About Semantic Enrichment of Strategic Data Models as part of Enterprise Models*

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Abstract. The paper presents the outcomes of a practical experiment aimed at the identification of the various types of annotations that can be attached to enterprise strategic data models. The work is part of a more extensive experimentation on different enterprise models perspectives developed inside the "Semantic Enrichment of Models and Architecture & Platforms" task group of the FP6 IST-508-011 NoE INTEROP, whose goal is to evaluate the appropriateness (and the possible incompleteness) of existing semantic enrichment concepts, techniques, services and tools. Besides the need for multiple ontologies, the experiment enlighten a rather new perspective with respect to the literature on semantic annotation, related to the fact that mathematical objects have to be taken into consideration.

1 Introduction

Semantic enrichment is the process of associating to data a description of their meaning, in order to improve human understanding, machine interoperability, and advanced automatic information management (retrieval, mining, presentation). Nowadays, semantic enrichment is almost a synonym of annotating source data with formal descriptions of concepts in a domain ontology. It is mainly considered in the semantic web scenario, where it is applied to semi-structured and unstructured documents [19, 8, 15, 20]. However, semantic enrichment has been applied also to structured data, like database schema, to enhance database interoperability and to enable intelligent access to heterogeneous sources [12, 10, 6]. Some approach to ontology mapping exploits semantic enrichment of ontologies as well [21]. To the best of our knowledge, few works in the literature takes the semantic enrichment problem from the perspective of a model-based view of enterprise systems (see e.g. [14] for semantic annotation of process models). Therefore, in the framework of the FP6 IST-508-011 INTEROP Network of Excellence (http://www.interop-noe.org), the research group entitled "Semantic Enrichment of Models and Architecture & Platforms" adopted a pragmatic approach to experience semantic enrichment of enterprise models. The aim of the

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intended experimentation is to pragmatically locate, by means of the analysis of case studies, the various types of annotations that can be attached to a model to make it more readable and exchangeable, in order to evaluate the appropriateness (and the possible incompleteness) of concepts, techniques, services and tools developed in the semantic web scenario [3]. This paper presents the outcomes of the study performed at the strategic enterprise level. At this level, enterprises develops a strategy through a complex planning and control cycle. In this cycle, a model of the enterprise is considered, that is compared against a "to-be" state, being it either the realization of a given vision and mission or a reference best practice. A gap analysis may then leads to the definition of the necessary steps to fill that gap. The models considered at this level by strategy experts and top management are defined by a set of measurable performance indicators coming from inside and outside the organization. In the information system view, the reference architecture for strategic support is based on the data warehouse (DW), that enables multidimensional analysis of performance indicators by means of OLAP tools and reports. Hence, we consider the DW model as part of an enterprise model at the strategic level. Also, an OLAP report can be considered as a view over the DW (and hence a view of the enterprise model), realized by slice-and-dice, roll-up and drill-down operations. However, a report may contain further information, derived from the DW and calculated at report generation time. Furthermore, reports are the main tool used by managers for their activity. For these reasons, in this paper we focus on OLAP reports, instead of the DW to study the kind of semantic information which can be found at the strategic enterprise level. The results of this study point out that annotations based on links to an ontology (that is the main kind of semantic annotation considered in the semantic web scenario) can be useful at this level, provided that different kinds of ontologies are provided. However they cannot by themselves express the whole body of semantic information appearing at the strategic level. In order to fully describe the meaning of strategic data, also a description of the way they have been generated has to be given. Hence, annotation languages should be defined that are expressive enough to describe the semantics of mathematical formulas, forecasting processes and models.

The rest of the paper is organized as follows: section 2 shortly introduces considerations about semantic annotation and annotation of models, section 3 briefly reviews the theory underpinning the definition of a strategy, section 4 describes the organization of strategic data and gives a reference example, derived from the analysis of the case study. This example is exploited in section 5 to review the different kinds of semantic information that are worth of being associated with strategic data. Section 6 ends the paper.

2 Semantic Annotations of Models

Annotate: to add a brief explanation or opinion to a text or drawing (Cambridge advanced learner's dictionary, *http://dictionary.cambridge.org/*)

Annotation: A comment attached to a particular section of a document. Many computer applications enable you to enter annotations on text documents, spreadsheets, presentations, and other objects. This is a particularly effective way to use computers in a workgroup environment to edit and review work... (Webopedia, *http://www.webopedia.com*).

