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# New approaches to the ontology alignment and identity resolution problems*

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**Abstract**

This paper describes approaches to the vocabulary normalization and identity resolution problems arising during the use of the LOD datasets to populate the content of scholarly knowledge bases. We have proposed new heuristics, using additional information extracted from full text sources of data. The first heuristics uses the full record track of a person and the second one uses self-citation networks. The dataset of the Open Archive of the Russian Academy of Sciences and several bibliographic datasets are used as test examples.

**Keywords:** Linked Open Data, SPARQL, ontology alignment, identity resolution, self-citation network

## Introduction

One of the projects carried out at the A.P. Ershov Institute of Informatics Systems of the Siberian Branch of the Russian Academy of Sciences (IIS SB RAS) is aimed at populating the Open Archive of the Siberian Branch of the Russian Academy of Sciences (SB RAS Open Archive, Open Archive)[1] [1, 2] with the data of the Open Linked Data cloud (LOD) [3]. A fragment of the Open Archive page devoted to Academician A.P. Ershov is shown in Fig. 1.

A four-step strategy for the integration of Linked Data into an application is proposed in [4]. The problems of access to linked data (1),

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[1] http://duh.iis.nsk.su/turgunda/Home, http://duh.iis.nsk.su/VirtuosoEndpoint/Home/Samples.

vocabularies (schema, ontology) normalization (2), identity resolution (3), data filtering (4) should be solved manually or semi-automatically in addition to the problems, specific for an application. Specialized tools for solving separate problems are becoming available [5–8]. However, according to [8], the large scale processing, schema mapping and data fusion are still in their infancy.

In our experiments we use a toolkit containing the previously developed ontology visualization program [9]. This program is extended by various facilities for SPARQL queries processing. Visualization-based methods for the exploration of ontologies and content of semantic systems have been developed in the IIS SB RAS, and their detailed description is presented in [2]. This paper addresses the problems (2), (3) and (4) and demonstrates methods for solving these problems.

The dataset of the Open Archive of the Russian Academy of Sciences structured by the BONE Ontology and several bibliographic datasets structured by the AKT Reference ontology [10] are used as test examples. Several sources of full-text documents such as Academician A. Ershov's Archive[2] and a digital library SpringerLink[3] have been used as well.

## 1 Experiments on ontologies alignment

The content of the SB RAS Open Archive provides various documents (photo documents mainly) reflecting information about people, research organizations and major events that have taken place in the SB RAS since 1957. The Open Archive contains information about the employments, research achievements, state awards, titles, and participation in conferences, academic and social events for each person mentioned in the Archive. The Open Archive has 20 505 photo documents, facts about 10 917 persons and 1519 organizations and events. The data sets of the Open Archive are available as an RDF triple store, as well as a Virtuoso endpoint[4] for the SB RAS Archive. Its RDF

[2]http://ershov.iis.nsk.su/ershov/english/scient.html

[3]http://link.springer.com/

[4]http://duh.iis.nsk.su/VirtuosoEndpoint/Home/Samples

triple store comprises about 600 000 RDF triples. The structure of the Open Archive knowledge base is organized with the so-called BONE Ontology, described in OWL and comprising 44 classes.

We are working with different data sets of the RKBExplorer.com, which brings together data from many well-known scholar datasets. For example, the RKB Explorer DBLP[5] contains the data of the DBLP Computer Science Bibliography[6], the RKB Explorer ACM[7] dataset corresponds to the data extracted from a digital library of the Association for Computing Machinery (ACM)[8]. The RKB Explorer Citeseer[9] dataset is taken from a digital library CiteSeerx[10]. The RKB Explorer IEEE[11] dataset contains information about IEEE publications[12] etc. It should be noted that the number of the RKBExplorer.com datasets is constantly increasing.

It is also important to note that the data sets of RKBExplorer.com are not the exact copies of the respective (reciprocal) libraries. For example, the RKB Explorer DBLP and DBLP Computer Science Bibliography have the same lists of publications and authors, but these data sets use different heuristics in the identification of synonyms and homonyms. However, all the errors of the identification of persons that occurred in the DBLP Computer Science Bibliography database are repeated in the dataset of RKBExplorer.com.

