An Ontology-Based Approach for Semantic Interoperability in Interorganizational IT Service Management

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***Abstract*—IT services are more and more offered by a combination of on- and off-premises or even cloud services. While for internally provided IT services guidelines and standards for the IT management exist, the IT management must be further supported by integrating management aspects of external IT services. Based on our previous concept of the inter-organizational Configuration Management Database, in this article, we concentrate on an ontology-based solution for the problem of heterogeneity issues caused by the autonomy in modeling CMDB contents in each of the observed IT service provider organizations. Our concept delivers a stepwise approach to handle semantic mismatches and is based on a hybrid Ontology mapping. Besides solving the heterogeneity of the service providers' management information systems and offering a holistic view of the overall IT infrastructure to the IT management, semantic mechanisms additionally allow to retrieve knowledge in an automated manner.**

I. Introduction

Within IT Service Management (ITSM) the overall goal is to align business and IT. Therefore, frameworks and standards like ISO/IEC 20000 [1] or the IT Infrastructure Library (ITIL) [2] have been established. In order to effectively achieve this goal they prescribe process building blocks for IT management. These building blocks serve as a blueprint for adapting it within one's own organization. They also contain analytical IT management processes like the Incident or the Problem management process. Within IT operations, these processes aim at solving Incidents quickly and thoroughly. In order to do so, database-oriented tools are used, the so called Configuration Management Database (CMDB). A CMDB contains a logical model of the IT infrastructure and shows relationships between the so-called configuration items, which are the components of the IT infrastructure like services, hardware, software, documentation. The service desk then uses the CMDB for diagnoses in form of impact and root cause analyses. Within an impact analysis it is investigated which effects faulty resources might have to services using this resource. In contrast, a root cause analysis tries to identify a single cause of a failure which caused one or more incident reports.

Traditional IT organizations are transformed more and more into service centers; this applies when on demand external IT services are ordered and flexibly integrated in existing internal business services. Such external services might also come in form of cloud services. However, such a setup is hidden from the business services users.

ITSM processes can be accomplished with the help of the CMDB's information quite easily, whereas in cross-organizational service scenarios, as we introduce it in the following, the description of ITIL is not sufficient. ITIL is mainly focusing on the management of internal IT services or organizations and addresses the management of services consisting of service parts provided by internal and external service providers mainly by using Service Level Agreements (SLA). An SLA describes then the agreement on the service parameters of both parties. However, in IT operations it is quite often necessary to react quickly. SLA offers a general frame for this but still more technical tool support is useful.

The challenging task within IT management is now to keep a comprehensive overview even if the IT services are composed of service parts delivered by different service providers. Autonomy of these service providers in shaping their own IT management systems increases this challenge even more. To assist inter-organizational ITSM (ioITSM) we have already introduced the concept of an inter-organizational CMDB (ioCMDB) in our previous work (see [3], [4]). Such an ioCMDB has interfaces to the CMDBs operated in the services providers' organizations.

In this article we are extending this concept by an approach, which enables now ioITSM procedures, as the above described impact analyses, but now it encompasses also the external service parts. We are using an ontology-based approach to be able to create the relevant knowledge needed in ioITSM procedures in automated manner.

In the following section II the problem within ioITSM is motivated by a scenario. We are using this to derive requirements for the interoperability issues to be solved. In section III related work is surveyed which offers to some extent building blocks for our described and prototyped solution in section IV. A conclusion and outlook is given in the final section V.

II. Inter-organizational IT Service Management and Ontology-based Methods

In the following section II-A the used methodical approach is outlined, in section II-B the challenges within ioITSM are motivated by describing an inter-organizational service scenario. Hereby, the introduced use cases is the Munich Hybrid Cloud (MHC) environment, which represents parts

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of the IT infrastructure of the Munich higher education institutions (c.f. [5]). This scenario serves to illustrate the requirements on ontology-based methods to assist ioITSM in section II-C. Based on these requirements our concept to integrate knowledge-based methods in ioITSM is described in section IV.

A. Methodical Approach

Our work is based on the Design Science method [6] and starts with the use case introduced in the next section. This use case illustrates the problem area within ioITSM and helps to identify requirements for our concept of ontology-based interoperability. As required in Design Science we investigate in section III to which extent related work can assist us to build a solution for our problem.

