Computer Standards & Interfaces 34 (2012) 48–59

Contents lists available at ScienceDirect

Computer Standards & Interfaces

journal homepage: www.elsevier.com/locate/csi

An ontology for the harmonization of multiple standards and models

César Pardo [a,b,*], Francisco J. Pino [a,b], Félix García [b], Mario Piattini [b], Maria Teresa Baldassarre [c]

[a] IDIS Research Group, Electronic and Telecommunications Engineering Faculty, University of Cauca, Calle 5 No. 4–70. Popayán, Cauca, Colombia
[b] Alarcos Research Group, Institute of Information Technologies & Systems, University of Castilla-La Mancha, Paseo de la Universidad 4, 13071 Ciudad Real, Spain
[c] Department of Informatics, University of Bari and SER&Practices SPINOFF, Via E. Orabona 4, 70126, Bari, Italy

A R T I C L E I N F O

Article history:
Received 28 February 2011
Accepted 10 May 2011
Available online 15 May 2011

Keywords:
Harmonization of multiple technologies
Software process improvement
Ontology
Standards
Models

A B S T R A C T

Harmonization plays an important role in organizations that are seeking to resolve manifold needs at their different hierarchical levels through multiple models such as CMMI, ISO 90003, ITIL, SWEBOK, COBIT, amongst others. A great diversity of models involves a wide heterogeneity not only about structure of their process entities and quality systems, but also with regards to terminology. This article presents an ontology which: provides the main concepts related to harmonization of multiple models; is supported by a web tool and; has been applied for the harmonization of COBIT 4.1, Basel II, VAL IT, RISK IT, ISO 27002 and ITIL.

1. Introduction

Since the nineties, software process improvement, also known by its initials SPI, has been promoted mainly as a means of satisfying the need to meet the requirements of various reference models and standards for internationally recognized quality; e.g. CMM, CMMI, ISO 9001, ISO 27000, ISO 20000, ISO 90003, just to name a few. These reference models have been institutionalized using different types of improvement models, which lead toward the change and improvement of an organization's processes; They include: the IDEAL model [1], PDCA [2], IMPACT [3], Agile SPI-Process [4], PmCOMPETISOFT [5]. However, although SPI currently plays a key role in the improvement of organizations' processes, it is important to take into account that improvement models defined so far have been designed to make management easier and to provide the necessary support in SPI projects where a single reference model is present and where no suitable environment to work simultaneously with more than one reference model is provided. On the other hand, at the moment organizations must struggle with the complexity and difficulty of understanding and interpreting several models at the same time. This is because each of the reference models defines its own scope, structure of process entities, definitions, terminology quality systems and approach, amongst other things. All this brings out a set of problems when the solution to the needs at different hierarchical levels in an organization is only possible through the implementation of multiple approaches.

Regarding the terminological differences existing between these models, some effort is being made to address this issue; an example is the efforts focusing on the analysis of inconsistencies and conflicts in terminology between models from different organizations, e.g. the comparison and mapping of widely-used models – mainly in those such as CMMI, ISO 9001, ISO 15504 and ISO 12207 [6]. However, the inconsistencies and conflicts related to the terminology also appear in the standards of the same bodies; an instance of this is the attempt to resolve the inconsistencies and terminological conflicts between models from the same organization carried out by the ISO/IEC, which is working on the harmonization of Systems Engineering Standards, such as ISO/IEC 15288, EIA 632, IEEE 1220 and other related ISO standards [7], to thereby guarantee the consistency and coherency amongst ISO models.

On the other hand, based on the results found in a systematic review on the harmonization of multiple reference models presented in [6], it is possible to see that the inconsistencies and terminological conflicts have also appeared in the techniques, methods and related concepts that have been established to support the harmonization of multiple models. That is due to the fact that each researcher has defined his/her own method or technique, where, in general, concepts can be the same as those developed by other authors but another term is used. On the other hand, they may be different concepts even if they have the same name; e.g. the use of *mapping* and *comparison*, *combine* and *integrate*, just to give a couple of instances.

The lack of a formal consensus based on a consistent terminology that allows us to give names to the methods, techniques and related

* Corresponding author at: IDIS Research Group, Electronic and Telecommunications Engineering Faculty, University of Cauca, Calle 5 No. 4, 70. Popayán, Cauca, Colombia.
E-mail addresses: cpardo@unicauca.edu.co (C. Pardo), fjpino@unicauca.edu.co (F.J. Pino), Felix.Garcia@uclm.es (F. García), Mario.Piattini@uclm.es (M. Piattini), baldassarre@di.uniba.it (M.T. Baldassarre).
URLs: http://www.unicauca.edu.co/idis/ (C. Pardo), http://www.unicauca.edu.co/idis/ (F.J. Pino).

0920-5489/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.csi.2011.05.005

concepts, only serves to encourage the development of a research environment that is disorganized. This makes it difficult to understand the main concepts involved when an organization decides to work with more than one model at same time. According to [8], the unification of terms and concepts in an ontology allows knowledge sharing, while ontological analysis clarifies the structure of knowledge. In that sense, an ontology that provides a vocabulary, terms, concepts and relationships that are specialized with respect to the topic of harmonization of multiple models, can eliminate the inconsistencies, confusion and terminological conflicts at different hierarchical levels, bringing about some benefits such as: i) the provision of precise and clear definitions of methods, techniques and related concepts used in this kind of research environment and ii) a more straightforward representation of processes, process models and reference models under the same structure, with uniform and formal vocabulary. On the other hand, by creating an ontology for this current research domain, we can decrease the compatibility problem, as well as the cost related to understanding and/or changing the structure from the different models, methods or techniques that exist. At the same time, we can also deal with all the aspects related to the unified use of other concepts involved in a harmonization environment, e.g. granularity, synergy, harmonization strategy, quality model, harmonization.

We are not aware of other attempts to address the way to resolve the conflicts and terminological confusion when multiple reference models are being harmonized. That being so, this paper describes an ontology that provides a consistent terminology for supporting and leading the implementation of improvement projects where multiple models are harmonized. The methodology used to construct the ontology is explained briefly. Moreover, in order to make it easier to implement improvement projects that involve multiple models, we developed a *Harmonization Framework* to support the work in these types of environments [9]. The ontology presented in this paper is one of the four elements of the *Harmonization framework*. The other three are: a guide to support *the determination of the harmonization goals*, a *Process for driving multi-model harmonization* [9], and a *Set of Methods and Techniques*. We have defined two techniques, which are: homogenization and comparison techniques; the *methods* for the implementation of each of these are described in [10] and [11], respectively. Now, however, a new element, a *harmonization of multiple model ontology*, called *H2mO*, is being added to the *Harmonization Framework*. This ontology is in charge of presenting the terms, concepts and relationships for supporting the harmonization of multiple models and it is based on the systematic review carried out in [6], and on an analysis that was carried out of the Methods and Techniques for the harmonization of multiple models identified from set theory.

This paper is organized as follows. After this introduction, Section 2 presents an analysis of the current situation. Then Section 3 introduces an ontology for harmonization of multi-models, which provides a cohesive set of concepts and their relationships within a consistent terminology that aims to serve as reference for the implementation of harmonization projects in multi-model environments. An analysis of set theory to improve the understanding and establishing of the relationships between some concepts in the ontology proposed is presented in Section 4. Section 5 describes our experience using this ontology in three real projects. Based on the results obtained in the use of our ontology, we present some considerations and conjectures which we believe should be taken into consideration in a harmonization project. Finally, conclusions and future work are presented in Section 6.

2. Background: an analysis of the current situation

In our search in the literature, we identified few efforts to develop formal ontologies to support the harmonization of multiple models. The work carried out in this sense has focused mainly on the development of ontologies to represent the key elements of particular domains, e.g. the ontology for representing the CMMI-SW model [12], engineering domain ontology based on SWEBOK developed by [13], and Software Process Ontology (SPO) developed by Liao, Qu and Leung, which allows us to express software processes at the conceptual level and which provides an extension for generating ontologies for specific process models, such as CMMI and ISO/IEC 15504 [14]. Other studies have focused on development ontologies to support the business process integration, a subject that is beyond the scope of this article.

Taking into account the situation set out above, we did not find any ontology that identifies the terms, concepts and relationships between them, which would support the domain of the harmonization of multiple models. That being the case, we decided to carry out the construction of our ontology, performing a comparison analysis of harmonization concepts and terminology, based on the previous analysis of the state of the art as presented in [2] and upgrading this with a systematic review carried out in [6]. Table 1 presents a brief summary of the studies found and classifies them according to the method or technique that these propose. The studies are grouped according to the activities performed or the definitions used in the methods or techniques identified in each study. Moreover, some related terms which have been identified during the analysis of the studies are also presented.

