Semantic Interoperability for dynamic product-service business ecosystems

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SEMANTIC INTEROPERABILITY FOR DYNAMIC PRODUCT-SERVICE BUSINESS ECOSYSTEMS

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***Abstract** - Dynamic Product-Service Business Ecosystems (DPSBEs) are collaborative forms that aim to handle product-service business actions in a business ecosystem by creating, sharing, using and re-using information across functional teams and enterprise boundaries. DPSBEs depend on the ability of their members' information systems to interoperate. This ability is related to making their semantics explicit and formal, so information can be interpreted and managed both by humans and systems. In this position paper, we establish the scientific background for the semantic interoperability for dynamic product-service business ecosystems.*

1. INTRODUCTION

Dynamic Product-Service Business Ecosystems (DPSBEs) are emerging collaborative forms that aim at organising and handling product-service business actions.

Product-Service System (PSS) is thought [1] as "a market proposition that extends the traditional functionality of a product by incorporating additional services. Here the emphasis is on the 'sale of use' rather than the 'sale of product'. The customer pays for using an asset, rather than its purchase, and so benefits from a restructuring of the risks, responsibilities, and costs traditionally associated with ownership".

The PSS concept embraces an integrated view on the products and associated services, supporting networks and infrastructure and design and innovation strategy to achieve and implement this view. It assumes improved competitiveness, better customer satisfaction (more product customization and higher quality) and lower environmental impact than traditional business models [2][3][4][5][6].

Product-service paradigm requires the integration of autonomous, geographically distributed and heterogeneous stakeholders in business ecosystem creating, sharing and re-using information across functional teams and enterprise boundaries. In a DPSBE, information management is a fundamental process in order to support after-sales services and next round of product-service innovations to the market. This management is carried out across the boundaries of potentially many enterprises - actors within one DPSBE.

In terms of the collaboration aspects of DPSBEs, they are similar to the so-called Virtual Breeding Environments (VBE) – the pools of organizations and related supporting institutions that have both the potential and the will to cooperate with each other through the establishment of a "base" long-term cooperation agreement and interoperable infrastructure [7]. Then, this infrastructure is capable to give birth to so-called virtual enterprises - the temporary networks of independent enterprises (organizations), who join together quickly to exploit fast-changing opportunities and then dissolve [8].

Research on PSS involves a diversity of scientific and research topics: interoperability of Enterprise Information Systems (EIS), organizational theory, business process management, enterprise architecture, ontology, and knowledge management. Most of these topics are separately largely addressed, but the semantic interoperability of EISs lacks of extended research results in PSS context. Although many EU projects tried to setup a common unified view of business ecosystems, they did not propose any solutions to the problems related to the complex semantic issues underlying interoperability barriers among collaborative enterprises.

The ability of DPSBEs members' information systems to interoperate is one of the key issues in a Product-Service System (PSS). Many projects that deal with interoperability issues, such as ATHENA, INTEROP NoE, ENSEMBLE, UNITE and COIN use semantics as a facilitator for interoperability.

The HORIZON 2020 Framework Programme for research and innovation emphasizes that semantic interoperability is one of the pillars the future research roadmaps. It is important to consider that semantic interoperability goes beyond mere data exchange; it assumes fewer technical preconditions and it deals particularly with data interpretation, where this interpretation is highly dependent on a given context. In this position paper, semantic interoperability is tackled within the perspective of the product-service systems.

So far, none single initiative has addressed the problem of semantic interoperability in PSS context in an emerging Service Economy, to such extent as to manage delivering practical solutions or a larger engagement of the scientific community. Although a range of tools and methodologies for designing PSS exist, they typically represent minor developments of the conventional product design processes, with serious lack of evidence and justification of such tools and methods [1].

2. DISCUSSION

Future research on the semantic interoperability for DPSBEs should build upon the following complementary scientific topics: a) Foundational aspects of semantic interoperability; b) Formal models for DPSBEs; c) Semantically interoperable EISs - implementation and application issues.

The future research on these topics may be considered as a transversal multi-domain approach. Areas to be considered are: complex systems, knowledge management, enterprise interoperability, product-service systems and networked organizations.

2.1. Foundational aspects of semantic interoperability

Foundational aspects should deal with theoretical aspects of semantic interoperability - definition, evaluation, knowledge representation requirements and languages.

In defining the foundational aspects for semantic interoperability, we follow the approach of John Sowa [9] and define semantic interoperability as follows:

"A sender's system S is semantically operable with a receiver's system R if and only if the following condition holds for any data p that is transmitted from S to R: For every statement q that is implied by p on the system S, there is a statement q' on the system R that: (1) is implied by p on the system R, and (2) is logically equivalent to q. The receiver must at least be able to derive a logically equivalent implication for every implication of the sender's system.".

