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VALATAVIČIUS

ENTERPRISE APPLICATION INTEROPERABILITY EVALUATION USING AUTONOMIC COMPUTING

SUMMARY OF DOCTORAL DISERTATION

Natural Sciences,
Informatics N 009P

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SUMMARY

1. INTRODUCTION

1.1. Research area

Application interoperability evaluation is required for gaining knowledge on whether different software applications could be able to exchange data between one another. Application services describe the data structure of these applications. Analysis of such application service descriptions allow to infer whether different applications have some common ground, from data perspective. Syntactical and semantical application web service description documents were analyzed in this research. Similarity information between operations, objects, field names and field types was retrieved from web services and analyzed using edit distance, bag of words and latent semantic analysis methods. The autonomic computing in theoretical part of the research plays a role to paint broader picture of possibilities of the implemented research. Experiment results only cover three components of autonomic component: monitoring, analysis, and knowledge. The autonomic computing component was introduced for analysis of possibility of automating interoperability process within dynamic business environment.

1.2. Relevance of the problem

Application interoperability becomes essential part for dynamic business, growing IOT usage and ever growing complexity and variety of enterprise applications. Enterprise applications are now used in almost all medium to large sized companies, and interoperability projects are becoming relevant because of the need to optimize business process, reduce redundand work, increase efficiency of data maintenance along different applications within an enterprise. The challenge is that the knowledge requirements for integrating different systems is great and there is high risk for failure of integration and interoperability projects. To measure the potential of applications to be interoperable it is first needed to evaluate their capability of interoperability.

In informatics field, the interoperability subject is quite old and stem from requirement that devices, satellites or other military or civil equipment would be able to exchange data. For example, for the NASA (Di & Kobler, 2000) it was important to have the satellites that are able to communicate with the ground stations and exchange important telemetry data. Application integration and interoperability projects have tendency to fail at marked almost 70% (Trotta, 2003; van der Bosch, et al., 2010), mainly due to lack of knowledge of application, growing complexity and dynamic nature of business. The interoperability process is analyzed and architectured on different levels: syntactic, semantic, cross domain (Chen, et al., 2008). Each level concerns different issues with interoperability solution. According to research by (Rezaei, et al., 2014) there are different granularity issues for interoperability, researchers review complexity of the subject and techniques until 2014.

1.3. The aim and Tasks of the Research

The goal of this research is to create a method for enterprise application interoperability evaluation, based on causal relationships extracted by comparing architectures.

The object of this research is an enterprise which business process is dynamic (changing) and that use applications from more than one provider, that might face interoperability issues such as: data redundancy, duplication of business processes.

To realize the aim of research the main tasks where established:

1. Analyze problems of a enterprise application integration and interoperability solutions, used methods and their principals.
2. Analyze enterprise application interoperability evaluation methods, their advantages and flaws, underline principles of the proposed method.
3. Create enterprise application capability of interoperability evaluation method using business process architecture (CIM – computation independend models) and enterprise application architecture (PIM – platform indipendend models).
4. Create an experiment using proving that enterprise applications interoperability can be avaluated using proposed

text analysis methods for interoperability capability evaluations.

1.4. Scientific Novelty

1. Established theory of possibilities to computationaly evaluate enterprise applications interoperability by using multiple data source domains, such as: business process models, autonomic computing, deep knowledge extraction from application web service architecture descriptions.
2. Proposed the text processing method for enterprise application interoperability capability evaluation; capability evaluation depend on text processing methods such as edit-distance, latent semantic analysis, bag of words.
3. Applied edit-distance methods: Levenshtein, Jaro-Winkler, Jaccard, and Longest Common Subsequence, gathered results showing each application capability to interoperate with another application.
4. Applied latent semantic analysis for beter semantic extraction capabilities from application web service architecture to better evaluate capability of applications to be interoperable.

1.5. Statements to be Defended

1. Enterprise architecture (EA) frameworks and model driven architecture (MDA) can be applied when solving enterprise application interoperability issues, by visualizing and identifying relationships between application components and business process causal relationships.
2. Proposed enterprise applications interoperability capability evaluation solution is sufficient to evaluate similarities between applications in syntactic and semantic level.
3. It is possible to use CIM and PIM models to evaluate applications interoperability by extracting causal dependencies between business processes and their counterparts, that are transformed to match application processes.
5. Enterprise application interoperability evaluation solution based on autonomic computing technologies enables

detection changes in dynamic business processes and show the changes affecting enterprise application interoperability.

1.6. Approbation of the Research

The results of the research were published in two peer-reviewed journals, in seven peer-reviewed conference proceedings and were presented and discussed in four national and international conferences. Intermediary results and discussions were presented in two national workshops.

1.7. Outline of the Dissertation

The dissertation consists of seven chapters and references. The chapters of the dissertation are as follows: Introduction; Review of enterpise application interoperability solutions; Measures of enterprise application interoperability; Application interoperability evaluation experiment description; Results of application interoperability evaluation experiment; Conclusions and recommendations. This work contains 83 pages that include 28 figures and 8 tables, list of references consist of 55 sources.

2. REVIEW OF ENTERPISE APPLICATION INTEROPERABILITY SOLUTIONS

In this chapter enterprise application interoperability and integration solutions are reviewed. Methods that solve interoperability and integration problems are uncovered. List of main interoperability problems is established. These problems and methods are used to make applications integrated or interoperable within a business domain, but they pose a problem of high maintenance and high knowledge requirement that is sometimes too difficult that most integration projects fail (Trotta, 2003), thus new solutions should be discovered.

