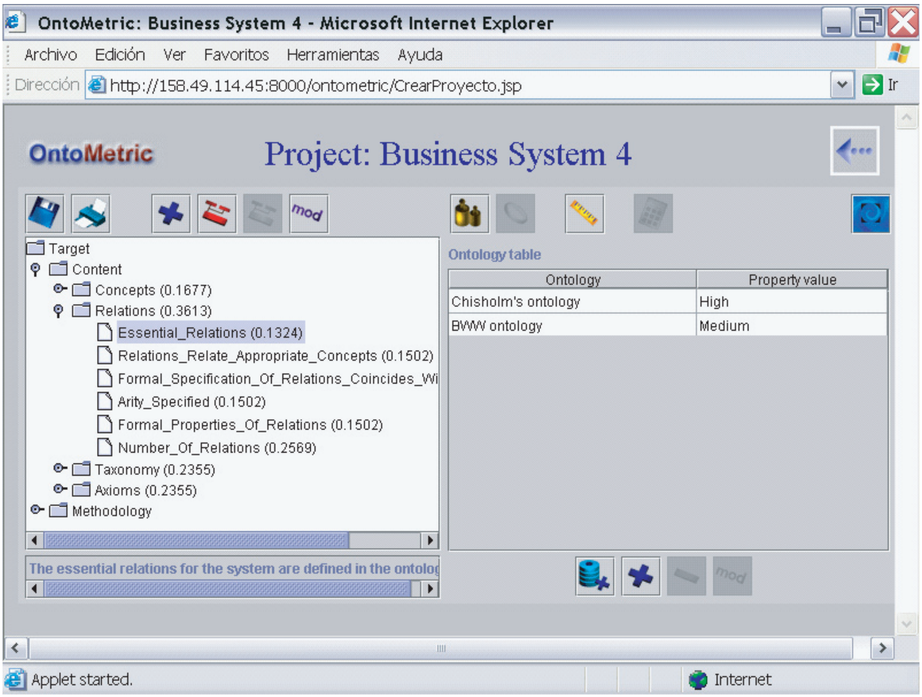
STEP 1: Specify the objectives of the project. The engineers should know the exact guidelines of their company and available resources in relation to the new business. For example, for business systems analysis, the evaluators must state the objectives and the aims of their analysis. They must decide on the importance of the terms of the ontology, the precision of the definitions, the suitability of relations between concepts, the reliability of the methodology used to build the ontology, etc.

STEP 2: Build the decision tree from the MTC, so that the objective, "select the most appropriate ontology for a new software project", is placed at the root node; the dimensions (content, language, methodology, tool and costs) are placed at the first level; the factors of each dimension at the second level; and underneath these factors, the sub-trees of specific characteristics of the particular evaluation project. The general characteristics of all types of ontologies (shown in tables 2, 3, 4, 5 and 6) should be specialised according to: the particular ontology, the specific target project and the organization that will develop the project. *OntoMetric Tool* provides the default criteria tree with the characteristics identified in the *Reference Ontology*, but the users can adapt it to their needs.

Figure 4 shows an example of adaptation of the criteria tree for the selection of ontologies in business systems analysis. This evaluation project considers that the only relevant dimensions are "content" and "methodology". The example considers that "language", "tool" and "costs" are not important dimensions because they bear no relevance in the analysis of the business system.

STEP 3: For each set of brother nodes, make the pairwise comparison matrixes with the criteria of the decision tree. These comparisons depend on the objectives and aims identified in Step 1. The *eigenvectors* are calculated from these matrixes. You can use the pairwise

Figure 4: Adaptation of the multilevel tree of characteristics using OntoMetric Tool. Evaluation of two ontologies to be used on business systems analysis: Chisholm's ontology and BWW ontology.



comparison matrixes module (figure 5) of *OntoMetric Tool* to do this assessment and calculus.