We intend to use these datasets as a source of additional data for the Open Archive. For example, we would like to extend the Open Archive knowledge base with information about the publications by the people who previously worked at the A.P. Ershov Institute of Informatics Systems. Since these data sets are structured with the AKT reference ontology, we need to establish mappings between the several classes and relations of the BONE ontology and the AKT Reference ontology.

[5] dblp.rkbexplorer.com
[6] http://www.informatik.uni-trier.de/~ley/db/index.html
[7] acm.rkbexplorer.com
[8] dl.acm.org
[9] citeseer.rkbexplorer.com
[10] http://citeseer.ist.psu.edu
[11] ieee.rkbexplorer.com
[12] http://ieeexplore.ieee.org/ Xplore/guesthome.jsp

| | | | | | |
|---|---|---|---|---|---|
| | 1976 | 1988 | участник | заместитель заведующего кафедой вычислительной математики ММФ | Новосибирский государственный университет |
| | 1979 | 1988 | первое лицо | председатель | Комиссия по системному математическому обеспечен Координационного комитета по Вычислительной техн СССР (КОСМО ККВТ АНСССР) |
| | | | участник | участник | Событие "Общим собранием Академии наук избраны п Сибирск..." |
| | | | организатор | организатор | Празднование 10-летия Отдела программирования |
| | | | участник | | Третий всесоюзный симпозиум "Системное и теоретич программмирование" |
| | 1964 | 1988 | участник | заведующий отделом | Институт вычислительной математики и математическ геофизики СО РАН |
| | 1959 | 1964 | участник | заведующий отделом программмирования | Институт математики им. С.Л. Соболева СО РАН |
| отраж. в документе | Отражение | | | | |

Figure 1. A fragment of the Open Archive page devoted to Academician A.P. Ershov

A specific feature of the BONE ontology is that it uses a Link Data modeling pattern called "qualified relation pattern" [11]. It means that the entities usually described by means of a relationship in other ontologies may be described as an instance of a class in the BONE ontology. This template compensates for the lack of attributes of the RDF predicates.

For example, using the "from-date" and "to-date" properties of the *bone:participation* class, we are able to specify facts such as "Academician A.P. Ershov was the head of a department at the Institute of Mathematics SB AS from 1959 to 1964 and the head of a department at the Computing Center SB USSR AS from 1964 to 1988".

For the same reasons, such classes as *bone:dating*, *bone:naming*, *bone:authorship* are used in the BONE ontology instead of predicates such as *akt:has-author*, *akt:has-date* or *akts:has-pretty-name*, used in the AKT Reference ontology.

This augmentation of expressive possibilities complicates the problem of data integration, since a need arises to systematically establish a correspondence between the groups of classes and relations of ontologies.

More precisely, a correspondence between one or several groups of the form "Class1 - relation1 - Class2" of the AKT Reference ontology and one or several groups of the form "Class3 - relation2 - Class4 - relation3 - Class5" of the BONE ontology should be created. In particular, a new instance of the Class4 for every triple <Class1:instance1, relation 1, Class2:instance2>should be created. This kind of translation can be carried out by an appropriate SPARQL-query.

A simplified template of a SPARQL query that generates instances of the Class4 is as follows:

```
PREFIX iis:<http://iis.nsk.su#>
PREFIX akt:<http://www.aktors.org/ontology/portal#>
PREFIX akts:<http://www.aktors.org/ontology/support#>
CONSTRUCT {
_ :p a iis:Class4.
_ :p iis:relation2 ?instance1.
_ :p iis:relation3 ?instance2.
```

```
}
WHERE {
?instance1 akt:relation1 ?instance2.
?instance1 a akt:Class1.
?instance2 a akt:Class2.
}
```

Since the needed SPARQL-queries are rather tedious, we have created a program that can generate this kind of queries using the visualization of two ontologies. An example of generating instances of the *bone:participation* class with respect to the *akt:has-affiliation* relation is shown in Fig. 2. The two ontologies are drawn side-by-side and several additional buttons are used to control the alignment process. When the "Fix matching" check box is activated, we can choose groups of classes and relations for alignment in both visualization panels. The group "<Person>has-affiliation <Organization>" of the AKT Reference ontology is selected in the left panel and the group "<sys-obj>participant <participation>in-org <org-sys>" of the BONE ontology is selected in the right panel. A SPARQL query that generates the instances of the *bone:participation* class is generated automatically.