The purpose of annotations is to describe the content of "something" (we will call it the *annotated object*) and therefore annotations may be considered as meta-data. They have been used for a while for texts and hypertext documents as well as in some communities like biologists [2, 8]. They may be provided under different forms, like links, paths, notes, comments, highlights of selected words, numbered steps in a process, etc.

Hereafter, we present a review of the annotation concept, describing the typology of annotations together with the link between annotations and ontologies (section 2.1), the requirements for annotations to be consistently first provided and second interpreted (section 2.2), and the possible services for annotations (section 2.3). Finally, we illustrate the annotation of models (section 2.4).

2.1 Typology of Annotations

Different types of annotations may be distinguished; these include:

1. *Textual annotations* that consist in added notes and comments to the *annotated object*.
2. *Link annotations* that extend the textual annotation notion: the annotation content is reachable through a provided link.
3. *Semantic annotations*: while textual annotations and link annotations are primarily intended toward humans, semantic annotation content is some semantic information intended to be readable by humans as well as machines. For instance, the current work on semantic annotations of Web resources and services is intended to serve for sophisticated Web resources retrieval, discovery and composition as well as for reasoning [20].

Further, annotations may appear as informal (like a margin note) or formal: That means that the annotation expressions may range from annotation expressed according to a given structured language (like RDF and RDF Schema) with a formal syntax, to annotations expressed in some sound and well-founded language (like First Order Logic, Description Logic, etc.), which have also a formal semantics. It is obvious that the more formal the semantics of the language is, the more the machine-readability of the annotation increases. This assumes that no implicit assumptions are made and no ambiguity persists to enable a common interpretation and understanding of the annotations.

Therefore, in addition to the annotation definition language used, a common understanding of the provided annotations is required. Part of this common understanding may rely on the use of one or several ontologies that provide "a representation of a shared conceptualization of a particular domain"[23]. It means that *(i)* the conceptualization has to be agreed by the authors of the annotation (let us call them the *annotation providers*) and by the ones who exploit the annotations (let's call them the *annotation consumers*) and that, *(ii)* for some types of annotations, the annotation contents are linked to concepts in the ontology.

2.2 Semantics of Semantic Annotations[3]

Additionally, in order for the annotation to be interpreted and processed consistently, *annotation consumers* need to understand the meaning of the annotations that are provided to them [1]. Consider a very simple example: a theorem being stated in a document. What types of annotations may be associated with it? One can annotate that theorem providing a link to its demonstration or providing the demonstration itself, someone else may annotate the document with a list of possible applications of the theorem, etc. The interpretation and the processing of the annotations are then obviously different.

As an illustration of types of annotation contents, [1] introduces a classification considering a resource U#X annotated with a concept expression C, U being the URL of a web page and X being an XPointer expression leading to a region of the document. That classification includes the following types of annotations.

- *Decoration*: annotations are comments associated with the resource;
- *Linking*: annotations are links;
- *Instance Identification*: the annotated object (U#X) is an instance of a given class and the annotation content may be a link to that class;
- *Aboutness*: no assertion is made about the existence of an instance of the concept C, but there is a loose association with the concept;
- *Pertinence*: the target of the annotation may be of interest for the *annotated object*.

2.3 Services for Annotations

Another matter concerns the way the annotations are actually provided and associated with the *annotated object*. There is a progressive move from manual to automatic or semi-automatic annotation provision (for some example of annotation tools, see for instance *http://annotation.semanticweb.org/tools/* and [16]). An *annotation provider* uses at the same time ontology management services and annotation management services while modelling the various enterprise perspectives that may constitute a model of an enterprise : annotations that are incorporated into a model or into parts of a model refer to given ontologies. Since the content of some types of annotations relies on given ontologies, it seems clear that ontology services (like querying or browsing an ontology) have to be coupled with annotation services.

From a software architecture perspective, [13] distinguishes between a proxy based approach and a browser based approach for annotating web resources. In

[3] Title borrowed from [1].

the proxy based approach, annotations and annotated documents are merged by the proxy; the browser only services the merged documents. In a browser based approach, an application of the browser merges the annotations with the documents while browsing. In addition, annotations can be stored separately and provided thanks to an annotation service offered by an annotation server.

