2016 30th International Conference on Advanced Information Networking and Applications Workshops

From Business Process Models to Cloud deployment: a Semantic Approach

Beniamino Di Martino*, Antonio Esposito†, Giuseppina Cretella‡
Department of Industrial and Information Engineering,
Via Roma 29, Real Casa dell'Annunziata,
Aversa (CE), Italy
Email: *beniamino.dimartino@unina.it, †antonio.esposito@unina2.it, ‡giuseppina.cretella@unina2.it

***Abstract*—In the recent years great interest has been shown by both private organizations and independent researchers on Business Processes definition and management, which resulted in the development of several tools for their design and execution, and in proposals of standards for their formal representation, such as BPMN. At the same time, Cloud Computing solutions have reached a good level of maturity, with a high number of services and offers currently available to customers who, in turn, would benefit from a tool suggesting the most suitable Cloud services to leverage according to their specific requirements. In this paper a tentative approach for the mapping of Business requirements (expressed through BPMN diagrams) to Cloud services is proposed. In particular, semantic-web technologies such as OWL are proposed to ease the mapping process and to suggest users the best suitable Cloud services to leverage and compose.**

I. Introduction

Thanks to the extremely wide variety of services and resources made available by providers, many new customers are being attracted to the Cloud. Especially small and medium enterprises are looking at the benefits offered by a full or hybrid Cloud deployment to reduce their expenses (operational and management costs in particular) and to better manage the equipment they already own. Whilst security and privacy issues, especially when it comes to data management, are still among the main concerns expressed by customers, the possibility to negotiate on Service Level Agreements (SLAs) which guarantee minimum levels of service has eased the issue. Interoperability and portability of services and applications are also another concern, on which many research [13], [9], [12] and standardization efforts [2], [3] are being carried out, with very positive results in defining new architectures for federated Clouds and in reducing vendor lock-in issues. Being the Cloud such an attractive technology, it is a natural consequence that field experts seek to exploits its potential to improve their business and fasten the deployment and execution of their Business Processes. With the contemporary up-rise of Business Processes related standards and tools, the necessity to provide a set of methodologies and techniques to support their integration to Cloud technologies has become urgent. The idea of merging these two fields is relatively new, and the issues to be addressed are surely challenging: it can be extremely difficult for a Business Process designer to determine the Cloud services best matching each of the Business tasks she has modelled, or even to understand if a Cloud deployment of such tasks is feasible. That is why a methodology or an approach to suggest developers which are the best suited Cloud services to deploy her processes would represent an important advancement to the current state of the art, and would provide the perfect baseline for the development of automated tools for the automatic deployment of such processes on the Cloud. In this work, we present a semantic based approach for the matching between Business Process models and Cloud Services, aiming to create the baseline for the future development of tools which would suggest (and then fully automatize) the best matching among them.

The remainder of this paper is organized as follows: section II reports the State of the Art in the field of Business Process modelling and Cloud Services representation, with a focus on semantic approaches; section III describes the proposed approach; section IV provides a simple case study showing the potentialities of the proposed approach; finally section V reports some considerations and provides directions for future works.

II. Related work

A. Standards and tools for Business Processes modelling

As we have already stated, Business Processes definition and management has become quite a hot topic in the past years. Among the most used formalisms to declare a Business Process, we can cite the **Business Process Execution Language** (BPEL) [5] and the **Business Process Model Notation** (BPMN) [25], which aim at formalizing business processes in order to make their definition uniform and easily shareable among domain experts, but also at creating a shared notation for everyone to use. In particular, BPEL proposes formats and templates, based on XML, to define Business Process and manage their orchestration efficiently. However, since it has no graphical representation so far, it is being less and less used, in favour of BPMN. Indeed, BPMN provides a rich set of graphical elements to represent each possible component of a Business Process, giving the opportunity to designers to easily compose their models without the need to work with a complex XML notation directly. At the same time, more advanced users can deal with the XML notation directly to provide personal customizations and more complex behaviours. Also, many tools have been developed in order to

978-1-5090-2461-2/16 $31.00 © 2016 IEEE
DOI 10.1109/WAINA.2016.123

support the definition, management and even simulation of BPMN diagrams: mmong these tools, remarkable examples are represented by **Camunda**, **Activiti**, **Bonita** or **jBPMN**.
In the following we will focus on the BPMN standard to provide a representation of the Business Processes we want to work on, so the example provided in the use case section IV will be expressed using such a graphical notation. Being extremely straightforward, we do not find useful to indulge in the notation description, which is nevertheless available in [25] for consultancy.