However, in order to use these queries effectively, we must select people described in the Open Archive from the RKBExplorer list. In other words, the identity resolution problem should be solved.

## 2 Identity resolution and data filtering

The step of identity resolution is very important for populating the Open Archive content. We have to match properly the persons described in the Open Archive with the data about these persons extracted from other data sets. The problem is complicated by the fact that the Open Archive uses names written in Cyrillic, and most of the RKBExplorer data sets use Latin names to identify the same persons. Thus, we have a cross-language entity linking problem to solve. The problem is known to have two other complicating features: entities can be referred to by using multiple name variants (aliases or misspellings) and several entities can share the same name (for example, there are many people called Petr Ivanov).

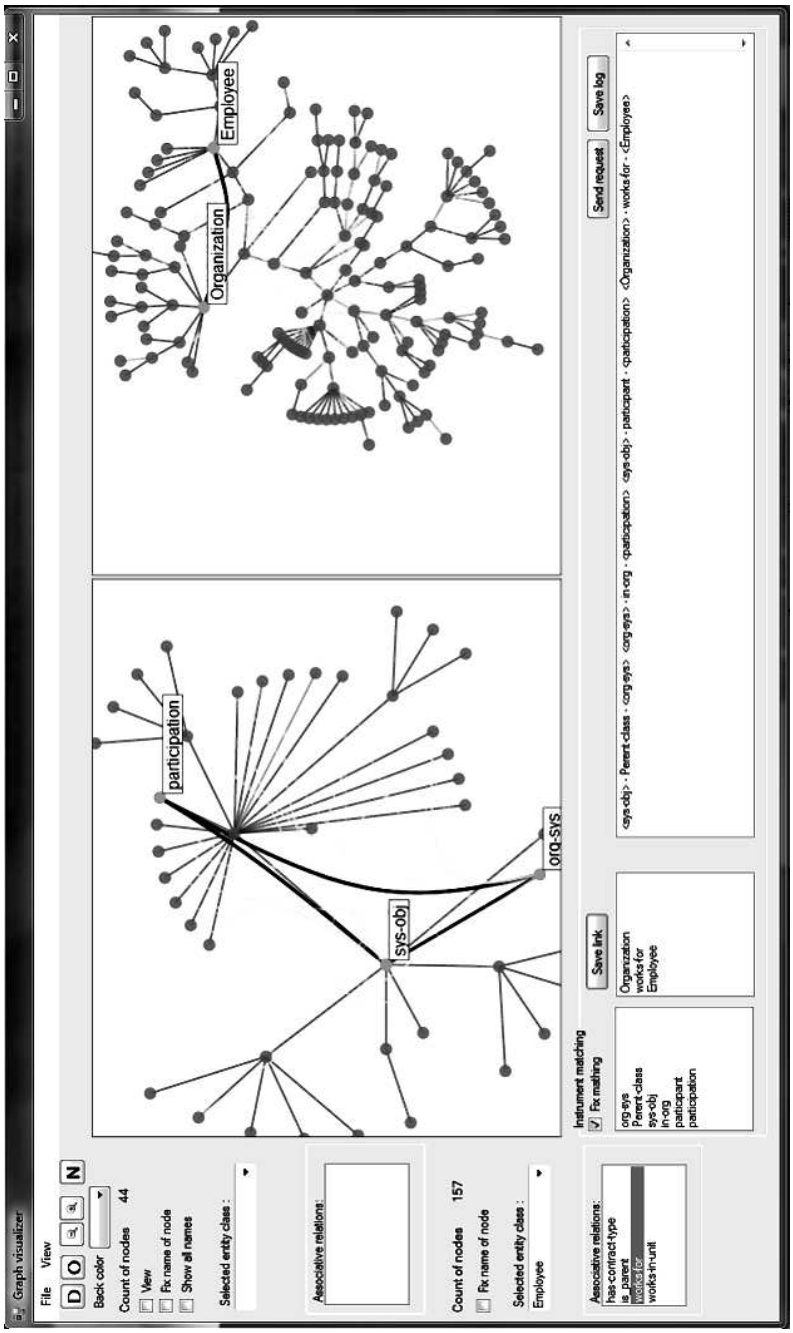


Figure 2. Interactive matching between two groups of classes and relations

One might ask of course, why not use one of the Russian data sources, such as eLIBRARY.RU, to populate the database. Indeed, this digital library provides information about Russian researchers, but this is a relatively recent database, and the time period covered by eLIBRARY.RU is rather short. Therefore, it can be very useful for identifying the people and their publications pertaining to the last 10–15 years, but it becomes of little use when we are interested in somebody like Academician Andrei Petrovich Ershov, who died in 1988. Neither is there any information about B.A. Trakhtenbrot, V.E. Kotov or many other researchers who laid the foundations of the Soviet and Russian computer science. To compare, the DBLP contains information about publications dating from 1936.

In the SB RAS Open Archive, all persons are specified by means of the "*bone:name*" attribute. The format of this attribute is <Last Name, First Name Middle Name>. This attribute has two options: the Russian-language version and the English-language version. The English version is a transliteration of the Russian version. Every Russian name, however, can be transliterated in many ways. For example, the Russian family name *Ершов* can be spelt as Ershov, Yershov, Jerszow, and the first name *Андрей* can be written as Andrei, Andrey, Andrew.

Therefore, the first step of our identity resolution procedure is transliterating a name in the language of a dataset (i.e. English) and then performing a monolingual name matching in that language. We have used the following procedure to identify candidates for monolingual name matching with the RKBExplorer data sets:

1) Generate all possible transliteration variants for each normalized *bone:name*.

2) Generate all possible formats of *akt:full-name* for each *bone:name*.

