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ONTOLOGY-AIDED MANAGEMENT

Summary. This work investigates advantages of ontologies as the means for semantic integration of management activities. Semantic technologies are recently recognized as crucial management technologies in domains, which intensively exploit ICT and automation. Ontologies facilitate intra- and inter-organizational integration of different layers, functions, domains and processes of management. Ontologies enhance changeability, mostly in reference to business resources and processes. New forms of organizational structures and processes may also emerge.

Keywords: ontologies, management, semantic integration, changeability

ZARZĄDZANIE ZE WSPOMAGANIEM ONTOLOGII

Streszczenie. W artykule analizuje się zalety ontologii jako narzędzia integracji semantycznej w zarządzaniu. Technologie semantyczne są ostatnio uznawane za bardo ważne technologie zarządzania tam, gdzie intensywnie wykorzystuje się informatyzację i automatyzację. Ontologie mogą wspomagać integrację wewnątrz- i międzyorganizacyjną w odniesieniu do różnych szczebli, funkcji, obszarów i procesów zarządzania. Ontologie wspomagają osiąganie podatności na zmiany, zwłaszcza w przypadku zasobów i procesów gospodarczych. Ponadto, możliwe jest kreowanie nowatorskich struktur organizacyjnych i procesowych.

Słowa kluczowe: ontologie, zarządzanie, integracja semantyczna, podatność na zmiany.

1. Introduction

Among the major developments, which were affecting the human civilization in recent years many were driven by innovations in information and communication technologies (ICT) and automation technologies (AT). Among the key enabling technologies of that kind there were: Web services, SOA (Service-Oriented Architecture), semantic technologies, smart embedded systems, remote mobile terminals. Simultaneously systems and processes, which integrate humans and technical components, were experiencing increasing spatial spread, networking, complexity and coupling. Exemplifications of such developments are visible in many areas: social life, economy, urbanization, weapons etc.

Followingly extreme challenges were emerging, particularly in reference to development and operation of business resources and processes. Intensive progress, reflected by shortening life-cycles, was demanding of increasingly frequent changes. They were ranging from limited modifications, through reconfigurations up to evolutionary transformations. Changeability has become an important asset for management activities. This concept can be applied in different contexts and has various instances, e.g.: flexibility, agility, modularity, re-configurability, transformability [1]. Later on re-configurability and transformability will be much focused, as they refer to those structural changes, which affect business resources and processes.

When extraordinary challenges coexist with novel enabling possibilities, it may provide extraordinary opportunities. The Facebook can be given as a good example. It revolutionized global social communication. But apart of that, Facebook also provided some interesting business applications. The focus of this work is management, and particularly of business resources and processes. If new management technologies are facilitated by some frontier ICT/AT provisions, new ideas concerning business structures and processes may emerge, which go beyond the current mainstream paradigms. Although such considerations are not the major concern of this work, some highlights in relation to this topic will be addressed.

Many modern business systems and processes are specific by high level of complexity, networking, coupling and spatial spread. It is reflected by many cross-layer, cross-functional, cross domain and cross-process interactions and integrations, which need intensive use and exchange of knowledge. The importance of re-configurable and transformable resources and processes provides another challenge. Semantic technologies merged with distributed system technologies, such as SOA, provide a response to these demands [2]. Ontologies can work as core common platforms for various applications used by interlinked management activities. These may incorporate analytics, semi- or fully-automated decision making, real-time control and execution of operations [3, 4]. The operations strategy process is taken below as an illustrative example, to explain the perspective for the problem domain in more details.

When assessing acceptability of any business process, holistic estimation of performance characteristics is normally required [5]. They may be of economical, operational or technical nature. Similarly, diversified estimations are needed in case of feasibility evaluation. Both activities rely on the aids used to proof efficiency of new business processes and technologies. In most cases some conceptualizations and modelizations are required. Similar or often same means are needed, when reconfigurations are implemented, then when operations are running. It appears that distant aspects and perspectives of management are coupled in terms of aids and may imply similar or overlapping requirements for the aids. And it is visible again, that effective kernels to facilitate diverse but coupled integrations could be ontologies.