It is known that integration and interoperability of applications differ by goal business: to create a single holistic system to cover all processes, or to effectively use multiple applications that would efficiently exchange data and would not be limited to a single

application provider. In other words integration encompasses all domain, while interoperability focuses on parts of the same domain that should effectively exchange data and functionality (Chen, et al., 2008).

In a dynamic organization, there could be multiple obstacles that do not allow legacy and new applications to interoperate automatically. Mainly these obstacles are (Fig. 1):

- Business processes change when new applications are introduced – this causes dependent process failures, data errors, time delays and has overall demanding requirements for organization adaptability.
- Applications are dynamic; their schema might be changed over time – this causes failures in schema matching, interoperability and integration solution failures, dependend business process failures and time delays.
- Multiple applications are used in a single domain – this causes data ambiguity and duplication between application, new processes appear to solve these issues, causing higher human resource requirements.
- There are no common methods to describe collaboration among multiple different applications – this causes ambiguity, different application architecture strategies, new integration protocols development or requirement for heightened maintenance.
- Application changes usually impact business process. Therefore, previous business process models become invalid and cannot be used for knowledge extraction – this is caused by one time modeling, and therefore after some time model could not represent the current status of an enterprise.
- To ensure interoperability, the integration expert needs to perform the following tasks:
    - Perform schema alignment (Hophe & Woolf, 2004), (McCann, et al., 2005) (Peukert, et al., 2012), (Rahm & Bernstein, 2001), (Silverston, et al., 1997), (Silverston, 2011);
    - Ensure record linkage and data fusion (Dzemydienė & Naujikienė, 2009), (Kasunic, 2001)
    - Ensure orchestration – the timing of each data migration;

- The choreography of application services and data objects – sequence and order in which applications would share data.

- Lack of skills and knowledge – this causes integration and interoperability project delays and failures.

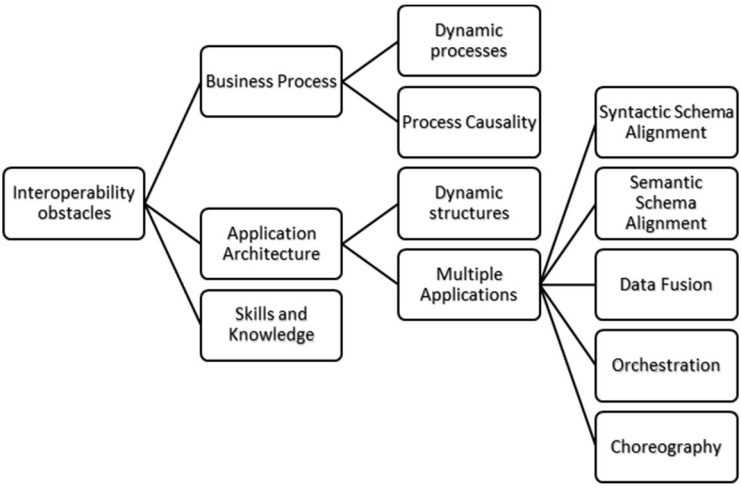

Fig. 1 Tree of interoperability obstacles.

Lack of necessary skills is a barrier to implementing interoperability solutions. Lack of necessary knowledge on used applications is also a barrier to implementing interoperability solutions. The full tree of interoperability obstacles is represented in Tree of interoperability obstacles figure (Fig. 1). Previously interoperability layers were called barriers in earlier documents of EIF (IDABC, 2008). Data from one system cannot be interoperable with similar data in another system without passing these barriers . The five layers of interoperability:

- Governance layer – decisions on interoperability structures, roles, responsibilities policies, and agreements.
- Organizational layer – these barriers relate to the structure of the organization and how an organization is dealing with constant and rapid changes. Usually, a structure of organizations and especially its processes must be discovered and evaluated. Some integration

solution can help improve business processes and therefore, get over the organizational barriers (Valatavičius & Gudas, 2015).

- Legal layer – ensure that the data will not be abused or leaked to the public during the interoperability operations. This layer also might include, for example, new general data protection regulation (GDPR) that allow people to get all related data from business applications.
- Semantic layer - Semantic or conceptual layers cover semantic differences of information, for example, the use of different software systems leads to the semantic differences.
- Technical layer – is a layer in which interface specifications, communication medium, interconnection services, data integration services, and other aspects are analyzed.

Interoperability area describes the object of the interoperability solution. As there could be multiple layers of interoperability, a different aggregation and granularity of data are taken into perspective. Interoperability areas investigated by other researchers are as follows (Chen, et al., 2008): data, services, processes, and business. The interoperability of data covers different issues of the complex data integration from diverse sources with different schemas. The interoperability of services covers different issues of the heterogeneous data enveloped to the shell of web-services of applications that designed and implemented independently. In this level of interoperability, it might be easier to deal with different schemas and solve semantic issues. The interoperability of processes solves the problem of process sharing or optimizing a value chain for a company. Processes are optimized by developing good interoperability of services/data that are used in these processes. Recent research showed that it might be possible to get internal models from the business process and apply it as knowledge in integration solutions (Valatavičius & Gudas, 2015). The interoperability of business cover B2B integration problems and focuses on issues of data sharing between businesses, but all previous interoperability options must be assured to have a successful business.

