Ontologies and Conceptual Models in Industrial Enterprises and Software Development Processes

Marcela Vegetti,[*], Silvio Gonnet[*], Horacio P. Leone[*], Gabriela P. Henning[#]

[*] Instituto de Desarrollo y Diseño (INGAR), CONICET-UTN, Avellaneda 3657, (3000) Santa Fe, Argentina, {mvegetti, sgonnet, hleone}@santafe-conicet.gov.ar

[#] Instituto de Desarrollo Tecnológico para la Industria Química (INTEC), CONICET-UNL, Güemes 3450, (3000) Santa Fe, Argentina, ghenning@intec.unl.edu.ar

1. Research statement

Our group is interested in developing conceptual models and domain ontologies in the field of industrial enterprises and software development processes. We completely agree with the view of domain ontologies as explicit and formal models of specific knowledge fields, which satisfy the requirement of reflecting the consensus of a community. The reasons why the group has been involved in the development of conceptual models and domain ontologies in the past 20 years are the following: (i) They play an essential role in describing and understanding complex fields; (ii) As a shared notation and a conceptual foundation, they facilitate the communication, discussion, exchange of case studies, etc., among the members of a community; (iii) Since knowledge is explicitly and formally expressed, conceptual models and ontologies support inference processes and, therefore, the development of intelligent systems; (iv) By providing a declarative, machine readable representation, ontologies can enable unambiguous communication between software agents that would otherwise be difficult or impossible. In this way, ontologies play a central role in solving nowadays problems associated with islands of automation by providing a semantic integration foundation to the enterprise applications integration field.

2. Main research lines

Section 2.1. presents the more established research lines associated with ontologies and conceptual models for industrial enterprises. They are related to the development of conceptual and reference models, domain ontologies, architectures and collaborative tools to reach integration within organizations, as well as among different industrial enterprises. Some of these models and ontologies support the underlying reasoning mechanisms of some intelligent systems in the areas of industrial planning and scheduling. In addition, they include the development of tools that support the modeling and design of collaborative business processes. On the other hand, Section 2.2 describes more recent research lines associated with ontologies and conceptual models that participate in software development processes.

2.1. Ontologies and Conceptual Models for industrial enterprises

SCONTO

It is a **S**upply **C**hain **ONTO**logy whose development has an enormous importance in the context of extended supply chains (SCs), where several partners belonging to distinct organizations, and having different information systems, need to interplay, communicate and exchange information in a seamless fashion. SCONTO represents SC processes in a formal way and extends the SCOR reference model, overcoming most of its limitations [1]. SCONTO can unambiguously describe the SC processes and activities, their scope, associated organizational units and resources, as well as their interrelationships. Besides, it can formally capture the SC structure, its participating organizations, along with the resources that partake in the different supply chain business processes, explicitly representing their roles and flows. In addition, SCONTO includes an explicit, comprehensive, and formal representation of the assessment related concepts (metrics and best practices) [2] [3] that are involved in a SC evaluation system. This view is totally integrated with the other ones.

The ontology has been developed following the methodological guidelines devised by Methontology. As the main result of its conceptualization phase, a semiformal conceptual model was built using the UML language and OCL constraints. Later, this model has been formalized and implemented in OWL. To test the ontology, different case studies concerning extended supply chains were carried out, and are still being addressed.

PRONTO

PRONTO is a domain ontology which captures information of industrial products. It defines and integrates two hierarchies: the abstraction hierarchy (AH), and the structural one (SH). This last hierarchy is associated with bill of materials (BOM) information [4]. PRONTO modifies the traditional two-level product family representation since its AH establishes three different abstraction levels for the definition of products: Family, VariantSet and Product [5]. Furthermore, the ontology includes appropriate mechanisms to consistently maintain structural information among the different abstraction levels [6]. The extension of PRONTO with a hierarchical product-property model [7] allows managing huge amounts of structural and non-structural information in a systematic way, with minimum replication. Besides, an unambiguous criterion, based on the properties of variants, for identifying families and variant sets has been proposed.

Two implementations of PRONTO have been developed: (i) A ConceptBase formal specification of PRONTO that focuses on the structural hierarchy of products. This hierarchy is a tool to handle product information associated with the multiple recipes or processes to manufacture a particular product or a set of similar products [8]. (ii) An OWL implementation [9]. This last one is the basis for a Semantic Web-based architecture that was proposed to support the formulation of queries about the structure of products whose components are manufactured by different nodes of a supply chain that operates under the collaborative product development paradigm.

Production Processes and their Operations

Intelligent support systems in the areas of production planning and scheduling, both predictive and reactive, need to have an explicit representation of the domain in order to ground their domain-based reasoning mechanisms. With this idea in mind, an ontology that explicitly represents in an integrated fashion the resources involved in production processes, their associated production recipes or manufacturing routes, as well as scheduling related concepts, disruptive events and temporal information is being developed [10]. These different views have been organized into subontologies.

The underlying generic representation allowed specializing the ontology for specific types of industrial plants. Up to now it has been specialized to represent multiproduct, multistage batch plants, as well as flexible manufacturing systems, and has supported the reasoning mechanisms associated with a reactive scheduling framework [11]. Future work involves addressing other types of industrial processes, as well as supporting reasoning mechanisms coupled with the automatic development of scheduling models based on mathematical and constraint programming techniques.

The ontology has been developed according to the guidelines of the well established ANSI/ISA-S88 and ANSI/ISA-S95 international standards. Besides the goals that were presented in the previous paragraph, it is expected to serve as the foundation for the integration of the many informatics applications that nowadays coexist in industrial shop floors.