The SOA architecture as a mean to enhance interoperability and openness, in reference to both, internal and external integrations, is accompanied by another important development. It is the Semantic Web initiative led by the World Wide Web Consortium (W3C). It is expected to provide an open infrastructure for intelligent agents and Web services [6]. It uses ontologies as domain formalizations, linked on the Web. W3C defined the Web Ontology Language (OWL), as the standard for representing ontologies. OWL can describe complicated relationships among different entities, in terms of structured knowledge. To underline, using of Semantic Web tools is not restricted to the Semantic Web or Web services [7].

Later on the enabling potential and advantages of ontology engineering will be reflected in reference to the ICT/AT intensive management domains. The re-configurability and transformability aspects will be focused. In relation to the structurization issue, the novel architectures of distributed environments will be also addressed.

2. Ontological foundations

As it was argued in the former section, ontologies can be used as core conceptualizations for different applications that are applied by various management activities. Ontology is a formal representation of a shared and common knowledge about a particular domain [8]. Ontologies are means to communicate knowledge between humans and application systems in a transparent and consistent way. Hence they have to be standardized for a certain group of humans and applications in a particular domain. Ontology engineering provides the principles and methods for activities and processes that support creation, management, exploitation and maintenance of ontologies, e.g. ontology languages, automated reasoners etc.

A particular property of ontologies, which enables a distinction between ontologies and system models, is the open-world assumption, which states that anything not explicitly expressed is unknown. Hence ontology is a partial description and accepts under-specification as a mean of abstraction. In contrast, system models assume that what has not been specified is either implicitly disallowed, or implicitly allowed, which is the closed-world assumption. However, it must be underlined, that the above argumentation applies to management science and computer science, while it may not be valid in reference to other disciplines, e.g. in the area of engineering.

Typically models in the management science are understood as partial and explicit representations of a reality as seen by the people, who wish to use them to understand, change, manage, and control that part of reality [9]. This definition exposes another possible distinction between models and ontologies. Model is an abstraction from reality developed as its specification, i.e. it reflects structure and behavior of part of reality. Model is developed for some particular purposes, i.e. for some specific uses. Models are prescriptive, while ontologies are descriptive[1]. Principally they may be used for various purposes, including run-time uses by different applications. Hence ontologies are reusable. A summary of the major distinctions between ontologies and models is given below [Tab. 1].

Table 1

Distinctions between ontologies and system models

Ontologies	System models
open-world assumption	closed-world assumption
descriptive	prescriptive
formal	not necessarily formal
no focus on realization	focus on realization
enable knowledge exploitation	knowledge exploitation impossible
possible run-time use	run-time use impossible
reusable	limited reusability, if at all
can support reasoning	cannot support reasoning

Source: own work.

Deviating from its original philosophical meaning, in the context of ontology engineering the term ontology is understood as formal explicit specification of a shared conceptualization [11]. Such rigid approach may confuse, as it is not aligned with the preceding argumentation. Nevertheless it is understandable, as ontologies can be encapsulated into software models, or directly into applications [12]. In such circumstances they have to describe a given domain as completely as possible, and also to meet rigid requirements of software engineering. Current approaches to software development put a lot of attention towards modularity and reusability of applications. Facilitation of such qualities requires for both, an understanding of the tasks to be performed by the software, and knowledge about the domain. Recent progress in software engineering is centered on the development and use of models. Models are specified using formal languages, e.g. UML, and then used directly to generate codes. Software models require a method for both, making the domain knowledge explicit, and for integrating it with the conceptual model of the application [13]. Recent approaches to software development were limited in this regard, as they are not able to separate conceptual and domain models. Hence, software cannot be ported between domains without altering its conceptual model and consequently the whole software model. As it was explained before, these shortcomings can be avoided by using ontologies. An approach for this purpose is proposed below.

