Evaluation of Inria theme
Data and Knowledge Representation and Processing

Project-team mOeX

https://moex.inria.fr/

03/10/2019

Project-team title: evolving knowledge

Scientific leader: Jérôme Euzenat

Research centers: Grenoble Rhône-Alpes

Common project-team with: Univ. Grenoble Alpes (UGA)

1 Personnel

Current composition of the project-team:

Research scientists and faculty members:
- Manuel Atencia, Associate professor (UGA)
- Jérôme David, Associate professor (UGA)
- Jérôme Euzenat, Research director (INRIA)

Ph.D. students:
- Yasser Bourahla (joining 2019-10-01)
- Khadija Jradeh
- Line van den Berg

Administrative assistant:
- Alexandra Fitzgerald

Personnel at the start of the evaluation period (01/01/2016)

	INRIA	CNRS	University	Other	**Total**
DR (1) / Professors	1				**1**
CR (2) / Assistant professors			2		**2**
ARP and SRP (3)					
Permanent engineers (4)					
Temporary engineers (5)					
Post-docs					
PhD Students	2		1		3
Total	**3**		**3**		**6**

(1) "Senior Research Scientist (Directeur de Recherche)"
(2) "Junior Research Scientist (Chargé de Recherche)"
(3) "Inria Advanced Research Position" and "Inria Starting Research Position"
(4) "Civil servant (CNRS, INRIA, ...)"
(5) "Associated with a contract (Ingénieur Expert, Ingénieur ADT, . . .)"

Personnel at the time of the evaluation (03/10/2019)

	INRIA	CNRS	University	Other	**Total**
DR / Professors	1				**1**
CR / Assistant professors			2		**2**
ARP and SRP					
Permanent engineers					
Temporary engineers					
Post-docs					
PhD Students	1		2		**3**
Total	**1**		**4**		**6**

Changes in the scientific staff

DR / Professors / ARP CR / Assistant Professors / SRP	INRIA	CNRS	University	Other	**Total**
Arrivals					**0**
Departures					**0**

Current position of former project-team members

- Tatiana Lesnikova, PhD 2016, post-doc 2016, currently engineer at Cognizant, Lyon
- Armen Inants, PhD 2016, currently post-doctoral researcher at INRIA (Convecs team), Grenoble (after working for the HeadSense company and the American University of Armenia).
- Zhengjie Fan, PhD 2014, currently researcher at China mobile, Beijing
- Melisachew Wudage Chekol, PhD 2012, currently post-doctoral researcher at Universität Mannheim

Last INRIA enlistments

None.

Other comments:

Moex started officially in 2017 (created as an INRIA team in November 2017), following the Exmo team.

The permanent team membership is 2 full-time equivalent researchers. There is no evolution of the permanent team membership since 2013.

Concerning non permanent members, we trained relatively few PhD students during the period: two finished at the very beginning of the period and two started at the end. This is the result of project funding availability (funding for a PhD requires at least a three years project, and is usually assigned at the start, and given the size of the team we cannot carry out too many such projects at once).

2 Research goals and results

2.1 Keywords

Artificial intelligence – Knowledge representation – Knowledge extraction – Relational concept analysis – Semantic Web – Ontology matching – Data interlinking – Multi-agent simulation – Cultural evolution – Reproducibility

2.2 Context and overall goals of the project

This section is devoted to the activities of the last year of the Exmo team (2016) and the first three years of the Moex team (2017–2019). The two teams show both continuity and rupture.

Exmo has been dedicated to the development of the semantic web since 2000. The semantic web blends the communication capabilities of the web with knowledge representation. The goal of Exmo was the development of theoretical, experimental and software tools for communicating formalised knowledge. In particular, we developed a unique expertise in the domain of **ontology matching**: finding and exploiting relationships between ontological entities. We contributed defining the notion of ontology alignments (the set of relationship between two ontologies), developing software to support their manipulation (the Alignment API), designing algorithms to match ontologies, and initiating and running the yearly campaign on matcher evaluation (OAEI). In the period, we completed our work on the use of algebras of relations for expressing alignments. However, we estimate that our contributions to this field are behind ourselves, hence this topic is not any more a Moex objective and will not be presented here.

On the contrary, since 2010 we have invested in **data interlinking**, i.e. finding links between resources described in the Resource Description Framework (RDF). This is very important task to exploit linked open data, i.e. RDF data sources available on the web. This activity is continued in Moex and led to various results: the investigation of techniques to interlink cross-lingual data sources, the design of probabilistic rule-based methods for data interlinking, the development of a generalisation of keys, link keys, to identify resources.

As a new direction, Moex addresses the **evolution of knowledge** representations in individuals and populations. This is an important and challenging topic in the context of the semantic web, as well as more widely whenever knowledge is not simply learnt and exploited, but has to be communicated, e.g. social robotics. We aim at acquiring a precise understanding of knowledge evolution through the consideration of a wide range of situations, representations and adaptation operators. For that purpose, we combine knowledge representation and cultural evolution methods. The former provides formal models of knowledge; the latter provides a well-defined framework for studying situated evolution. We consider knowledge as culture and study the global properties of local adaptation operators applied by populations of agents by jointly:

- *experimentally* testing the properties of adaptation operators in various situations using experimental cultural evolution, and
- *theoretically* determining such properties by modelling how operators shape knowledge representation.

2.3 Research axis 1: Cultural knowledge evolution

Personnel

Permanent researchers: Jérôme Euzenat, Manuel Atencia, Jérôme David
PhD students: Line van den Berg[2018–10→]

Project-team positioning

Cultural evolution considers how culture spreads and evolves with human societies [R13]. It started in anthropology but is now considered in a variety of fields. In computer science, after the pionneering experiments of Robert Axelrod [R5], Luc Steels developed a broad programme applying convincingly experimental cultural evolution to natural language [R18].

Continuing this thread, cultural knowledge evolution considers knowledge as the culture of a population of agents that evolves through communication with other agents and learning from the environment. Knowledge, as developed in artificial intelligence, may be considered as a kind of culture which may better evolve seredenpitously than through one-shot ontology matching.

Work has recently been developed for evolving alignments between ontologies. It can be used to repair alignments better than blind logical repair [R9], to create alignments based on entity descriptions [R1], to learn alignments from dialogues framed in interaction protocols [R4, R7], or to correct alignments until no error remains [R6][16] and to start with no alignment [15]. Each study provides new insights and opens perspectives.

The specific position of Moex is its goal to explore this field in more breadth and depth: not necessarily stopping at alignment evolution but considering all knowledge evolution as well as the evolution of the social structure, and considering changing environments and different agent populations.

Scientific achievements

2.3.1 Experiments in cultural alignment repair

We tested experimental knowledge evolution on alignment repair, i.e. the improvement of incorrect ontology alignments. For that purpose, agents only know about their ontologies and alignments with others' ontologies and they act in a fully decentralised way. We performed a series of experiments in which agents react to failures in playing a simple game (guessing the class of an object). They apply adaptation operators to their knowledge (the alignments) in order to avoid repeating the same mistake. We showed that cultural alignment repair is able to converge towards successful communication through improving the objective correctness of alignments [R9].

Expansion and relaxation We repeated these experiments and, using new measures, showed that the quality of previous results was underestimated. We allowed agents to go beyond the initial operators of [R9] in two ways [16]: they can generate new correspondences when they discard incorrect ones, and they can provide less precise answers. The combination of these modalities satisfies the following properties: (1) agents still converge to a state in which no mistake occurs, (2) they achieve results far closer to the correct alignments than was previously found, (3) they reach 100% precision and coherent alignments.

Starting with empty alignments The former results suggest that agents could develop alignments from scratch. We explored the use of expanding repair operators for that purpose. When starting from empty alignments, agents fail to create them as they have nothing to repair. Hence, we introduced the capability for agents to risk adding new random correspondences when no existing one is useful [15]. With it, when starting with empty alignments, alignments reach the same quality level as when starting with random alignments, thus providing a reliable way for agents to build alignments from scratch through communication.

Strengthening Our previous work was still missing some correspondences, and, thus, did not achieve 100% recall. We had conjectured that this was due to a phenomenon called reverse shadowing [16] that prevents finding specific correspondences.