Engineering Design Process

The objective of this research line is the development of an environment for modeling and managing collaborative engineering design processes. In particular, this line involves the definition of models and tools to represent and capture the experts' knowledge and rationale, as well as the products that are generated along with these design processes. Thus, the whole history of a design problem is retained in an integrated fashion.

CoMoDe. It is a **Co**llaborative **Mo**del for capturing and representing the engineering **De**sign process. It is based on a deductive object-oriented model that, in relation to an engineering design process, is able to capture the different elements that participate in it in an integrated fashion [12] [13]. In particular, it is able to represent (i) the activities, operations, and actors that have generated each design product, (ii) the imposed requirements, and (iii) the rationale behind each decision. Furthermore, it also offers an explicit mechanism to represent and trace the different model versions that have participated in the design process. Situation calculus is used to formally express the existence of an object in a given state of a particular design process.

TracED. Supported by CoMoDe, Traced is a tool that has been developed for capturing and **Trac**ing **E**ngineering **D**esign processes. This tool provides the mechanisms to capture the several products generated during an engineering design process, as well as the elements for specifying, executing, and capturing the operations that have generated them [14] [15]. Based on an extensible model, TracED allows the definition of the elements of particular work domains, as well as the operations that are suitable for them.

2.2 Ontologies and Conceptual Modeling in Software Development Processes

More recently, new research interests appeared, which extended the application domain to the software development processes. The conceptual models and ontologies that were generated in the two previous lines are now being extended to the software development field. In particular, CoMoDe has been extended to obtain a model for capturing how products are generated and transformed along the software architecture design process. Such model follows an operational perspective, where architectural design decisions are modeled by means of sequences of operations that are applied on the design products [16]. Also, a particular application domain was defined in TracED to allow using this tool for capturing and tracing software architecture design processes. The tool was used in a test project to design the architecture of Struts, the well known development framework [17]. The proposed model has also been successfully applied to the mobile systems software architecture domain [15]. Besides, the initial results have been extended to consider the representation of architectural artifacts [18] and the rationale generated by architects during the design process [19].

Additionally, the group is working to develop tools for software architects to allow them reusing the architectural solutions previously applied (either by the architects themselves or by other architects), when designing new architectures.

3. Brief Summary of the Group History

The group started in 1991 when Horacio Leone and Gabriela Henning returned to Argentina after completing their Postdoctoral stay at the Massachusetts Institute of Technology, where they developed MODEL.LA [20] [21], a conceptual modeling language for the process systems engineering domain. Back in Argentina, they started working on a language for Enterprise Modeling [22] [23].

Afterward, the modeling and management of collaborative engineering design processes research area was initiated [13] [12], and soon after, the development of an ontology for industrial products representation was undertaken [4] [5] [6] [7] [8] [9]. Later on, a research line on a supply chain ontology was started [1] [2] [3]. In the last few years other research areas were opened: (i) the development of an ontology for industrial processes and their operation (scheduling) [10] [11], and (ii) the extension of the collaborative engineering design processes models and tools to the software development process domain [14] [15] [16] [17] [18] [19]. The group currently has two senior researchers (Horacio Leone and Gabriela Henning), two junior researchers (Marcela Vegetti and Silvio Gonnet), two Postdoctoral fellows and six Ph. D. students.

The biography of the researchers is summarized below.

Marcela Vegetti received a Ph.D. degree in Information Systems from "Universidad Tecnológica Nacional, Facultad Regional Santa Fe" (UTN-FRSF), Santa Fe, Argentina, in 2007. She currently holds an Assistant Researcher position at CONICET, working at INGAR (CONICET-UTN). She also is an Assistant Professor at UTN-FRSF. Her research interests focus on models to support product knowledge representation in industrial enterprises. Besides, she is extending this research line to model product platforms in the software development process domain.

Silvio Gonnet received an Engineering degree in Information Systems from UTN-FRSF in 1998, and obtained his Ph.D. degree in Engineering from "Universidad Nacional del Litoral" (UNL) in 2003. He currently holds an Associate Researcher position at the National Council for Scientific and Technical Research of Argentina (CONICET), to work at "Instituto de Desarrollo y Diseño" (INGAR). He also is an Assistant Professor at UTN-FRSF. His research interests include models and tools to support engineering design processes, software architectures, and semantic web.

Horacio P. Leone is a Full Professor at the Information Systems Department of UTN-FRSF, where he is currently the Department Head. He also holds an Independent Researcher position at CONICET, working at INGAR. He obtained his Ph.D. degree in Chemical Engineering from UNL in 1986 and was a Postdoctoral Fellow at the Massachusetts Institute of Technology (1986–1989). His current research activities focus on software architectures, models for supporting the design process, semantic web applications to supply chain information systems and enterprise modeling. He has supervised several Ph.D. and Master students

Gabriela P. Henning is a Professor at UNL and holds a Principal Researcher position at CONICET, working at INTEC (CONICET-UNL). She received a Ph.D. degree in Chemical Engineering from UNL in 1986 and was a Postdoctoral Fellow at the Massachusetts Institute of Technology (1986–1989), specializing in applications of Artificial Intelligence in Process Engineering. Her current research interests include the development of integrated information systems for industrial organizations, models for supporting engineering design processes, as well as the solution of industrial scheduling and supply chain management problems by means of knowledge-based techniques. She has supervised several Ph.D. students

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