B. Semantic Heterogeneity within inter-organization's IT Service Management

In Figure 1 a simplified set-up of the MHC is illustrated. The Munich university is divided into various sub organizations like faculties or departments. These sub organizations reside in buildings; within these buildings a part of the IT infrastructure is operated. The example shows a PC, a System (this can be for Example a mail or directory system), a Switch and a Router. Some of these items are needed to offer network access to the universities' members. An application operated at university level is using the archiving system of a service provider. A switch at university site is connected with a router at the service provider's site. Though, the real IT infrastructure is much more complex, we use this illustration as an exemplification of the problem area. The following results of our analyses as well as our concept are, however, applicable to similar structured environments. Both at university as well as at provider side an intra-organizational CMDB is containing its view of the shown IT infrastructure. An ioCMDB contains the logical model of the inter-organizational relevant structure in order to assist ioITSM processes.

We have motivated the necessity to assist ioITSM by using an ioCMDB already in [7]. Such a tool serves for example Incident Management by identifying the relevant service provider and its location in case of an incident report and thus, enables a service technician fixing the incident more quickly by providing the correct coordinates. The illustrated organizations are designing their own internal ITSM autonomously. Thus, different CMDB models are the consequence. In Figure 2 this case is shown with the help of a concrete example of network-relevant components at the Technische Universität München (TUM) and Leibniz Supercomputing Centre (LRZ). In both organizations switches are vital elements in the network. At the TUM, a switch is modelled as an element called `Ressource`, at the LRZ the same part is named `Komponente` within the corresponding CMDB.

In principle, the following levels of heterogeneity might occur in integration scenarios according to [8]: technical, syntactical, structural and semantic heterogeneity. Even if there is only one of this kind in place potential conflicts have to be handled. Syntactical heterogeneity can be identified in our example in the usage of different languages and data models (object-oriented versus relational data models). Figure 3 shows an example of structural heterogeneity.

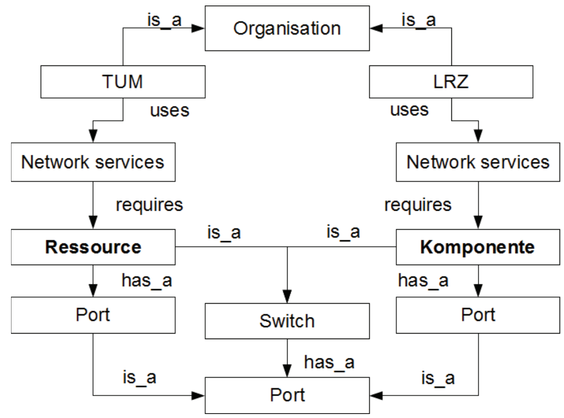

Fig. 2. Differences in modeling configuration items caused by organizations' autonomy

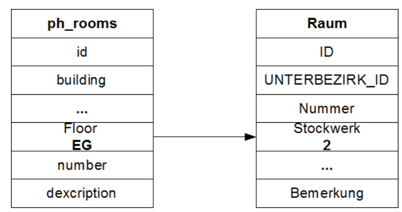

Fig. 3. Example of strucutral heterogenity

Although, in both cases an object-oriented modeling approach has been used, the same attribute is called `Floor` in the one and `Stockwerk` in the other data source. A structural heterogeneity results from using different domains for the same attribute, as for example using `Integer` and `String` values for the attribute prescribing the floor of a building (Stockwerk = 2 and Floor = EG in our case). Homonyms, i.e. words with the same spelling but different meaning, can be seen in our case in the term `System`. This term means PC at the TUM but server at the LRZ.