We introduced a new adaptation modality, called strengthening, to test this hypothesis. The strengthening modality replaces a successful correspondence by one of its subsumed correspondences covering the current instance. This modality is different from those developed before, because it requires agents to adapt their alignments when the game played is successful (previously, it only occured in case of failure).

We experimentally showed that, as expected, recall was greatly increased, to the point that some operators achieve 99% F-measure. However, the agents still do not reach 100% recall.

Populations We started taking the population standpoint on experimental cultural evolution. For that purpose we introduced the concept of population within the experiments. So far, a population is characterised as a set of agents sharing the same ontology. Such agents play the same alignment repair games as before with agents of other populations.

The notion of population enables to experiment with different transmission mechanisms found in cultural evolution: vertical transmission, in which culture spreads, like genes, from parents to sibblings, and horizontal transmission, in which it spreads among all members of a population. We implemented explicit horizontal transmission through a synchronisation procedure in which, at a given interval, agents of the same population exchange their knowledge, i.e. alignments.

The synchronisation procedure is reminiscent of what is called 'alignment' in [R18] and which is described as always speeding up game convergence. It was thus our surprise to observe that in the case of the alignment repair game, it was actually slowing it down. The explanation lies in the type of implemented synchronisation: if agents exchange the information they have, they tend to be very conservative, though if they exchange the information they gained, this would spread adoption.

Link with interactor-replicator Cultural evolution may be studied at a 'macro' level, inspired from population dynamics, or at a 'micro' level, inspired from genetics. The replicator-interactor model generalises the genotype-phenotype distinction of genetic evolution. We considered how it can be applied to cultural knowledge evolution experiments [17]. More specifically, we consider knowledge as the replicator and the behaviour it induces as the interactor. We showed that this requires to address problems concerning transmission. We discussed the introduction of horizontal transmission within the replicator-interactor model and/or differential reproduction within cultural evolution experiments.

2.3.2 Modelling in dynamic epistemic logic

We explored how closely these operators resemble logical dynamics. We developed a variant of Dynamic Epistemic Logic to capture the dynamics of the cultural alignment repair game. The ontologies are modelled as knowledge and alignments as beliefs in a variant of plausibility-based dynamic epistemic logic. The dynamics of the game is achieved through (public) announcement of the game issue and the adaptation operators are defined through conservative upgrades, i.e. modalities that transform models by reordering world-plausibility. This allowed us to formally establish some limitations and redundancy of the operators [21]. More precisely, for a complete logical reasoner, the operators are redundant and some may be inconsistent with the agent knowledge.

These results hold for one agent in the game but not necessarily for the other that may not know the classes by which the alignment is repaired, nor the relations between them. The former can be dealt with by declaring that agents are aware of the signature of both ontologies (public signature assumption) but this does not allow ontologies to evolve. We are currently investigating partial semantics as a more dynamic alternative solution to this problem.

This work is part of the PhD thesis of Line van den Berg.

2.3.3 Experiment reproducibility

Experiments are described and performed in our *Lazy lavender* platform which offers scripts to specify, run, and analyse experiments. We document them so that others and ourselves can repeat them, eventually leading to reproducibility. Although these descriptions may currently be considered ad hoc, they are a first step towards automated experiment performance and analysis. In particular, *Lazy lavender* generates a Docker container specification that can perform experiments in the same conditions or with updated software. The publication of the experiments on our Wiki platform is also eased by this process.

Collaborations

So far, this work has been independently developed.

At the occasion of the MIAI chair (see §4), we plan to work with local (Nabil Layaïda, Pierre Genevès, Tyrex; Yves Demazeau, LIG) and international (Valentina Tamma and Terry Payne, U. Liverpool; Luciano Serafini, FBK Trento; Marco Schorlemmer, IIIA Barcelona) colleagues.

External support

This activity receives currently no external support.

Our MIAI chair on Knowledge communication and evolution focusses on this topic (see §4).

2.4 Research axis 2: Link keys for data interlinking

Personnel

Permanent researchers: Manuel Atencia, Jérôme David, Jérôme Euzenat
PhD students: Tatiana Lesnikova$^{\rightarrow 2016-12}$, Khadija Jradeh$^{2018-10\rightarrow}$

Project-team positioning

Links are important for the publication of RDF data on the web. We call data interlinking the process of generating links identifying the same resource described in two data sets. Data interlinking parallels ontology matching: from two data sets it generates a set of links between entity identifiers of both data sets corresponding to the same resource.

Different approaches and methods have been proposed to address the problem of automatic data interlinking [R10, R14]. Two main trends are used to tackle this problem: numerical methods and logical methods. Numerical methods usually compute a similarity between resources based on their property values to establish links between those that are very similar [R15, R19]. Logical methods use an axiomatic characterisation of what makes two resources the same. Such characterisations are usually keys [R17, R3] or rules [R12][10]

We have introduced the notion of a link key extending database keys in a way which is more adapted to the context of description logics and the openness of the semantic web. A *link key expression* [3] specifies the pairs of properties to compare for linking individuals belonging to different classes of the data sets. An example of a link key expression is:

$$\{\langle \mathsf{auteur}, \mathsf{creator}\rangle\}\{\langle \mathsf{titre}, \mathsf{title}\rangle\}\ \mathit{linkkey}\ \langle \mathsf{Livre}, \mathsf{Book}\rangle$$

stating that whenever an instance of the class Livre has the same values for the property auteur as an instance of class Book has for the property creator and they share at least one value for their property titre and title, then they denote the same entity.

Link keys express conditions under which instances of two classes of different RDF data sets may be considered as equal. As such, they can be used for data interlinking. Link keys are not necessarily made of keys and may exist even when there exist no keys. We had designed algorithms to extract link key candidates from RDF data sets and different measures have been defined to evaluate the quality of link key candidates individually [R2].

Scientific achievements

2.4.1 Link key extraction

During the period, we investigated the relationships of the algorithm of [R2] with formal concept analysis, and we proved their equivalence. We also extended the approach with the help of relational concept analysis. This yields an elegant formulation of extracting link keys in presence of circular dependencies (§2.4.1).

The work on link key extraction is implemented in our Linkex prototype (§3.2).

Link key extraction and relational concept analysis We first described our extraction approach [R2] in the framework of formal context analysis (FCA, [R11]). We recently showed that link keys extracted by formal concept analysis are equivalent to an extension of those which were extracted by our former algorithm [R2].

Furthermore, we used relational concept analysis (RCA, [R16]), an extension of FCA taking relations between concepts into account. We showed that it is possible to encode the link key extraction problem in RCA to extract the optimal link keys even in the presence of cyclic dependencies [3]. Moreover, the proposed process does not require information about the alignments of the ontologies to find out from which pairs of classes to extract link keys.

Link key extraction under ontological constraints We investigated the use of link keys taking advantage of ontologies. This can be carried out in two different directions: exploiting the ontologies under which data sets are published, and extracting link keys using ontology constructors for combining attribute and class names.

Following the latter approach, we extended our existing algorithms to extract link keys involving inverse ($^{-1}$), union ($\sqcup$), intersection ($\sqcap$) and paths ($\circ$) of properties. This helps providing link keys when it is not possible otherwise (without inverse, there is no correct correspondence if one data set is using the parent property and the other is using a child property). We showed how the paths could be normalised to reduce the search space.

We evaluated this method on real data sets; this resulted in finding the correct link keys that could not be found without them.

Combining link keys For certain data sets, it may be necessary to use several link keys, even on the same pair of classes, for retrieving a more complete link set. We introduced operators to combine link keys over the same pair of classes, investigated their relations and extended measures to evaluate their quality. We defined different link key composition operators and investigated strategies to extract the best disjunctions of link key candidates from RDF data.

2.4.2 Reasoning with link keys

Link keys can also be thought of as axioms in a description logic. As such, they can contribute to infer ABox axioms, such as links, terminological axioms, or other link keys. Yet, no reasoning support existed for link keys. We extended the tableau method designed for the $\mathcal{ALC}$ description logic to support reasoning with link keys in $\mathcal{ALC}$ [18]. In the context of the Elker project, we extended this work. We showed how this extension enables combining link keys with classical terminological reasoning with and without ABox and TBox and generating non-trivial link keys. We have proven that this method terminates, is sound, complete, and that its complexity is 2EXPTIME.