2.4 Annotation of Enterprise Models in a Model Based Approach

In a model-based approach, various levels of models and instances are considered, every level having its proper concepts, rules and constraints, and it may be linked to other levels using various types of relationships (is_instance_of, derives_from, etc.). Figure 1 illustrates such types of levels and instances [5, 7], where:

- the meta-model level concerns the ways models are designed, specified, validated, instantiated, etc. This level itself may be specified as a (meta)model;
- the generic/specific model level comprises the specification of models. When these are generic, they may serve for deriving specific models. Models at these levels are instances of the meta-model level.
- the model instance level: while the two preceding levels are abstract ones, this level comprises concrete objects like resources allocated to some tasks, task assignments to actors, software systems assigned for realizing activities.
- the instance level is the level of the actual objects and activities.

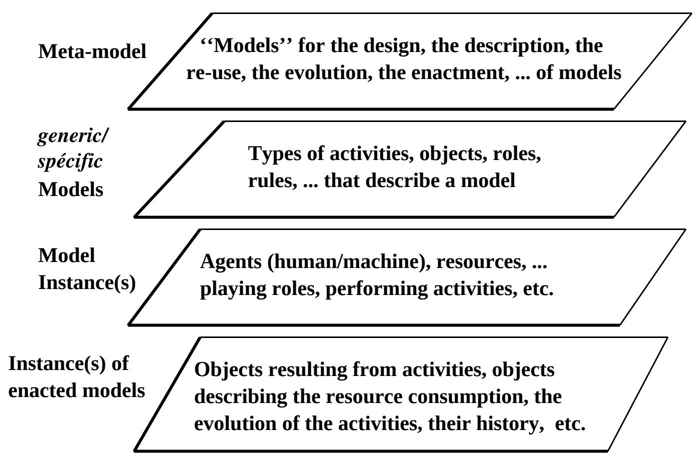

Fig. 1. Model and instance levels

Every level may be fitted with appropriate software support, which means that the set of enterprise applications and software systems may cover the levels horizontally (i.e. a software support is provided for the activities that are performed at a given level) as well as vertically (i.e. a support is provided for "going down" from one level to another).

The consequence is that interoperability is required within a level and between levels. For example, at the generic/specific model level, one can imagine that various enterprise modelling tools or environments are cooperatively used to specify an enterprise model according to their respective meta-models as described at the meta-model level.

This figure becomes more complex when we consider networked enterprises interoperability where every "node" of the networked enterprises may have its proper meta-models, generic/specific models, software systems and platforms, and so on. This means that interoperability ranges from very fine granule objects and software (for example, a function that concatenates strings) to the interoperability of two or more networked organizations.

Therefore, for interoperability purposes, intra-levels and inter-levels semantic annotations are conceivable to enable consistent model exchange and model sharing between actors in an enterprise as well as in a networked enterprise. However, at this stage of our work, we are not able to provide a complete list of the types of annotations that may be suited for each level and for moving between levels. To the best of our knowledge, few work is reported in the literature about semantic enrichment of models since most of the on-going work mainly deals with Web resources and services. Therefore, we adopted a pragmatic approach to experience semantic enrichment of enterprise models.

The role of the intended experimentations is to help in the identification of the various types of annotations that can be attached to a model to make it more readable and exchangeable. The next section reports on the current state of that identification with respect to enterprise strategic models. Further details about additional enterprise models perspectives can be found in [3].

3 Strategic planning

One of the most comprehensive definitions of strategy is given by [11, p. 14]: "Strategy determines and reveals the organizational purpose in terms of long-term objectives, action programs, and resource allocation priorities; ...; attempts to achieve a long-term sustainable advantage in each of its businesses by responding appropriately to the opportunities and threats in the firm's environment, and the strengths and weaknesses of the organization...".

Strategic planning is a complex process of "dynamic, continuous activities of self-analysis" [17, p.37] oriented to the definition of a strategy. Strategic planning strongly recommends to base the analysis on a set of measurable, objective indicators characterizing internal and external facts that are relevant to the enterprise vision and mission. In the literature different complementary methodologies have been devised to perform this strategic information needs analysis, like Critical Success Factors, Key Performance Indicators, Management Accounting and Balanced Score Card methods [4, 18]. These methodologies have been adopted to define a set of indices for our case study. We do not go deeper into the process of information needs analysis due to lack of space and since it is out of the scope of the present paper.