Ontology is an explicit specification of a common concept in a domain and enables the automated processing of knowledge [9]. By using Ontology for the modeling of CMDB contents, the ioITSM can use such derived knowledge within its processes. Therefore, interference policies are used, as for example the following:

- If is_a(A,X) AND is_a (B,X), then <=> (A,B)
- If needs(A,B) AND is_a(B,C), then needs (A,C)
- If needs(A,B) AND <=> (B,C), then needs (A,C)

Even by using Ontology for modeling purposes, still mismatches in the representation of information models are possible. In [10] such mismatches are divided at a language level in Syntax, Semantic, Representation and Expressivity and at the Ontology level in modeling style, conceptual and terminological mismatch. By having such mismatches in place, problems can occur, as for example in our scenario within ioITSM in the performing of the impact or root cause analyses within Incident management. There, all terms or concepts, as for example in our case `Ressource` or `Kompomente` have to be known beforehand in order to make correct queries. We have demonstrated this on a simple inter-organizational

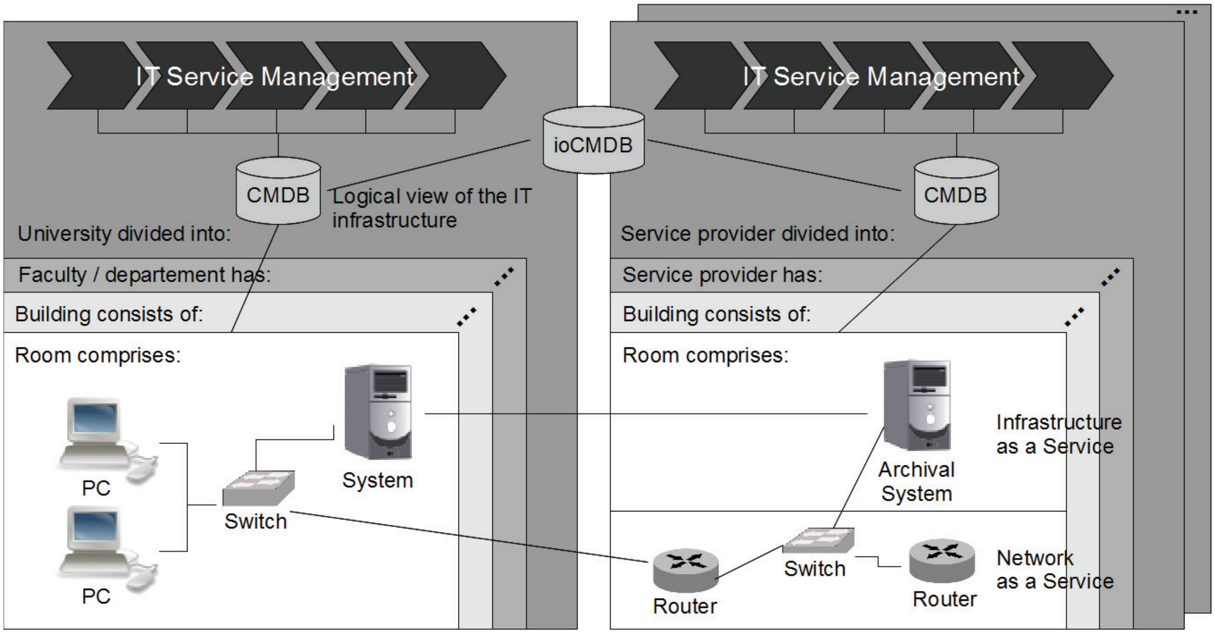

Fig. 1. Infrastructure of the MHC, simplified

scenario with only a few configuration items and two organizations in place. But the likelihood of occurring mismatches rises the more independent organizations are taking part in a certain service offering. Furthermore, the more dynamic an environment is, i.e. because of substituting service providers, the more of the described integration effort into the inter-organizational ITSM has to be done.

C. Requirements for an ioCMDB

The above described scenario will be used to derive requirements for tackling the interoperability issues for ioITSM in this section. The main categories of requirements are shown in Figure 4; those are requirements concerning the information modeling, the integration and interoperability and the usage of the ioCMDB within ioITSM activities, like the inter-organizational fault management (see [11]).

A) Autonomous organizations might use different modeling approaches for their CMDB contents, therefore the following requirements apply:

1) A top-down modeling approach should enable a common view of the ioCMDB's contents. Bottom-up approaches are less appropriated since in dynamic environments comprising several organizations a permanent need for reconditioning would arise because of continuously occurring changes.
2) The case of Synonyms and Homonyms should be solved automated at best, for example by using a reference Ontology.
3) Information relevant for ioITSM should be contained in the ioCMDB in order to offer a comprehensive service view.
4) In case of dynamic organizational setup, i.e. new service providers, further CMDB of the new organization should be easily integrated into the ioCMDB.