2.1. Issues found

Having analysed the studies, we present some issues found in the terms used to name the methods and techniques:

- Some studies use terms such as *synergy* or *compatibility* to establish the level of relationship between models. However, not all use a *comparison scale* that allows us to know what range of similarity or difference there is between them.
- Synonymy 1, *combining* and *merger* are used to refer to several integrated models, but with the difference that the steps followed for their integration are not shown. Some works use the term *single model* or *universal model*. Likewise, *complementarity* is used to refer to models that take elements of other models in order to maximize their qualities.
- Synonymy 2, the techniques used are the same but are given different names, e.g. the activity performed to identify related elements between two models is called *comparison* or *mapping*. Only a few studies establish an additional characteristic in the mapping when this requires elements of greater granularity. In this case, some studies, such as those developed by Mutafelija in [25], establish a difference between a mapping at a high, middle or low level.
- Synonymy 3, *integration* and *unification* represent the same concept, e.g. PrIME project uses *integration* [15] and Yoo, et al. use the term *unified* [22].
- There is no uniform treatment of some basic software engineering concepts, such as model, reference model, process model, technology, standard. Although in theory each of those terms could be used to mean one single thing, there is in fact a great difference between the ways they are employed.
- There is no proposal that defines an ontology that harmonizes part of the conflicts in terminology with respect to harmonization of multi-models.

From the results obtained, we have been able to identify that, depending on an organization's needs, the multi-model environments are characterized by the implementation of various methods and techniques to support their harmonization. However, it is obvious that in the works analyzed several different terms are used to identify those methods and techniques. Taking into account that each study

Table 1
Techniques found in the works analyzed.

Method, technique, concept or term	Other related terms	Summary
Integration Unification	Harmonization Synergy Complement	Certain researchers and organizations are working on the definition of solutions related to *integration* or *unification* models. The SEI with its PRIME project [15–17] to integrate several models, the Enterprise SPICE [18] is a initiative to establish an Enterprise Integrated Standards-Based model for use with international standard ISO/IEC 15504 (SPICE), an ontology for quality standards integration in software Collaborative Projects [19] and the V-modell XT applied as a standard to integrate the different approaches towards development in Information technology (IT) projects in the public sector in Germany [20]. Others studies show the integration of two widely-used models, namely CMMI and ISO 9001 [21–23].
Comparison Mapping	Align Harmonization Correspondence Granularity Coverage Degree of coverage Degree of relationship	One *comparison* technique widely used for harmonizing models is *mapping*. Mapping is necessary from the point of view of the differences between models (structural and semantic) [20]. It is possible to find a wide range of literature dealing with the mappings of CMMI and ISO 9001 [24,25,26,27,28] and [29]. Other approaches are mapped with CMMI, e.g. SPICE [30], ISO 15504 [31,32], EIA IS 731 and SECM [33], Agile or Lean Development, Six Sigma, PMBOK, CMMI-DEV and ISO/IEC 15504 [11], CMMI-ACQ and ISO/IEC 12207:2008 [34], among others [35]. It is also possible to find the mapping of other models, e.g. the *aligning* of Cobit 4.1, ITIL V3 and ISO/IEC 27002 for Business Benefit [36], among others.
Syntactic analysis Homogenization	Harmonization strategy Harmonization structure	In some comparisons an analysis of the terms used in each model is carried out. However, this is not sufficient if the models are not structurally and semantically compatible, e.g. comparing the different ISO models does not imply major differences; the ISO organization has attempted to harmonize the differences between their models, e.g. the ISO 9001, ISO 90003 and ISO 14001 models. These have been defined with one common terminology and structure, in order to facilitate their adoption and integration as and when required. However, when models have large structural differences, it is necessary to carry out the alignment of the structures of each model. This will allow comparisons of conceptually-compatible process elements to be carried out.
Combine Combination Merger Single model Universal model	Harmonization	Other studies propose combined models, in which the model obtained is the integration of several models. In order to differentiate between these works and those related to integration, the works related to combination show combined models and not a solution to support their integration. However, the term combination may be synonymous with integration, and we thus consider combination to be an integration technique. Some combined models are iCMM [37], which is a combination of several CMMs with ISO 9001, Malcolm Baldridge National Quality Award criteria, International lifecycle and assessment standards and processes and related extensions to the safety and security, and the CITIL model, which combines ITIL with CMMI [38], and the integration of CMMI and six-sigma model [39].

was carried by different parties, it is normal that such differences exist, but at the same time this situation explains why an effort to resolve some differences and terminological conflicts in the environment of multi-model harmonization is required.

3. H2mO: an ontology for harmonization of multi-models

Taking into account our analysis of the current situation, we pursued the following goals for the definition of the *harmonization of multiple models ontology* or H2mO:

- Location and identification of terms, synonyms and homonyms, inconsistencies and terminological conflicts.
- Integration of the concepts found in the literature analyzed.

These goals can be achieved by means of a common ontology that represents the domain to harmonize multi-models. It must define all concepts, providing terms with definitions that are clear and concise, which identify the relationships between them clearly. An ontology in this research stream can serve as a basis for supporting harmonization requirements of an organization, which are mainly aimed at analysis, comparison and integration of several models.

There are many methodologies for systematizing the implementation of ontologies, e.g. the ontology-based knowledge management [40], Methontology [41], a translation approach to portable ontology specifications [42], Ontology and first-order logic [43], amongst others. After studying the different ontologies for the definition of H2mO, we decided to use the Representation Formalism for Software Engineering Ontologies (REFSENO) [44] (REFSENO) since: i) it is based on an adaptation of the methodology Methontology, which is widely used for defining ontologies in different fields, ii) REFSENO was particularly designed as a specialization of Methontology, but for the development of ontologies in software engineering by means of constructs to describe concepts, attributes and the relationships between them (three tables are used to represent these elements as concepts glossary, attributes and relationships), iii) unlike the methods cited above and other approaches, which only allow representations that are less intuitive for people not familiar with first order predicate logic or similar, REFSENO makes a distinction between the levels of knowledge: conceptual and context-specific, and iv) unlike other approaches, REFSENO provides several techniques for the analysis of the consistency of the ontology and instances at the level of implementation.

3.1. An ontology for the harmonization of multiple reference models

The following tables provide a summary of the REFSENO representation of the harmonization of multiple models Ontology by describing their concepts (Table 2) and relationships (Table 3); we have omitted the description of the terminal concepts attributes. In addition, Fig. 1 shows the graphical representation of the H2mO terms and relationships, using the UML (Unified Modeling Language).

The H2mO makes use of two additional ontologies to explain how to improve the domain of the ontology; the additional ontologies are: a *Process-Based Ontology,* part of the ontology is shown in [10], and some terms of the Software Measurement Ontology, which is presented in [45]. In that sense, H2mO has been organized around three main elements:

- *Harmonization Ontology,* which introduces the key concepts used in the definition and execution of a multiple model harmonization project.

The main goal of H2mO is the assigning of a formal and clear definition of the most widely-used techniques, methods and related terms in harmonization of multiple models, as found from the results of a systematic review performed.

- *Ontology of Process-reference Models (OPrM):* which establish and clarify the key elements to express process-based approaches of any reference model, such as CMMI, ISO 9001, SWEBOK, ITIL, and

Table 2
Definition of the terms in the H2mO.