4 The information system view of strategic planning

The reference architecture of information systems for strategic support is based on the data warehouse architecture. The logical data model in a data warehouse is the multidimensional model. In the multidimensional model, measured indices (the facts) are analyzed (i.e. aggregated/disaggrgated) w.r.t. different dimensions, like time, organization and product hierarchies.

Figure 2 gives a simplified example of data warehouse schema, showing part of the set of indices defined for the considered case study.

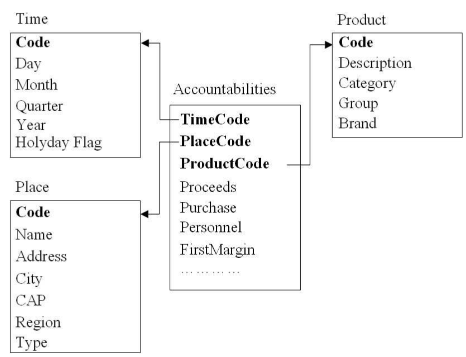

Fig. 2. A Simplified Data Warehouse Schema.

The data warehouse feeds OLAP analysis and presentation tools, like report generators. Figure 3 shows an example of the typical content and structure of an OLAP report, which is suited for the next discussion on semantic annotation.

				proceeds	purchase	personnel	first margin	amortization	other costs	various	income	sold products	unit cost
Products	Total	Quart.I	Actual	2,100	720	850	530	200	200	20	110	1,200	1,100
			BDGT	2,000	720	800	480	200	225	20	35	1,100	1,100
		Quart.II	Actual	2,000	750	800	450	200	300	15	-65	1,100	1,100
			BDGT	2,000	720	800	480	200	225	20	35	1,100	1,100
		Proj. To Year	Actual	5,600	2,210	2,400	990	600	800	60	-470	3,400	3,300
			BDGT	6,000	2,160	2,400	1,440	600	675	60	105	3,300	3,300
			Diff.	-400	50	0	-450	0	125	0	-575	100	0
	Batteries	Quart.I	Actual	1,400	480	567	353	133	133	13	73	800	733
			BDGT	1,333	480	533	320	133	150	13	23	733	733
		Quart.II	Actual	1,333	500	533	300	133	200	10	-43	733	733
			BDGT	1,333	480	533	320	133	150	13	23	733	733
		Proj. To Year	Actual	3,733	1,473	1,600	660	400	533	40	-313	2,267	2,200
			BDGT	4,000	1,440	1,600	960	400	450	40	70	2,200	2,200
	Mob. Phones	Quart.I	Actual	700	240	283	177	67	67	7	37	400	367
			BDGT	667	240	267	160	67	75	7	12	367	367
		Quart.II	Actual	667	250	267	150	67	100	5	-22	367	367
			BDGT	667	240	267	160	67	75	7	12	367	367
		Proj. To Year	Actual	1,867	737	800	330	200	267	20	-157	1,133	1,100
			BDGT	2,000	720	800	480	200	225	20	35	1,100	1,100

Fig. 3. An example of typical report.

5 Semantic Enrichment of Strategic Data

As already said, reports can be considered as views over the data warehouse, realized by slice-and-dice, drill-down and roll-up operations. Hence, if we accept that a data warehouse is the reference model at strategic level, the model of a report is part of an enterprise model; a specific report being an instance of its model. Models and instances can be both subject to annotations. An OLAP report may contains indices not explicitly stored in the data warehouse, calculated from the basic facts at report generation time. In our example, unit cost and all the rows labeled *Proj. to year* (which are estimates of the indices for the coming months) are elements of this type. Furthermore, reports are the main tool used by managers for their activity. For this reason, we focus our analysis on reports instead of the data warehouse.

By inspecting the report example we identified the following types of semantic information (see figure 4): (a) Meaning of a term (b) Temporal and metric unit information (c) Forecasting models (d) Derivation and aggregation rules.