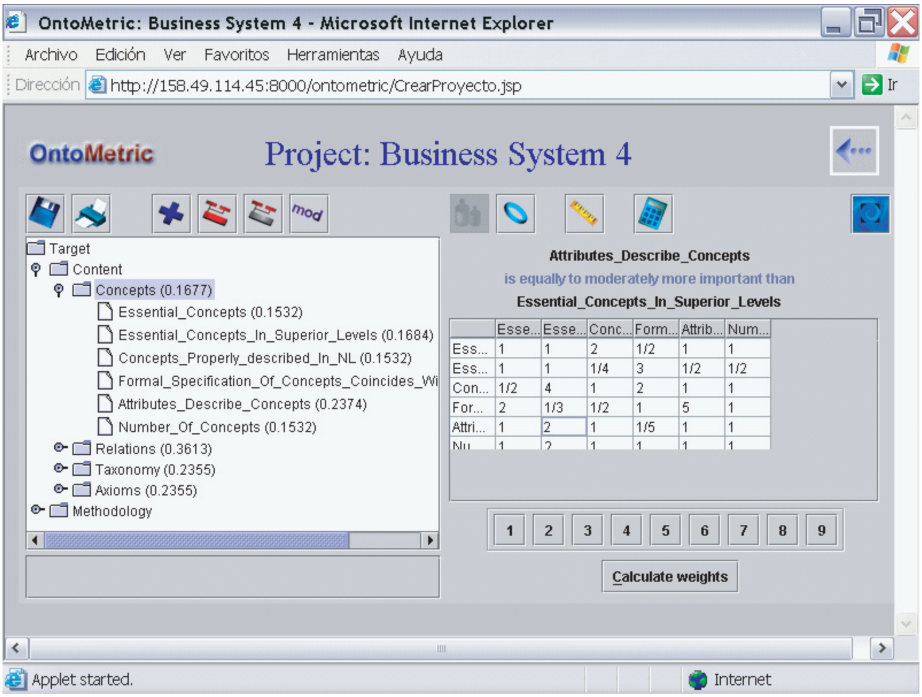
STEP 4: For each alternative ontology, assess its characteristics. These values will (always multiplying by the weights calculated in Step 3) ascend up to the superior nodes of the tree, until the node root is calculated. For each one of these characteristics, the engineer should establish a scale of appropriate ratings.

STEP 4.1: This method assigns linguistic values (non-numbers) to the alternatives because the human beings, in their daily activities, usually make this type of judgment. For example, if analysts evaluate the "essential relations for the system are defined in the ontology", they can assess this quality using the linguistic scale: *very_low*, *low*, *medium*, *high* and *very_high*. Figure 6 shows how *OntoMetric Tool* establishes the different scales. It is better than a numeric scale between zero and ten. In this process, it is important that the groups of the linguistic values are precisely defined.

However it is not possible to perform calculations with linguistic values. One possible representation of these linguistic values is fuzzy intervals (Gómez-Pérez, 1997). Their angular points in a scale from 0 to 10, as shown in Figure 6, determine the fuzzy intervals.

By assigning linguistic values with fuzzy intervals, let us perform basic mathematical operations for intervals. This

Figure 5: Building of the pairwise comparison matrixes using OntoMetric Tool.



way, it can be defined as the operations of: sum of intervals (1) and product by a constant (2):

$$(a_1,a_2,a_3,a_4)+(b_1,b_2,b_3,b_4) = (a_1+b_1,a_2+b_2,a_3+b_3,a_4+b_4) \quad (1)$$

$$n * (a_1,a_2,a_3,a_4) = (n*a_1, n*a_2, n*a_3, n*a_4) \quad (2)$$

STEP 4.2: With these established linguistic scales for each one of the criteria, the engineer will proceed to study each one of the ontologies that have been considered as alternatives, and to value them using these scales.

STEP 5: Lastly, combine the vectors of weights *W* obtained in step 3 with the values of the alternatives *V*, using the formula (e.g.): $\Sigma_n\ w_i\ \ v_i$. Figure 7 shows an example with the comparison of two alternatives (Chisholm's ontology and BWW ontology) in the factor "relations".

In large projects, which require a team of analysts, each person can provide their own values, and it will be necessary to reach an agreement. In this case, all the steps up to Step 4.1 should reach a common consensus among the members of the evaluation team. Later, each analyst can value each one of the candidate ontologies in an individual way. Finally, the suitable ontology is chosen based on the results obtained.

CONCLUSIONS AND FUTURE WORK

ONTOMETRIC is an adaptation of the AHP method to help knowledge engineers choose the appropriate ontology for a new project; in order to do this, the engineer must compare the importance