3. MEASURES OF ENTERPRISE APPLICATION INTEROPERABILITY

Various application interoperability methods are applied to create and maintain the interoperability of enterprise applications. The research varies among layers (e.g., organizational, legal, semantic and technical) and levels (system specific, documented data, aligned static data, aligned dynamic data, harmonized data) of conceptual interoperability model (Tolk & Muguira, 2003). Most researchers of integration subject use advanced methods such as agent technologies (Cintuglu, et al., 2016; Overeinder & Verkaik, 2008) which usually cover self-describing services which cannot be applied in RESTful protocol in applications. Moreover, as RESTful protocol becomes increasingly popular API protocol in business applications, this provides a difficulty to create automated bindings between different systems. Although even with good protocol description usually, lack of semantics could also be a blocking point for successful interoperability. Ontology-based technologies (Li, et al., 2005; Shvaiko & Euzenat, 2011). However, sophisticated methods of the process integration already exist, just not being applied in the application area (El-Halwagi, 2007). In a dynamic environment, business processes often need optimizing, similar the examples of business process integration (El-Halwagi, 2007; Pavlin, et al., 2009).

Some researchers underline the guidelines of measurements and give propositions of what methods should be used, but they are not presented in such a way that could be easily replicated. One of the favorite inspirers for this research Kasunic (Kasunic, 2001) proposed to evaluate systems interoperability using three views: Technical, Operational, and Systems. A similar approach to the business and information systems alignment measurement introduced in (Morkevičius, 2013).

	a) Technical view, Technical interoperability scorecard.	b) Systems view, Systems interoperability scorecard			
Source	Compliance to standards	S1	S2	S3	S4

S1 ExactOnline	Y		Y	Y	G
S2 PrestaShop	Y	Y		G	Y
S3 SuiteCRM	Y	Y	G		Y
S4 NMBRS	G	G	Y	Y	

Table 1. Selected systems interoperability capability measure by LISI method

Technical view table indicates that it needs more effort than anticipated to extract meta-data (Kasunic, 2001). Colors represent the usage of standards in Table 1 above inadequate (R), marginal (Y), or adequate (G). Conclusions: Such evaluation method could be biased by ones understanding on whether the system is standardized, and on thought how easily it could integrate providing interoperability.

The enterprise application (EA) interoperability measurement (between services) is the basis for improving interoperability methods. Some interoperability evaluation methods are known: Scorecard – DoD in (Kasunic, 2001), I – Score in (Ford, et al., 2008), and Comparison by functionality in (Dzemydienė & Naujikienė, 2009).

These EA interoperability evaluation methods are not enough because of the assessments obtained through questionnaires and expert judgment. We strive to develop a method that evaluates the characteristics of the systems being integrated - without using personal opinion or tests/questionnaires/ experiences. We aim to use only characteristics of software: metadata and systems network service architectures. It is reasonable to use structured (internal) models of systems than to fill out questionnaires. We are looking for a deterministic method that can evaluate or measure the capability of interoperability.

The principles of the second order cybernetics provide the methodological basis for the internal viewpoint and aim to disclose internal causal relationships of the domain. In our case, we need to explore the causal relationships between application software, and no access to use the questionnaires as stated by (Kasunic, 2001).

1.1. Interoperability evaluation using MDA, EA approach

Our study is based on a few assumptions. First, internal modeling with the MDA approach help determines the influence of domain causality to the interoperability of applications (Fig. 2). Second, it is possible to create an architecture of interoperable enterprise applications using only the enterprise architecture model and data for each service for enterprise software. Another assumption is as follows: interoperability should be evaluated by comparing web service operation names using edit distance calculations. The measurement of EAS interoperability capability serves as a basis for improving interoperability methods. In case that interoperability is required between these applications, how one should know whether these systems can have interoperability at all? The capability of interoperability of applications can be evaluated using their architectural design by comparing web service operation names using edit distance calculations.

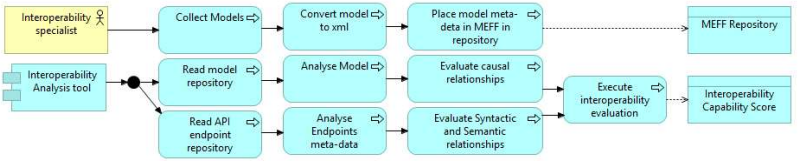

Fig. 2. Analysis of models from MDA cycle to produce interoperability capability score.

Levenshtein calculates edit distance by a minimum number of single character edits required to change one word into the other. Levenshtein algorithm was the first known method developed to compare string distances in 1965 (Левенштейн, 1965). For a given two strings b and a with a total character count of m and n. For each character pair from two strings if they not equal take the minimum amount of changes required to make them similar. Jaro-Winkler algorithm uses a formula out of 4 values that calculate similarity. Longest common subsequence edit distance, as the name suggests calculates edit distance removing characters, and counting how many characters removed to leave longest common subsequence. Jaccard edit distance calculates how many similar attributes are in both compared sets for an n-gram. For a given character sequence of each

string, a character matrix is formed where characters for each set represent the total number of characters have of the same value (matched).

Although string distance algorithms only provide syntactic similarity evaluation capabilities. For semantic evaluation capabilities, we have developed an ontology library describing data structure with semantic meaning. The steps to calculate interoperability capability (potentiality): 1) locate web-service reference documentation; 2) extract and parse meta-data of web service reference files; 3) categorize parsed metadata into operations, methods, objects, field names, and field types; 4) select operations and create meta-data for each operation: a) get source same; b) get service name; c) extract method GET, POST, PUT, DELETE, PATCH, HEAD); d) extract operation to the related method; e) Strip redundant information from operation (repeating meaningless keywords; 5) Save operation meta-data to Microsoft SQL Server database; 6) Using master data services and prepared SQL procedure scan through operations in the database table and compare it with other operations from different source; 7) Save each comparison for different method in a new table; 8) Visualize and explore results.