Aiming at synergy of ontologies and model driven application development, the following integration scheme can be defined. It makes distinction between core and application ontologies [Fig. 1]. The application ontology addresses ontology of the problem domain,

[1] Ontologies are not specifications, but descriptive conceptualizations in Seidewitz's sense [10].

i.e. the problem that application (software) is intended to service. The core ontology contains all categories relevant to some range of application domains.

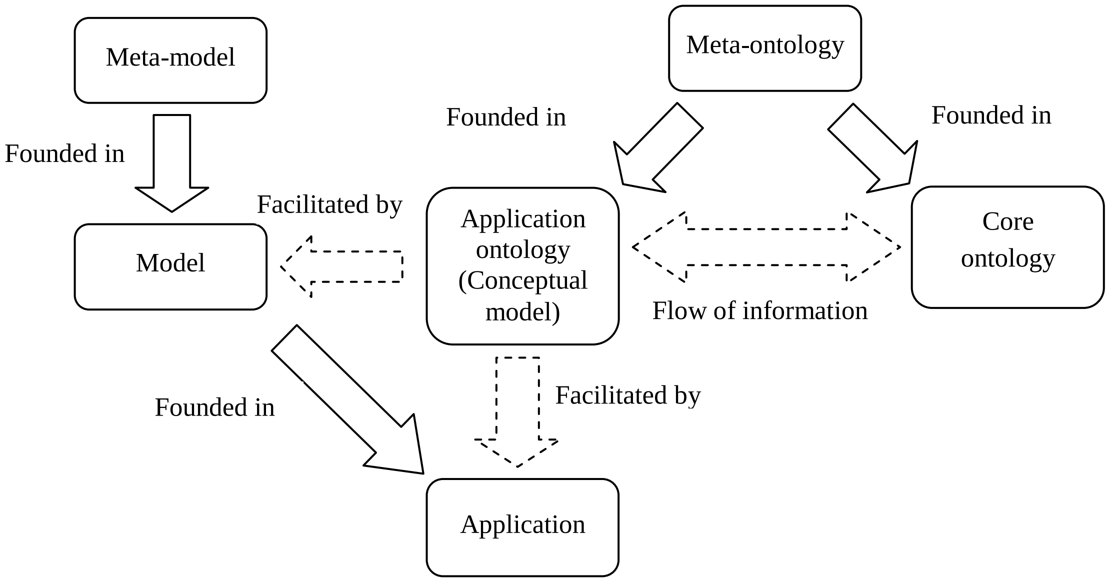

Fig. 1. Grounding scheme for integrated use of ontologies and models along applications development
Rys. 1. Ogólny schemat zintegrowanego wykorzystania ontologii w modelowaniu i rozwoju aplikacji
Source: own work.

The presented scheme enables to overcome the fundamental divergence, which still exists between current developments in the areas of ontology engineering and software engineering. It also provides a grounding idea for integration of various domains, their activities, and supporting applications, which have to be operated in a networked environment. Particularly, the domain ontologies may be used to provide replaceable components within application architectures.

The proposed scheme exploits ontological foundations of conceptual modeling, as well as other advances of semantic technologies. It is technically viable, e.g.: foundation relations between different items may be serviced by mappings, ontological translations or reductions; inconsistencies that may arise when ontologies are being merged, can be automatically detected and eliminated; etc.

The structure proposed for integrated use of ontologies and models along application development can be imitated within the management area. Different applications can share and exchange ontologies, eventually in the run-time mode. This way an intensive cross-layer, cross-functional, cross-domain and cross-process integration is made possible.

The exchange of ontologies may go in parallel with the data exchange that is normally supported by integrated database technologies. However, as it was presented above, from the management and ICT perspectives, ontologies have very different functional and operational role, than the data acquisition and exchange.

Ontologies may be externalized in many ways, including provision of external ontology services. They may facilitate different aspects of changeability. Finally, they can support decision making, including semi-automation or full automation, which is especially important when the domain is ICT/AT intensive.

3. Novel architectures

As semantic technologies play increasingly central role in systems engineering, a question about how they relate to application architectures assumes growing importance. Above, the SOA architectures were suggested as the crucial means to enhance interoperability and openness, in reference to both, internal and external integrations of business resources and processes.