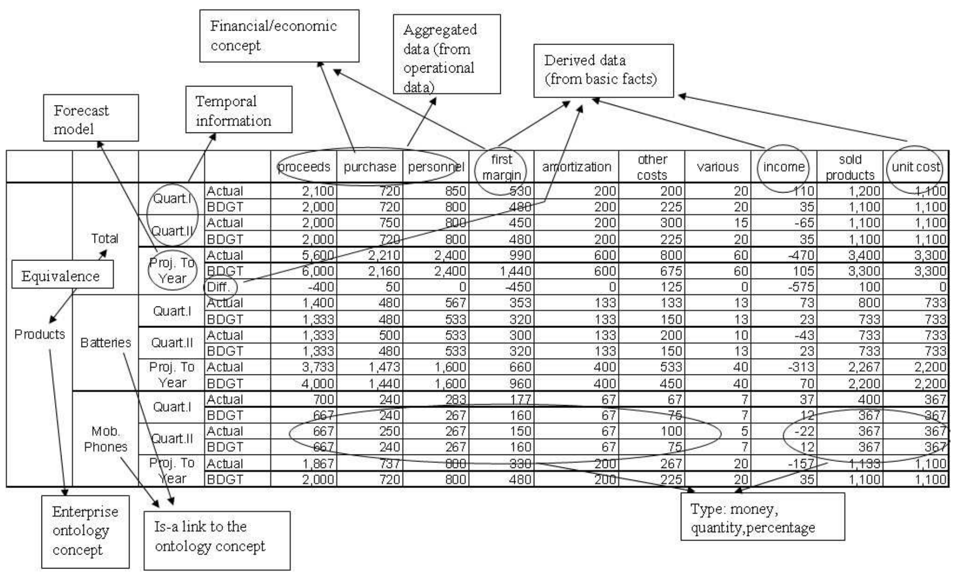

Fig. 4. Kind of relevant semantic information.

5.1 Meaning of terms

Meaning of terms can be expressed by linking the terms to concepts of a common domain ontology.

The Edinburgh Enterprise Ontology (EO) [24] has been taken into consideration. Report terms can be related to ontology concepts in different ways: for instance, terms like *Batteries* (*Mob. Phones*) can be considered an *instance of* the *Product* concept in EO, explaining that in our context, batteries (mobile phones) are particular kinds of products. Similarly, the term *Products* has an *equivalence* relation with the same ontology concept.

Other kinds of relations could be envisaged as well : for instance intra-model relations like a *part-of* relation between *Batteries* and *Mob. Phones*, or an *equivalence* relation between *Products* and *Total*.

At the strategic level, the enterprise ontology is no more sufficient, since indices express concepts that are better referred to the financial and economic domain, like purchase, cost, proceeds, margin, amortization and so on.

To express the meaning of such indices, we may refer to a specific ontology like the Financial Ontology by Teknowledge (http://ontology.teknowledge.com). For instance, we might define an instance-of relation between the term *proceeds* and the ontology concept *Income*.

5.2 Temporal and metric information

Metric information is perhaps the most standardized and well-known kind of information. Probably it is not necessary to define specific ontologies. Simple annotations reporting the symbol of the unit measure ($, %,. . .) might suffice. In some situation, information about unit conversion (e.g. from $ to euro) might be useful. In this case, rather than a fixed conversion, it is preferable to establish a link to an external, official exchange organization. Let us note that, despite its simplicity, information about unit measure gives important insights to understand the meaning of numbers in the report.

Temporal information appears in the report (e.g. the term *Quart.I*). It can be annotated in the simplest way by resorting to the Edinburgh Enterprise Ontology, which contains temporal concepts like Time_Interval, Time_Line and Time_Point. In order to enable temporal reasoning, more specific ontologies should be exploited.

5.3 Forecasting models

Intermediate reports usually contain estimates of quantities which are not already known. In the example, it is assumed that the report is generated at the end of the second quarter of the year, hence it contains performance indices which are calculated from transactional data for the first and second quarter, while it gives an estimate for the remaining part of the year. A fundamental information to understand the meaning of terms like *Proj. to year* is the actual method (for instance, linear or non linear regression) used to estimate the unknown quantity, on the basis of known data. This information can be given in different ways:

- by a link to a suited mathematical ontology
- by a link to a formal description of the method
- by a link to a formal description of the model

At the best of our knowledge, mathematical ontologies suited to our end does not exist. Formal description of the method means the description of the process which leads to the estimate, given in some process description language. It can either refers to an abstract description of the method or to the actual program which performs calculation. Finally, formal description of the model means for instance to give the parameters of the linear/non linear equation interpolating known data. Model description languages like the Predictive Model Markup Language (PMML) can be used to this end [9].