For the following systems (OpenCart, PrestaShop, LemonStand, NMBRS_ReportService, NMBRS_DebtorService, Zen Cart, NMBRS_CompanyService, NMBRS_Employees, SuiteCRM, KonaKart_StoreFront, KonaKart_Administration, MIVA, ExactOnline) used in the experiment, we describe its web-service interface protocol and complexity to extract data automatically (). According to the documentation SOAP and REST, development should follow design recommendations, but there are already many systems developed without SOA approach. Once a system implements web services, it is required to have an API which is not always created using common recommendations. Therefore, it is harder to automate data extraction. Additional steps are needed to get to the objects of web services - it is not enough to get the initial structure described in web-service for meta-data analysis. During the experiment, additional steps were carried invoking web service – for returning list of objects related to the operations described in SOAP WSDL files. REST web service meta-data description is not standardized, and it is more challenging to extract meta-data. A lack of common pattern following the description of objects exists, therefore need additional procedures

to extract and parse meta-data from API. The web service meta-data for each system data extracted to the database using a custom written C# algorithm and manual data entry from web service reference documentation. Data storage was setup using the Microsoft SQL Server database. From the database, data was analyzed, cleaned, and formed in such a way that it is usable with edit distance measurement algorithms. Edit distance algorithms were executed using Microsoft SQL Server Master Data Services to produce enterprise software system compatibility for interoperability result. Further results and data described in section six.

1.2. Interoperability evaluation and autonomic computing

Autonomic computing technology was presented by IBM researcher Jeff Kephart (Kephart & Chess, 2003). The purpose of autonomic computing technology is to raise automation level of computing solutions. With the intention to apply automomic computing technology to enterprise application integration and interoperability solution it was discovered that there ave big similarities between autonomic computing and elementary management cycle from business process modeling (Gudas, 2012). The IBM automomic computing component consists of components:

- Touchpoints – in this research domain it is URL addresses to application API reference source
- Knowledge – in this research domain it is application web-service description documents, business process diagrams and ontology models representing domain
- Autonomic manager – in this research domain it is the solution for interoperability evaluation
- Managed resourses – in this research domain it is applications that should be interoperable

Autonomic Manager consists of five main components:

- Monitor action – which is covered in experiment by scanning data sources in a scheduled fashion
- Analyse action – which is covered in experiment by determining interoperability score
- Plan action – is not covered in this research
- Execute action – is not covered in this research

- Knowledge storage – which is covered in experiment by storing intermediary results from edit-distance calculations, latent semantic analysis, etc.

Autonomic computing solution is usually depicted in similar view as applied IBM autonomic computing component architecture (Fig. 3). Monitor (M) reads data sources and analyze their structure, then analyze (A) evaluates interoperability. Plan (P) step, reads evaluation of object interoperability value and determines actions how to exchange data. Execute (E) step would initiatie another autonomic component capable of initiating data transfer between two or more applications, which in turn affects the application by migrating data.

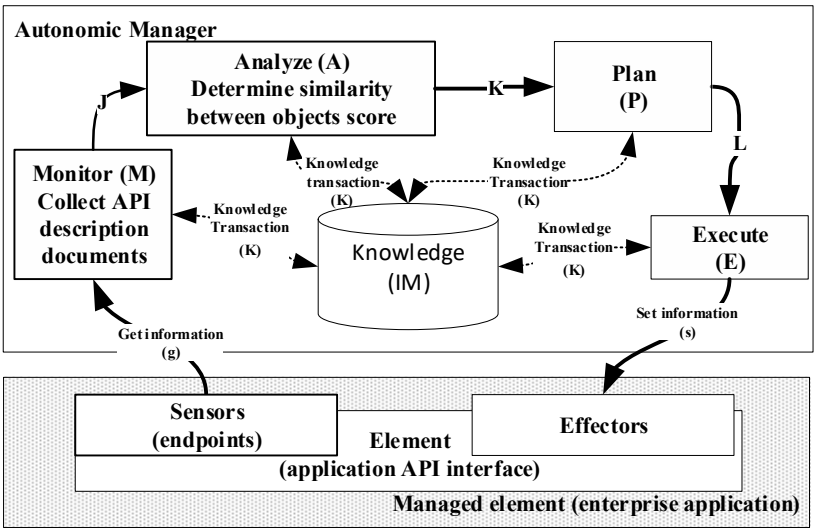

Fig. 3. IBM autonomic computing component architecture

The idea behind this solution is only valid on certain conditions:

- Application is developed with service oriented architecture in mind
- Application has API that is properly described regarding standards and agreements (such as SOAP, REST protocols)
- User can provide details about the endpoint to the interoperability solution.

The items described in autonomic computing component architecture (Fig. 3) only partially described in the dissertation and covers part of it since it was out of scope of this research.

4. APPLICATION INTEROPERABILITY EVALUATION EXPERIMENT DESCRIPTION

This research is limited to enterprise applications developed using service-oriented architecture and mostly focus on software that uses web services and SOAP and RESTful protocol for data transfer, which meta-data is usually described using standardized documents. Web service operations compared to multiple software system applications for the enterprise shows the difference in similarity scoring. Randomly picked applications presented in the table below (Table 2). Each application has some different roles and aspects of an enterprise. Although this research is limited to a few applications, the intention is to expand the research to involve more applications. The core set of applications are On-site e-commerce applications and some on-site accounting applications.