Term	Supercon	Definition	Resource
Comparison	Technique	Analysis of the high-level characteristics between models from a reference model.	Defined from [25,28]
Degree of coverage	Measure	The degree of relationship indicates the extent to which an entity of a model supports, addresses or has connection with an entity of another model; this expresses a many-to-one relationship.	Taken from [11]
Degree of relationship	Measure	The degree of relationship indicates the extent to which an entity of a model supports, or has any connection with an entity of another model; this expresses a one-to-one relationship.	Taken from [11]
Granularity	Concept	Measure used to understand the level of depth of a model.	New
Harmonization	Concept	Activity that seeks to define and to configure the most suitable harmonization strategy for achieving the strategic goals of an organization where two or more models are involved.	Defined from [15]
Harmonization strategy	Concept	A harmonization strategy is a process which is comprised of a set of methods and techniques defined systematically, which allows us to know “what to do”, as well as “how to put” two or more models in consonance with each other. The harmonization strategy is the main work product that any harmonization project must obtain to put two or more models in consonance.	Defined from [9]
Homogenization	Technique	Set of steps and tools by which one or more models are treated, to convert the structures of their process elements into homogeneous structures.	Defined from [10]
Homogenization structure	Concept	A homogenization structure allows us to carry out the homogenization of the process elements of two or more models from a set of common process elements. A structure must facilitate the analysis of the process elements described by different models under a common schema. Likewise, it must make it easier to understand the models and to identify differences and similarities between them.	Defined from [10]
Integration	Technique	Action or effect of joining or merging two or more models through the implementation of techniques such as those mentioned in this section.	Defined from [22,37]
Mapping	Comparison	Comparison technique that goes far beyond the simple identification of the differences and similarities between the elements of the models that are compared.	New
Measure	Concept	The defined measurement approach and the measurement scale. (A measurement approach is either a measurement method, a measurement function or an analysis model).	Taken from [45]
Method	Concept	General procedures and the techniques that are specific procedures applied to the definition or framework of a method. A method is a procedure which is generally oriented towards a specific purpose.	New
Quality model	Concept	The set of measurable concepts and the relationships between them which provide the basis for specifying quality requirements and evaluating the quality of the entities of a given entity class.	Taken from [45]
Relationship	Concept	Relationship identified between the definitions of a set of process element of different models. Similarity found between the definitions of process elements of different models.	New
Scale	Concept	A set of values with defined properties.	Cited in [45]
Semantic analysis	Analysis terminology	Process by which the human language is studied. Its main aim is to study the relationships between the subjects mentioned in a text.	New
Synergy	Concept	Integration of models that results in something larger than their simple sum, that is, when two or more models are synergistically united, this creates a result that takes advantage of, and maximizes, the qualities of each model.	New
Syntactic analysis	Analysis terminology	Process by which a text is analyzed with the objective of identifying its grammatical structure, taking a formal grammar as a basis.	New
Technique	Concept	Different ways of applying a method.	New
Terminology analysis	Concept	The terminology analysis is the process of analyzing a text. This allows a better understanding of the models through a syntactic and semantic analysis, thereby decreasing a large part of the ambiguity and subjectivity that is involved in understanding each model.	New
Type of scale	Concept	The nature of the relationship between values on the scale.	Cited in [45]
Unit of measurement	Concept	Particular quantity, defined and adopted by convention, with which other quantities of the same kind are compared, in order to express their magnitude relative to that quantity.	Cited in [45]

ISO 27001, amongst others. The main goal of OPrM is to introduce the concepts required to define process-based approaches. Based on the OPrM, a common schema or common structure of elements processes (CSEP) was defined, which is used along with a harmonization technique, to facilitate the harmonization of different models. Both the CSPE and a brief summary of the homogenization technique are presented in [10]. Due to the importance of obtaining models under certain specific requirements, the OPrM is currently being updated to extend the elements that it is made up of.

- We have taken some concepts of the subontologies: *Software Measures Ontology* and *Measurement Ontology*, which are part of Software Measurement Ontology (SMO). These subontologies establish and clarify the key elements in the definition of a software measure and the terminology related to the act of measuring software. To make the H2mO diagram clearer, we have divided it into two diagrams; Fig. 1, which shows the Ontology and terms related with SMO, and Fig. 2, which shows the terms related to H2mO and OPrM. Both diagrams Figs. 1 and 2 use the UML representation (Unified Modeling Language).

The precise definitions of the concepts included in the ontology are presented in Table 2, which is ordered alphabetically and organized in the following way: columns one and two show the term being described and its super-concept, then column three shows the definition of the term in H2mO. Finally, column four shows the source where the term has been adopted or adapted.

Some values used in the fourth column can be either:

- A reference to a source.
- Defined from [source], if the term has been defined from a source that does not provide a particular definition, that is, the term has been defined without highlighting, changing or complementing an existing term, but the work presented in it has been key to establishing a definition.
- New [term], if the term is used in the H2mO, or has a new meaning in this proposal.

Table 3
Relationships in the H2mO.

Name	Concepts	Descriptions
Allows harmonization	Technique–Quality Model	Harmonization allows us to know the granularity of a model. The granularity of a model may be known through its harmonization.
Allows know	Granularity–Harmonization	Granularity is obtained from harmonization of models. From harmonization of models it is possible to know the granularity of a model.
Belongs to	Scale–Type of scale	Every scale belongs to a type of scale. A type of scale may characterize several scales.
Defines	Homogenization–Homogenization structure	Homogenization defines a homogenization structure. One homogenization structure is defined in the homogenization.
Defines	Harmonization–Harmonization strategy	A harmonization project defines a harmonization strategy. A harmonization strategy is defined in a harmonization project.
Expressed in	Measure–Unit of measurement	A measure is expressed in one unit of measurement (only for measures whose type is interval or ratio). A unit of measurement is used to express one or more measures of interval or ratio types.
Found between	Synergy–Quality model	Synergy may be found between several models (more than two). A quality model could be synergistically related to other models.
Has	Measure–Scale	Every measure has a scale. A scale may serve to define more than one measure.
Has a	Quality model–Granularity	A quality model has a certain degree of granularity. A certain degree of granularity is described by a quality model.
Identifies	Degree of coverage–Relationship	Degree of coverage identifies relationships. One or more relationship is identified through degree of coverage.
Identifies	Degree of relationship–Relationships	Degree of relationships identifies relationships. One or more relationship is identified through degree of relationship.
Involves	Harmonization–Quality model	Harmonization of models involves several models (more than two). More than two models are involved during the harmonization.
Involves	Harmonization–Technique	A harmonization project could involve different techniques. Several techniques may be used in the harmonization of multiple models.
Is a	Integration–Complement	Integration is a sort of complement. The complement is performed through integration.
Is a	Comparison–Difference	Comparison is a sort of difference. The difference is performed through comparison.
Is a	Integration–Union	Integration is a sort of union. The union is performed through integration.
Is a	Comparison–Difference	Comparison is a sort of difference. The difference is performed through comparison.
Is a	Comparison–Intersection	Comparison is a sort of intersection. The intersection is performed through comparison.
Is applied to	Harmonization strategy–Quality model	A harmonization strategy is applied to one or more quality models. One quality model is used in one or more harmonization strategies.
Is comprised of	Harmonization strategy–Technique	A harmonization strategy is comprised of one of several techniques. A technique is part of one or several harmonization strategies.
Is detailed in a	Method–Technique	A method is detailed in a technique. A technique details a method.
Is related to	Quality model–Quality model	A quality model may be related to other models.
Needs	Integration–Comparison	Integration could use the comparison. The comparison may be used in the integration.
Obtained from	Synergy–Harmonization	Synergy is obtained from harmonization of multiple models (more than two). During the harmonization of models the synergy between them may be obtained.
Obtained from	Harmonization–Granularity	Granularity of a model is obtained from its homogenization. From the homogenization technique it is possible to know the granularity of a model.
Transformation	Measure–Measure	Two measures can be related by a transformation function; the kind of function will depend on the scale types of the scales.
Uses	Technique–Terminology analysis	A technique uses a terminology analysis. The terminology analysis is used in a technique.
Uses	Complement–Difference	Complement uses the difference. The difference is used by the complement.
Uses	Difference–Intersection	Difference uses the intersection. The intersection is used by the Difference.
Uses	Comparison–Homogenization	Comparison could use the homogenization. The homogenization may be used in the comparison.
Uses	Comparison–Measure	Comparison uses one or more measure. One or more measure is used in the comparison.

- Taken from [resource], if the term has been defined from a source.
- Cited in [resource], if the term has been cited by a resource and it is not the original resource. The term has not been modified.

3.2. Discussion

From the definitions introduced in the ontology, there are some terms that deserve special discussion. As so, in this section we extended the definition and analysis of some terms such as *harmonization, synergy, correspondence, comparison, integration, homogenization and mapping.*

(1) *Harmonization*; according to [15], is not: (i) About creating a master meta-model or a new single model that encompasses all other models or (ii) About declaring any single combination of models as the best, or suggesting a universal combination to suit all. Harmonization therefore, is rather the development of one suitable solution that allows an organization's goals to be satisfied.

(2) *Synergy*; according to definition of synergy introduced in the ontology, it is important to highlight that if there is synergy between models, then the affinity between them (found from a comparison) must exist as a prerequisite. Model integration is therefore only possible if there is affinity. An example of the synergy between models can be seen in [19].

(3) *Correspondence*; since each model describes its processes at a different level of detail, the correspondence cannot normally be completed. Therefore, a correspondence scale is often defined for the establishment of the relations, (e.g. see [46] and [28]). The scale correspondence defined allows us to classify the relationships identified from the models compared in an approximate range. The scale used could vary according to the expert criteria and the method used.

(4) *Comparison*; in the model comparison the need to know the level of equality and proportion between the things being compared should take priority. From the relationships found among the definitions of process entities of different models, it is possible to know how different they are.