This work is part of the PhD thesis of Khadija Jradeh, co-supervised with Chan Le Duc (LIASD).

2.4.3 Other data interlinking approaches

The following activities are the last ones carried out in the Exmo project. They are related to data interlinking.

Dealing with uncertainty in data interlinking We had modelled the problem of data interlinking as a reasoning problem on possibly decentralised data and designed an import-by-query algorithm that alternates steps of sub-query rewriting and of tailored querying of data sources. To effectively deal with incomplete and noisy data and to exploit uncertain knowledge, we introduced a framework based on probabilistic Datalog for modelling uncertain RDF facts and rules. We have designed an algorithm, ProbFR, based on this framework. Experiments on real-world data sets have shown the usefulness and effectiveness of these approaches for data linkage and disambiguation [10].

This work was part of the PhD thesis of Mustafa Al-Bakri, co-supervised with Marie-Christine Rousset (LIG/Slide), and developed in the Qualinca project.

Interlinking cross-lingual RDF data sets RDF data sets are being published with labels that may be expressed in different languages. Even interlinking systems based on graph structure ultimately rely on anchors based on language fragments. We proposed a general framework for interlinking RDF data in different languages and implemented two approaches: one approach is based on machine translation, the other one takes advantage of multilingual references, such as BabelNet.

Concerning machine translation for interlinking concepts, we conducted two experiments involving different thesauri in different languages. The first experiment involved concepts from the TheSoz multilingual thesaurus in three languages: English, French and German. The second experiment involved concepts from the EuroVoc and AgroVoc thesauri in English and Chinese respectively. We demonstrated that machine translation is beneficial for cross-lingual thesauri interlinking independently of a data set structure [20]. Concerning multilingual references, we found that results were not as good as the translation approach.

This work was part of the PhD of Tatiana Lesnikova [2] developed in the LINDICLE project (§4).

Collaborations

We collaborate with our partners from the ELKER project on data interlinking but most specifically on link keys:

- Amedeo Napoli, Miguel Couceiro, Nacira Abbas (Orpailleur, Nancy)
- Chan Le Duc, Myriam Lamolle, Jérémy Lhez (LIASD, Univ Paris 8)
- Marie-Christine Rousset (LIG, Grenoble)

We also collaborate within the CNRS PEPS RegleX-LD with:

- Cássia Trojahn, Élodie Thiéblin (IRIT, Toulouse)
- Fatiha Saïs, Nathalie Pernelle (LRI, Orsay)
- Liliana Ibanescu (INRA, Paris)

This allowed to start a collaboration on the extraction of link keys based on complex alignments.

Cross-lingual data interlinking was performed in the context of the ANR LINDICLE project in collaboration with Juanzi Li (Tsinghua U.) and Zhichun Wang (Beijing Normal U.).

External support

- This activity benefits from the ANR ELKER project support (§4). The work of §2.4.1 and 2.4.2 was partially supported by this project.
- Collaborations with the French ministry of culture and the Bibliothèque nationale de France have been supported by these actors (§4).
- We also participate in a small CNRS (PEPS) RegleX-LD action.

2.5 Self-assessment

We grouped the team self-assessment for both axes.

The main strength of the MOEX team is to be focussed on two precise and exciting topics:

- The study of link keys for which we have a precise workplan, reasonable funding and adapted collaborations.
- The development of the field of cultural knowledge evolution for which we have encouraging results and a lot of enthousiasm.

On both topics the members of the team have a good experience and visibility.

We previously involved a lot of our time transferring knowledge to the semantic web infrastructure and more recently to smart cities. We decided that it was time to go back to the drawing board to have something to transfer in the future. Thus, the profile of our research has been reoriented towards more fundamental research.

The transition between Exmo and Moex took more time and energy than expected. We managed to properly end Exmo before starting Moex. But this had impact on PhD trainees and publications. A remaining difficulty is the identification of the best research 'community' for our cultural knowledge evolution work.

The resources of the team are limited (2 equivalent full-time researchers) and, solicited on data interlinking. This is a weakness which leads to delay devoting efforts to knowledge evolution. The creation of an interdisciplinary artificial intelligence institute in Grenoble (MIAI) is a clear opportunity for the team. This is the reason why we have dedicated time in its elaboration.

2.6 Evolution of research directions during the evaluation period

The main evolution has been the transition between Exmo and Moex (described in §2.2). The objectives of Moex have not changed.

We have just started an effort to build pedagogical material for explaining our research, targeted towards children (see §3.7.2).

We plan to pursue our efforts towards reproducible research. There is also an opportunity to develop research on that topic by exploiting semantic web technologies in research product descriptions. However, in both cases, this cannot progress seriously without increased resources.

3 Knowledge dissemination

3.1 Publications

	year1 2016	year2 2017	year3 2018	year4 2019
PhD Theses	2			
H.D.R. (*)				
Journals			1	1
Conference proceedings (**)	3	2		
Workshop proceedings (**)	1	1	2	4
Book chapters	1	1		
Books (written)				
Books and journal (edited)		1	2	
Patents				
General audience papers				
Technical reports				

(*) HDR Habilitation à diriger des Recherches
(**) Conferences with a program committee

A few selected important publications are as below:

1. Jérôme Euzenat, Interaction-based ontology alignment repair with expansion and relaxation, Proc. 26th International Joint Conference on Artificial Intelligence (IJCAI), p. 185–191, Melbourne (AU), 2017 [16]
2. Manuel Atencia, Jérôme David, Jérôme Euzenat, Amedeo Napoli, Jérémy Vizzini, Link key candidate extraction with relational concept analysis, *Discrete applied mathematics*, 2019 [3]
3. Armen Inants, Manuel Atencia, Jérôme Euzenat, Algebraic calculi for weighted ontology alignments, Proc. 15th International semantic web conference, p. 360–375, Kobe (JP), 2016 [19]
4. Mustafa Al-Bakri, Manuel Atencia, Jérôme David, Steffen Lalande, Marie-Christine Rousset, Uncertainty-sensitive reasoning for inferring sameAs facts in linked data, Proc. 22nd european conference on artificial intelligence (ECAI), p. 698–706, Der Haague (NL), 2016 [10]

Major journal in the field (and publications by the team):

1. *Journal of web semantics*
2. *Semantic web journal*
3. *Artificial intelligence*
4. *Journal of artificial intelligence research*

Major conference in the field (and publications by the team):

1. International Semantic Web Conference (ISWC, ≈20%) (1)
2. International Joint Conference on Artificial Intelligence (IJCAI, ≈15%) (1)
3. European Conference on Artificial Intelligence (ECAI, ≈30%) (1)
4. International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS, ≈24%)

3.2 Software

Alignment API http://alignapi.gforge.inria.fr

We have designed a format for expressing alignments in a uniform way. The goal of this format is to share available alignments on the web. The API itself [R8] is a Java

description of tools for accessing the common format. We provide an implementation for this API which can be used for producing transformations, rules or bridge axioms independently from the algorithm which produced the alignment.

It further integrates the implementation of link keys in the EDOAL language and their transformations into SPARQL queries (§2.4).

The Alignment API is used in the Ontology Alignment Evaluation Initiative data and result processing. It is also used by more than 60 other teams worldwide[1].

The Alignment API is freely available since december 2003, under the LGPL licence and has been registered by APP.

LINKEX https://gitlab.inria.fr/moex/linkex

LINKEX is a tool for extracting and evaluating link key candidates between two RDF data sets. It is aimed at integrating our results on the topic (see §2.4.1). It implements the extraction of candidates with formal concept analysis. It is able to extract candidates with inverse and composed properties and to generate compound link keys.

LINKEX can evaluate link keys candidates using various measures, including our discriminability and coverage. It can also evaluate them according to reference set of links given as input. The set of candidates can be rendered within the Alignment API's EDOAL language or in dot. The Alignment API can generate other formats.

Lazy lavender https://lazylav.gforge.inria.fr/

Lazy lavender is a simulation tool for cultural knowledge evolution, i.e. running randomised experiments with agent adjusting their knowledge while attempting to communicate. It is the basis of our work on cultural knowledge evolution.

The web site also features detailed report and data from the performed experiments and directions to repeat them.