B. Semantic enrichment of BPMN

Several research efforts have been carried out to provide semantic support to business process modelling. The work presented in [28] provides a detailed insight on the practical consequences of applying semantics to Business Process Modelling, describing how the **Semantic Business Process Management** can positively affect the entire life-cycle of a process model, from the requirement analysis to the process maintenance.
The work presented in [11] proposes to enrich the BPMN structure with appropriate tags for the connection to existing ontologies. Also, the authors have proposed a modelling tool that, by analysing the names of the tasks and roles present in the BPMN, automatically suggests the most suited concept to associate to them. This approach is very interesting, since the structural information contained within the BPMN are not disrupted and lost and semantics are easily added to the process. The Semantic Business Process Management is also at the core of the work presented in [20], where the authors explain how the use of semantic Web-services can enhance process models and help to automatize the shift from the model itself and an executable version of the process. This approach represents the base of several other works, such as [21] and [17], mostly developed within the European funded project **SUPER - Semantics Utilized for Process management within and between EnteRprises** [4]. SUPER has provided a very complex framework for the modelling, management and semantic enrichment of business processes, focusing on the BPMN graphical notation and on the **Web Service Modeling Ontology** (WSMO) [26] to provide the semantics. The work presented in [15] provides a preliminary research effort for the definition of a framework intended to semantically annotate BPMN documents, using both a structural ontology and a set of domain ontologies: among the objectives declared, Cloud deployment is taken in consideration, even if it is not the main focus of the proposed approach.

C. Semantic description of Cloud services

Semantic approaches to service descriptions have been successfully applied, in order to overcome the limits related to automated processing and reasoning. In particular, **Cloud Ontologies** have been developed to annotate and describe Cloud services and ease their discovery and composition. Darko et al. in [6] provided an extensive overview of Cloud Computing ontologies, their types, applications and focuses. The authors identified four main categories of Cloud Computing ontologies:

1) The **Cloud resources and services description** category collects ontologies used to describe Cloud resources and services, classify the current services and pricing models or define new types of Cloud services.
2) The **Cloud security** category collects ontologies which deal with security issues directly, by identifying and classifying security threats and solutions.
3) The **Cloud interoperability** category considers ontologies which support programmers and developers in achieving interoperability among different Cloud providers and their services.
4) The **Cloud services discovery and selection** consists of ontologies used to discover and select the best Cloud service alternative, according to a set of requirements expressed by users.

Among the ontologies which belongs to the first category we can find the ones described in [29], in which the authors describe the Cloud as a composition of five main layers: applications, software environments, software infrastructure, software kernel and hardware. Also in [8], ontologies are used to model billing models and actors. Deng et al. in [10] presents a formal catalog representation of Cloud services in which they model with ontologies a range of Cloud services and their processes. The Cloud security category also contains interesting ontology definitions. In [27] the authors use ontologies to describe cyber security operational information, such as data provenance and resource dependency. Another remarkable work belonging to the same field has been presented in [23], in which the authors propose an ontological model for reaction rules to malware detection, which can be used in a prevention system. A considerable number of works falls in the interoperability and portability category. A remarkable example is represented by the mOSAIC Cloud ontology [24] developed within the mOSAIC FP7-funded project [16]. As of today, the mOSAIC cloud ontology has been adopted by the IEEE P2302 Working Group (Intercloud) [1] for the development of the Intercloud Interoperability and Federation (SIIF). The research carried out by such working group is illustrated in several papers, among which [7] illustrates how ontologies can be used to allow collaboration among Cloud vendors, by exploiting a common and shared ontology of Cloud Computing resources, thus dealing with providers heterogeneity. The work proposed in [19] describes an ontology-based methodology to support the selection of interoperable Cloud services according to users' requirements, which can be refined and categorized against a common semantic structure. Since discovery of Cloud services is also among the objectives of such a methodology, it partially overlaps with the Cloud Services Discovery and Selection category, which also contains many ontology examples. A complex methodology, based on a Cloud ontologies, a matchmaking system and intelligent agents, to discover and determine similarities among Cloud services, has been proposed by Han and Sim in [18]. In this system the users can identify the Cloud services required by means of three kinds of requirements: functional requirement (like programming language for PaaS), technical requirement (like CPU clock or RAM for IaaS) and cost requirement (like max price) as input parameters.