3) Compare the generated *full-name* variants with the full-names of the RKBExplorer data sets.

Two remarks can be made concerning the above procedure. First, an important source for authority control at the international level is becoming available. VIAF [12] focuses mainly on national libraries and countrywide union catalogs. It is possible to find there many-language variants of the spelling of the names of prominent people but ordinary

researchers are not represented; also, it mainly collects information about books, not about journals or conference papers. Second, using string distance metrics for name-matching is not a new field of research and has an extensive bibliography [13–15]. Therefore, it suffices to say that a tokenized version of the Jaro-Winkler similarity metric has been used [13]. It means that the family names of the SB RAS Open Archive have been compared with the *akt:full-name*s of the RKBExplorer by using a very high threshold value, and variants of first name and patronymic have been compared with a lower threshold. At this stage, we are more interested in recall than in precision, and false positive results are quite common. Approximate name matching is a prerequisite for ensuring the completeness of the search, as unusual versions of the Latin spelling of the Russian names not covered by the rules of transliteration were regularly detected. For example, a person named as A.P. Yershóv has been found in the RKB Explorer DBLP.

The result of this procedure is a list of persons of the Open Archive who have matching persons in a dataset of the RKBExplorer. As a rule, a person of the Open Archive has several matches in the RKBExplorer with distinct spellings, and each person of the RKBExplorer has its own list of publications. For example, we have discovered 18 distinct persons whose *akt:full-name* is Andrei P. Ershov, two persons with *akt:full-name* as Andrew Yershov, another two persons whose *akt:full-name* is A.P. Yershóv, one person named as A. Ershov, and one person whose name is A. Yershov at the RKB Explorer DBLP.

The person identified as http://dblp.rkbexplorer.com/id/people-e1ac8593dbc7db6ec5766ea313914be4-1211d4d9974a0a977bd166da859d-928f and named as Andrei P. Ershov is the author of the "Mixed computation in the class of recursive program schemata". Another person identified as http://dblp.rkbexplorer.com/id/people-e1ac8593-dbc7db6ec5766ea313914be4-2fd1e3b39206345ab05fd9be97bc0d00 and named as Andrei P. Ershov has a publication entitled "Time sharing: the need for re-orientation." Another person identified as http://dblp.rkbexplorer.com/id/people-8d3 cb5ddb6e9bf9c359369b3cf3fb965-955fb11eb7908a9dd2bb137161f8cb3d and named as Andrew Yershov is the author of paper entitled "Unified

Evaluation System for Audio Steganography Methods".