5.4 Derivation and aggregation rules

Index values are calculated by elaborating upon transactional data. Basically, we can distinguish two kinds of elaboration:

- *Aggregation*: used to generate synthetic data at different levels of granularity. Aggregation is performed by functions like average, sum, etc.;
- *Derivation*: used to calculate derived indices (e.g., in the example the first margin concept is defined as the difference between proceeds and the costs for purchase and personnel)

We point out that the actual definition of the function used to calculate a derived index is the most important semantic information to give about the index: as a matter of fact, an important limitation to interoperability at strategic level, even in homogenous environments like a single enterprise, is the semantic heterogeneity of derived indices. Although theoretically enterprises could/should define a standardized set of indicators, this is not actually the case for many true enterprises. The reason is related to the existence of some form of autonomy for organization units: this is the case for example of public administrations, multiple division structures, franchising etc. This autonomy can lead organization units to define their own indicators and hence to heterogenous indices definition. For instance, the *unit cost* can be simply defined as the total cost divided by the total number of goods produced, but the calculus of total cost is not a standardized procedure, which may or may not include some type of cost, relate the cost to the production volume by either a linear or non linear function etc. Similarly, a *productivity* index might be defined either by the ratio between proceeds and the number of employees, or between the net income and the number of employees. Employees can be counted by “heads”, or by “hours-equivalent”, taking into consideration part-time and full-time contracts. As another source of heterogeneity, indicators can change in time, due to different analysis needs, or modified external and internal conditions like changes in enterprise rules or national/international laws. In this scenario, the usage of annotation can be envisioned to enhance communication and comprehension among managers, simply the process of budget formation by comparison and reconciliation of local performance indicators, or to compare and reason on reports generated at different times.

6 Conclusions

The simulation of a strategic information needs analysis for the case study we used, allows to enlighten novel kinds of information which is typical of strategic planning and control activities. This information comes in the form of financial and economic concepts, aggregated and derived data, and forecasting models.

Hence it is argued that a single enterprise ontology is not sufficient to describe the concepts in OLAP reports, and that specific financial/economic and mathematical ontologies are needed. Also, it is argued that the traditional mapping of terms to ontology concepts cannot by itself express the whole body of semantic information appearing at the strategic level. Rather, annotation languages should be defined which are expressive enough to describe the semantics of mathematical formulas, forecasting processes and models. The problem of semantic description of mathematical objects has been addressed only recently, by the MathML [25] and the OpenMath [22] standards. The best known language for the description of forecasting (or predictive) models is the Predictive Model Markup Language (PMML) [9]. Further work will be devoted to evaluate the appropriateness of these languages for our purpose, and to device specific annotation services and tools.

From a more general standpoint, considering the variety of enterprise models perspectives, we feel that a single ontology may not cover all the reequired types of annotations. Will we then fall in the problem of heterogeneous ontologies?

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References

1. S. Bechhofer, L. Carrand C.A. Goble, S. Kampa, and T. Miles-Board. The Semantics of Semantic Annotation. In *Proceedings of CoopIS/DOA/ODBASE*, pages 1152–1167, Irvine, California, USA, October 30-November 1 2002. LNCS# 2519.
2. N. Boudjlida, M-D. Devignes, and M. Smal-Tabonne. Services for a Genomics Open Distributed Environment, a position paper. In *XEWA-00, The XML Enabled Wide-Area Searches for Bioinformatics Workshop*, League City, Texas, December 2000. http://www.casc.llnl.gov/xewa/.
3. Boudjlida, N. et alii. A practical experiment on semantic enrichment in a homogeneous environment. Deliverable DTG4.1, IST-508 011 NoE INTEROP, 2006.
4. Bracchi,G.,Francalanci,C. and Motta,G. *Sistemi Informativi e Aziende in Rete.* McGraw-Hill Italia, 2001.
5. G. Canals, N. Boudjlida, J.C. Derniame, C. Godart, and J. Lonchamp. *ALF: A Framework for Building Process-Centered Software Engineering Environments*, chapter 7, pages 153–187. Research Studies Press, Taunton, Somerset England, 1994. In "Software Process Modeling and Technology", A. Finkelstein, J. Kramer and B.A. Nuseibeh, editors.
6. Castellanos, M. Semantic Enrichment of Interoperable Databases. In *IEEE Workshop on Research Directions in Interoperability*, April 1993.