III. The general approach

In this section we describe the approach we intend to follow to support the entire life-cycle of a Business Process Model, from its design to its execution, focusing on the suggestion of eventual Cloud services which can be used to implement the tasks.

A. Semantic representation of BPMN

In order to enable the automatic analysis of Business Processes and their mapping to Cloud Services, the first step we intend to follow is to provide a semantic representation of the BPMN, comprehending both its structure and the orchestration of its tasks. In order to achieve this, two separate representations has to be taken in consideration:

- A **Structural Ontology** for the definition of the static characteristics of the BPMN file;
- A **Dynamic Ontology** for the representation of the BPMN orchestration.

We have decided to separate the representation of static structural elements from orchestration dynamic concepts in order to ease the mapping process between the BPMN tasks and their Cloud Service counterparts: indeed in this way, we can focus on one aspect at a time and reduce the complexity of the query to be issued against the knowledge base to infer the equivalences. In [15] the reasons behind such a decision are discussed more deeply. The *Structural Ontology* must contain information relative not only to the definition of the different tasks and connectors (gates) existing in the BPMN standard, but need to provide classes for the representation of the tasks' (allowed) executers, the expected input and output of each activity, eventual restrictions and connections to error handlers. This can be easily achieved using a OWL ontology, since one only needs to create the basic concepts and then define their relations via object and data properties. Figure 1 reports a graphical representation of a OWL ontology which represents the base for the representation of BPMN structural aspects. The entities shown in figure describe the basic elements needed to represent a BPMN:

- **Business Process** represents the main concept of the ontology, which is used to collect tasks and executers of the BPMN;
- **Objective** is used to define the objective of the process and of the single tasks;
- **Scope** can represent the overall scope of the entire process or of the tasks composing it;
- **Task** is a fundamental entity which can represent the several tasks a process is composed of. It is a general concept, which is specialized in: **Human Task** for activities which can be executed by humans with the aid of automatic services; **Script Task** describes tasks which are automatically executed via scripts, managed by a local BPMN engine, and which do not require human intervention; **Manual Task** provides a holder for tasks which can be executed by humans only; **Service Task** describes activities which are delegated to remote services via **connectors**.
- **Executer** collects all the executers of BPMN tasks; as the *Task* class, it is further specialized into: **Human** which represents human executers; **Script** defining scripts manageable by the BPMN engine itself; **ExternalService** pointing to remote services not directly managed by the BPMN engine.
- **Parameter** simply represents the **Input** and **Output** parameters of each task.

Table I reports the main properties used to connect the concepts defined in the ontology, with a brief description of them.

As regards the orchestration part, the representation of the tasks' relations and connections can be dealt with the concept portrayed by the OWL-S ontology [22]. Such an ontology contains the entities needed to represents several control structures which can be used to organize processes and their inherent tasks: a **Sequence** can be used to represent consecutive tasks; **Iteration** can describe loops and cycles in the BPMN diagram; **If-Then-Else** can represent a choice point (a gate in the BMPN). These are only some of the available control structures, which can be combined together to provide complex behaviours. OWL-S enable the representation of **Composite Processes** which can be identified with a whole Business Process or a complex task, decomposable in sub-processes in turn, whilst simple tasks can be represented via **Simple Processes**. Among the other useful characteristics provided by OWL-S, there is the possibility to specify input and output parameters of each task, and to connect the individuals in the ontology with external definitions, thus providing the means for a context-aware annotation of the BPMN.