We self-rank our (meaningful) software on the INRIA scale:

	Audience	Originality	Maturity	Maintainance	Distribution
Alignment API	4	4	4	3	5
LINKEX	3	4	3↗4	3	4
Lazy lavender	3	4	4	3	4

All our software are open source and distributed along a permisive license (LGPL and/or CeCILL-C).

3.3 Technology transfer and socio-economic impact

We have had two small contracts with the French ministry of culture in 2018:

- The first one, Ginco V3 consisted of supervising the integration of our ontology matching software within their terminology management system (Ginco).
- The second one consisted of evaluating data interlinking solutions on bibliographic data resources from the ministry, the French national library and the bibliographic agency for higher eduction (ABES). This work is likely to continue, even in the absence of support, in particular to evaluate the solutions developed in the ELKER project.

3.4 Teaching

3.4.1 Responsibilities

- Jérôme David is coordinator of the Master "Mathematiques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes);

[1] https://alignapi.gforge.fr/impl.html

– Manuel Atencia has been coordinator of option "Web, Informatique et Connaissance" of the first year of Master "Mathematicques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes) until 2017;
– Manuel Atencia is co-responsible of the 2nd year of Master "Mathematiques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes), since 2017;
– Jérôme Euzenat has been coordinator of the "AI and the web" option of the second year of research Master in computer science and applied mathematics (Univ. Grenoble Alpes) until 2018.

3.4.2 Lectures

– Licence: Jérôme David, Algorithmique et programmation par objets, 70h/y, L2 MIASHS, UGA, France
– Licence: Jérôme David, Introduction à Python, Licence ESSIG, 24h/y, UGA, France
– Licence: Jérôme David, Système, L3 MIASHS, 18h/y, UGA, France
– Licence: Manuel Atencia, Technologies du web, LP ESSIG, 18h/y, UGA, France
– Licence: Manuel Atencia, Introduction aux technologies du Web, 60h/y, L3 MIASHS, UGA, France
– Master: Jérôme David, Programmation Java 2, 30h/y, M1 MIASHS, UGA, France
– Master: Jérôme David, JavaEE, 30h/y, M2 MIASHS, UGA, France
– Master: Jérôme David, Développement Web Mobile, 30h/y, M2 MIASHS, UGA, France
– Master: Jérôme David, Web sémantique, 3h/y, M2 MIASHS, UGA, France
– Master: Jérôme David (until 2017), Manuel Atencia (since 2018), Formats de données du web, 30h/y, M1 MIASHS, UGA, France
– Master: Manuel Atencia, Introduction à la programmation web, 30h/y, M1 MIASHS, UGA, France
– Master: Manuel Atencia, Intelligence artificielle, 7.5h/y, M1 MIASHS, UGA, France
– Master: Manuel Atencia, Web sémantique, 27h/y, M2 MIASHS, UGA, France
– Master: Jérôme Euzenat (until 2016), Manuel Atencia (since 2017), Semantic web: from XML to OWL, 22.5h/y, M2R MoSIG, UGA, France
– Master: Jérôme David (since 2017), Stage de programmation, 10h/y, M2 MIASHS, UGA, France
– Post-graduate level: Jérôme Euzenat, "Ontology matching", 1h30, Tutorial, 13th international conference on concept lattices and applications (CLA), Moskow (RU), 2016

3.5 Supervision

3.5.1 PhD

– Armen Inants, "Qualitative calculi with hererogeneous universes", Univ. Grenoble Alpes, 2016-04-25 (Jérôme Euzenat)
– Tatiana Lesnikova, "RDF data interlinking: evaluation of cross-lingual methods", Univ. Grenoble Alpes, 2016-05-04 (Jérôme David and Jérôme Euzenat)
– Nacira Abbas, "Link key extraction and relational concept analysis", in progress since 2018-10-01 (Jérôme David and Amedeo Napoli)
– Khadija Jradeh, "Reasoning with link keys", in progress since 2018-10-01 (Manuel Atencia and Chan Le Duc)
– Line van den Berg, "Knowledge Evolution in Agent Populations", in progress since 2018-10-01 (Manuel Atencia and Jérôme Euzenat)

3.5.2 Master

- Mashruf Chowdury, "Agreement and disagreement between ontologies", M2R Informatics, Univ. Grenoble Alpes, June 2016
- Irina Dragoste, "Ontology evolution through interaction", M2R Informatics, Univ. Grenoble Alpes, September 2016
- Maroua Gmati, "Reasoning with link keys", M2R Informatics, Univ. Grenoble Alpes, June 2016
- Jérémy Vizzini, "Data interlinking with relational concept analysis", M2R Informatics Data science, Univ. Grenoble Alpes, June 2017
- Iris Lohja, "Improving semantic recall of ontology alignments in cultural knowledge evolution", M2R Informatics, Univ. Grenoble Alpes, June 2018
- Khadija Jradeh, "Link key extraction under ontological constraints", M2R Informatics, Univ. Grenoble Alpes, June 2018
- Fatima Danash, "Horizontal and vertical knowledge transmission in experimental cultural knowledge evolution", M2R Informatics, Univ. Grenoble Alpes, June 2019

3.6 Juries/PhD panels

- Jérôme Euzenat had been external examiner of the computer science PhD of Filip Radulovic (Universidad Politécnica de Madrid) "RIDER: a recommendation framework for exploiting evaluation results and user quality requirements" supervised by Asunción Gómez-Pérez, 2016
- Manuel Atencia had been external examiner of the computer science PhD of Daniel Vila Suero (Universidad Politécnica de Madrid) "A framework for ontology-based library data generation, access and exploitation" supervised by Asunción Gómez-Pérez and Jorge Gracia del Rio, 2016
- Jérôme Euzenat had been external examiner of the computer science PhD of Damien Graux (Université Grenoble Alpes) "On the efficient distributed evaluation of SPARQL queries" supervised by Nabil Layaïda and Pierre Genevès, 2016
- Jérôme Euzenat had been panel chair of the computer science PhD of Anthony Hombiat (Université Grenoble Alpes) "OF4OSM: Un méta-modèle pour structurer la folksonomie d'OpenStreetMap en une nouvelle ontologie" supervised by Jérôme Gensel and Marlène Villanova-Oliver, 2017
- Jérôme Euzenat had been reviewer of the computer science PhD of Nguyen Thinh Dong (Université Paris 8 – Vincennes) "Révision d'ontologies fondée sur tableaux" supervised by Myriam Lamolle and Chan Le Duc, 2017
- Jérôme Euzenat had been external examiner of the computer science PhD of Zlatan Dragisic (Linköping university) "Completion of ontologies and ontology networks" supervised by Patrick Lambrix, 2017
- Jérôme Euzenat had been panel chair of the computer science PhD of Jie Sun (Université Clermont-Auvergne) "Intelligent flood adaptive context-aware system" supervised by Kun Mean Hou, Gil de Sousa and Catherine Roussey, 2017
- Jérôme Euzenat had been external examiner of the computer science PhD of Abdelfettah Feliachi (Université Paris-Est) "Interconnexion et visualisation de ressources géoréférencées du Web de données à l'aide d'un référentiel topographique de support" supervised by Bénédicte Bucher, Fayçal Hamdi and Nathalie Abadie, 2017
- Jérôme Euzenat had been panel chair of the computer science PhD of Abdullah Abbas (Université Grenoble-Alpes) "Static analysis of semantic web queries with ShEx schema constraints" supervised by Nabil Layaïda, Pierre Genevès and Cécile Roisin, 2017