SOA supports service orientation, which is a way of integrating ICT resources by interlinked services and the outcomes that they bring. Service orientation enables applications to invoke each other as a service, i.e. a repeatable task which meets some specified requirements, is discoverable, is self-describing and can be managed through governance. Whereas a software component is a unit of code that can be executed to provide functionality, a service is a component that is actually running, often in its own process, which is hosted independently from the applications that are invoking it. Actually, applications themselves can be broken into parts that each run in their own process and invoke each other through services. This makes a composite application, which is a set of related and integrated services that support a particular process, e.g. business process, which is built on SOA. SOA offers the potential to provide the necessary system visibility and device interoperability in complex systems, particularly those mixing ICT with some kind of automation, and subjected to frequent changes.

SOA is basically an architectural paradigm that defines mechanisms to publish, find, plan and coordinate services, adopting loose coupling logic and openness. Hence, the SOA paradigm is particularly applicable for such environments, which require frequent re-configurability and transformability. This is the case of ICT/AT intensive business resources and processes.

Expanding the use of the service-oriented architecture (SOA) paradigm, implemented through Web services, networking of technical components and humans is possible, based on adoption of unified technologies [14]. This approach can be extended to support all levels, functions, domains and processes of business management [Fig. 2].

SOA puts the granularity of intelligence to the lowest level, i.e. of distributed intelligent agents. These could be also smart devices or smart embedded systems. Intelligent behavior at upper levels can be achieved by composing configurations, which provide incremental fractions of intelligence. This way self-diagnosability and improved performance of resources and processes can be facilitated.

Furthermore, involvement of distributed ontologies enables re-configuration of loosely coupled elements, instead of re-programming of large centralized hierarchical systems. Increased robustness and dependability of resources and processes is indirectly but effectively facilitated this way.

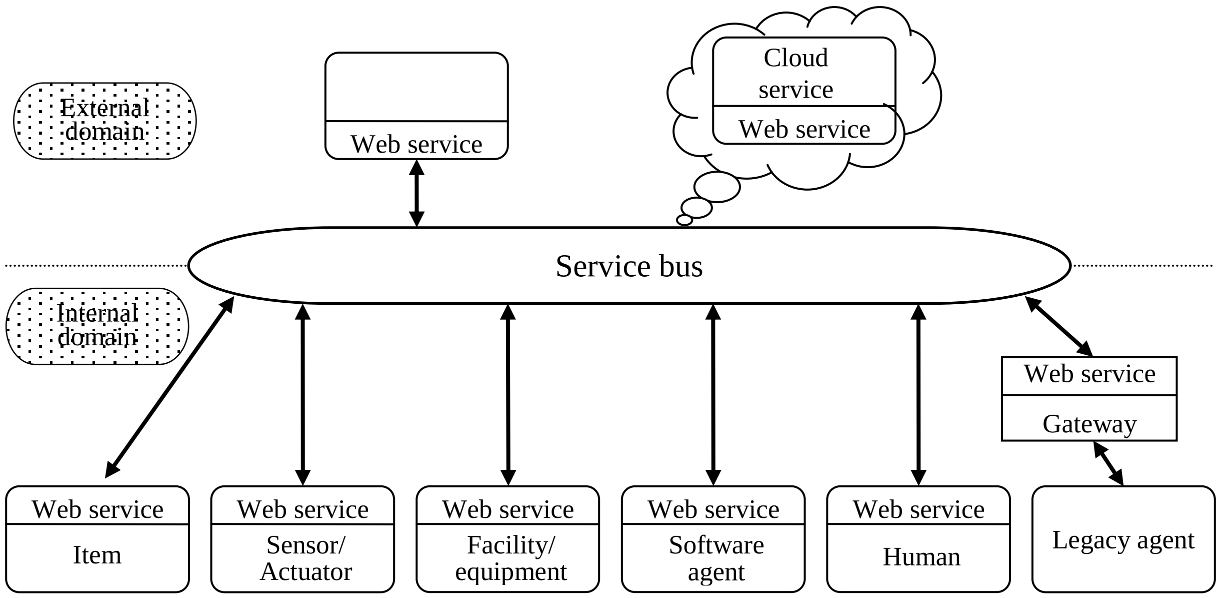

Fig. 2. Grounding scheme of SOA based architectures for business resources and processes
Rys. 2. Ogólny schemat architektury zasobów i procesów opartych na wykorzystaniu SOA
Source: own work.