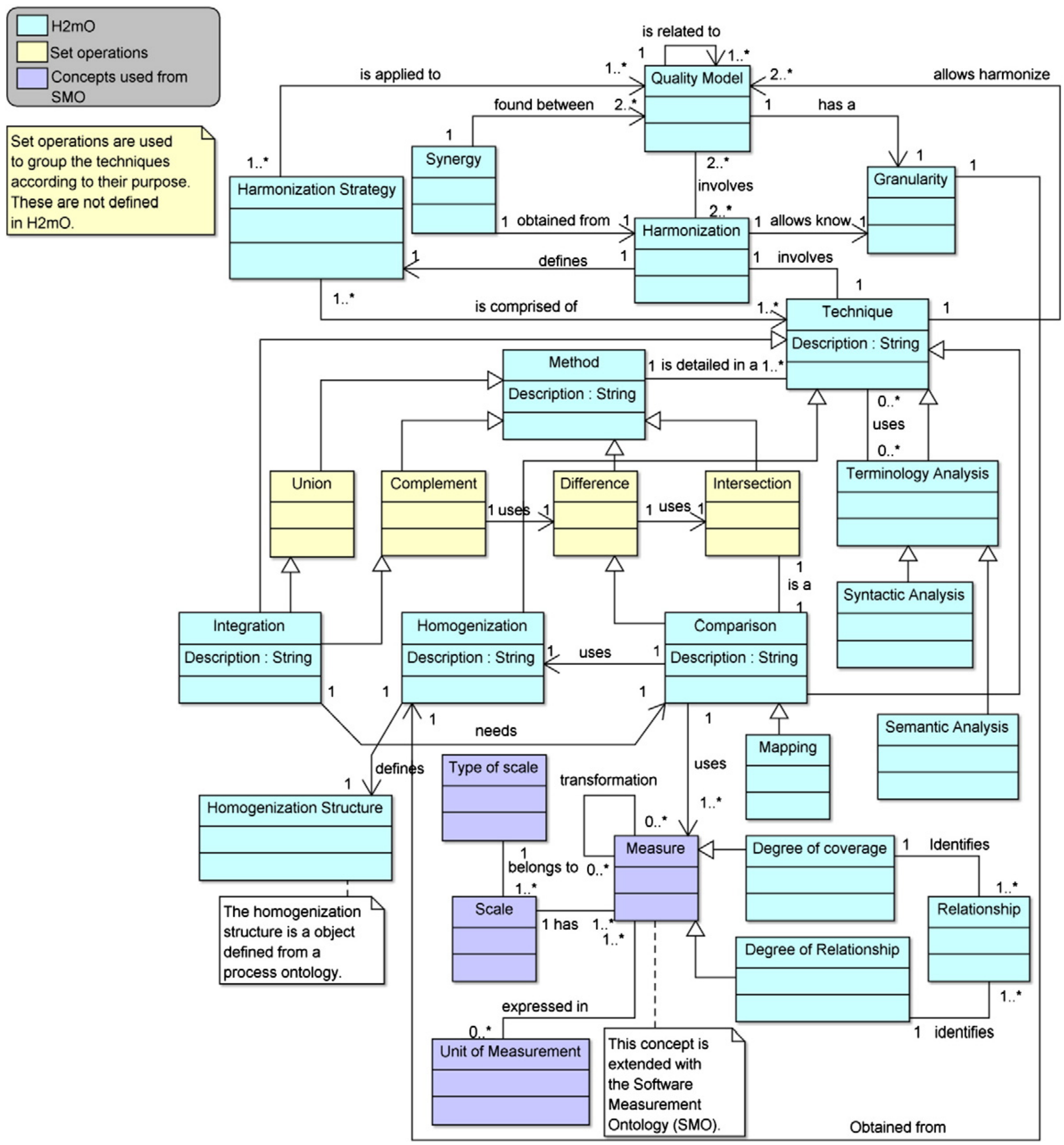

Fig. 1. UML representation of H2mO concepts, attributes and relationships.

(5) *Integration*; the major goal of some projects and harmonization initiatives is to support the integration of multiple models with an integration framework. Integration allows different models to be harmonized when collaboration between them is necessary in an organization. In [22] and [37] the integration of multiple models is carried out, and the techniques used are mainly aimed at the merger or combination of recommendations of the models analyzed.

(6) *Homogenization*; Since each model defines its own internal structure, the process elements used may be different. Although these might contain similar elements, each model defines different levels of detail. We believe that the homogenization technique that we have developed [10], is a good reference of support to enable other techniques to be implemented, e.g. comparison techniques, integration, analysis of terminology and so forth.

(7) *Mapping*; given the definition in the ontology, mapping should involve a low-level abstraction comparison. That is, mapping requires the analysis of the model elements involved in the mapping, e.g. the activities, the work products, roles, tasks and so forth, and not process entities of high-level abstraction, such as processes and process group.

4. Applying set theory to understanding and establishing the relationships between concepts in H2mO

In this section we set out how *set theory* and its main operations have been used to better understand and establish the terms, definitions and some relationships defined in H2mO. Based on the features found in the models, set theory was a good reference through which to improve the illustration of some elements involved in the harmonization of multiple models.

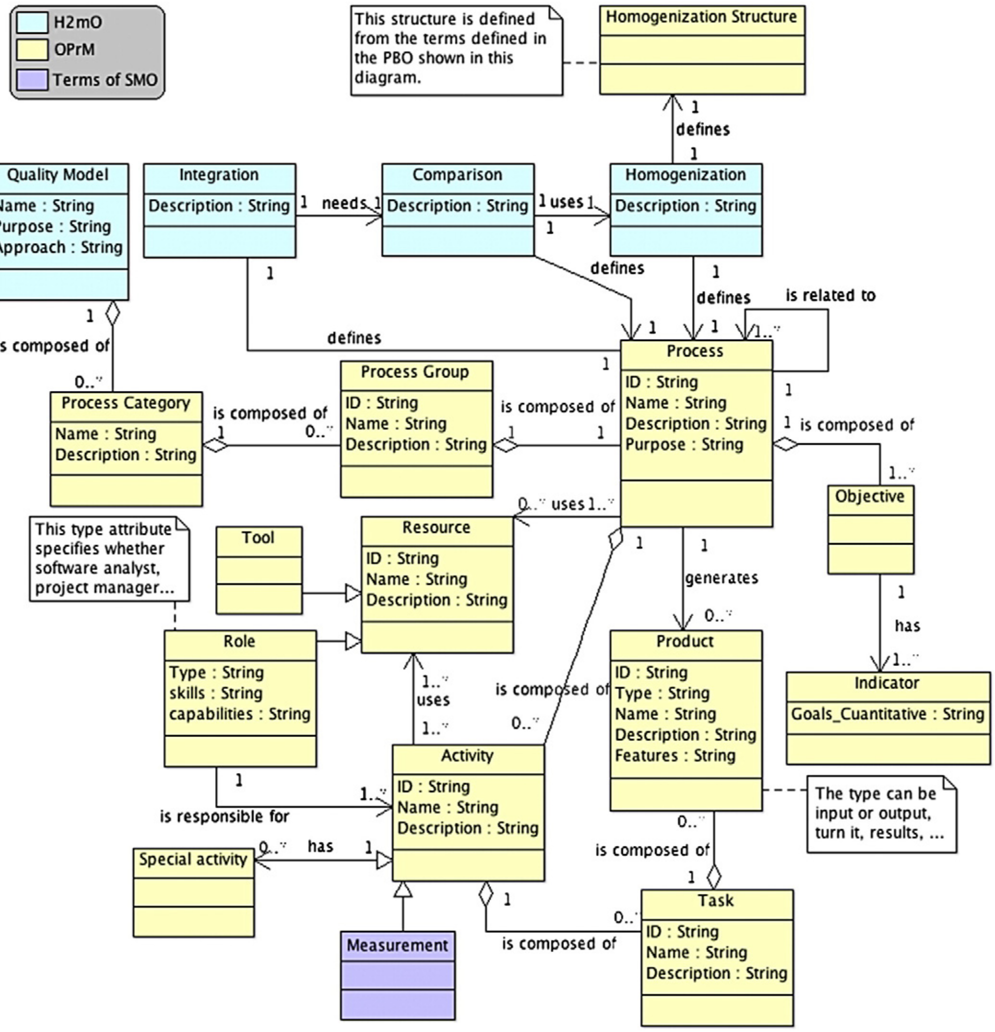

Fig. 2. UML representation of relationships between H2mO and OPrM.

The analysis of the harmonization of models from *set theory* M is shown as follows.

4.1. Analysis of the operations between models

The *set operations* considered were: *union, intersection, difference* and *complement*. We also used *Venn diagrams* in order to illustrate the relationships between models better. Based on our experience, some examples with every set operation are presented; these examples have allowed us to enhance the understanding of the operations between models. Because of the complexity and effort that model harmonization requires, we believe that it should be carried out in groups of two models. In that sense, figures presented in this section only show the harmonization of two models.

4.1.1. Intersection

The common elements between models are represented by the intersection of two or more models. As the major goal of the intersection is to identify the common elements between models, this is considered to be a comparison operation, and it is therefore necessary to define the direction of the comparison. The intersection of models should also permit the common elements in the models to be identified at a low and/or high level.