- Jérôme Euzenat had been reviewer of the computer science PhD of Quentin Cohen-Solal (Université de Caen-Normandie) "Un cadre algébrique pour le raisonnement qualitatif en présence d'informations hétérogènes: application aux raisonnements multi-échelle et spatio-temporel" supervised by Maroua Bouzid and Alexandre Niveau, 2017
- Jérôme David had been panel member of the computer science PhD of Valentina Beretta (IMT Mines Alès) "Évaluation de la véracité des données: améliorer la découverte de la vérité en utilisant des connaissances a priori" supervised by Sylvie Ranwez and Isabelle Mougenot, 2018
- Jérôme Euzenat had been panel member of the computer science PhD of Paula Chocrón (Universitat Autònoma de Barcelona) "A pragmatic approach to translation: vocabulary alignment through multiagent interaction and observation" supervised by Marco Schorlemmer, 2018
- Jérôme Euzenat had been panel chair of the computer science PhD of Louis Jachiet (Université Grenoble-Alpes) "On the foundations for the compilation of web data queries: optimization and distributed evaluation of SPARQL" supervised by Nabil Layaïda and Pierre Genevès, 2018
- Jérôme Euzenat had been reviewer of the computer science habilitation of Chan Le Duc (Université Paris 8) "Raisonnement et révision pour des ontologies en logique de description", 2018
- Jérôme Euzenat will be reviewer of the computer science PhD of Élodie Thiéblin (Université Toulouse 3 Paul Sabatier) "Automatic generation of complex ontology alignments" supervised by Ollivier Haemmerlé and Cássia Trojahn, 2019

3.7 General audience actions

3.7.1 Talks

- Jérôme Euzenat gave a training conference in computer science for high-school teachers on "Language and semantics", INRIA, Montbonnot (FR), 2016-02-10
- Jérôme Euzenat gave a talk to the local #FranceIA day "Intelligence artificielle et communication", Grenoble (FR), 2017-03-02
- Manuel Atencia animated the workshop "Modéliser les ontologies: cas d'application d'une ontologie pour l'annotation de photos" at the 4th Journées du développement logiciel (JDev), Marseille (FR), 2017-07-06
- Jérôme David animated the workshop "Comment faire une application avec des données liées: annotation de photos en utilisant les technos du web sémantique avec Jena" at the 4th Journées du développement logiciel (JDev), Marseille (FR), 2017-07-06
- Jérôme Euzenat gave an interview "Dans 50 ans, les ordinateurs écriront des succès littéraires?" for the INRIA web site, Montbonnot (FR), 2017-10-24
- Jérôme Euzenat gave a talk on "Artificial intelligence: a broad view" to BEST Spring course, Grenoble (FR), 2018-04-16
- Jérôme Euzenat gave a talk on "mOeX: évolution de la connaissance" INRIA "Mon projet en 180 secondes", Grenoble (FR), 2018-05-29
- Jérôme Euzenat gave a talk on "Evolving knowledge: different facets of Artificial Intelligence" to the French-American Doctoral Exchange (FADEx) seminar, Grenoble (FR), 2018-06-27

3.7.2 Mediation activity

We are developing mediation material for explaining to the general public what knowledge representation is and how it may evolve. Its main goal is to show children that the

same individuals may be classified in different and evolving ways and that it is possible to communicate such classifications without expressing them. For that purpose, we have designed a card game called *Class?* which allows players to guess the hidden ontology of another player. It has been presented to school classes from year 5 of primary school (fourth graders) to year 11 (tenth graders), albeit shows features of interest for a wider audience.

We are currently designing a more progressive session allowing to not just play the game but understand how to classify, learn decision tree, and find ontology alignment.

3.8 Visibility

3.8.1 Visits of International Scientists

- Karima Akli (USTHB, Algiers) visited Exmo in September 2016, working on rough sets for link key extraction.
- Yan Zhang (U. Tsinghua) and Zhichun Wang (Beijing Normal University) visited Exmo in September 2016 in the framework of the Lindicle project, working on cross-lingual data interlinking and query-driven ontology matching.
- Kate Revoredo (UNIRIO) visited Moex in May 2017, working on mixing theory revision with cultural evolution.

3.8.2 Research Stays Abroad

Jérôme Euzenat had benefited from a special visiting researcher grant from the Brazilian Ciência sem Fronteiras program on "Methodology and algorithms for ontology refinement and matching" (2015-2017). He worked with the team of Fernanda Baião and Kate Revoredo at the Universidade Federal do Estado do Rio de Janeiro (UNIRIO). Together, they investigated methods for evolving ontologies and alignments which involve users and agents. The goal of the project is to design methods and algorithms using theory revision to deal with knowledge evolution in a reliable manner and obtaining better quality alignments. Jérôme Euzenat visited the Universidade Federal do Estado do Rio de Janeiro (UNIRIO) for two months in March and November 2016 and for one month in November-December 2017.

3.8.3 Chair of Conference Program Committees

- Jérôme Euzenat had been program chairman of the "French national artificial intelligence conference (CNIA)" [29], Nancy (FR), 2018.
- Manuel Atencia had been workshop and tutorial chairman (with Marieke van Erp) of the 21st EKAW, Nancy (FR), 2018.

3.8.4 Member of the Organizing Committees

- Jérôme Euzenat had been organiser of the Ontology matching workshop:
  - 11th edition at the 15th ISWC, Kobe (JP), 2016 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, Michele Cheatham, Oktie Hassanzadeh and Ryutaro Ichise),
  - 12th edition at the 16th ISWC, Wien (AT), 2017 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, Michele Cheatham and Oktie Hassanzadeh)
  - 13th edition at the 17th ISWC, Monterey (CA US), 2018 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, Michele Cheatham and Oktie Hassanzadeh)

  - 14th edition at the 18th ISWC, Auckland (NZ), 2019 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, Cássia Trojahn and Oktie Hassanzadeh)
- Jérôme Euzenat had been organiser of the Workshop on Interaction-Based Knowledge Sharing (WINKS)
  - First edition at the 3rd Joint Ontology Workshop (JOMO), Bozen-Bolzano (IT), 2017 (with Dagmar Gromann and Kemo Adrian)
  - Second edition at the 5th Joint Ontology Workshop (JOMO), Graz (AT), 2019 (with Dagmar Gromann, Kemo Adrian, Ernesto Jimenez Ruiz, Marco Schorlemmer and Valentinna Tamma)
- Jérôme David had been organiser of the workshop on Symbolic methods for data-interlinking of the 21st EKAW, Nancy (FR), 2018 (with Miguel Couceiro)

3.8.5 Member of Conference Program Committees

- Jérôme David and Jérôme Euzenat had been programme committee members of the "International joint conference on artificial intelligence (IJCAI)" 2017, 2018 and 2019; Manuel Atencia in 2019;
- Manuel Atencia, Jérôme David and Jérôme Euzenat had been programme committee members of the conference "European conference on artificial intelligence (ECAI)" 2016
- Jérôme David and Jérôme Euzenat had been programme committee member of the "National conference on artificial intelligence (AAAI)" 2018
- Jérôme Euzenat had been programme committee member of the "International conference on Knowledge Representation and Reasoning (KR)" 2016
- Manuel Atencia and Jérôme Euzenat had been programme committee members of the "International semantic web conference (ISWC)" 2016, 2017, 2018, 2019 (Jérôme David 2017)
- Manuel Atencia, Jérôme David and Jérôme Euzenat had been programme committee members of the "European Semantic Web Conference (ESWC)" 2016
- Jérôme David and Jérôme Euzenat had been programme committee members of the "European Semantic Web Conference (ESWC)" 2017
- Jérôme Euzenat had been programme committee member of the "International World-wide web Conference (www)" 2017;
- Manuel Atencia, Jérôme David and Jérôme Euzenat had been programme committee member of the "Web Conference (www)" 2018 and 2019;
- Jérôme Euzenat had been programme committee member of the "International Conference on Formal Ontologies for Information Systems (FOIS)" 2016
- Jérôme Euzenat had been programme committee member of the "International conference on knowledge engineering and knowledge management (EKAW)" 2018
- Jérôme David had been programme committee member of the "Pacific Rim Knowledge Acquisition Workshop (PKAW)" 2018
- Jérôme Euzenat had been programme committee member of the "International Conference on Conceptual Structures (ICCS)" 2016
- Jérôme Euzenat had been programme committee member of the "13th International Conference on Semantic Systems (Semantics)" 2017, 2018 and 2019
- Jérôme Euzenat had been programme committee member of the "International Conference on Web Information Systems and Technologies (WebIST)" 2016 and 2017
- Tatiana Lesnikova and Jérôme Euzenat had been scientific committee member of the "Language resources and evaluation conference (LREC)" 2016
- Jérôme David had been programme committee member of the ISWC "Ontology matching" workshop (OM) 2016, 2017, 2018 and 2019

- Manuel Atencia had been programme committee members of the ISWC "Ontology matching" workshop (OM) 2017, 2018 and 2019
- Jérôme David had been programme committee member of the "French national artificial intelligence conference (CNIA)" 2018.
- Jérôme Euzenat had been programme committee member of the "French fundamental artificial intelligence days" (JAIF) 2016, 2017, 2018 and 2019.
- Jérôme David had been programme committee member of the "Journées francophones d'ingénierie des connaissances (IC)" 2017 and 2018
- Jérôme David had been programme committee member of the EGC workshop on "quality of linked open data" (QLOD) 2016
- Jérôme David and Jérôme Euzenat had been programme committee members of the "French Extraction and gestion des connaissances conference (EGC)" 2017
- Manuel Atencia and Jérôme David had been programme committee members of the "French Extraction and gestion des connaissances conference (EGC)" 2018
- Jérôme Euzenat had been programme committee member of the ESWC workshop on "Completing and Debugging the Semantic Web (CoDeS)", 2016.
- Jérôme Euzenat had been programme committee member of the ECAI workshop on "Diversity-aware artificial intelligence", 2016.