B) In order to assist ioITSM processes the following criteria concerning the ioCMDB's usage are relevant:

1) Knowledge of the ioCMDB's content should be gained automatically by using logical rules within a reasoner.
2) The ioCMDB Ontology should directly assist ioITSM processes.

C) Requirements concerning integration and interoperation are vital aspects of interfaces between ioCMDB and the CMDBs.

1) The data of sources (CMDB) should be integrated automated into the inter-organizational Ontology (ioCMDB).
2) Relevant extensions of the Ontology, i.e. caused by adding data of further new CMDBs, should be added efficiently.

The listing of these requirements serves as a foundation for assessing related work in the following section.

III. Related work

As part of the selected design science method, we analyze within this section whether related work from the knowledge base can be used to meet the above described requirements and to which extent.

Common ITSM frameworks and standards do provide a comprehensive input for ITSM within an organization. But for applications in inter-organizational use cases we have already explained previously (e.g. [12]) that concepts like ITIL do not deliver appropriate solutions. In ITIL Version 3 the Configuration Management System (CMS) is built up upon an integrated CMDB which forms an information integration layer. This layer somehow integrates the information of various CMDBs [2]. But no direct guidance is given on the "how to" within ITIL [13]. The concept of CMDB federation (CMDBf)

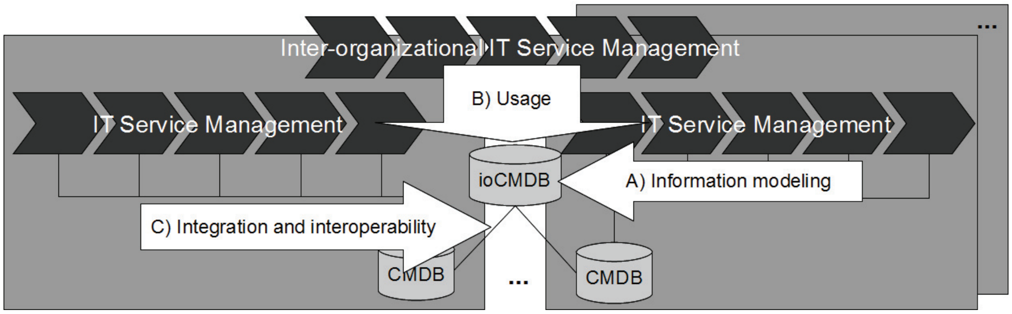

Fig. 4. Requirement categories

as introduced in [14] addresses the integration of tools of different vendors, the so called Management Data Repositories (MDR), into a single CMDB. For this CMDBf specifies web services; but the focus is merely on data communication aspects between the various MDRs and the CMDB installed within a single organization. In an inter-organizational scenario, the CMDBf interface has to be implemented in every organization. But even then, the CMDBf only covers data exchange aspects without specifying data types and their corresponding information models (c.f. [15], [16]). Therefore, the CMDBf concept can only be used without further enhancement, if the same CMDB tools or respectively information models are used in the different organizations. This has been implemented for example in [17], [18] but, such a scenario is contradictory to our presumption of dealing with autonomous organizations having their individual information models in place as stated above.