In semantically interoperable systems, there is no need for any kind of data structures or meta-information which is typically used to assign values so the receiving system can understand the meaning of those values. Instead, exchanged information is considered as a logical statement or a set of the logical statements which describe the semantics of the message from one system to another.

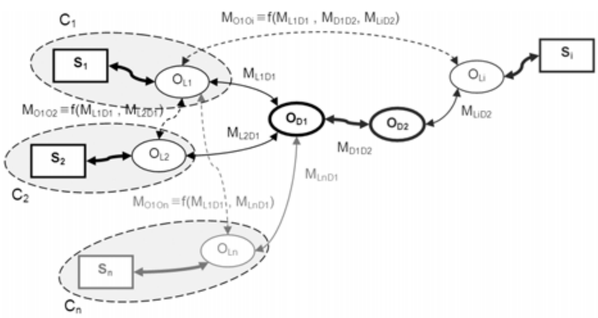

Fig.1. Semantic interoperability of systems

These messages are interpreted by the semantic infrastructure [10] (see Fig.1) which encloses: 1) explicit formal models of the systems (S_i) that need to interoperate (namely, local ontologies O_{Li}); 2) domain formal models with explicitly defined common semantics (namely, domain ontologies O_{Di}); and 3) correspondences (mappings) between the concepts of each of the local and domain ontologies (M_{LiDi}). Then, the mappings between the concepts of two interoperating local ontologies (and corresponding systems' models) can be inferred as logical functions of their mappings with domain ontology.

2.2. Formal models for DPSBEs

Formal models for DPSBEs should provide explicit and formal descriptions of the organizational environment whose actors need to interoperate - formal models of enterprise architectures and reference collaboration models. Although the problem of formalizing the enterprise environment is widely addressed by the scientific community, now it has to be reconsidered in context of PSS.

The research of formal models for DPSBEs needs to take into account existing standards, enterprise architectures and models and formal models. Relevant standards include: ISO 15704 - Requirements for Enterprise Reference Architecture and Methodologies [11], EN/ISO 19439 – Enterprise Integration – Framework for Enterprise Modeling [12] and IEEE 1471 - Recommended Practice for Architectural Description of Software-Intensive Systems-Description [13]. The relevant architectures and models are: Computer Integrated Manufacturing Open System Architecture [14] (CIMOSA), ARIS [15], Zachman Framework [16], The Open Group Architecture Framework [17] (TOGAF), GRAI Integrated Methodology [18], Purdue Enterprise-Reference Architecture [19] (PERA) and Department of Defense Architecture Framework [20] (DoDAF). Finally, the formal models for DPSBEs should benefit from the existing work in enterprise ontologies, such as: TOVE (TOronto Virtual Enterprise) ontology [21], The Enterprise Ontology [22], IDEON^{TM} ontology [23] and Supply Chain Operations Reference (SCOR) Ontology [10].

Although many of the reference works are complementary, the synthesis of the above results in context of DBPSPEs should take into account a certain amount of existing redundancies and consequently, a need for harmonization. This harmonization has been already started in the development of unifying models, such as Generalized Enterprise-Reference Architecture and Methodology [24] (GERAM).

Enterprise architectures developed in the past are contextual, in the sense that they reflect the background and purpose of their developers: CIMOSA for computer integrated manufacturing, GRAI for production management, PERA for system engineering, Zachman for information systems and DoDAF for military operations management. GERAM is considered as the best candidate as a reference architecture to which the concepts of these architectures can be mapped, analyzed and compared [25].

The context in which the above models need to be reconsidered is provided by the trend of "servitization" of products [27] and "productization" of services, where these two trends are converging to have a product and a service as a single offering. The occurrence of such PSS have many consequences on the relationships between the manufacturers (including their suppliers and involved services providers) and a customer, related to the business model of a product-service delivery, governance of the process, ownership of the product, etc.

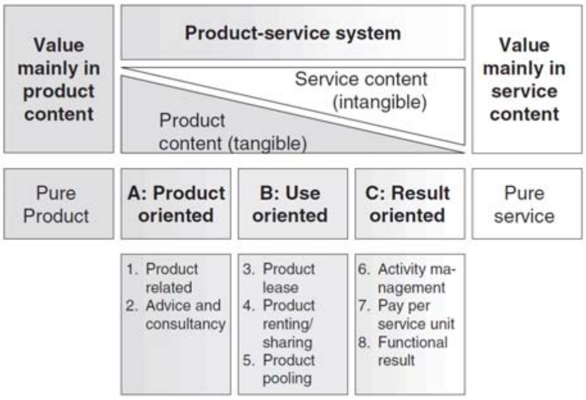

Fig.2. Structure of PSS

The PSS can take a form [26] (see Fig.2) of the product-oriented PSS (where, e.g. after-sale services, such as maintenance, repair or recycle are also included in the original act of product sale), use-oriented PSS (e.g. providing the availability of the product, instead of a product itself) or result-oriented PSS (providing the product capability instead of the product).