3.9 Journal

3.9.1 Member of Editorial Boards

- Jérôme Euzenat is member of the editorial board of *Journal of web semantics* (area editor), *Journal on data semantics* and the *Semantic web journal*.
- Jérôme Euzenat had been guest editor of a special issue of the *Semantic web journal* on "Semantic technologies and interoperability in the build environment" (with Álvaro Sicilia, Pieter Pauwels, Leandro Madrazo, and María Poveda-Villalón), 2018 [26].
- Jérôme Euzenat had been guest editor of a special issue of the *Semantic web journal* on "Ontology and linked data matching" (with Michelle Cheatham, Isabel Cruz, and Catia Pesquita), 2017 [23].

3.9.2 Reviewer - Reviewing Activities

- Manuel Atencia had been reviewer for *Semantic web journal*, *ACM transactions on database systems*, *Knowledge-based systems*, *VLDB journal*, *Journal of web semantics* and *Applied ontology*.
- Jérôme David had been reviewer for *Artificial intelligence review*, *Semantic web journal*, *Information system journal* and *Ingénierie des systèmes d'information* (special issue on "Impact des Open et/ou Linked Data dans les systèmes d'information").
- Jérôme Euzenat had been reviewer for *IEEE transactions on knowledge and data engineering*, *Knowledge and information systems*, *Artificial intelligence review*, *ACM transactions on the web*, *Mobile information systems* and *International journal on metadata, semantics and ontologies*.

3.9.3 Invited Talks

- "Extraction de clés de liage de données", Invited talk, 16e conférence internationale francophone sur l'extraction et la gestion des connaissances (EGC), Reims (FR), 2016-01-21 (Jérôme Euzenat).

- Series of four seminars at UniRio, Rio de Janeiro (BR): "Introduction to ontology matching and alignment" 2016-03-11, "Repairing alignments and cultural evolution" 2016-03-17, "Data link key extraction (and relation with Formal concepts analysis)" 2016-03-22, "(Belief) revision in networks of ontologies" 2016-03-30 (Jérôme Euzenat).
- "Introduction to ontology matching and alignment", Seminar IBM Research, Rio de Janeiro (BR), 2016-03-23 (Jérôme Euzenat).
- "Semantic web evolution: tectonic quake or gentle drift?", Invited talk, 12th International Conference on Web Information Systems and Technologies (WebIST), Roma (IT), 2016-04-24 (Jérôme Euzenat).
- "Knowledge change, failure, adaptation, and evolution", Invited talk, 2nd Joint ontology workshops (JOWO), Annecy (FR), 2016-07-06 (Jérôme Euzenat).
- "Data interlinking with formal concept analysis and link keys", Invited talk, 13th international conference on concept lattices and applications (CLA), Moskow (RU), 2016-07-19 (Jérôme Euzenat).
- "Fixing knowledge in the distributed age", Invited tutorial, 10th international conference on scalable uncertainty managament (SUM), Nice (FR), 2016-09-21 (Jérôme Euzenat).
- "Symbolic methods for RDF data interlinking", Lecture at EGC, Grenoble (FR), 2017-01-23 (Jérôme David)
- "Data interlinking using link keys", Seminar Trinity college, Dublin (IE), 2017-04-13 (Jérôme Euzenat)
- "Cultural knowledge evolution: motivations and experiments", Seminar Trinity college, Dublin (IE), 2017-04-13 (Jérôme Euzenat)
- "Enhancing Link Keys: Extraction and Reasoning", Workshop on Ontology Reasoning, Knowledge and Semantic Web", Université Paris 8, Montreuil (FR), 2017-06-22 (Manuel Atencia)
- "Linked data", Tutorial at the 4th Journées du développement logiciel (JDEV) 2017, Marseille (FR), 2017-07-06 (Manuel Atencia)
- "Knowledge diversity under socio-environmental pressure", Invited talk, International Conference on Computational Approaches to Diversity in Interaction and Meaning, Venezia (IT), 2017-10-08 (Jérôme Euzenat)
- "Ontology matching, adaptation and evolution", GDRI in Web science Workshop, PUC-Rio, Rio de Janeiro (BR), 2017-12-04 (Jérôme Euzenat, Fernanda Baião, Kate Revoredo)
- "Towards cultural knowledge evolution: experiments with alignments repair", Seminar LIP6, Paris (FR), 2018-10-15 (Jérôme Euzenat)
- "Enhancing Link Keys: Extraction and Reasoning", BNF workshop on "Données liées et données à lier: quels outils pour quels alignements?", Paris (FR), 2018-07-10 (Manuel Atencia)
- "Link key extraction with a variation of relational concept analysis", EKAW workshop on symbolic methods for data interlinking, Nancy (FR), 2018-11-12 (Jérôme Euzenat)
- "For knowledge", ISWC keynote speech, Auckland (NZ), 2019-10-29 (Jérôme Euzenat)

3.9.4 Leadership within the Scientific Community

- Jérôme Euzenat is member of the scientific council of the CNRS GDR on Formal and Algorithmic Aspects of Artificial intelligence.
- Jérôme Euzenat is EurAI fellow.
- Jérôme David is member of the board of the Extraction and gestion des connaissances (Knowledge extraction and management) conference series.

3.9.5 Scientific Expertise

- Jérôme David had been consulting for the start-up Budplace (2017).
- Manuel Atencia had been evaluator for CAPES-COFECUB projects (BR) (2018)
- Jérôme Euzenat had been member of the scientific evaluation committee "CE23: Data, knowledge, big data, multimedia content – artificial intelligence" of the French national research agency (ANR, 2018)
- Manuel Atencia had been evaluator for the French national research agency (ANR, 2018)
- Jérôme Euzenat had been member of the recruitment committee of Université Grenoble Alpes for the associate professor position 27MCF330, 2019.
- Jérôme David had been co-organising LIG keynote speeches (2014–2018)

4 Funding

Financial resources of the team have been declining during the exercise.

We used to rely on European projects whose collaboration prospect were very good and the funding adequate. However such projects have become less research-driven at the moment when we turn to more fundamental objectives. In consequence, they have become both less attractive and more difficult to obtain.

We also have relied on ANR funding which allows to carry out exciting research. However, the main part of its funding is dedicated to hire PhD students with not much accompanying funds.

We did not benefit much from local projects, mostly because they are most of the time oriented towards particular topics and forms of collaboration. We performed, in 2018, two small contracts with the Ministry of Culture and Communication and the French national library.

Hence, the day-to-day funding of our work relies on a small (INRIA) "dotation" which is nowadays insufficient.

Our chair proposal for the Grenoble answer (MIAI) to the call for French Artificial Intelligence Interdisciplinary Institutes has been accepted and is planned to start in 2019. However, at the date of writing we have no information on implementation.

National initiatives

ELKER

- Program: ANR-PRC
- Project acronym: ELKER
- Project title: Extending link keys: extraction and reasoning
- Duration: October 2017 - September 2021
- Coordinator: LIG/Manuel Atencia
- Participants: Manuel Atencia Arcas, Jérôme David, Jérôme Euzenat
- Other partners: INRIA Lorraine, Université de Vincennes
- Project funding: 504k€
- Granted to MOEX: 170k€
- Web site: https://project.inria.fr/elker/
- Abstract: The goal of ELKER is to extend the foundations and algorithms of link keys (see §2.4) in two complementary ways: extracting link keys automatically from data sets and reasoning with link keys.