By checking the DBLP Computer Science Bibliography, the counterpart of RKB Explorer DBLP, we can find persons with the same names and the same publications. The only difference between RKB Explorer DBLP and the DBLP Computer Science Bibliography is that the DBLP Computer Science Bibliography brings persons with equal full-names together: there is one person per one variant of a name. Thus, there are five persons who might be a homonym of Andrei Petrovich Ershov of the SB RAS Open Archive: Andrei P. Ershov, Andrew Yershov, A.P. Yershóv, A. Ershov, A. Yershov. Each of these persons has its own lists of publications. A person identified as A. Ershov has a publication "A. Ershov, A. Nariniany, I. Mel'chuk: RITA – An Experimental Man-Computer System On A Natural Language Basis. IJCAI 1975: 387-390", and a person named as A.P. Yershóv has the following two publications:

1) A. P. Yershóv: **ALPHA – An Automatic Programming System of High Efficiency.** J. ACM 13(1): 17-24 (1966)

2) A. P. Yershóv: **One View of Man-Machine Interaction.** J. ACM 12(3): 315-325 (1965)

Experiments with other persons of the Open Archive have shown that the publications of people with Russian names written in English are scattered between several "virtual" persons. On the other hand, the publications of several distinct persons are often attributed to one person. A similar situation is observed with the counterparts of the RKBExplorer data sets. It means that we have to answer the following questions:

1. Which of these identifiers correspond to the same physical object, and, therefore, can be connected by the relation *owl: sameAs* and which of them describe distinct physical objects?

2. Do all publications attributed to a person belong to this person?

This is a well-known name ambiguity problem. Of course, name disambiguation has an extensive literature [16]. Personal names can be disambiguated by comparing attributes and relations associated with

each entity using facts such as e-mail, personal website, affiliation, etc. However, it is important to note that datasets such as the DBLP have their own authority control and disambiguation procedures [17]. The fact of the existence of several "virtual persons" corresponding to one real-world person in this data set indicates that the conventional methods of entity linking have failed and that additional efforts in entities disambiguation need to be made.

An additional source of information is the Open Archive itself as it provides the so-called "track records" – a list of affiliations with a related period for every person. Basically, these data could be used to disambiguate persons by comparing them with the data of RKB-Explorer (if available). Regrettably, there is little or no information about affiliations and job periods are not specified at all. This is the reason why we are trying to answer these questions by checking full-text versions of the publications.

Besides, authors usually cite their earlier publications. This might allow several people with distinct identifiers but related with the self-citation relation to be considered as a single person. The citation information is represented by the *akt:cites-publication-reference* relation on RKBExplorer. This information is also incomplete. The citation network generated on the basis of the *akt:cites-publication-reference* relationship between the publications of a single author is sparse, with many isolated nodes. However, this information can be also extracted from the text of a paper. Nowadays, plenty of full-text resources are becoming available, which enables an increased knowledge discovery.

The first group of our experiments has been carried out using Academician A. Ershov's Archive. A complementary data source was the digital library SpringerLink. Finally, a significant number of publications have been available online. Two heuristics have been tested.

1) **Check the workplace and its dates**. The publication date and authors' affiliation are extracted from the textual version of the publication and compared with the person's list of jobs of the Open Archive.

2) **Check the self-citation list**. The name of the author of each publication is compared with the names of the authors of cited publi-

cations. If a coincidence of the names is found, the current publication is added to the set of the publications of the reference list. Then, the same procedure is applied to the added publications.

Here are several examples demonstrating our approach.

**Example 1.** (A. Ershov vs. A. P. Yershóv)

The list of the publications of the person referred to as http://dblp.rkbexplorer.com/id/people-caaa3c31d151bb7e83f5d6b37aa9de2e-855ed1acf622531e224916a6afa900fb in the RKBExplorer.com data set and having the *akt:full-name* attribute equal to "A. Ershov" contains a single entry referred to as "A. Ershov, A. Nariniany, I. Mel'chuk RITA – An Experimental Man-Computer System on A Natural Language Basis".

Does this publication belong to Academician A.P. Ershov from the SB RAS Open Archive and as such, should it potentially fall into the list of all publications attributed to the RKB Explorer DBLP person with the *akt:full-name* attribute, equal to Andrei P. Ershov? Since we have Academician A. Ershov's Archive at our disposition, it suffices to compare this title with the titles of the papers specified in this archive to answer positively.