B. Semantic representation of Cloud Services

The semantic representation of Cloud services is needed to map the tasks defined in the BPMN to the right Cloud solution automatically. The provision of an ontology for Cloud services description, discovery and composition has been already considered in [14], where a multi-layered semantic-based description of Application and Cloud patterns, with their composing services, has been provided. The reference architecture of such a solution is reported in figure 2: as for the proposed BPMN ontology, it provides a structural representation of the Cloud services with their characteristics (vendor, input and output parameters, methods and operations) and their orchestration via OWL-S.

C. Suggesting the mapping between tasks and Cloud Services

Both the considered semantic representations share a set of common concepts which can be used to execute the mappings among tasks presented in the BPMN diagrams and Cloud services. Concepts like **Objective** and **Scope**, present in both

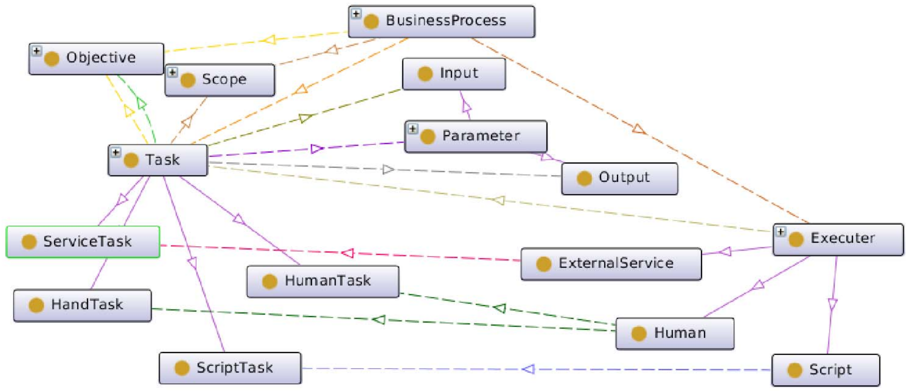

Fig. 1. Basic elements of the structural BPMN ontology

TABLE I
OBJECT PROPERTIES USED IN THE ONTOLOGY SHOWN IN FIGURE 1

Property Name	Domain	Range	Description
hasObjective	Business Process, Task	Objective	Defines the objective of a Process or a task
hasScope	Business Process, Task	Scope	Defines the scope of a Process or a task
hasTasks	Business Process	Task	Lists the task belonging to a process
hasExecuters	Business Process	Executer	Lists the executers belonging to a process
hasParameter	Task	Parameter	Lists the parameters of a task
canExecute	Executer	Task	States if an Executer can execute a Task

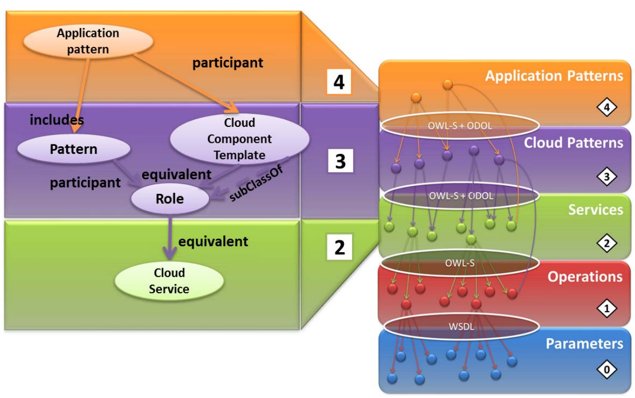

Fig. 2. Multi-layer semantic description of Cloud Patterns and Services

representations, can be used to suggest to the Business Process modeller a set of possible Cloud services to use for the implementation of the tasks she has defined. Semantic match-making techniques are required to ensure that equivalences among different terms, having similar meaning, are inferred. Using an external reference domain ontology may reduce the inconsistencies, since only a set of common terms would be available. While the use of objectives and scopes can be useful to select a first set of possible corresponding services, it is necessary to narrow the possibilities: in order to do so, a subset of services can be selected according to the input and output parameters they accept and/or the operations exposed. Such information is useful to exclude from the selection those services which do not accept the required parameters, or whose exposed operations cannot be matched to the specific task to match. Another important restriction to be considered is that *Manual Tasks* cannot be handled automatically by a Cloud service, but they need to be executed by a human being. In this cases, it is necessary to either leave the task as it is, or to suggest a different implementation of the same process, not involving manual tasks. However, this would require the definition of some Process Patterns, which can be reused and applied in different contexts and situations.

