Neural Networks usage in Ontology Matching: a Literature Review

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***Abstract*—The paper contains analysis of researches, that provide ontology alignment techniques, based on the usage of neural networks for a part of alignment process of for while process. From each found paper the main purpose of using neural networks have been identified as well as learning algorithm. In addition, the results of benchmarks for reviewed alignment techniques have been marked out form the papers, and especially results of the OAEI tests that is main test repository for proving efficiency and accuracy of ontology alignment techniques.**

I. Introduction

The usage of ontologies for knowledge representation is one of the core technologies for knowledge management in our time. Usage of ontologies gains popularity in science and the industry, besides ontologies are the cornerstone of a semantic world wide web. Apart of all advantages of using ontologies, there are many tasks that require effective solutions. One of the main issue in the field of knowledge management is ontology matching. This is urgent issue because of the rapid development of Web 3.0 also known as Semantic Web, where all resources are presented with ontologies that are specific for different problem domains [1]. To gather information between separated knowledge sources or to create a server composition for complex task solving it is needed to find correspondences between sources' or services' ontologies. This problem can be solved with ontology matching techniques.

For ontology matching, there are many solutions, based on the different technologies that are based on the semantic of ontology concepts, structure of the ontology of on both semantics and structure [1]. Many researchers claim that this task can be reduced to a problem of classification of already existing concepts of ontologies. In this regard, solutions which use any algorithms of machine training and neural networks are distinguished from all ways of ontology alignment.

The main point of current research is to improve existing solutions for ontology matching task by using combination of different neural network. It is proposed to use two types of neural network: classifying neural network for ontology concepts matching and graph neural network for ontologies structure matching. This article is aimed on the providing of a review over researches that describe the usage of neural networks for solving the ontology matching problem. The review goal is to answer the following research questions:

- RQ1: What is the main purpose of using neural networks in ontology matching task?
- RQ2: What machine-learning techniques are usually used for network learning?
- RQ3: How effective can be the proposed solutions?

II. Selection of papers

The following main related topics has been selected for researches search based on the review goals. The first topic is a neural network, which can be combined with machine learning or artificial intelligence. The second one is the ontology matching. Often, in different papers authors use another same topic, like ontology alignment or ontology mapping.

Generally, search of articles has been run on the SCOPUS references database, where the following search terms have been used:

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TITLE-ABS-KEY ("neural network" AND ontolog* AND (match* OR alignment* OR mapping*))
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In addition, few solutions have been marked out from books and articles about all ways of ontology matching [1], [2].

Fig.1 illustrates publication activity in the field of ontology matching with using neural networks, since 2005.

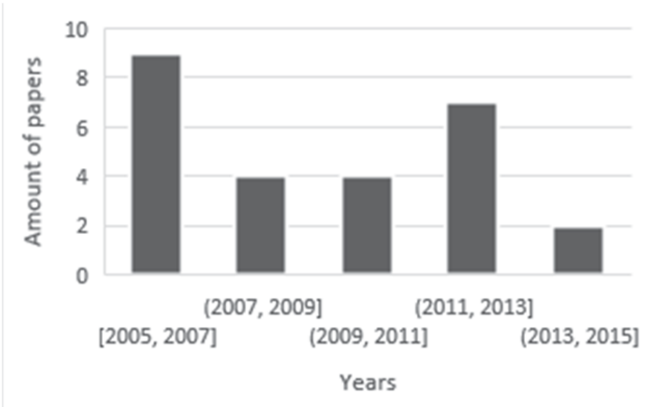

Fig. 1. Publication activity in the field of ontology matching using neural networks

III. Analysis

A. Neural network (NN) Purpose

RQ1: What is the main purpose of using neural networks in ontology matching task?

Many reviewed papers contains solutions based on classifying concepts of ontologies for resolve ontology matching task. In article [3] authors propose the solution with usage of recursive neural network algorithm. Authors of paper [19] present artificial neural network for the semantic web that match ontology concepts by their classifying. In papers [21], [22] the system is presented that does not match ontologies, but match databases by finding corresponding attributes with few neural networks based on classifying task. In another papers [8], [9], [18], [23], [24], [27], [28] authors describe their systems with different way to use neural networks for solving task of ontology alignment by classifying of ontology patters, too.

The second popular purpose described in the papers is a function approximation. Article [20] describe system that uses neural networks for learning the high-level abstract representations of classes and properties from their descriptions to acquire the potential correlations for the computing of the similarities between classes and properties. In papers [4], [6], [7], [10], [25], [26] described ways of using neural network for finding optimal weights for functions, which define ontology similarity.

Papers contains another purpose too. For example, in articles [13], [14], [15] authors write about system PRIOR+. They describe a way of ontology matching, based on solving constraint satisfaction. For this issue authors use interactive activation and competition (IAC) neural network.