Software Application	API protocol	Objects	Description
OpenCart	REST	24	On-site e-commerce application
PrestaShop	REST	49	On-site e-commerce application
LemonStand	REST	76	On-site e-commerce application
NMBRS_ReportService	SOAP	80	On-site accounting application
NMBRS_DebtorService	SOAP	106	On-site accounting application
Zen Cart	REST	208	On-site e-commerce application
NMBRS_CompanyService	SOAP	444	On-site accounting application
NMBRS_Employees	SOAP	1107	On-site accounting application
SuiteCRM	SOAP	1426	On-site CRM application
KonaKart_StoreFront	SOAP	1644	On-site e-commerce application
KonaKart_Administration	SOAP	2425	On-site e-commerce application
MIVA	REST	4322	Cloud e-commerce application
ExactOnline	REST	6043	Cloud accounting application

Table 2. Randomly picked software applications for analysis

For these applications and their services (Table 2), API reference data is collected and parsed to evaluate interoperability. Microsoft SQL Server, PostgreSQL, R, Microsoft Visual Studio, and Tableau was used to acquire data from web services. We used Microsoft SQL Server to for collecting initial data from C# script written to extract and parse API reference descriptions. C# reference parser was good for a limited amount of applications, but more time needed to expand to enable it to work with a more extensive data set. C# script loaded meta-data from API, parsed and stored in Microsoft SQL server. Later for edit distance analysis, R script was used to determine similarities between operations, objects, and fields of sets between multiple applications. Data stored into the PostgreSQL server. Data was finally analyzed and represented using Tableau software. Activity diagram below depicts a proposed solution of interoperability capability analysis tool (Fig. 4).

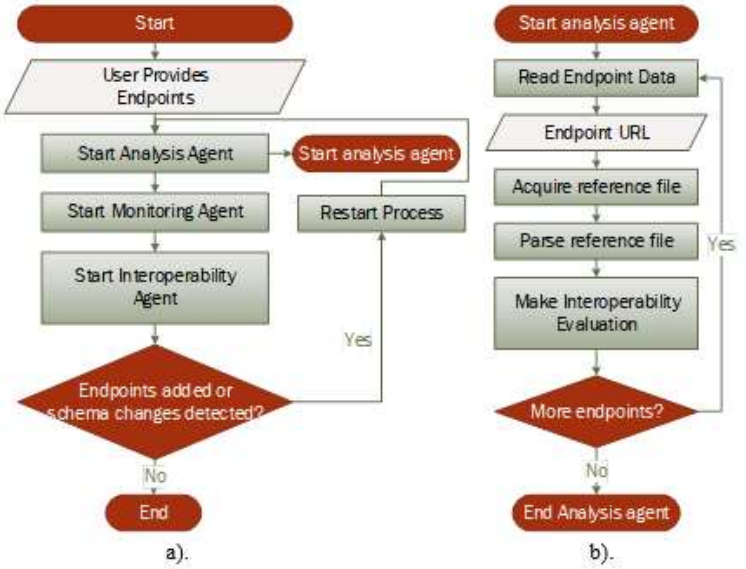

Fig. 4. Activity diagram of a proposed solution of interoperability capability analysis and interoperability tool.

From the figure above (Fig. 4 b) – a simple process of analysis agent depicted. This agent takes part in the job done manually by data integration specialist. It reads endpoint data from the endpoint URL, acquires reference file then parse it and runs evaluation scripts, then

repeats all the process for more endpoints. In the holistic view for software interoperability, there should be three steps: Analysis, Monitoring and Action (interoperability) hence, the three blocks in activity diagram (Fig. 4). The interrelation between activity diagrams in a) and b) in figure file is that subactivities of analysis agent might be running independently from any other agent activity, such as monitoring or interoperability.

5. RESULTS OF APPLICATION INTEROPERABILITY EVALUATION EXPERIMENT

For each enterprise application, it is possible to gather meta-data of web service and API descriptions. Some meta-data automatically extracted from these services (therefore can be automated), others EA require more efforts to do the extraction, but with careful rethinking, the meta-data extraction can be automated as well. Section 5 describes the interoperability capability (potentiality) evaluation experiment of 9 different enterprise software applications (see Section 5). Some of the applications are repeated in the list (Table 2) because web services have several descriptions for different packages with different endpoints. Using the meta-data of web services, we counted for each system how many operations can be carried out using its web services (Fig. 5).

The largest analyzed enterprise application is MIVA – a cloud computing based e-commerce application. Automated parsing determined 3908 data related operations for this specific application. For “ExactOnline” and NMBRS (employees related web service) counted operations 293 and 265 respectively. KonaKart, ZenCart, SuiteCRM contained the smaller number of web service operations below 150.

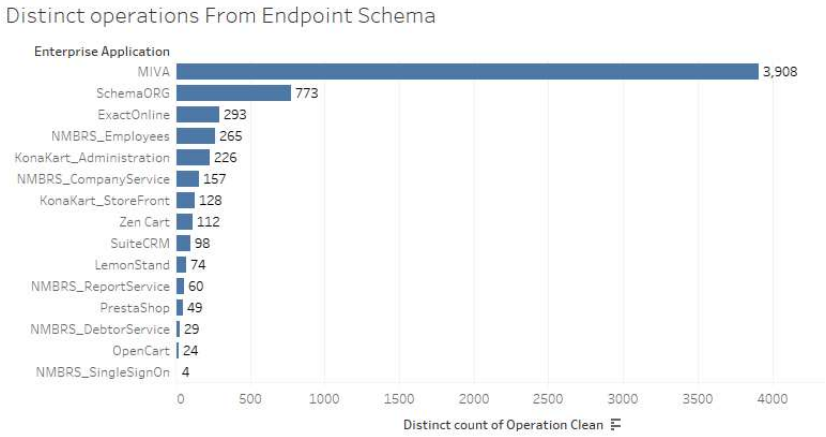

Fig. 5. The number of distinct operations in EA packages.

Additionally the number of distinct operations in EA packages list included an additional collection of meta-data from Schema.org added background knowledge and semantics for other applications (Fig. 5).

Considering only the number of operations can be carried out by EA packages, some conclusions can be drawn:

- MIVA – the most extensive software package from a test set;
- MIVA – contains more modules and data management points than other systems;
- Other systems are smaller, or their web services are limited or split (e.g., NMBRS).