IV. A CASE STUDY

In this section we provide a simplified case study to verify the applicability of the proposed approach. Figure 3 reports the BPMN diagram of a book loan process. An automatic system receives a book loan request (via a not specified message), and after checking for its availability it replies to the human requester (the originator of the message), who can checkout the book. However, if the book is not available, the system waits for a message event to occur: a message with a request to cancel the loan, to hold it or to wait for availability (for almost one week) can arrive. The process ends if the book is checked out, if the loan request is cancelled or expires (after two weeks). In order to to deploy such an application on a Cloud environment, there are a few things to consider:

1) Almost all the considered tasks and events involve the send and receive of messages, which have to handled differently according to their particular content.

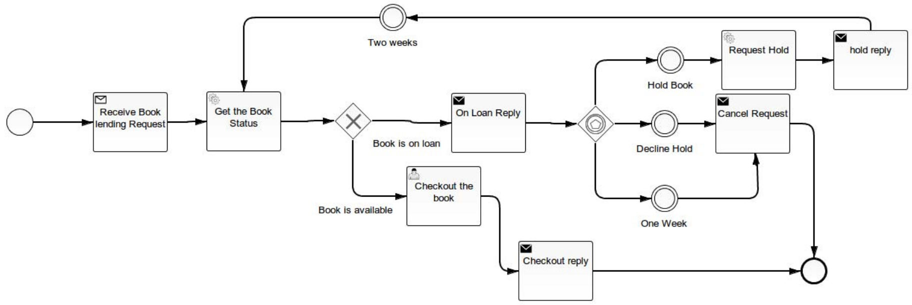

Fig. 3. A simple Book loan process in BPMN

2) Only one of the used tasks is a *Human Task* (Checkout the book) and thus require a human intervention.
3) When accessing the book information, it seems legit to speculate that a database is being used, even if it is not clearly declared in the process.

Table II reports a possible set of correspondences between the tasks described in the BPMN and target Cloud services. In particular, we have focused on services exposed by Amazon and Microsoft Azure. As it is shown in the table, the tasks involving the exchange of messages and the handling of events based on the content of such messages have been annotated with the labels *Send/Receive message* and *Message event*. Such labels enable the recognition of two specific Cloud services, that is the **Simple Queue Service** from Amazon and **Service Bus** from Microsoft Azure: both of them can handle the sending and receiving of messages in different formats and can handle the execution of events. The tasks involving the check for book availability are instead connected to database services, namely the Amazon Simple DB and Azure SQL Database services. What is not inferred from the simple semantic labelling of the existing tasks is the necessity to instantiate some virtual machine instances in order to support the logic and computation needed to handle events and computations. However, these are implicitly declared as requirements for the queue and database services exploited for the cloudification: such information is contained in the semantic representation of the Cloud services provided in [14].

Figure 4 reports a possible implementation of the book lending process in Cloud, using Amazon services. In particular, the workflow related to a successful lending of a book is reported: a user sends a message to the Simple Queue Service requesting a book; the Amazon service acts upon the arrival of such a message by requesting the availability of the book, passing through the Amazon EC2 service to query the SimpleDB database; when the availability check is successful, a message is sent to the user who can then checkout the book. As we have anticipated, the EC2 service which is not directly addressed in the table II is used in the proposed solution, since it is needed to deal with the logic behind the entire system (and eventually to implement a web interface for the users to interact with).

TABLE II
TASKS AND CLOUD SERVICES CORRESPONDENCES

Task Name	Objective/Scope	Corresponding Service
Receive Book Lending Request	Send/Receive Message Message Event	Amazon SQS Azure Service Bus
Get the Book Status	Availability Check Database Access	Amazon SimpleDB Azure SQL Database
Checkout the book	Retrieve item	
Checkout reply	Send/Receive Message Message Event	Amazon SQS Azure Service Bus
On Loan Reply	Send/Receive Message Message Event	Amazon SQS Azure Service Bus
Request Hold	Database Access Message Event	Amazon SimpleDB Azure SQL Database Amazon SQS Azure Service Bus
Cancel Request	Send/Receive Message Message Event	Amazon SQS Azure Service Bus
Hold Reply	Send/Receive Message Message Event	Amazon SQS Azure Service Bus