LINDICLE

- Program: ANR-Blanc international 2
- Project acronym: LINDICLE
- Project title: Linking data in cross-lingual environment
- Duration: January 2013 - December 2016
- Coordinator: INRIA EXMO/Jérôme David
- Participants: Jérôme Euzenat, Manuel Atencia Arcas, Jérôme David, Tatiana Lesnikova, Adam Sanchez Ayte, Armen Inants
- Other partners: Tsinghua university (CN)
- Project funding: 254k€
- Granted to MOEX: 254k€
- Website: http://lindicle.inrialpes.fr
- Abstract: The LINDICLE project investigates multilingual data interlinking between French, English and Chinese data sources (see §2.4.3).

European projects: none

Industrial contracts: none

Inria Project Labs, Exploratory Research Actions and Technological Development Actions: none

Associated teams and other international projects: none

Other funding

FNE

- Program: Framework agreement INRIA-Ministère de la culture et de la communication
- Project acronym: FNE
- Project title: Algorithmes d'aide à la définition de clés de liage et d'alignement d'autorités
- Duration: November 2017 - December 2018
- Coordinator: Jérôme David
- Participants: Jérôme David, Manuel Atencia Arcas, Jérôme Euzenat
- Other partners: Bibliothèque nationale de France
- Project funding/Granted to Moex: 15k€
- Abstract: The goal of the FNE cooperation is to evaluate the suitability of link key extraction algorithms to matching authorities from BnF, ABES and the ministry of Culture and to improve such algorithms if necessary.

Ginco V3

- Program: Framework agreement INRIA-Ministère de la culture et de la communication
- Project acronym: Ginco V3
- Project title: Outil d'aide à l'alignement pour l'élaboration du graphe culture
- Duration: November 2017 - December 2018
- Coordinator: Jérôme David
- Participants: Jérôme David, Jérôme Euzenat, Manuel Atencia Arcas
- Project funding/Granted to Moex: 15k€
- Abstract: The Ginco V3 project aims at extending the Ginco tool with ontology alignment capabilities.

RegleX-LD

- Program: Projets Exploratoires Premier Soutien (CNRS, INS2I)
- Project acronym: RegleX-LD
- Project title: Découverte de règles expressives de correspondances complexes et de liage de données
- Duration: January 2019 – December 2019
- Coordinator: IRIT/Cássia Trojahn
- Participants: Manuel Atencia Arcas, Jérôme David, Jérôme Euzenat
- Other partners: IRIT Toulouse, INRA Paris, LRI Orsay
- Project funding: 10k€
- Granted to Moex: not split
- Abstract: RegleX-LD aims at discovering expressive ontology correspondences and data interlinking patterns using unsupervised or weakly supervised methods.

5 Follow up to the previous evaluation

The last evaluation concerned Exmo. It was very positive on the results achieved and very encouraging for the future project. It provided the following recommendations:
“ Because the team is at the end of its cycle, our recommendation are focused on the sustainability of the team and its research output:

- Consider incorporating maintenance of the Alignment API in the next project (and, if it happens, have an ADT to harden the software)
- In the new project, build on the early ideas of applying cultural evolution paradigms to knowledge evolution
- The problems for smaller team to hire personnel should be solved on a policy level within INRIA: it should be specifically targeted that teams that do not have the target size of 15–20 people should be supported in recruiting personnel.

”

Here is the status regarding these:

Concerning the maintenance of the Alignment API, it is still maintained and used, as it has been since 2003. We think that this comment was a misunderstanding of our statement that it was not an *objective* of Moex (it was not an objective of Exmo either). We held discussions with people using ADT and with the local head of the experimentation and development (in charge of ADTs) who confirmed that the ADT is not the appropriate structure for maintaining software.

It seems that we indeed followed the encouragements in pursuing the Moex goals in cultural knowledge evolution. However, pursuing these new and ambitious objectives would require training more students in this developing phase. We started recruiting anew and expect this situation to improve with the MIAI chair (see §4).

Unfortunately, the third item has not been followed up by action.

6 Objectives for the next four years

Our two research directions are described in more details in the parts dedicated to results and achievements (§2.3 and 2.4).

In Moex, all three team members are involved in all activities. Thus, although there are two distinct sets of objectives, this does not lead to different subteams.

The Moex project started relatively recently. Hence, its objectives are still those set at its beginning. We describe them along the two axes: link keys and cultural knowledge evolution.

6.1 Link keys

6.1.1 Objectives

Our goal is to fully investigate the potential of the notion of link keys. Link keys may be paralleled with keys in the relational database model: it cannot be claimed that they solve all data deduplicating problems, but it cannot be claimed that they are useless. This is the reason why link keys should be thoroughly studied: to become one solid and reliable tool.

This involves extending the foundations and algorithms of link keys in two complementary ways: extracting link keys automatically from data sets, and reasoning with link keys.

6.1.2 Approach

In both cases, we define the semantics of link keys, we develop algorithms and we prove their properties with respect to that semantics. Finally, we cooperate with application partners to take advantage of the proposed solutions. We started with limited cases, e.g. inexpressive logics, simple link key forms, and have extended them already to composed properties, compound link keys, dependent and cyclic link keys.

6.1.3 Four-years plan

We plan to fully invest in four directions.

- Continuing the work on link key extraction by extracting more expressive link keys and better evaluation measures;
- Continuing the work on reasoning with link keys by considering more expressive ontology languages and achieving an actual implementation;
- Connecting extraction and reasoning by exploiting the reasoning capability during extraction;
- Applying this work in real-world cases, the most likely candidate being libraries.

6.2 Cultural knowledge evolution

6.2.1 Objectives

Our overall goal is to develop a comprehensive understanding of mechanisms by which a society evolves its knowledge through continuous adaptation to its environment and to other societies. More specifically, we assess under which conditions local adaptation operators lead to global epistemic properties.

6.2.2 Approach

We address this by combining local adaptation techniques coming from the knowledge representation field with evolutionary modelling. We consider knowledge representation as a culture and study the global properties of local adaptation operators applied by populations of agents by either performing multi-agent simulation or theoretically proving these properties.

The current focus on symbolic knowledge is justified by its prominent use in explicit communication. However, knowledge may also be grounded on the perceived environment, so the whole approach needs to be combined in a consistent way with machine learning.

6.2.3 Four-years plan

We plan to develop our work in the following directions:

- Increasing the variety of phenomena evolved in experiments, in particular, evolving ontologies;
- Developing the population approach and investigating vertical transmission and synchronisation of knowledge;
- Dealing with evolution in the face of disruptive events and considering whether diversity is an advantage in this context;
- Considering mechanisms to embed adaptation constraints in machine learning algorithms and their results;
- Investigating further the connection between this work and generalised evolution;
- Developing a full theoretical and general model of cultural knowledge evolution (with dynamic epistemic logics or other formalisms);
- Finally, developing a semantic experiment notebook allowing to describe experiments in a computer-interpretable way.

This is the broad programme that faces us. We will develop it depending on our capabilities and opportunities. In particular, we do not expect reaching a significant impact on the last point in isolation.

7 Bibliography of the project-team

Doctoral Dissertations and Habilitation Theses

[1] A. Inants, Qualitative calculi with heterogeneous universes, Theses, Université Grenoble Alpes, April 2016, [hal:tel-01366032].

[2] T. Lesnikova, RDF Data Interlinking : evaluation of Cross-lingual Methods, Theses, Université Grenoble Alpes, May 2016, [hal:tel-01366030].

Articles in International Journals

[3] M. Atencia, J. David, J. Euzenat, A. Napoli, J. Vizzini, Link key candidate extraction with relational concept analysis, *Discrete Applied Mathematics*, 2019, [doi:10.1016/j.dam.2019.02.012], [hal:hal-02196757].

[4] M. Chekol, J. Euzenat, P. Genevès, N. Layaïda, SPARQL Query Containment under Schema, *Journal on Data Semantics 7*, 3, April 2018, p. 133–154, [doi:10.1007/s13740-018-0087-1], [hal:hal-01767887].