Although each model usually specializes in a set of specific practices and different levels of abstraction and detail, it is possible to identify similar elements that may exist between models. Fig. 3(a) shows the *intersection* of sets (Model A *intersection* Model B), which is represented for the elements in ISO 9001 and CMMI. An example of the intersection of elements at a high-level might be the establishment of

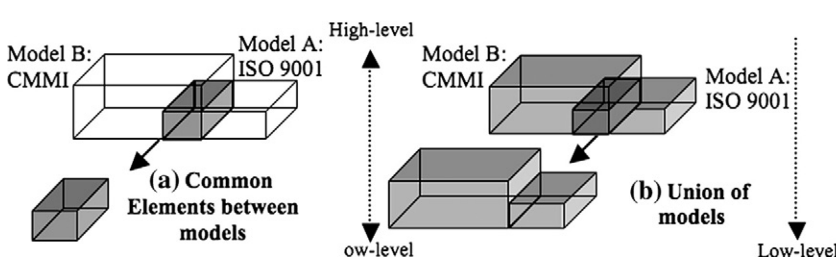

Fig. 3. Intersection and Union between models.

the relations between ISO *Clauses* and the CMMI *Generic Goals* (GG), or at a low-level between the ISO *Clauses* and the CMMI *Specific Practices* (SP). The common elements are identified by analyzing the descriptions of each model. However, the precision level of the descriptions depends on the model [19]. Intersection can also be found in more than two models, but on the basis of the experience gained with harmonization of multiple models such as ISO 27001 and ISO 20000 (part 2), and the definition of IT Governance Model for Banking (ITGMB), which was defined from the harmonization of six models such as COBIT 4.1, Basel II, VAL IT, RISK IT, ISO 27002 and ITIL V3, we recommended the intersection of the models to be carried out in groups of two. This allows the complexity to be reduced, in order to establish the relationships. Both the process used and the results obtained from the harmonization of ISO 27001 and ISO 20000, and ITGMSB are presented in [9]; a more detailed analysis about the comparisons and an extract of the ITGMSB Model can be seen in [47].

4.1.2. Union

We believe that the joining of models concerns the development of one harmonized solution based on the practices and recommendations defined in more than one model; there is a better analysis with the union of models. The union of models results in a single model process reference or unified model. One of the benefits of using a single model process reference is that the improvement efforts involve the same vocabulary [37]. Although each organization has a different priority process dimension, the development of a single model represents a considerable effort as regards time, people and money. Moreover, it does not make sense to create a universal single model for only one organization [15].

Fig. 3(b) shows the set union (Model A *Union* Model B). The resulting set is larger than the two separate models (see [21] and [22]). Moreover, it covers more practices if only the ISO 9001 or the CMMI model are used, or vice versa [28]. No matter which models are integrated, the union of two or more reference models allows the weaknesses of the models that an organization uses to be strengthened, and we therefore believe that the union of models enables a powerful formula to satisfy an organization's multiple needs. On the basis of the experience obtained with the definition of ITGMSB [47], we believe that the union of models must be carried out at a low-level; this allows the descriptions of the models elements to be unified in an objective way.

4.1.3. Difference

Difference allows us to compare and discover the differences between two or more models with reference to elements they do not have in common. Similarly, as noted earlier in the intersection operation, the difference should permit the definition of the abstraction level or detail that will be used in the model comparison. Moreover, in the case of the difference it is also important to define the directionality of the comparison, which depends on the model that is in use or which is institutionalized in an organization. The degree of relationship identified depends on the direction of the comparison [34].

Fig. 3(a) shows an example of the difference operation implemented in two models: the ISO 9001 Model and the CMMI Model. The possible operations will depend on the directionality of comparison chosen. In this case, the figure shows the comparison made to identify the different elements between the ISO 9001 model and the CMMI model, and vice versa. From the intersection of elements, it is possible to know the elements present in B and not in A or *Model B–Model A* and vice versa. The difference operation allows us to know the non-common elements between two models. In that sense, both intersection and difference are different types of comparison of multiple models.

4.1.4. Complement

The complement of a Model A is represented by the elements in Model B that do not belong to A. This means that the complement of Model A is all those elements that are not defined in A and that are defined in a B model. The complement can be obtained by using the models' difference. That is, the difference between Model B and Model A (Model B – Model A) is called the complementary of A with regard to B. This also occurs with the difference between Model A and Model B, where the result obtained is the complement of B with regard to A, see Fig. 3(a). Therefore, the complement is a means to obtain the difference between models, and this entails carrying out the identification of missing elements in one model with regard to another.

4.2. Relationships identified from the set theory

Fig. 1 shows the relationships between *set operations*, *methods* and *technique* harmonization that have been identified. We consider that *methods* are general procedures and that *techniques* are specific procedures applied to the definition or framework of a *method*. That is, a *method* is a procedure which is generally oriented towards a specific purpose, while the *techniques* are different ways of applying the method.

Before establishing the relationships between methods and techniques in H2mO, at first sight all the set operations gave the impression of being comparison techniques. However, on the basis of the analysis performed, it was possible to classify them within *general procedures* or *method*s, which are: *complement*, *integration*, and *comparison*. The analysis technique is performed implicitly in each technique, but it is not always implemented in the same way. In H2mO two ways to carry out the analysis of the models are established, which are: syntactic analysis and semantic analysis. We nevertheless recommend using it to make it easier to implement the other techniques, e.g. the *complement* and *integration* techniques use the *comparison* and *analysis* techniques to enable the models to be understood by analyzing their *terminology* (analysis syntactic and/or semantic) or through the *homogenization* of their process structure.

In Fig. 1, *method and techniques* are differentiated; in addition, each *method* can specialize in different *techniques* e.g. *homogenization*, comparison and integration. Likewise, each technique can specialize in another kind of technique or specific procedure, e.g. it is possible to use either a *merger* or a *combination* method to carry out the *integration*. This first version is not intended to encompass all the existing *techniques* and *methods*, but rather those which are most common, as well as those used in the works analyzed, thus permitting their future adaptation and updating.

5. Using the ontology

The ontology summarized and presented in this paper has been used with success in three cases of implementation. The first two cases of implementation refer respectively to a group of researchers and an organization, both interested in the harmonization of multiple models. The high level of cooperation has allowed H2mO to be put into operation in real environments. The information shown in the first two cases is related to the creation of instances from H2mO as part of the validation of its concepts and relationships. In the third case the ontology was used to develop a software tool. We give a brief outline of its implementation in the cases below:

5.1. A model for Information Technology Government

The first case of implementation involved a group of researchers, whose main goal was to define a model for the Information Technology Government applicable to the Superintendence of Banks of Guatemala and to the banking sector in general, taking into account

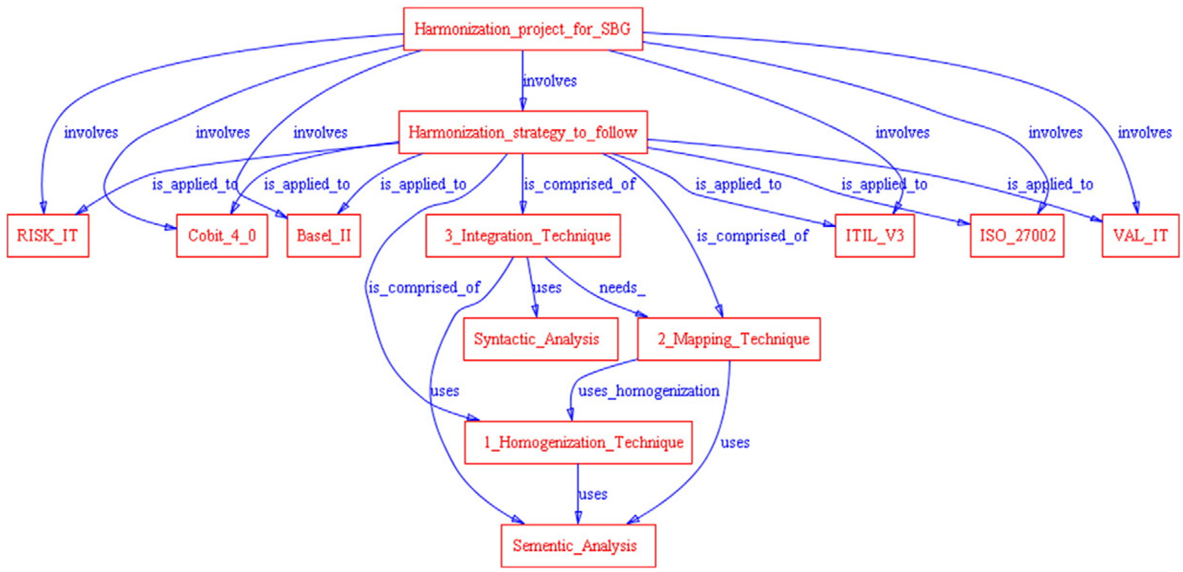

Fig. 4. Extract of the instance of the harmonization project for SBG using Protégé.

several regulations to which the banking sector is subject to, such as IT governance, managing the investment of IT and IT risk, management of information security. To meet such requirements, this case involved the harmonization of six models, more specifically: COBIT 4.1, Basel II, VAL IT, RISK IT, ISO 27002 and ITIL V3. With the harmonization of these models, a model called IT Governance Model for Banking or ITGMSB was defined, which is an IT governance model for banking in general. A detailed summary of this model is presented in [47]; the harmonization process and harmonization strategy followed for its definition and experience and lessons learned can be seen in [9] Pardo et al. [9] and Pardo et al. [53] respectively. Bearing in mind the difficulty of harmonizing six models, the H2mO was a good reference for understanding the relationships between the terms involved in this domain. In a similar vein, it has allowed us to define a *widespread harmonization strategy* (WHS), which can be implemented and adapted to the harmonization requirements of any organization.