If such information were not be available, we would have to apply a more complex procedure: to extract the author's name, title, affiliation, and the list of references from the text of the publication (available online).

The author of the textual version is specified as "A. P. Ershov"; his affiliation is "Computing Center, 630090, Novosibirsk, USSR", which matches the data of the Open Archive. In this way, we obtain another affirmative answer to our question.

The text analysis of this publication has an additional value: it allows us to correctly identify another paper attributed to the person referred to as http://dblp.rkbexplorer.com/id/people-5c092dbe2d3183e777182210f00d40b4-faefb1714b3e31775353e4fae216a87e and having the attribute akt:full-name, equal to "A. P. Yershóv". This person has the publication entitled "One View of Man-Machine Interaction" mentioned in the list of references of the publication "RITA – An Experimental Man-Computer System on A Natural Language Basis". Thanks

to this information, persons with differing names can be merged and matched with a single person of the Open Archive. By checking the list of publications in Academician A. Ershov's Archive we can validate this choice. The self-citation network of Academician A. P. Ershov is shown in Fig. 3.

**Example 2.** (A paper not mentioned in the Academician A. Ershov's Archive) The paper "Axiomatics for memory allocation" is attributed to the person identified as http://dblp.rkbexplorer.com/id/-peoplee1ac8593dbc7db6ec5766ea313914be4-ea3c7cab911196a0b2f40f9f0a1242e2 and named Andrei P. Ershov by RKB Explorer DBLP. However, this title does not exist in Academician A. Ershov's Archive. On the other hand, the SpringerLink digital library attributes this paper to Prof. A.P. Ershov and indicates his affiliation as "Computing Center, 630090, Novosibirsk, USSR". In addition, "Axiomatics for memory allocation" is mentioned in the reference list of another publication "The Transformational Machine: Theme and Variations" attributed to Academician A.P. Ershov by both Academician A. Ershov's Archive and RKB Explorer DBLP. Taking into account this information, it is possible to attribute the paper to Academician A.P. Ershov and add it to the Open Archive. This situation is illustrated in Fig. 4. The leftmost column corresponds to Academician A. Ershov's Archive, the central column – to SpringerLink, and the rightmost column – to RKB Explorer DBLP.

## Conclusion

In this paper, we have considered the problem of populating the scholarly knowledge base using bibliographic data sets of LOD cloud and approaches to its solution. It was demonstrated that the conventional tools used for name disambiguation perform poorly in the cross-language context. We have proposed new heuristics, using additional information extracted from full text sources of data. The first heuristics uses the full record track of a person and the second one uses self-citation networks.