7. J-C. Derniame, B-A. Kaba, and D. Wastell, editors. *Software Process: Principles, Methodology and Technology.* Springer-Verlag, LNCS# 1500, 1999.
8. European Bioinformatics Institute. *Symposium on Semantic Enrichment of Scientific Literature*, Hinxton, Cambridgeshire, UK, February 2006.
9. Grossman, R., Hornik, M. and Meyer, G. Evolving Data Mining into Solutions for Insights: Data Mining Standards Initiatives. *Communications of the ACM*, 45(8):59–61, August 2002.
10. Hakkarainen, S. *Dynamic Aspects and Semantic Enrichment in Schema Comparison.* PhD thesis, Stockholm University, 1999.
11. Hax, A. C. and Majluf, N. S. *The Strategy Concept and Process, A Pragmatic Approach.* Prentice Hall, Upper Saddle River, NJ, 1996.
12. Hohenstein, U. Using Semantic Enrichment to Provide Interoperability between Relational and ODMG Databases. In *International Hong Kong Computer Society Database Workshop*, pages 210–232, 1996.
13. M-R. Koivunen and R. Swick. Metadata Based Annotation Infrastructure offers Flexibility and Extensibility for Collaborative Applications and Beyond. In *Proc. of the KCAP 2001 Workshop on Knowledge Markup & Semantic Annotation*, 2001.
14. Lin, Y., Strasunskas, D., Hakkarainen, S., Krogstie, J., and Solvberg, A. Semantic Annotation Framework to Manage Semantic Heterogeneity of Process Models. In *Proc. of the 18th Conference on Advanced Information Systems Engineering*, Luxemburg,2006, Springer-Verlag, LNCS, to appear.
15. Missikoff, M. et alii. Ontology-Based Integration and Interoperability of Enterprise Modelling, Architectures and Platforms: State of the Art and State of the Practice. Deliverable no. DWP8.1, FP6 IST-508 011 NoE INTEROP, November 2004.
16. Reeve, L., Han, H. Survey of semantic annotation platforms. In *Proc. of the 2005 ACM symposium on Applied Computing*, pp.1634–1638, Santa Fe, New Mexico, 2005
17. Rowley, D. J., Lujan, H. D., and Dolence, M.G. *Strategic Change in Colleges and Universities.* Jossey-Bass Publishers, San Francisco, CA, 1997.
18. Seung Ki Min, Eui-Ho Suh and Su-Yeon Kim. An Integrated Approach Toward Strategic Information Systems Planning. *The Journal of Strategic Information Systems*, 8(4):373–394, 2000.
19. SEWASIE: SEmantic Webs and AgentS in Integrated Economies. IST-2001-34825 EU Project. http://www.sewasie.org/.
20. S. Sivashanmugam, K. Verma, A. Sheth, and J. Miller. Adding Semantic to Web services Standards. In *Proceedings of the 1st Intern'l Conference on Web Services (ICWS'03)*, pages 395–401, Las Vegas, Nevada, June 2003.
21. Su, X., Hakkarainen, S. and Brasethvik, T. Semantic enrichment for improving systems interoperability. In *ACM Symposium on Applied Computing*, pages 1634–1641, 2004.
22. The OpenMath Society. *The OpenMath Standard Version 2.0.* http://www.openmath.org/cocoon/openmath/standard/om20-2004-06-30/omstd20.pdf, 2004.
23. M. Uschold and M. Gruninger. Ontologies: Principles, Methods and Applications. *Knowledge Engineering Review*, 11(2), 1996.
24. Uschold, M., King, M., Moralee, S. and Zorgios, Y. The Enterprise Ontology. *The Knowledge Engineering Review*, 13, 1998.
25. W3C Math Working Group. *Mathematical Markup Language (MathML) Version 2.0 (Second Edition).* http://www.w3.org/Math, Oct. 2003.