Obviously, the consideration of the product value chain is different in a PSS than in a conventional product-centric environment, because of the increasing service value element, effect to the customization as well as value of use (including reduced costs due to using less energy or even due to releasing from the responsibilities of asset ownership). This is especially the case in the latter two forms of PSS.

The infrastructure for supporting above scenarios should be provided by the DPSBEs. In a way, DPSBE concept inherits the concept of Virtual Breeding Environment (VBE) for virtual enterprises; it builds upon VBE by considering also new or revised business models, delivery processes, product development processes, etc. It also needs to consider early involvement of the customer in product-service design.

2.3. Implementation and application issues of semantically interoperable EISs

Implementation and application issues of semantically interoperable systems are related to the practical aspects - implementation of semantically interoperable EISs, impact to system architectures, reverse engineering methods, etc.

The implementation is based on the semantic infrastructure (see Fig. 3) which includes:

1) formal and explicit domain models (see section 2.2), namely domain ontologies (D_{oi});

2) formal explicit system models, which transforms the implicit models of the EISs (S_i), used by product manufacturers (PM_i) or service providers (SP_i), to computable formal and explicit ontologies, namely local ontologies (L_{oi}); and

3) application models, namely problem ontologies (P_{oi}), which formalize specific problems related to the DPSBEs infrastructure, such as: selection of product or service providers or calculation of the cost of PSS use, rent or lease.

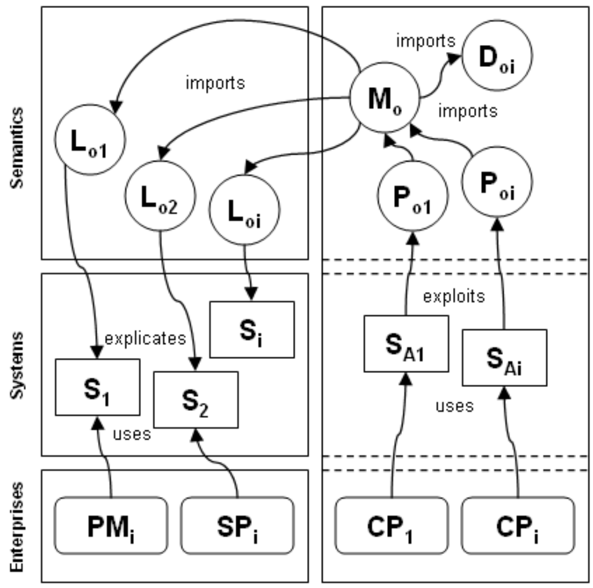

Fig.3. Semantic infrastructure for DPSBE

All three types of the above described formal models in the semantic infrastructure are interrelated by defining the logical correspondences between their respective concepts and relations, so to achieve a semantic interoperability of the systems which are using those (see section 2.1). These mappings are stored in unifying or mapping ontology (M_o).

Then, access to the overall knowledge of DPSBE (knowledge-of-systems and knowledge-of-domain) is enabled through the collaborative semantic applications (SA_i), used by the coordination service providers of DPSBE (CP_i).

Each of the semantic application is used to resolve individual problem of DPSBE, formalized by the problem ontologies (P_{oi}) which import the central mapping ontology.

3. CONCLUSIONS

The future work on pursuing the topics above should be strongly inter-related, because it involves the research on the three different perspectives on the individual problem: modelling, organizational and technical. At the same time, it addresses theoretical, foundational and practical issues. Thus, it is expected to provide the holistic view on the semantic interoperability in DPSBEs.

In this paper, we propose the foundations of semantic interoperability, candidate formal models for DPSBEs and approach to develop a semantic framework which would achieve the semantic interoperability.

The high innovative potential of the results of the research above draws from the fact that it enables organizations to interoperate without a need to fulfill the complex technical requirements. Thus, interoperation may easily become accessible (even as a service) for SMEs or any other organization that wants to participate in DPSBEs. Obviously, capability to quickly establish an infrastructure supporting the specific PSS is critical, since it contributes to the increased openness and flexibility and decreased interaction costs in DPSBE.

The end-users of the DPSBEs research are all organisations engaging in collaborative activities, especially PSS actions, whose performance depends on their capability to exchange information to support after-sales services and next round of product-service innovations to the market. One of the success factors of the industrial SMEs is their ability to participate in as many supply chains as possible, where each of them poses different manufacturing or service requirements and standards. Semantic interoperability could help in transferring this diversity manageable. Therefore, it is expected to increase the flexibility of SMEs and consequently, their capability to take part in DPSBEs.

In the long term, the advances in research on DPSBEs could lead to the establishment of new PSSs, in a global market undergoing a transition from being a product provider into being a value provider by integrating services into core-products offerings and vice-versa.

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