The differences in information modeling of CMDB contents as introduced in section II-B are not a new phenomenon in general. The reason for this lies as already stated above in the autonomy of the organizations resulting in diverse kinds of heterogeneity which have been categorized in [8] into technical, syntactical, structural and semantic heterogeneity. In the domain of distributed databases or information systems solutions for dissolving these heterogeneities are already in place: see for example [19] or the usage of mediators like introduced in [20]. These solutions are not directly applicable to the problem domain described within this article since we do not assume that native database access will be granted to the IT management tools (CMDB, ioCMDB) for the different service providers for ioITSM reasons. Furthermore, the internal consistency of the CMDB could be violated, because its contents should only be altered via defined tool interfaces, as for example the ones implemented for change management processes. The above-described use cases show that besides syntactical or structural mismatch also semantic mismatch has to be managed. For the later ontology-based methods are suitable solution candidates. Therefore, Ontology languages, especially those supporting predicate logic, can be used. According to [21] these are better scalable, flexible by enabling intelligent reasoning (interference) and they are more dynamic. Previous works in [22], [23] demonstrate the implementation of a CMDB Ontology. However, both studies concentrate on intra-organizational use cases. Because of this, in [22] a bottom-up approach was used which is not suitable for our use case according to requirement A.1 where we explicitly demand a top-down approach. A vital finding of both of these works is that more expressive languages as the used OWL Frames and RDFS should be used. This will allow the derivation of knowledge according to requirement B.1. The OWL (Web Ontology Language) is a family of Ontology languages developed by the W3C consortium. OWL examples are for example OWL Frames and OWL Full [24]. OWL is compatible to the RDFS (Resource Description Framework Schema) [25]. In [23] OWL was used for the implementation because it causes less processing overhead compared to RDFS. Using OWL DL (Description Logic, DL) instead of OWL Full has the advantage that it still allows a maximum of expressiveness and at the same time enables full processability which is not the case when OWL Full is used [24].

There are already existing approaches that handle interoperability issues in inter-organizational use cases. These approaches can be assigned to the scope of work of this article. In [26] a one-to-one mapping of ontologies and a Top-Level-Ontology is described, in [27] a hybrid approach is described additionally. A Top-Level-Ontology approach uses a global Ontology. All information sources are integrated via mappings. When applying a one-to-one mapping any information source is described in its own Ontology and afterwards bilateral mappings occur. In the hybrid approach any information source is mapped to its own local Ontology but the semantic of a domain is described with a reference Ontology. In the hybrid approach a mapping between the local Ontologies and the global reference Ontology is necessary. According to our requirement in using a top-down approach the top-level-ontology or the hybrid approach are possible solutions. However, as described in [28] the hybrid approach has the advantage to develop its local Ontology independently from other sources. The hybrid approach eases the integration effort and the adding and removal of information sources can be easily addressed. This is also relevant within our scenario because of independence of organizations as well as dynamics, i.e. changes of the organizations' setup. The first step of mapping local information sources to its local Ontology as described in [28] can be applied for the problem solution as a building block in our concept.

In general, ontology-based approaches have proven to solve heterogeneity issues. This is why we concentrate on the usage of semantic methods in the following. Our goal is to support the processes of ioITSM by representing and preparing information in an ioCMDB.

IV. SOLUTION AND PROTOTYPED IMPLEMENTATION

In this section we describe the steps necessary for the integration of heterogeneous information sources with the help of Ontologies according to the hybrid approach. These steps are:

1) Creation of the information model as reference Ontology: The reference Ontology specifies the structure of the ioCMDB, but it contains no data from a CMDB yet. The reference Ontology already contains the terminology, i.e. all classes, relationships between the classes and terms defined for the ioCMDB.
2) All information sources (CMDBs) with differences in the data modeling that have to be integrated are represented in a common representation language: As described above OWL-DL is one of the suitable representation languages, because it offers automatic knowledge retrieval. The data which are existent in a specific format are exported into an individual Ontology that preserves its data and its relationships (e.g. database table/attribute structure). In the next step, this specific Ontology is mediated iteratively with the reference Ontology (elaborate descriptions see [29])
3) Iterative mediation of the specific import-ontologies with the ioCMDB representing the reference Ontology: Starting with the reference Ontology all the specific import Ontologies are gradually integrated by using Ontology alignment and Ontology merging. The Ontology alignment retrieves new Ontology mapping rules by similarity comparison, in order to integrate the already previously integrated Ontology (initially this is the reference Ontology) and the next specific import Ontology. This is accomplished both on class/conceptual level and on instance level. Afterwards the next integrated Ontology is created by Ontology merging which comprises the previous integrated Ontology, the actually to be integrated specific import Ontology as well as the already found Ontology mapping rules between them.