The WHS is comprised of three techniques, which are: homogenization, comparison and integration (see [10] and [11] respectively). At present, we are defining a widespread integration technique from the steps and activities followed in this case of implementation. The WHS was defined from the relationships established between techniques introduced in the ontology. Moreover, the WHS was implemented in the harmonization of the six models involved in this case implementation. In that sense, H2mO has been of great help in the design and configuration of this new widespread harmonization strategy. Fig. 4 shows an extract of the instance created from H2mO of this harmonization project by using Protégé [48]. It also shows the models used and the relationships between the techniques that make up the harmonization strategy. It is possible to see that the ontology provides the relationships and concepts to support the representation of all concepts used in this domain.

5.2. Harmonization of ISO 27001 and ISO 20000 part 2

The second case of implementation involved an organization called Audisec, which focuses on the consultancy and support to the certification of standards such as IT Service Management Standard ISO 20000 and the Information Security Management System (ISMS) ISO 27001. The harmonization of ISO 27001 and ISO 20000 part 2 focused on resolving the following needs: (i) to compare and identify their differences and similarities, (ii) to identify the level of complementarities between them, and (iii), to carry out a consultancy in the certification of organizations in ISO 20000, taking into account the efforts and practices institutionalized previously in certification and knowledge of ISO 27001. A detailed summary of this experience is presented in [9]; the harmonization framework used is presented in [49]. Fig. 5 shows an extract of the instance created from H2mO of this harmonization project by using Protégé [48], where it is possible to see that, as in the case presented above, the ontology provides the relationships and concepts needed to support the representation of the entities used in this case. The main lesson learned and expressed by the organization of this case was: "to manage a harmonization project that involves multiple models, several terms, concepts and the relationships between them must be made clear. Knowing the domain of this research stream through an ontology was a great help in understanding and implementing the harmonization process, the harmonization strategies obtained and the techniques involved".

5.3. Software tool to support the management of harmonization projects

The final case is HProcessTOOL [50]. It is a web tool, which facilitates the management of the harmonization projects based on

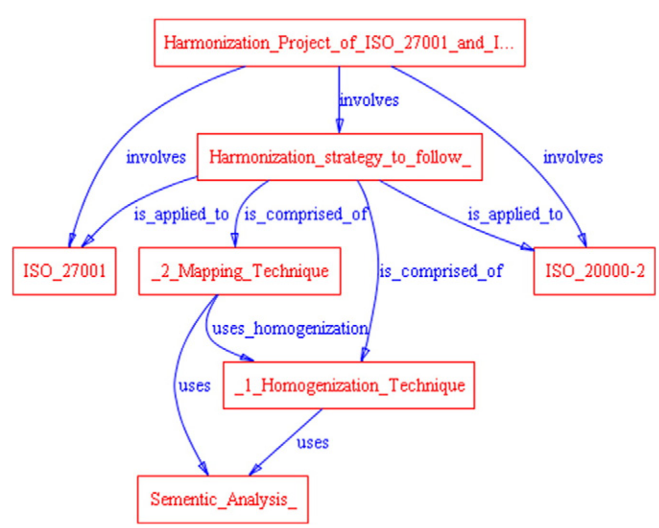

Fig. 5. Extract of the instances of the harmonization project of ISO 27001 and ISO 20000-2 using Protégé.

the *harmonization process* defined in [9] (a more complete and detailed version of the process is available in [51]). This makes it easier to identify, define and configure the strategies that are suitable for putting multiple models into consensus and harmony. Several concepts defined in the ontology have been taken into account for the developing of HProcessTOOL; e.g. the harmonization *techniques, methods*, their relationships with OPrM and other concepts such as *harmonization strategy*, *homogenization structure, measure,* amongst others, gave support to the configuration of the harmonization strategies defined in the cases of implementation presented above. Given the generality of H2mO, its support is also extended to the concepts involved in the management of the harmonization projects by using the tool, e.g. *quality model*, *harmonization, synergy, granularity*, amongst others. Our tool is not finished yet, but it has demonstrated that the development of HProcessTOOL, based in the ontology, has been a good way of proving the worth of our ontology. Fig. 6 shows an example of the management of the harmonization project of ISO 27001 and ISO 20000 part 2 (we maintain the original screen shot, which is in Spanish).

5.4. Lessons learned

Having put this proposal into practice, we have learned several lessons, reported below, which we believe could be taken into consideration as useful guidelines when implementing harmonization techniques in multi-model environments.

Rules of absorption. When the major goal of the harmonization is not simply that of carrying out a comparison, but is also the integration of the common or different elements identified from the comparison between models, we believe that it is necessary to establish rules or absorption criteria amongst the elements being integrated. This will allow making more appropriate decisions that will make it more possible to integrate their descriptions, recommendations or practices. We believe that the *absorption* concept in this context could refer to two states: (i) that the description of the element with less detail is supported and contained in the description of the element with greater detail, or (ii), if the description of the element with greater or less detail is not contained in the other element, the two elements could be absorbed in a single element that will allow us to strengthen their descriptions. With regard to the two states, we propose one set of criteria for making the integration of the compared elements easier.

A. First state:

- When the common element of Model A offers a greater amount of description or detail than Model B, the element of B could be *absorbed* by the element of A.
- When the common element of Model A offers an equal amount of description or detail to that in Model B, the element of B could be *absorbed* by the element of A.
- When the common element of Model A offers less description or detail than Model B, the element of B could be *absorbed* by the element of B.

B. Second state:

- When the common element of Model A offers a greater amount of description or detail than Model B, the element of B could be *absorbed* by the element of A.

Other considerations. On the basis of the set theory analysis, we have identified some additional considerations and conjectures that we believe are important to bear in mind. These are:

- The level of analysis of the relationships amongst the elements compared is carried out through a syntactic and semantic analysis, thus improving the understanding and the relationships established. The syntactic analysis identifies differences in the terminology of the models compared (see [52]). A semantic analysis allows us to enhance comprehension of the meaning of the descriptions of the elements compared, along with the identification of relations, differences and their integration [11].
- Because of the complexity and effort that process harmonization requires, we recommend that it be carried out in groups of two models.
- The result obtained in the union and intersection implemented on models is a third set with which it is also possible to perform operations with regard to other models.
- The difference and intersection sets are comparison operations. The difference allows the different elements to be identified, and the intersection allows the common elements to be identified.
- The harmonization of models is used to define an organization's more detailed processes. Similarly, harmonization can also be used to define new reference process models.

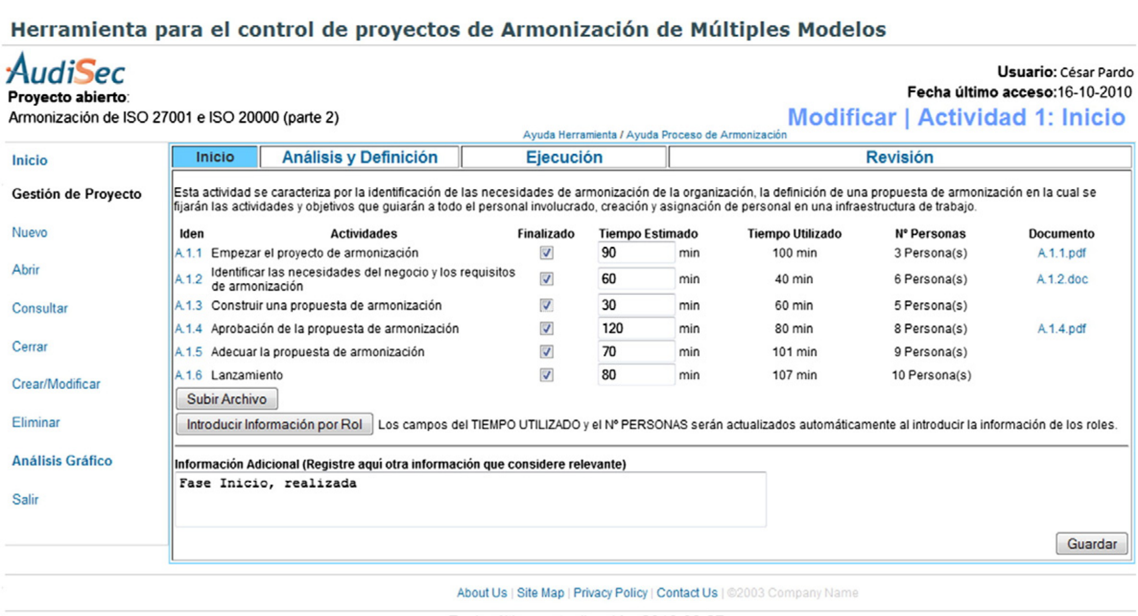

Fig. 6. HProcessTOOL starting activity.