There are 5323 distinct operations overall EA used in the experiment. On average EA has 116 operations per system provided by their web service (excluding SchemaOrg and MIVA). The experiment results are the analysis of similarity for each operation name in each enterprise application. If the edit distance for each operation name is high enough, this indicates that most operations are similar in that pair of EAS packages. Results in Figure 5 summarize the outcome of the edit distance calculations for e-commerce packages. The heatmap of possible interoperability (Fig. 6) shows the edit distance score of operations. Consider the “Prestashop” to “KonaKart_StoreFront” interoperability comparison. Red spots indicate < 50 % operation similarity as opposed to other operations (green), the white area indicates around 50% similarity. Red spots also

indicate a higher probability of operations being similar. For example, “PrestaShop” operation „categories“ matches “KonaKart_StoreFront” operation „category“ by 75% using an ensemble of edit distance calculation.

Fig. 6. Operation interoperability scoring - a heat map using the average ensembled score of edit distance algorithms, green spots indicate above 50% similarities.

In operation interoperability scoring figure (Fig. 6) is apparent similarity of operations of e-commerce products presented. In this example, syntactic overlap can compare and evaluate syntactic overlap of operations between software applications. Results from multiple edit distance methods (Levenshtein, Jaccard, Jaro-Winkler, Longest Common Subsequence) presented further in text. An average score of all selected methods taken as it was not in the scope of this research to evaluate edit distance methods, but rather provide an overview of the capability of evaluation.

1.3. Interoperability evaluation using ensemble method

Evaluation of the next results is presented using the ensemble method. Ensemble method is the average of all similarity scores from the edit distance algorithms. After looking at the results from the operation level, we see that operations of web services are similar to each

application: accounts; absences, addresses (Fig. 7). The results of the operations interoperability scoring leads to conclusions as follows: In ExactOnline (E) and NMBRS (N) there exist operations that are similar: E Addresses – N Address (85%); E BankAccounts – N BankAccount (91%); E Cost centers – N CostCenter (90%); E Cost units – N CostUnit (88%); E Departments – N Department (90%); E Employees – N Employee (88%); E Schedules – N Schedule (88 %).

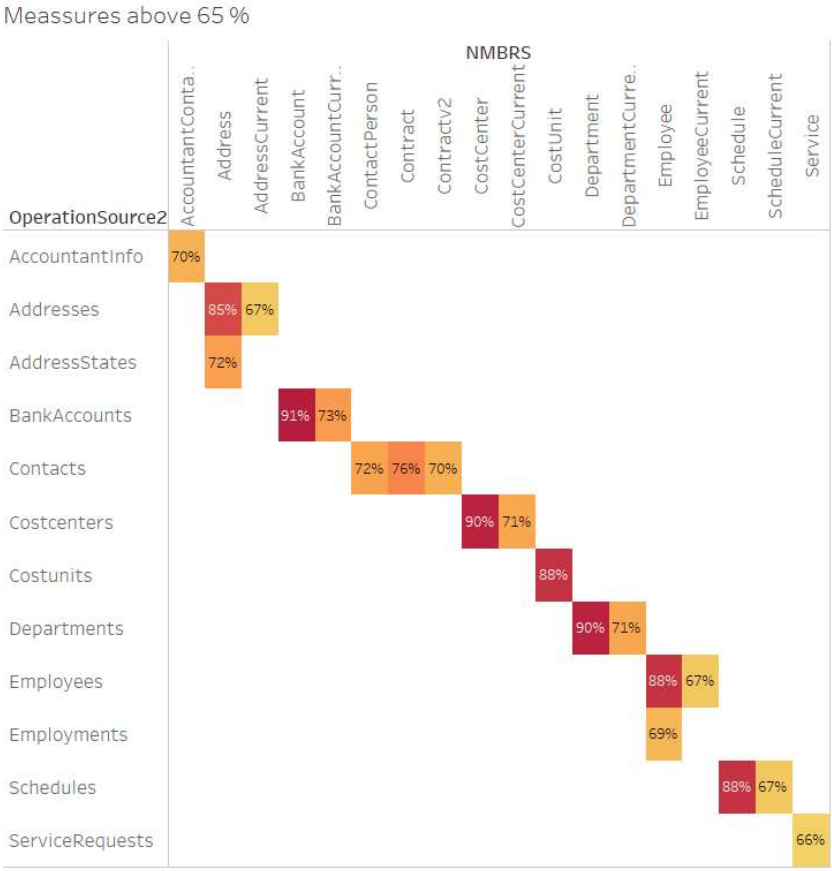

Fig. 7. Similarity results greater than or equal to 65 % (Exact Online, NMBRS).

In Exact Online (E) and NMBRS (N) there exist operations that are confused: E Contacts – N Contract (76%); E Contacts – N

ContractPerson (72%) – these share some similar data, but need to evaluate from data structure perspective for this operation; E Contacts – N ContractV2 (70%);

Exact Online with NMBRS has 20 operations with a result higher than 65%. We can analyze and determine thresholds by semantic meaning trying to avoid mismatching. As can be seen, Exact Online 285 NMBRS 130 operations have only 20 operations possible interoperability with score > 65%. Further, compared Exact Online (E) and PrestaShop (P) where similarity results are above or equal to 70 %. In research results exist cases with full similarity (100%) between a few objects: Addresses; Contacts; Currencies; Employees; Warehouses. However, the algorithms are not precise, so some confusion can be found, for example, at (74%): E Projects – P products (74%)..