The SOA based approach poses many advantages, but also raises new questions. It focuses interactions among the ICT resources and effectively facilitates execution of services, including planning and coordination. However, the surrounding business resources and processes are not directly addressed, as they are only known and reflected through services. This means that integration of business resources and processes in terms of interdependencies and discrepancies remains hidden [15]. Different aspects of this issue are discussed below.

4. Coupling and complexity

Ontology engineering merged with SOA can provide advantageous opportunities, concerning the semantic integration of networked resources and processes. However, some important aspects of integration, which are not directly reflected in the methodological foundation of ontology engineering and SOA, have to be separately addressed. Business resources and processes can be easily described in ontologies, as structures and elements, i.e. classes. However, they may compose large complexities, in terms of interdependencies and discrepancies, both of static and dynamic nature [16]. The complexities may be rooted in spatiality of structures of resources, eligible flows, process related precedences, discrepancies between technical characteristics of resources and processes, temporary requirements, enforced synchronizations of events and states, mereological relations of tasks and resources, e.g. temporary aggregations and disaggregations of tasks and transformable resources etc.

Such complicated relationships between different entities in a particular domain may be represented in ontologies, than exploited using general frameworks of semantic technologies and SOA. An example of architecture from the manufacturing area that follows this approach is presented below [Fig. 3]. It is the ESCOP architecture dedicated to the shop floor control.

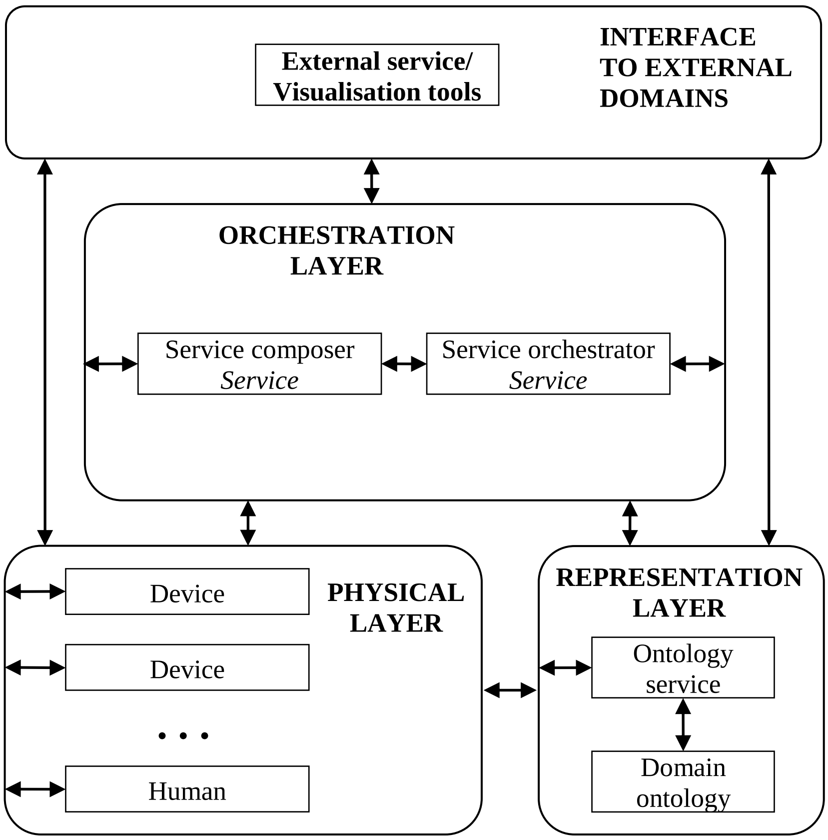

Fig. 3. Grounding scheme of the ESCOP architecture
Rys. 3. Ogólny schemat architektury ESCOP
Source: own work; based on developments from the EU ARTEMIS Program, project no. 332946.