– The harmonization of models reduces the effort and costs associated with the separate implementation of multi-models.
– When a comparison technique is implemented, it is necessary to take into account that when the elements compared describe more than two activities or tasks, these should be divided, in order to understand the comparisons that can be established better.

6. Conclusions

At the present time, environments in which multiple models are applied, are characterized by the fact that they require greater effort, time and associated costs than conventional software process improvement projects. Taking that into account, some researchers and research groups have defined a number of proposals to support the work within this research stream. However, the efforts have been performed without taking into account a common and consistent terminology that allows us to create and share the knowledge generated around this research domain. This has increased the confusion and terminological conflict affecting both researchers and organizations that make use of that knowledge. A consistent terminology for harmonization of multiple models can provide an important instrument for understanding and supporting the harmonization of multiple models in an organization, as well as for strengthening this research domain.

This paper has presented a summary of a semi-formal ontology for the harmonization projects of multiple models. The common vocabulary provided by H2mO resolves several issues of consistency and completeness that had been identified. We do not want to infer that H2mO resolves all problems or that it is agreed on by all parties; our main objective is to provide a basis for discussion of the terms, concepts and relationships identified in this research domain. As support to our assertions we have also provided a first application of the ontology to the harmonization of ISO 27001 and ISO 20000 and the harmonization of COBIT 4.1, Basel II, VAL IT, RISK IT, ISO 27002 and ITIL V3. Also, it is important to highlight an initial version of this ontology was used to harmonize ISO 9001 and CMMI, which is presented in [29].

The information obtained from this work will be used to tackle two streams, the first of which will focus on analyzing and detailing the definition of those techniques that have not been dealt with, e.g. the integration technique and semantic analysis. The goal is to detail these techniques at the level of the processes that describe what to do and how to implement them. The second stream focuses on up-dating and extending the ontology, with the addition of more concepts which can be contained in the literature, in order to provide a complete ontology for the harmonization of multiple models.

Acknowledgments

This work has been funded by the projects: ARMONÍAS (JCCM of Spain, PII2I09-0223-7948), PEGASO/MAGO project (Ministerio de Ciencia e Innovacion MICINN and Fondo Europeo de Desarrollo Regional FEDER, TIN2009-13718-C02-01) and ALTAMIRA (Junta de Comunidades de Castilla-la Mancha, Fondo Social Europeo, PII2I09-0106-2463) Francisco J. Pino acknowledges the contribution of the University of Cauca, where he works as Associate Professor.

References

[1] R. McFeeley, IDEAL: A Users Guide for Software Process Improvement, Handbook CMU/SEI-96-HB-001, Software Engineering Institute Carnegie Mellon University, 1996, Available from: http://www.sei.cmu.edu/publications/documents/96.reports/96.hb.001.html.
[2] E.W. Deming, Out of the Crisis, MIT Center for Advanced Engineering Study, 1982.
[3] L. Scott, R. Jeffery, L. Carvalho, J. D'Ambra, P. Rutherford, Practical Software Process Improvement – The IMPACT Project, Proceedings of the Australian Software Engineering Conference, 2001, pp. 182–189.
[4] J. Hurtado, F. Pino, J. Vidal, C. Pardo, L. Fernandez, Agile SPI: Software Process Agile Improvement, A Colombia approach to software process improvement in small software organizations, in: M. Piattini, H. Oktaba (Eds.), Software Process Improvement for Small and Medium Enterprises: Techniques and Case Studies, Idea Group Inc, USA, 2008, pp. 177–192.
[5] F.J. Pino, J.A.H. Alegría, J.C. Vidal, F. García, M. Piattini, A process for driving process improvement in VSEs, Proceedings of the International Conference on Software Process: Trustworthy Software Development Processes, Springer-Verlag, Vancouver, B. C., Canada, 2009, pp. 342–353.
[6] C. Pardo, F.J. Pino, F. García, M. Piattini, M.T. Baldassarre, Trends in Harmonization of Multiple Reference Models, in: L.A. Maciaszek, P. Loucopoulos (Eds.), ENASE 2010, CCIS, Springer-Verlag, Berli Heidelberg, 2011, pp. 61–73.
[7] P.R. Croll, Interoperability of Systems Engineering Standards-Harmonizing World and National Perspectives, 5th Annual Systems Engineering Conference, Tampa, 2002, p. 30.
[8] B. Chandrasekaran, J.R. Josephson, V.R. Benjamins, What are ontologies, and why do we need them? IEEE Intelligent Systems 14 (1999) 20–26.
[9] C. Pardo, F.J. Pino, F. García, M. Piattini, M.T. Baldassarre, A process for driving the harmonization of models, The 11th International Conference on Product Focused Software Development and Process Improvement (PROFES 2010). Second Proceeding: Short Papers, Doctoral Symposium and Workshops, Limerick, 2010, pp. 53–56.
[10] C. Pardo, F. Pino, F. García, M. Piattini, Homogenization of models to support multi-model processes in improvement environments, 4th International Conference on Software and Data Technologies ICSOFT'09, Sofía, 2009, pp. 151–156.
[11] F. Pino, M.T. Balssarre, M. Piattini, G. Visaggio, Harmonizing maturity levels from CMMI-DEV and ISO/IEC 15504, Journal of Software Maintenance and Evolution: Research and Practice 22 (2010) 279–296.
[12] S. Gokhan Halit, M.K. Mieczyslaw, An OWL ontology for representing the CMMI-SW model. Available from: http://km.aifb.kit.edu/ws/swese2006/final/soydan-full.pdf 2010.
[13] O. Mendes, A. Abran, Software engineering ontology: A development methodology, Metrics News, Québec, 2004, pp. 68–76.
[14] L. Liao, Y. Qu, H.K.N. Leung, A Software Process Ontology and Its Application, 4th International Semantic Web Conference, Galway, 2008.
[15] J. Siviy, P. Kirwan, L. Marino, J. Morley, The value of harmonization multiple improvement technologies: a process improvement professional's view, Software Engineering Institute, Carnegie Mellon, 2008 Available from: http://www.sei.cmu.edu/process/research/prime.cfm.
[16] J. Siviy, P. Kirwan, J. Morley, L. Marino, Maximizing your process improvement ROI through harmonization, Software Engineering Institute (SEI), Carnegie Mellon University, 2008 Available from: http://www.sei.cmu.edu/process/research/prime.cfm.
[17] J. Siviy, P. Kirwan, V. Renato, K. Peter, G. Gerhard, SEPG Europe 2008, Multimodel Improvement in Practice, Munich, 2008, p. 23.
[18] SPICE, Enterprise SPICE. An enterprise integrated standards-base model. Available from: http://www.enterprisespice.com/.
[19] A. Ferchichi, M. Bigand, H. Lefebvre, An ontology for quality standards integration in software collaborative projects, First International Workshop on Model Driven Interoperability for Sustainable Information Systems, Montpellier, 2008, pp. 17–30.
[20] S. Biffl, D. Winkler, R. Höhn, H. Wetzel, Software process improvement in Europe: potential of the new V-modell XT and research issues, Software Process: Improvement and Practice 11 (2006) 229–238.
[21] C. Yoo, J. Yoon, B. Lee, C. Lee, J. Lee, S. Hyun, C. Wu, An integrated model of ISO 9001:2000 and CMMI for ISO registered organizations, Proceedings – Asia-Pacific Software Engineering Conference (APSEC), Busan, 2004, pp. 150–157.
[22] C. Yoo, J. Yoon, B. Lee, C. Lee, J. Lee, S. Hyun, C. Wu, A unified model for the implementation of both ISO 9001:2000 and CMMI by ISO-certified organizations, Journal of Systems and Software 79 (2006) 954–961.
[23] P. Jalote, CMM in practice: processes for executing software projects at Infosys, Addison-Wesley Professional, Massachusetts, 1999.
[24] B. Mutafelija, H. Stromber, Architecting Standard Processes with SWEBOK and CMMI. Systems and Software Consortium, SEPG 2006 Conference, Nashville, 2006, p. 38.
[25] B. Mutafelija, H. Stromber, ISO 9001:2000 – CMMI V1.1 Mappings, Software Engineering Institute, 2003, Available from: http://www.sei.cmu.edu/cmmi/adoption.
[26] M.C. Paulk, Comparing ISO 9001 and the Capability Maturity Model for Software, Software Quality Journal 2 (1993) 245–256.
[27] M.C. Paulk, A comparison of ISO 9001 and the capability maturity model for software, Software Engineering Institute, 1994. Available from.
[28] M.C. Paulk, How ISO 9001 compares with the CMM, IEEE Software 12 (1995) 74–83.
[29] M.T. Baldassarre, D. Caivano, F.J. Pino, M. Piattini, G. Visaggio, A Strategy for Painless Harmonization of Quality Standards: A Real Case, in: (Eds.), Product-Focused Software Process Improvement, Springer Berlin/Heidelberg, 2010, pp. 395–408.
[30] T.P. Rout, SPICE and the CMM: is the CMM compatible with ISO/IEC 15504? AquIS, Venice, Italy, 1998, p. 12.
[31] A.T. Terence, P. Rout, Harmonizing ISO/IEC 15504 and CMMI, Software Process: Improvement and Practice 12 (2007) 361–371.
[32] T.P. Rout, A. Tuffley, Harmonizing ISO-IEC 15504 and CMMI, John Wiley and Sons Ltda, Chichester, UK, 2007.
[33] I. Minnich, EIA IS 731 compared to CMMI^{SM}-SE/SW, Systems Engineering 5 (2002) 62–72.
[34] F.J. Pino, M.T. Baldassarre, M. Piattini, G. Visaggio, D. Caivano, Mapping Software Acquisition Practices from ISO 12207 and CMMI, in: L.A. Maciaszek, C. González-