Exact online with PrestaShop has 18 operations with a result higher than 70 %. As can be seen, Exact Online 285 PrestaShop 72 operations have only 18 operations possible interoperability with score > 70 %. Other results are overviewed as follows and presented in Table 3. The experiment confirms that it is possible to evaluate the interoperability capability, i.e., identify the pairs of specific operations that potentially can be interoperable.

	Similarity >=		100 %				
	60%	70%	Ensemble	Levenshtein	Jaro-Winkler	Jaccard	Longest Common Subsequence
ExactOnline X NMBRS	40	20	-	-	-	-	-
ExactOnline X Prestashop	54	18	5	5	5	5	5
ExactOnline X SuiteCRM	48	12	-	-	-	8	-
NMBRS X Prestashop	11	6	1	1	1	1	1
MMBRS X SuiteCRM	7	-	-	-	-	-	-
SuiteCRM X Prestashop	13	6	1	1	1	5	1

Table 3. Count of Operations with a given score for each software interoperability combination.

In the similarity of sources using edit distance calculations a) Levenshtein, b) Jaro-Winkler, c) Jaccard, d) Longest common subsequence, e) ensemble the similarity of applications using different edit distance calculations is depicted (Fig. 8). All edit distance algorithms determine the same similarity between the EAS (Fig. 8).

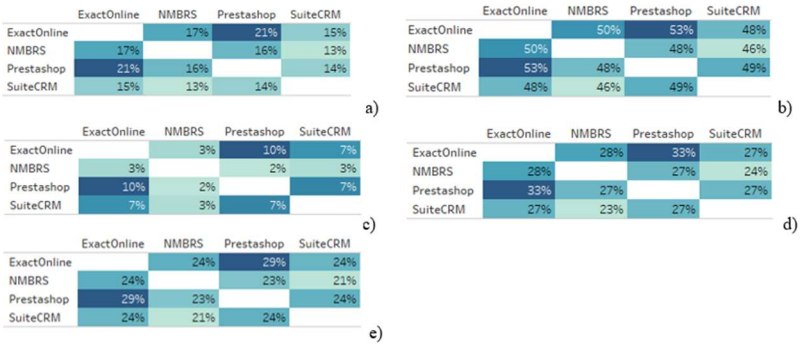

Fig. 8. The similarity of applications using edit distance calculations a) Levenshtein, b) Jaro-Winkler, c) Jaccard, d) Longest common subsequence, e) ensemble.

The scoring amplitudes are somewhat shifted (a – [13;21], b – [46;53], c - [2;10], d - [23;33], e – [21;29]) because of the difference of the edit distance calculation methods. The method can compare the different amount of procedures. The lower the percentage - the more procedures tried to compare, but the score was lower because of the different amounts. It is still more important to check per each comparison method rather than looking for a difference in each of them.

1.4. Interoperability evaluation using bag of words

Bag of words is a good model to simplify visualisations of data that was used in the experiment. In this research bag of words method for data visualization and further decision making on experiment steps. We also used bag-of-words solution to split addative words such as “sendInvoice” so we could analyze separate words for example

"send" and "invoice" separately. This helps determine that "send" is a verb and is used in action to the noun "invoice" which is an object in the application that is being analyzed. Determining and displaying bag of words helps visualyy see the application similarity results. An example is given using "KonaKart", "Zen Cart" and "Suite CRM" application analysis in text analysis figures A, B and C (Fig. 9).

Fig. 9. Textual analysis comparison between applications using bag-of-words method.

From the textual analysis comparison with bag-of words method we see the biggest words expressed that have most of related operations (Fig. 9). The operations, that are verbs impact objects that are nouns, and we can clearly see that KonaKart (A) and Zen Cart (B) has product object that is possibly related. We can certainly say that (A) and (B) share same objects and therefore can be interoperable because we know that both applications are E-Commerce solutions, and the method above gives us calculatable, objective view of the latter statement.

1.5. Interoperability evaluation using latent semantic analysis

The assumption, that words in applications are semanticaly similar if they repeat in the similar places of text – also known as distributed semantics. Based on this assumption, we can use Latent Semantic Indexing (LSI) method to improve edit-distance method experiment results and improve the monitoring and analysis actions of autonomic computing component. For latent semantic analysis we used R language version 3.5.1 and these libraries:

- RODBC – data reading and writing
- tm – text mining tool

- quanteda – text analysis tool with latent semantic analysis capability.

Experiment tests are carried out using Latent Semantic Analysis tool from Quanteda library pacakage. Latent semantic analysis is described in Information Retrieval, Algorithms and Heuristics book (Grossman & Ophir, 2012).

In the first experiment we compare ExactOnline and SuiteCRM applications, for only operations that are 100 match and try to see if they are similar by adding Objects, Fields, and Field Type information, hence the semantic knowledge about operation. We can clearly see that ExactOnline objects are more separate from SuiteCRM package objects (Fig. 10)