Summary from all articles allows to allocate two main ways of using neural networks in ontology alignment task. The most frequent way is a using of classification neural network to classify concepts of matching ontologies. The second popular way is a function approximation that finds potential correlation based on the high-level abstract representation of ontology concepts.

B. Learning methods

RQ2: What machine-learning techniques are usually used for network learning?

Despite purposes of neural networks, the most using training method is the backward propagation of errors algorithm (backpropagation) or its variants. For example, article [4] present system X-SOM. It is complex solution where neural network uses backpropagation learning method with sigmoid for ontology similarity function approximation. Authors of paper [19] also use backpropagation learning method for training neural network, which classifying concepts of ontologies.

C. Benchmarks

RQ3: How effective can be the proposed solutions?

For review of efficiency of the all solutions, it was decided to check results of the open ontology evaluation initiative (OAEI) tests. Description of OAEI benchmark tests are the following:

- #101-104: O_R and O_T have the same representation and conceptualization
- #201-210: O_R and O_T have the same structure but different linguistic
- #221-247: O_R and O_T have the same linguistics but different structure
- #248-266: Both structure and linguistics are different between O_R and O_T
- #301-304: O_T are real-life bibliographic ontologies

Table I present OAEI benchmark of systems and algorithms presented in the review above.

TABLE I. BENCHMARK RESULTS OF OAEI TESTS

<table>
<tr><th># OAEI test</th><th>X-SOM [4], [5]</th><th>XMap++ [6], [7]</th><th>MoTo [27]</th><th>CIDER / CIDER-CL [8], [9]</th><th>(Manjula Shenoy) [10]</th><th>PRIOR / PRIOR+ [11], [12], [13], [14], 15]</th><th>ERSOM [20]</th></tr>
<tr><td>101</td><td rowspan="3">0.99 / 0.986 / —</td><td rowspan="3">1 / 1 / —</td><td rowspan="6">—</td><td rowspan="4">0.85 / 0.67 / 0.75</td><td>1 / 0.92 / 0.85</td><td rowspan="25">0.85 / 0.31 / 0.46</td><td rowspan="25">0.787 / 0.79 / 0.793</td></tr>
<tr><td>102</td><td>—</td></tr>
<tr><td>103-104</td><td rowspan="8">0.96 / 0.89 / 0.84</td></tr>
<tr><td>201</td><td rowspan="7">0.816 / 0.754 / —</td><td rowspan="2">0.11 / 0.12 / —</td></tr>
<tr><td>202</td><td>—</td></tr>
<tr><td>203</td><td rowspan="17">0.9 / 0.89 / —</td><td rowspan="15">0.85 / 0.67 / 0.75</td></tr>
<tr><td>204</td><td>0.92</td></tr>
<tr><td>205</td><td>0.54</td></tr>
<tr><td>206</td><td>0.65</td></tr>
<tr><td>207 - 210</td><td>—</td></tr>
<tr><td>221</td><td rowspan="11">0.99 / 0.99 / —</td><td>0.63</td><td rowspan="15">—</td></tr>
<tr><td>222</td><td>0.99</td></tr>
<tr><td>223</td><td>0.95</td></tr>
<tr><td>224 - 227</td><td>—</td></tr>
<tr><td>228</td><td>0.97</td></tr>
<tr><td>229 - 232</td><td>—</td></tr>
<tr><td>233</td><td>0.4</td></tr>
<tr><td>236 - 238</td><td>—</td></tr>
<tr><td>239</td><td>0.95</td></tr>
<tr><td>240</td><td>0.88</td></tr>
<tr><td>241, 246 - 247</td><td rowspan="2">—</td></tr>
<tr><td>248 - 266</td><td>0.26 / 0.26 / —</td><td>—</td></tr>
<tr><td>301</td><td rowspan="3">0.94 / 0.67 / —</td><td rowspan="3">0.875 / 0.825 / —</td><td>0.66</td><td rowspan="3">0.85 / 0.67 / 0.75</td></tr>
<tr><td>302 - 303</td><td>—</td></tr>
<tr><td>304</td><td>0.86</td></tr>
</table>

Results of Table I are gathered from the reviewed articles and shown as values of the following measures: *Precision/Recall/F-Measure*. *Precision* and *recall* are the commonplace measures in information retrieval. They are based on the comparison of an expected result and the effective result of the evaluated system. Given a reference alignment R, the precision of some alignment A is given by

$$Precision(A,R) = \frac{|R \cap A|}{|A|}$$

and recall is given by

$$Recall(A,R) = \frac{|R \cap A|}{|R|}$$

F-measure is a combination of precision and recall and given by

$$F = 2 * \frac{Precision * Recall}{Precision + Recall}$$

Results of tests, which authors carried out on the data sets that are different from the OAEI tests, are given in the table II.

Fig. 2 provides a distribution of average values for benchmarks measures. Most of them have value more than 0.7. Based on that the conclusion can be made that neural networks are appropriate instrument for solving ontology matching task.