The ESCOP architecture distinguishes three layers. All complexities are incorporated as a part of ontological representation of a manufacturing system, i.e. in the representation layer. Manufacturing system is coordinated by the orchestration layer, in terms of planning and controlling operations. Resources, i.e. the physical layer, are locally controlled by RTU (remote terminal units), or are run by operators equipped with smart or mobile terminals. Both types interact with orchestration services, in order to execute manufacturing processes. An alternative approach that goes beyond the systemic paradigm is proposed in [17]. It is rooted in the multi-agency paradigm. Distributed technologies, i.e. SOA and semantic technologies, are exploited to provide a complete solution for distributed intelligent coordination of manufacturing processes, which is driven by plural selection of controlling agents. Like in the ESCOP architecture, all coupling relations are described in the distributed ontologies.

The above proposal brings a question about the emergent potential of all novel management technologies, which are discussed in this work. A simple, but spectacular example may be obtained from the logistics domain. While it is well demonstrated that tracking technologies are able to accurately capture the detailed operational information, it remains a fundamental challenge to thrive this abundance of information for accurate and timely control decisions. Movable items can be easily networked, using semantic technologies and SOA. Distributed coordination by semi-independent intelligent agents is another possible realistic development. But despite that logistics operations are still managed by large centralized monolithic management systems.

Looking forward, it is realistic to presume, that advancements in semantic technologies together with other ICT/AT developments, will result in provisions of powerful methods and techniques, making possible the distributed management of business systems, first of all in the ICT/AT intensive sectors. Such systems could be composed of autonomous entities, each one equipped with some limited intelligent perception, capable to reason and seamlessly integrate and interact with other units. More effective and straight management, and particularly easy reconfiguration of resources and processes, will be enabled this way.

5. Conclusions

It is advocated in this work, that developments of semantic technologies and distributed systems technologies achieved a critical mass and acceptable level of maturity, to be widely adapted by the management area. Particularly, in reference to the challenges and requirements discussed before, ontologies offer significant advantages, including the following:

1. Using and sharing knowledge in distributed environments, by humans and smart applications, including the run-time mode; this way distributed intelligence is facilitated.
2. Significantly enhanced re-configurability and transformability of business resources and processes; this also applies to all management activities.
3. Improved openness, interoperability, integrability, convertibility and also scalability, increased potential for cross-layer, cross-functional, cross domain and cross-process integrations, including intra- and inter-organizational integrations.
4. Better performance, robustness and dependability of resources and processes.

The above conclusions call for extended effort concerning diffusion of the discussed concepts.

The particular challenging areas of further developments are: (a) novel business processes, to fully exploit broken organizational barriers and all advantages of ICT/AT achievements; (b) new structures of business resources, thriving from advanced concepts of distributed systems; (c) new concepts of management, emerging from the power of modern management technologies and (d) new paradigms, possibly rooted in bio- and eco-mimetic imitations.

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Omówienie

Artykuł rozpatruje zalety ontologii jako narzędzi integracji semantycznej w zarządzaniu. Ontologie są uważane za jedną z najbardziej prorozwojowych technologii zarządzania w tych organizacjach i sektorach, które intensywnie wykorzystują technologie informatyczne i komunikacyjne (ICT) oraz automatyzację. Technologie semantyczne ułatwiają integrację wewnątrz- i międzyorganizacyjną różnych szczebli, funkcji, obszarów i procesów zarządzania. Stosowanie ontologii wspomaga podatność na zmiany, zwłaszcza struktur zasobowych i procesów, umożliwiając obniżkę pracochłonności oraz skrócenie cykli wdrożeń przy ich rekonfiguracji. Technologie semantyczne, łącznie z innymi technologiami ICT i automatyzacji, umożliwiają generowanie nowych wartości dodanych oraz kreowanie nowych konceptualizacji, będących podstawą nowatorskich struktur organizacji i ich procesów.