The basic steps of our concept have been applied to the above-introduced example of the MHC environment. The following means have been used for the application:

- OWL-DL for representing the occurring individual ontologies,
- The tool Protégé was used to edit and view the occurring ontologies and to create the reference Ontology [30],
- A specific Ontology importer tool has been implemented for importing the individual database exports (CMDB contents) represented in different database schemas,
- Ontology alignment on conceptual level was done with the help of the Alignment-API,
- Ontology alignment on the individual level was based on the Pellet reasoner; Pellet has been chosen because it is efficient in handling big amounts of individuals [31],
- The Protégé-Plugin OntoGraf was used to visualize the reference model.

The reference Ontology was created based on the previously created information model (see [32]). In Figure 5 the class hierarchy with the help of Protégé is shown.

The excerpt of a class in the OWL representation is as the following:

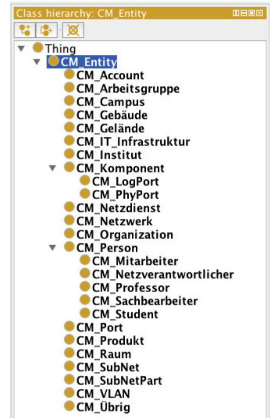

Fig. 5. Excerpt of the reference Ontology

Fig. 7. Impact Analysis

```
<owl:Class␣rdf:about=
"file:///Users/.../iocmdb.owl#CM_Account">
<rdfs:subClassOf␣rdf:resource=
"file:///Users/.../iocmdb.owl#CM_Entity"/>
</owl:Class>
```

The visualization of our example is shown in Figure 6. The differences in the line coloring illustrate the differences in the investigated relationship types, as for example <hasCM_Netzwerk> (purple) or <hasCM_Produkt> (yellow). This reference Ontology contains initially the terminology, i.e. all classes, their relationships and concepts but no data yet, i.e. the so-called individuals. The individuals' data are exported by the implemented importer into corresponding import Ontology. In the next step, these import ontologies are integrated with the reference Ontology by Ontology alignment, first on conceptual, then on the individual level. Finally, the Ontology merging is done.

By applying these steps, the ioITSM should be supported. For actual usage, for example within inter-organizational fault management, the cross connections of the CMDBs are relevant. These are usually difficult to capture, but our approach of using a reference Ontology and integrating the local, specifically ones, allows now the application to ioITSM. The following example shows an impact analysis in our scenario. Figure 7 shows the results of a query about effects of a failure of a dedicated network component `Netzdoku_KOMPONENTE_0`). The query's result shows, that in the case of such a failure, three VLANS are affected.

V. CONCLUSION, EVALUATION AND OUTLOOK

IT services composed of service parts provided by various service providers are facing different challenges to the IT management. To assist the IT Management in such environments we have introduced the concept of