Figure 6: Establishing scales using OntoMetric Tool

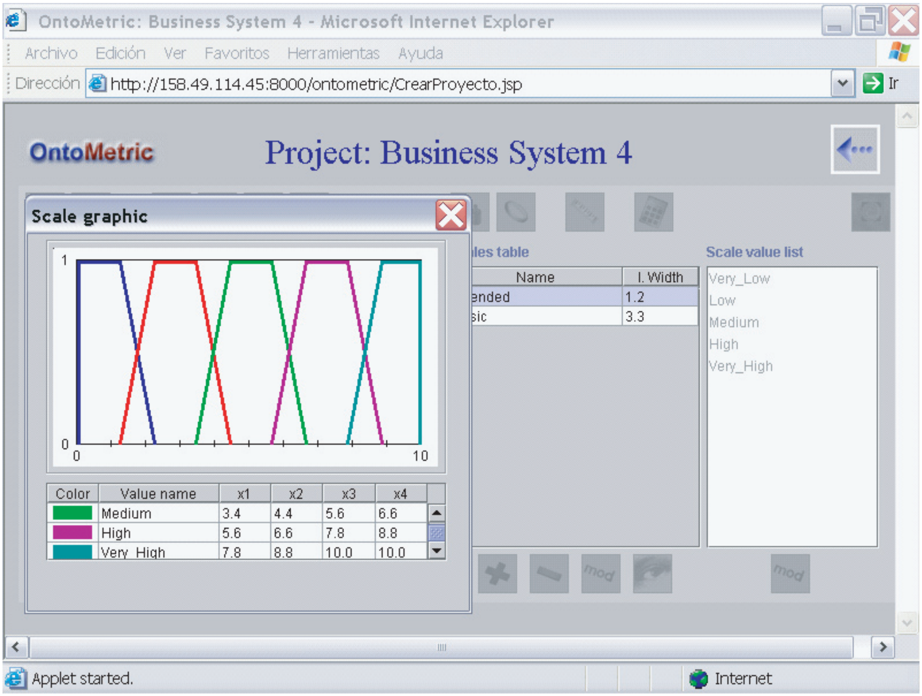
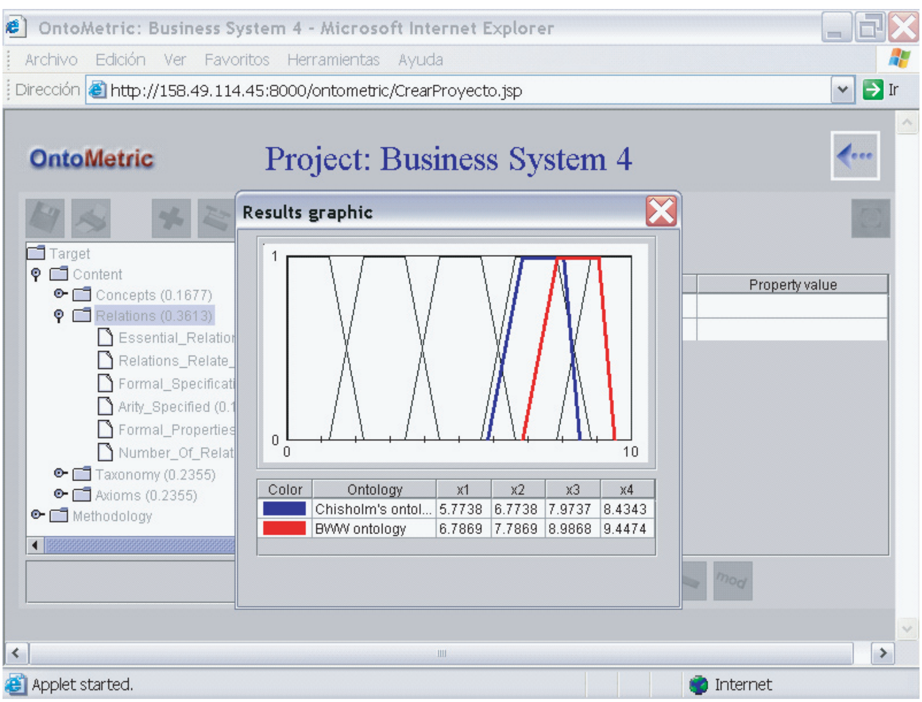


Figure 7: Suitability comparison of two ontologies (Chisholm's ontology and BWW ontology) in the factor "relations" using OntoMetric Tool



of the objectives, and study carefully the characteristics of ontologies. Although the specialisation of the characteristics and the assessment of the criteria of a particular ontology require considerable effort, the above framework provides a useful schema to carry out complex multi-criteria decision making. For example, the method can be applied to decide on the most appropriate ontology for business systems analysis. However, the evaluators need to specify in detail the aims of their analysis.

Feedback from project managers who have used the method reveals that specifying the characteristics of a certain ontology is complicated and takes time, and its assessment is quite subjective; however, they state that once the framework has been defined and if it is applied to one particular type of ontology, *ONTOMETRIC* helps to justify decisions taken, to "clarify ideas", and to weigh the advantages and the risks involved in choosing one ontology from other options. The software tool, *OntoMetric Tool* (http://158.49.116.183:8000/ontometric), assists the knowledge engineer in applying the method. Shortly, it will be integrated in WebODE platform (Arpírez, 2001).

Future work will consist of adapting the method to different ontology scenarios (Uschold, 1999), and establishing formal metrics to assess the suitability of instances in knowledge-based systems for different domains.

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