Table III provides the summary of reviewed researches with describing of neural network usage purpose and learning techniques applied to neural network learning.

TABLE II. BENCHMARK RESULTS WITHOUT OAEI TESTS

Papers	Authors	Name	Precision / Recall / F-Measure
[28]	Ehrig, M., Staab, S., Sure, Y.	APFEL	0.777 / 0.485 / 0.597 0.542 / 0.359 / 0.432
[25]	Huang J., Dang J., Jos´e M. Vidal, Huhns, M.N.	—	0.85 / 0.73 / —
[24]	Ichise, R.	Malfom-SVM	0.525 / 0.925 / 0.67
[21], [22]	Li, W.-S., Clifton, C.	SEMINT	0.8 / 0.9 / — 0.2 / 0.38 / —
[23]	Nattawuttisit, S., Usanavasin, S.	—	0.948 / 0.825 / —
[19]	Stegmayer, G., Caliusco, M., Chiotti, O., Galli, M.	—	— / 0.75 / —

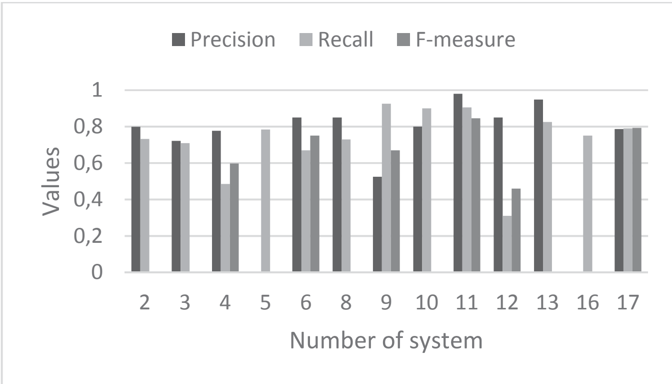

Fig. 2. Average values of measures

TABLE III. SUMMARY TABLE OF NEURAL NETWORK-BASED APPROACHES FOR THE ONTOLOGY MATCHING

#	Papers	Authors	Name	NN Purpose	Learning method
1	[3]	Chortaras, A., Stamou, G., Stafylopatis, A.	—	classification	?
2	[4], [5]	Curino, C., Orsi, G., Tanca, L.	X-SOM	approximation	backpropagation
3	[6], [7]	Djeddi, W.E., Khadir, M.T.	XMap++	approximation	resilient backpropagation
4	[28]	Ehrig, M., Staab, S., Sure, Y.	APFEL	classification	?
5	[27]	Esposito, F., Fanizzi, N., d'Amato, C.	MoTo	classification	?
6	[8], [9]	Gracia, J., Bernad, J.,Mena, E., Asooja, K.	CIDER/CIDER-CL	data analysis, classification	?
7	[26]	Hariri, B.B., Abolhassani, H., Sayyadi, H.	—	approximation	supervised
8	[25]	Huang J., Dang J., Jos´e M. Vidal, Huhns, M.N.	—	approximation	?
9	[24]	Ichise, R.	Malfom-SVM	classification	support vector machine (SVM)
10	[21], [22]	Li, W.-S., Clifton, C.	SEMINT	clustering, classification	self-organising map (SOM), backpropagation,
11	[10]	Manjula Shenoy, K., Shet, K.C., Dinesh Acharya, U.	—	approximation	?
12	[11], [12], [13], [14], [15]	Mao, M., Peng, Y., Spring, M.	PRIOR/PRIOR+	constraint satisfaction	?
13	[23]	Nattawuttisit, S., Usanavasin, S.	—	classification	backpropagation
14	[16], [17]	Peng, Y., Munro, P., Mao, M.	—	data analysis	complex
15	[18]	Rubiolo, M., Caliusco, M.L. et al.	—	classification	k-fold cross-validation, Levenberg-Marquardt
16	[19]	Stegmayer, G., Caliusco, M., Chiotti, O., Galli, M.	—	classification	backpropagation
17	[20]	Xiang, C., Jiang, T., Chang, B., Sui, Z.	ERSOM	approximation	unsupervised representation learning

IV. CONCLUSION

The flexibility of neural networks allows to use in for any kind of task. The main goal of this review was to find and compare existing solutions for using the neural network in ontology matching. During the analysis or the research works the following specifics of neural network usage for ontology matching had been found:

- There are two main purposes for using neural network in ontology alignment task. One is a classification of ontology concepts and the other is function approximation.
- The most using training method is the backward propagation of errors algorithm (backpropagation) or its variants.
- Test of matching techniques shows a high accuracy of matching.

The analysis provided in paper shows that neural network techniques are fully appropriable to the task of ontology matching. The future work in this field will be concentrated on the usage of neural networks for searching the pattern that was used for designing an ontology. The idea is to use these patterns in ontology matching as anchor points for further matching that will be based on the ontologies structure analysis.

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