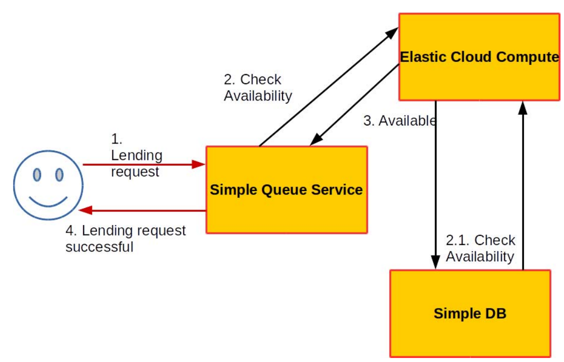

Fig. 4. Possible implementation of the Lending process in Cloud

V. CONCLUSIONS AND FUTURE WORK

In this paper a preliminary approach to the implementation of Business Processes, expressed via BPMN, and their deployment on the Cloud has been presented. In particular, the proposed approach leverages semantic-based technologies for both the description of the BPMN elements and of Cloud Services, and exploits a yet-to-define mapping to match the corresponding processes tasks and services. A very simple use case scenario has been also presented to clarify how we intend to proceed in the development of our approach. In the near future we intend to further develop the approach, by defining the structural and dynamic ontologies needed to correctly represent and annotate the BPMN. Also, a prototype implementation of a tool for the annotation of existing BPMN and the automatic suggestion of the best suited Cloud service for their deployment is needed and is currently in course.

ACKNOWLEDGMENT

This research has been supported by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n 256910 (mOSAIC Project), by PRIST 2009, "Fruizione assistita e context aware di siti archeologici complessi mediante dispositivi mobili"and CoSSMic (Collaborating Smart Solar-powered Micro-grids - FP7-SMARTCITIES-2013).

REFERENCES

[1] Ieee p2302 working group (intercloud). http://grouper.ieee.org/groups/2302/.

[2] Oasis topology and orchestration specification for cloud applications (tosca) tc. https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=tosca.

[3] Occi core specification. http://ogf.org/documents/GFD.183.pdf.

[4] SUPER - Semantics Utilized for Process management within and between EnteRprises [online],. http://projects.kmi.open.ac.uk/super/.

[5] Tony Andrews, Francisco Curbera, Hitesh Dholakia, Yaron Goland, Johannes Klein, Frank Leymann, Kevin Liu, Dieter Roller, Doug Smith, Satish Thatte, et al. Business process execution language for web services, 2003.

[6] Darko Androcec, Neven Vrcek, and Jurica Seva. Cloud computing ontologies: A systematic review. In *MOPAS 2012, The Third International Conference on Models and Ontology-based Design of Protocols, Architectures and Services*, pages 9–14, 2012.

[7] David Bernstein and Deepak Vij. Intercloud directory and exchange protocol detail using xmpp and rdf. In *Services (SERVICES-1), 2010 6th World Congress on*, pages 431–438. IEEE, 2010.

[8] Markus Bhm, Stefanie Leimeister, Christoph Riedl, and Helmut Krcmar. Cloud computing–outsourcing 2.0 or a new business model for it provisioning? In *Application management*, pages 31–56. Springer, 2011.

[9] Yuri Demchenko, Canh Ngo, Cees de Laat, Marc X Makkes, and Rudolf Strijkers. Intercloud architecture framework for heterogeneous multi-provider cloud based infrastructure services provisioning. 4(2), 2013.

[10] Yu Deng, M.R. Head, A. Kochut, J. Munson, A. Sailer, and H. Shaikh. Introducing semantics to cloud services catalogs. In *Services Computing (SCC), 2011 IEEE International Conference on*, pages 24–31, July 2011.

[11] Chiara Di Francescomarino and Paolo Tonella. Supporting ontology-based semantic annotation of business processes with automated suggestions. 1(2):59–84, 2010.

[12] B. Di Martino, G. Cretella, A. Esposito, A. Willner, A. Alloush, D. Bernstein, D. Vij, and J. Weinman. Towards an ontology-based intercloud resource catalogue – the ieee p2302 intercloud approach for a semantic resource exchange. In *Cloud Engineering (IC2E), 2015 IEEE International Conference on*, pages 458–464, March 2015.