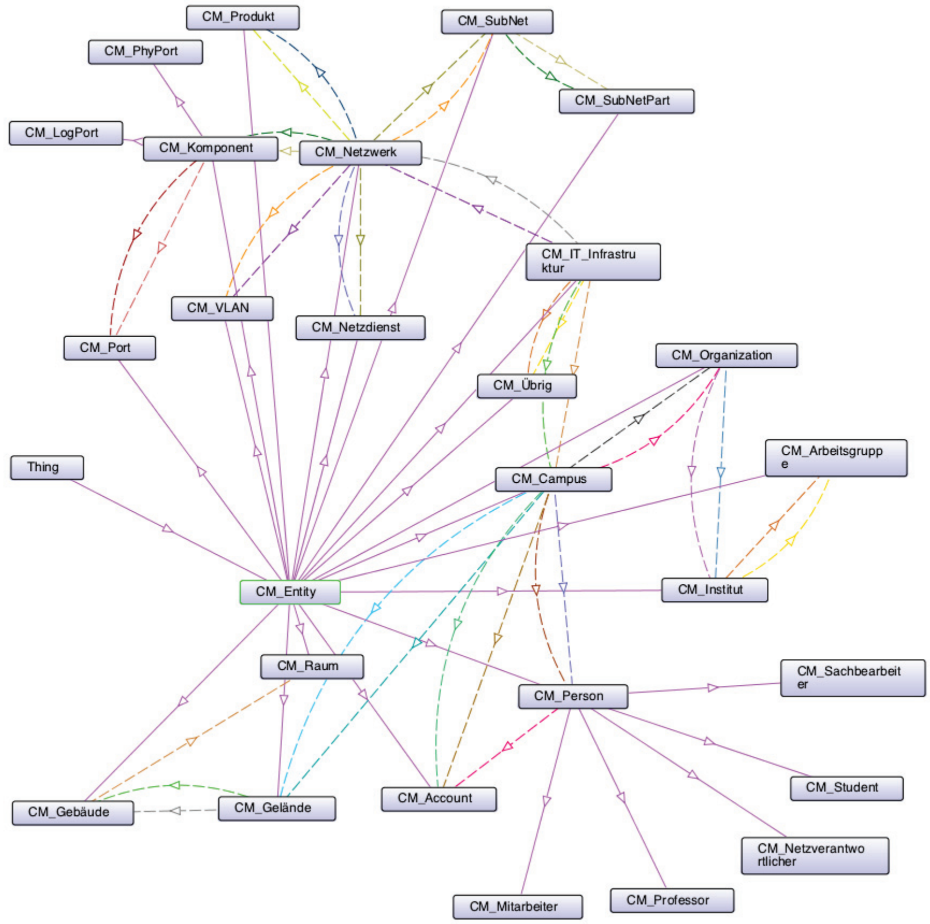

Fig. 6. Visualization of the ioCMDB reference Ontology

the inter-organizational Configuration Management Database (ioCMDB). The ioCMDB integrates information of the CMDBs of the relevant IT service providers and, thus, enables a holistic view. We motivated on the basis of the Munich Hybrid Cloud the problem of semantic heterogeneity when management information from CMDBs needs to be integrated into the ioCMDB. Examples of heterogeneity are differences in the naming of identical configuration items or differences in the meaning of the same term across the organizations.

Our solution focuses on the dissolution of this semantic heterogeneity by using an Ontology-based approach. Therefore, we took into consideration: (1) a top-down method for the information modeling, (2) the possibility of integrating further relevant sources of information dynamically and (3) the automated support of inter-organizational IT Service Management processes illustrated at the Incident management example.

The concept consists of three building blocks: (1) The reference Ontology is forming the information model of the ioCMDB. (2) The contents of the CMDBs of the service providers that have to be integrated into the ioCMDB are transformed into an individual Ontology in each case. By doing this, the implicit knowledge contained in the CMDB can be represented by using an individually developed Importer. (3) These ontologies are then integrated into the structure of the ioCMDB Ontology by using mediation techniques. A mediation tool exclusively developed for this purpose solves then the problem of semantic heterogeneity.

The implementation of our concept was done in the case study introduced above. Although, this case was simplified for reasons of brevity, our concept can be applied to similar structured use cases. The requirements concerning modeling, integration and support of inter-organizational IT Service Management process support have been met by our concept and have been illustrated on the impact analysis example. The holistic view for the IT management could be achieved by modeling of a reference Ontology. Heterogeneity which we found in form of Synonyms and Homonyms could be dissolved mainly automatically. By applying the stepwise approach of our concept iteratively, further management information systems in form of CMDBs of other service providers can be integrated. The implicit knowledge within such service provider collaborations could be represented by using a combination of importer and reasoner which allows the solving of the analytical tasks within inter-organizational IT service management.

In this article we demonstrated how the semantic interoperability of various management information systems can be overcome by using Ontology and, thus, enabling the support of IT management in cloud-like service scenarios by automated knowledge derivation. We believe the automation of knowledge intensive IT service management processes, like the introduced Incident management, is the next consequent step in order to better align IT management to the businesses need of being faster and more efficiently. Based on these findings further work can be undertaken in analyzing the aspects of scalability and dynamics, i.e. when service provider organizations are changing or new ones need to be integrated. For this, our concept provides the iterative application of the stepwise approach, but further investigation is needed on how the earlier derived knowledge can be reused to potentially improve scalability. Further work can address the establishment of a global valid reference Ontology. In our solution many single steps of transformation have been necessary. Therefore, we wonder if a dedicated implementation of logic within the databases would be possible and which further kind of automation means would be possible.

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