Pérez, S. Jablonski (Eds.), Evaluation of Novel Approaches to Software Engineering, Springer, Berlin Heidelberg, 2010, pp. 234–247.
[35] SEI, Publications on CMMI mappings and comparisons. Available from: http://www.sei.cmu.edu/cmmi/adoption/comparisons.html.
[36] ITGI, Aligning Cobit 4.1, ITIL V3 and ISO/IEC 27002 for Business Benefit. IT Governance Institute (ITGI) and Office of Government Commerce (OGC). Available from: http://www.isaca.org/Knowledge-Center/Research/ResearchDeliverables/Pages/Aligning-COBIT-4-1-ITIL-V3-and-ISO-IEC-27002-for-BusinessBenefit.aspx2008.
[37] L. Ibrahim, A. Pyster, A Single Model for Process Improvement, IT Professional 6 (2004) 43–49.
[38] CITIL. CMMI + ITIL. Available from: http://www.wibas.de/publikationen/referenzmodelle/was_ist_cmmi/index_de.html.
[39] L.-C. Lin, T.-S. Li, J.P. Kiang, A continual improvement framework with integration of CMMI and six-sigma model for auto industry, Quality and Reliability Engineering International 25 (2009) 551–569.
[40] D. Fensel, Ontology-Based Knowledge Management, Computer 35 (2002) 56–59.
[41] M. Fernández, A. Gómez-Pérez, N. Juristo, METHONTOLOGY: from ontological art towards ontological engineering, Proceedings of the AAAI97 Spring Symposium Series on Ontological Engineering, Stanford, USA, 1997, pp. 33–40.
[42] T. Hikita, M.J. Matsumoto, Business process modelling based on the ontology and first-order logic, Proc. 3rd Int. Conf. on Enterprise Information Systems (ICEIS'2001), 2001, pp. 717–723.
[43] T.R. Gruber, A translation approach to portable ontology specifications, Knowledge Acquisition 5 (1993) 199–220.
[44] C. Tautz, C. Gresse Von Wangenheim, REFSENO: a representation formalism for software engineering ontologies, Fraunhofer IESE-Report No. 015.98/E V1.1, 1998, Available from: http://publica.fraunhofer.de/dokumente/PX-55706.html.
[45] F. García, M. Bertoa, C. Calero, A. Vallecillo, F. Ruiz, M. Piattini, M. Genero, Towards a consistent terminology for software measurement, Information & Software Technology 48 (2006) 631–644.
[46] R.S. Oshana, R.C. Linger, Capability maturity model software development using cleanroom software engineering principles – results of an industry project, Hawaii International Conference on System Sciences, Maui, 1999, p. 260.
[47] S.M. Lemus, F.J. Pino, M. Piattini, Towards a Model for Information Technology Governance applicable to the Banking Sector, V International Congress on IT Governance and Service Management (ITGSM 2010), Alcalá de Henares, 2010, pp. 1–6.
[48] Protégé, The Protégé Ontology Editor and Knowledge Acquisition System. Available from: http://protege.stanford.edu.
[49] ARMONÍAS, A process for driving multi-models harmonization, ARMONÍAS Project. Available from: http://alarcos.esi.uclm.es/armonias/.
[50] C. Pardo, F.J. Pino, F. García, F.R. Romero, M. Piattini, M.T. Baldassarre, HProcessTOOL: A Support Tool in the Harmonization of Multiple Reference Models, in: B. Murgante, O.G., A. Iglesias, D. Taniar, B. Apduhan (Eds.), ICCSA 2011 Proceedings, Vol. 6786, Springer, Heidelberg, Santander, 2011, pp. 370–382.
[51] ALARCOS, A process for driving multi-models harmonization, ARMONÍAS Project. Available from: http://alarcos.esi.uclm.es/armonias/.
[52] D.H. Kitson, R. Vickroy, J. Walz, D. Wynn, An initial comparative analysis of the CMMI Version 1.2 Development Constellation and the ISO 9000 Family, Software Engineering Institute, Carnegie Mellon, 2009 Available from: http://www.sei.cmu.edu/library/abstracts/reports/09sr005.cfm.
[53] C. Pardo, F.J. Pino, F. García, M. Piattini, M.T. Baldassarre, S. Lemus, Homogenization, Comparison and Integration: A Harmonizing Strategy for the Unification of Multiple-Models in the Banking Sector, in: G. Visaggio, D. Caivano, M. Oivo, M.T. Baldassarre (Eds.), The 12th International Conference on Product Focused Software Development and Process Improvement (PROFES 2011), Vol. 6759, Springer, Heidelberg, Bari, 2011, pp. 59–72.

César Pardo received his master's degree in Computer Science in 2009. He has been a member of the ALARCOS research group since 2008 working as a collaborator for preparing his PhD in Computer Science from the University of Castilla-La Mancha (UCLM), Spain. He is currently a researcher in a project on Harmonization of multiple models and Quality Characteristics of Process-Supported Software Products. He also is a member of the IDIS Research Group and his research interests are Software process improvement and Harmonization of multiple improvement technologies. Contact details: Escuela Superior de Informática, Paseo de la Universidad 4, 13071, Ciudad Real, Spain; cpardo@unicauca.edu.co.

Francisco J. Pino has a European PhD in Computer Science from the University of Castilla-La Mancha (UCLM), Spain. He is currently an associate professor at the Electronic and Telecommunications Engineering Faculty at the University of Cauca, in Popayán (Colombia). He is a member of the IDIS Research Group and his research interests are Software process improvement in small companies and Harmonization of multiple improvement technologies. Contact details: Universidad of Cauca, Calle 5 No. 4-70, Popayán, Colombia; fjpino@unicauca.edu.co.

Félix García received his MSc. (2001) and PhD (2004) degrees in Computer Science from the University of Castilla-La Mancha (UCLM). He is currently an associate professor in the Department of Information Technologies and Systems at the UCLM. He is a member of the Alarcos Research Group and his research interests include business process management, software processes, software measurement, and agile methods. Contact details: Escuela Superior de Informática, Paseo de la Universidad 4, 13071, Ciudad Real, Spain; Felix.Garcia@uclm.es.

Mario Piattini is a full professor at the UCLM. He holds the PhD degree in Computer Science from the Technical University of Madrid and leads the Alarcos Research Group. He is CISA, CISM, CGEIT and CRISC by ISACA. His research interests include software quality, metrics and maintenance. He is the Director of the Joint UCLM–Indra Software Research and Development Center and the Institute of Information Systems and Technologies. Contact details: Escuela Superior de Informática, Paseo de la Universidad 4, 13071, Ciudad Real, Spain; Mario.Piattini@uclm.es.

Maria Teresa Baldassarre received a degree with honours in informatics at the University of Bari, Italy, where she has also received her PhD. She is currently an assistant professor. Her research interests focus on: empirical software engineering, harmonization of multiple improvement technologies, quality assessment and improvement in software. She collaborates in several research projects and carries out controlled and in field experimentation within small and medium enterprises. She is a partner of the SER&Practices spin off company. Currently she is the representative of the University of Bari in the International Software Engineering Research Network (ISERN), and is involved in various program committees related to software engineering and empirical software engineering international conferences.