[13] B. Di Martino, A. Esposito, and G. Cretella. Semantic representation of cloud patterns and services with automated reasoning to support cloud application portability. PP(99):1–1, 2015.

[14] B. Di Martino, A. Esposito, and G. Cretella. Semantic representation of cloud patterns and services with automated reasoning to support cloud application portability. PP(99):1–1, 2015.

[15] Beniamino Di Martino, Antonio Esposito, Stefania Nacchia, and Augusto Salvatore Maisto. Semantic annotation of bpmn: current approaches and new methodologies. In *Proceedings of the 17th International Conference on Information Integration and Web-based Applications & Services*. Springer, 2015.

[16] Beniamino Di Martino, Dana Petcu, Roberto Cossu, Pedro Goncalves, Tams Mhr, and Miguel Loichate. Building a mosaic of clouds. In *Euro-Par 2010 Parallel Processing Workshops*, pages 571–578. Springer, 2011.

[17] Marin Dimitrov, Alex Simov, Sebastian Stein, and Mihail Konstantinov. A bpmo based semantic business process modelling environment. 251, 2007.

[18] Taekgyeong Han and Kwang Mong Sim. An ontology-enhanced cloud service discovery system. In *Proceedings of the International MultiConference of Engineers and Computer Scientists*, volume 1, pages 17–19, 2010.

[19] Ke-Qing He, Jian Wang, and Peng Liang. Semantic interoperability aggregation in service requirements refinement. 25(6):1103–1117, 2010.

[20] Martin Hepp, Frank Leymann, John Domingue, Alexander Wahler, and Dieter Fensel. Semantic business process management: A vision towards using semantic web services for business process management. In *e-Business Engineering, 2005. ICEBE 2005. IEEE International Conference on*, pages 535–540. IEEE, 2005.

[21] Martin Hepp and Dumitru Roman. An ontology framework for semantic business process management. page 27, 2007.

[22] Burstein Mark, Hobbs Jerry, Lassila Ora, Mcdermott Drew, Mcilraith Sheila, Narayanan Srini, Paolucci Massimo, Parsia Bijan, Payne Terry, Sirin Evren, Srinivasan Naveen, and Sycara Katia. OWL-s: Semantic markup for web services. http://www.w3.org/Submission/2004/SUBM-OWL-S-20041122/.

[23] Cristian Adrin Martnez, Gustavo Isaza Echeverri, and Andrs G Castillo Sanz. Malware detection based on cloud computing integrating intrusion ontology representation. In *Communications (LATINCOM), 2010 IEEE Latin-American Conference on*, pages 1–6. IEEE, 2010.

[24] Francesco Moscato, Rocco Aversa, Beniamino Di Martino, T Fortis, and Victor Munteanu. An analysis of mosaic ontology for cloud resources annotation. In *Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on*, pages 973–980. IEEE, 2011.

[25] Object Management Group (OMG). Business process model and notation (bpmn) version 2.0, jan 2011.

[26] Dumitru Roman, Uwe Keller, Holger Lausen, Jos de Bruijn, Rubn Lara, Michael Stollberg, Axel Polleres, Cristina Feier, Christoph Bussler, Dieter Fensel, et al. Web service modeling ontology. 1(1):77–106, 2005.

[27] Takeshi Takahashi, Youki Kadobayashi, and Hiroyuki Fujiwara. Ontological approach toward cybersecurity in cloud computing. In *Proceedings of the 3rd international conference on Security of information and networks*, pages 100–109. ACM, 2010.

[28] Branimir Wetzstein, Zhilei Ma, Agata Filipowska, Monika Kaczmarek, Sami Bhiri, Silvestre Losada, Jose-Manuel Lopez-Cob, and Laurent Cicurel. Semantic business process management: A lifecycle based requirements analysis. In *SBPM*, 2007.

[29] Lamia Youseff, Maria Butrico, and Dilma Da Silva. Toward a unified ontology of cloud computing. In *Grid Computing Environments Workshop, 2008. GCE'08*, pages 1–10. IEEE, 2008.