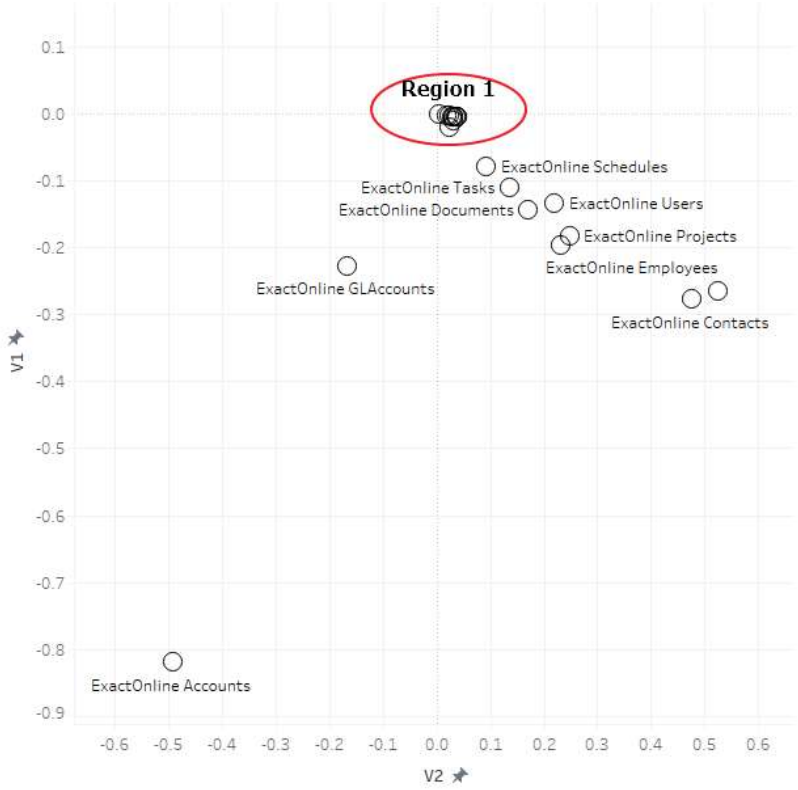

Fig. 10 ExactOnline comparison to SuiteCRM structural similarity using LSI method.

From ExactOnline comparison to SuiteCRM figure it is seen that vectors V1 and V2 reflect objects positions in a plane (Fig. 10). The closer are the objects in this plain then more related semanticaly they are, hence increasing a total possibility for applications to have interoperability.

6. CONCLUSIONS AND RECOMMENDATIONS

1. Most common problems of application integration and interoperability were listed and compared showing that most important problems are schema matching, orchestration and choreography in interoperability solutions.
2. Review of currently existing interoperability evaluation methods show that they mostly rely on manual analysis, questionairs and there are no automated approaches to derermine whether multiple applications can be interoperable.
3. Main analyzed interoperability evaluation methods LISI, I-Score, Comparison by functionality. LISI and Comparison by functionality methods are quire similar, but LISI is more developed for multiple business layer, and comparison by functionality deeply depends on the observer subjective view on the domain. I-score method is more technical and closer to the topic of his research but it does cover only very low technical level and does not deal with schema matching orchestration and choreography problems.
4. The proposed solution for autonomic interoperability evaluation was laid in dissertation theoretical part. In the proposition it was argued that multiple knowledge sources of business domain can be used to add to evaluation of interoperability. The proposed method suggest that knowledge can be gathered from business process, application architecture description files, and other ontology sources that could be added to the existing experiment and compared with target application, which would allow to determine coverage of business layer to application layer and how well CIM represents software architecture PIM models in enterprise architecture domain.

5. The presented experiment defends the statement proposed method is able to autonomically detect similarity between applications by the highest level using web service description documents and edit-distance, latent semantic analysis methods to get the quantative evaluation of interoperability.
6. Enterprise applications where analyzed and evaluated the level of capability to be interoperable. The goal to asses interoperability through the knowledge available by automated algorithms has not yet been covered in the available solutions.
7. This research opens a possibility for a machine to machine interaction evaluation, helping people that work on integration projects.
8. Current research results might be helpful as decision support to gain knowledge of compatibility between systems quickly.
9. In the experiment, 13 software systems were compared by difference edit-distance methods and give the output of evaluation of the capability of interoperability in the form of similarity score.
10. The negative side of such scoring is that the summary of API operation similarity score does not provide a full picture of similar objects and operation count difference in all applications and might affect this scoring method.
11. Jaccard, Jaro-Winkler, Levenshtein, and Longest Common Subsequence methods show the same separation of interoperability measure. Methods have a different level of precision estimating not such similar strings (below 60%).
12. This research could be expanded on the topic how autonomic component can evaluate interoperability when its managed application systems are not designed using service oriented architecture (SOA).

This research provides the basis for supporting Business Process alignment to Application Processes and may impact the quality of application interoperability when using business process models. The idea is that after measuring whether software systems are interoperable, it is possible to measure the alignment to business processes and see which operation fall outside of the business process model.

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LIST OF PUBLICATIONS ON THE TOPIC OF DISSERTATION

The results of the research were published in two peer-reviewed journals:

1. Valatavičius, A., Gudas, S., Apie taikomųjų programų sąveikumo metodologiją, grindžiamą giluminėmis žiniomis. Informacijos mokslai, 79(79), pp.83-113.
2. Publikuotas straipsnis: Gudas, S., Valatavicius, A., 2017. Normalization of Domain Modeling in Enterprise Software Development. Baltic Journal of Modern Computing, 5(4), pp.329-350.

The results of the research were punlished in six peer-reviewed conference proceeding journals:

1. Valatavičius, Andrius & Gudas, Saulius, 2015. Towards business process integration using autonomic computing. Informacinės technologijos 2015: Konferencijos pranešimų medžiaga, pp.81–84.
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The resulst of the research were presented at six national and international conferences:

1. Tarptautinė konferencija: Dalyvauta Doktorantų konsorciume BIR 2015 Estijoje tema: “Enterprise Software System Integration using Autonomic Computing“;
2. Tarptautinė konferencija: DB&IS 2016 Latvijoje tema: “Modelling Dynamic Enterprise Environment to Maintain Interoperability of Applications“;
3. Tarptautinė konferencija: DAMSS „Data Analysis Methods for Software Systems“ 2016;
4. Konferencija: XVIII tarptautinėje kompiuterininkų konferencijoje LIKS 2017, tema: Towards deep knowledge based interoperability of applications. Straipsnis priimtas publikacijai žurnale „Informacijos Mokslai“;

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