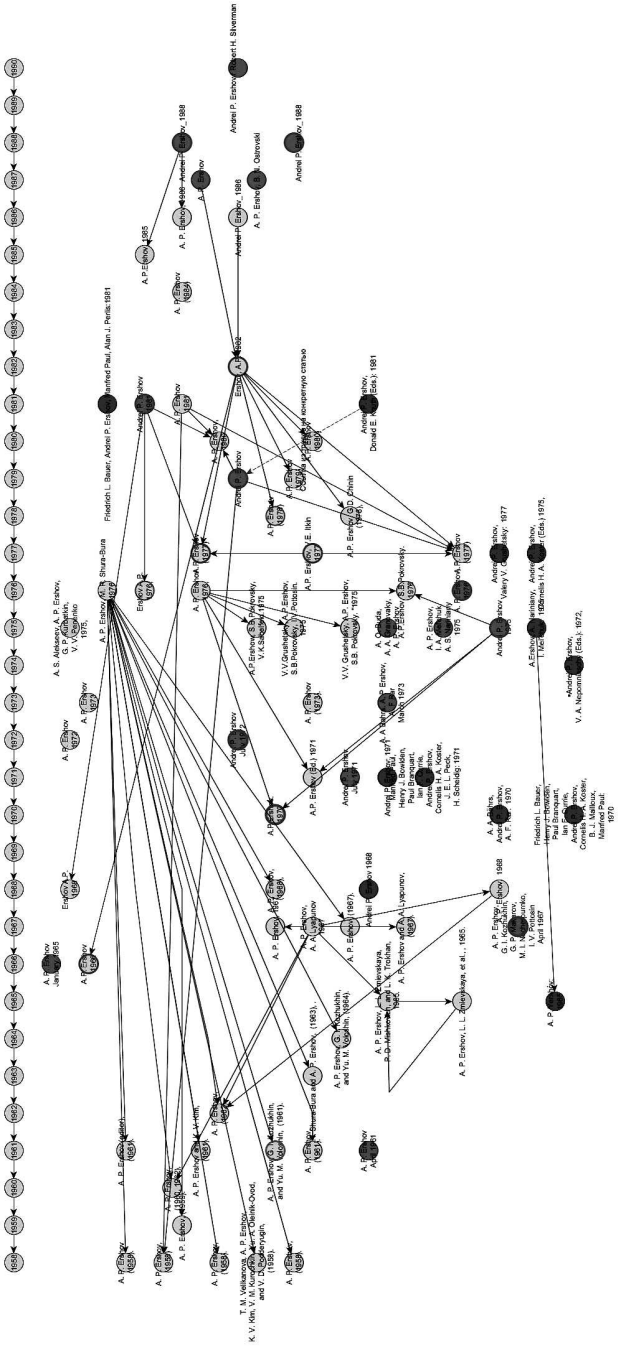

Figure 3. Self-citation network of Academician A. P. Ershov

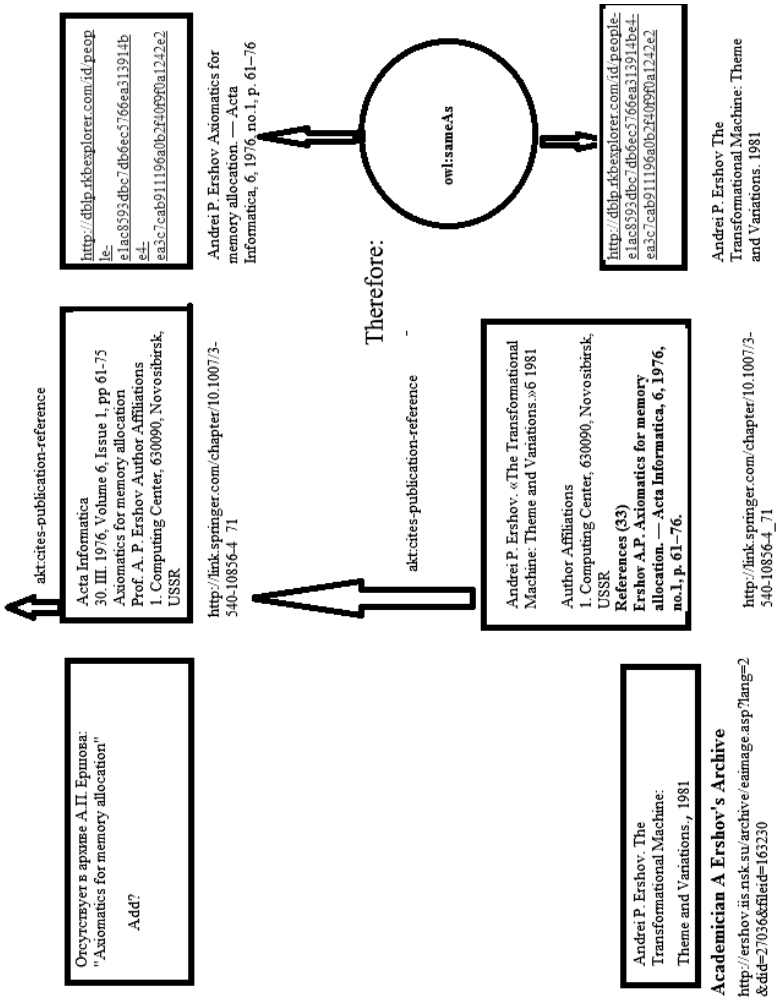


Figure 4. The relationship between the two publications in the three databases

To verify this approach, we have compared the data extracted from the RKBExplorer datasets with the data of Academician A. Ershov's archive and eLIBRARY.RU. The experiments allowed us to identify as a single person many different persons of RKBExplorer.com. Besides, several publications by Academician A.P. Ershov missing from Academician A. Ershov's archive, and several newer-existing papers attributed to him have been discovered. However, this approach needs further development and experiments. We plan to use full-sized citation networks for our experiments.

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