Articles in National Journals

[5] J. Euzenat, De la langue à la connaissance: approche expérimentale de l'évolution culturelle, *Bulletin de l'Association Française pour l'Intelligence Artificielle 100*, April 2018, p. 9–12, [hal:hal-01953227].

Invited Conferences

[6] J. Euzenat, Extraction de clés de liage de données (résumé étendu), *in: 16e conférence internationale francophone sur extraction et gestion des connaissances (EGC)*, B. Crémilleux, C. de Runz (editors), Hermann, p. 9–12, Reims, France, January 2016. euzenat2016a, [hal:hal-01382101].

International Conferences with Proceedings

[7] N. Abbas, J. David, A. Napoli, Linkex: A Tool for Link Key Discovery Based on Pattern Structures, *in: ICFCA 2019 - workshop on Applications and tools of formal concept analysis, Proc. ICFCA workshop on Applications and tools of formal concept analysis*, p. 33–38, Frankfurt, Germany, June 2019. abbas2019a, [hal:hal-02168775].

[8] M. Achichi, M. Cheatham, Z. Dragisic, J. Euzenat, D. Faria, A. Ferrara, G. Flouris, I. Fundulaki, I. Harrow, V. Ivanova, E. Jiménez-Ruiz, K. Kolthoff, E. Kuss, P. Lambrix, H. Leopold, H. Li, C. Meilicke, M. Mohammadi, S. Montanelli, C. Pesquita, T. Saveta, P. Shvaiko, A. Splendiani, H. Stuckenschmidt, É. Thiéblin, K. Todorov, C. Trojahn dos Santos, O. Zamazal, Results of the Ontology Alignment Evaluation Initiative 2017, *in: OM: Ontology Matching, CEUR Workshop Proceedings*, 2032, p. 61–113, Wien, Austria, October 2017. achichi2017aOM is co-located with the 16th International Semantic Web Conference (ISWC), [hal:hal-01670238].

[9] M. Achichi, M. Cheatham, Z. Dragisic, J. Euzenat, D. Faria, A. Ferrara, G. Flouris, I. Fundulaki, I. Harrow, V. Ivanova, E. Jiménez-Ruiz, E. Kuss, P. Lambrix, H. Leopold, H. Li, C. Meilicke, S. Montanelli, C. Pesquita, T. Saveta, P. Shvaiko, A. Splendiani, H. Stuckenschmidt, K. Todorov, C. Trojahn dos Santos, O. Zamazal, Results of the Ontology Alignment Evaluation Initiative 2016, *in: OM: Ontology Matching, CEUR Workshop Proceedings*, 1766, p. 73–129, Kobe, Japan, October 2016. achichi2016aOM is co-located with the 15th International Semantic Web Conference (ISWC), [hal:hal-01421833].

[10] M. Al-Bakri, M. Atencia, J. David, S. Lalande, M.-C. Rousset, Uncertainty-sensitive reasoning for inferring sameAs facts in linked data, *in : 22nd european conference on artificial intelligence (ECAI)*, IOS press, p. 698–706, Der Haague, Netherlands, August 2016. albakri2016a, [doi:10.3233/978-1-61499-672-9-698], [hal:hal-01366296].

[11] M. Atencia, J. David, J. Euzenat, A. Napoli, J. Vizzini, Link key candidate extraction with relational concept analysis (extended abstract), *in : Proc. International semantic web conference: journal track, Aukland (NZ)*, p. 1599–1602, 2019.

[12] J. da Silva, F. Araujo Baião, K. Revoredo, J. Euzenat, Semantic interactive ontology matching: synergistic combination of techniques to improve the set of candidate correspondences, *in : OM 2017 - 12th ISWC workshop on ontology matching*, No commercial editor., p. 13–24, Wien, Austria, October 2017. silva2017a, [hal:hal-01670205].

[13] J. da Silva, K. Revoredo, F. Araujo Baião, J. Euzenat, Interactive ontology matching: using expert feedback to select attribute mappings, *in : OM 2018 - 13th ISWC workshop on ontology matching*, No commercial editor., p. 25–36, Monterey, United States, October 2018, [hal:hal-01964686].

[14] J. David, J. Euzenat, P. Genevès, N. Layaïda, Evaluation of Query Transformations without Data, *in : WWW 2018 - Companion of The Web Conference*, ACM Press, p. 1599–1602, Lyon, France, April 2018, [doi:10.1145/3184558.3191617], [hal:hal-01891182].

[15] J. Euzenat, Crafting ontology alignments from scratch through agent communication, *in : PRIMA 2017: Principles and Practice of Multi-Agent Systems*, B. An, A. Bazzan, J. Leite, S. Villata, L. van der Torre (editors), Springer Verlag, p. 245–262, Nice, France, October 2017. euzenat2017b, [doi:10.1007/978-3-319-69131-2_15], [hal:hal-01661140].

[16] J. Euzenat, Interaction-based ontology alignment repair with expansion and relaxation, *in : IJCAI 2017 - 26th International Joint Conference on Artificial Intelligence*, AAAI Press, p. 185–191, Melbourne, Australia, August 2017. euzenat2017a, [doi:10.24963/ijcai.2017/27], [hal:hal-01661139].

[17] J. Euzenat, Replicator-interactor in experimental cultural knowledge evolution, *in : Proc. 2nd JOWO workshop on Interaction-Based Knowledge Sharing (WINKS), Graz (AT)*, 2019.

[18] M. Gmati, M. Atencia, J. Euzenat, Tableau extensions for reasoning with link keys, *in : 11th ISWC workshop on ontology matching (OM)*, No commercial editor., p. 37–48, Kobe, Japan, October 2016. gmati2016a, [hal:hal-01421834].

[19] A. Inants, M. Atencia, J. Euzenat, Algebraic calculi for weighted ontology alignments, *in : 15th International semantic web conference (ISWC)*, P. Groth, E. Simperl, A. Gray, M. Sabou, M. Krötzsch, F. Lécué, F. Flöck, Y. Gil (editors), Springer Verlag, p. 360–375, Kobe, Japan, October 2016. inants2016b, [doi:10.1007/978-3-319-46523-4_22], [hal:hal-01382098].

[20] T. Lesnikova, J. David, J. Euzenat, Cross-lingual RDF thesauri interlinking, *in : 10th international conference on Language resources and evaluation (LREC)*, No commercial editor., p. 2442–2449, Portoroz, Slovenia, May 2016. lesnikova2016a, [hal:hal-01382099].

[21] L. van den Berg, Epistemic alignment repair, *in : Proc. 31st ESSLLI student session , Riga (LV)*, 2019.

National Conferences

[22] J. David, J. Euzenat, J. Vizzini, Linkky: Extraction de clés de liage par une adaptation de l'analyse relationnelle de concepts, *in : IC 2018 - 29es Journées Francophones d'Ingénierie des Connaissances*, S. Ranwez (editor), AFIA, p. 271–274, Nancy, France, July 2018, [hal:hal-01839642].

Scientific Books or Book Chapters)

[23] M. Cheatham, I. Cruz, J. Euzenat, C. Pesquita, Semantic web journal: Special issue on ontology and linked data matching, *8*, 2, IOS Press, 2017, cheatham2017a, [hal:hal-01661137].

[24] O. Kovalenko, J. Euzenat, Semantic matching of engineering data structures, *in: Semantic web technologies for intelligent engineering applications*, M. S. Stefan Biffl (editor), Springer, 2016, p. 137–157, kovalenko2016a, [doi:10.1007/978-3-319-41490-4_6], [hal:hal-01416191].

[25] M.-C. Rousset, M. Atencia, J. David, F. Jouanot, O. Palombi, F. Ulliana, Datalog revisited for reasoning in linked data, *in: Reasoning Web. Semantic Interoperability on the Web. Reasoning Web 2017*, G. Ianni, D. Lembo, L. Bertossi, W. Faber, B. Glimm, G. Gottlob, and S. Staab (editors), *Reasoning Web International Summer School*, *LNCS*, 10370, Springer Verlag, 2017, p. 121–166, rousset2017a, [doi:10.1007/978-3-319-61033-7_5], [hal:hal-01661141].

[26] A. Sicilia, P. Pauwels, L. Madrazo, M. Poveda Villalón, J. Euzenat, Semantic web journal: Special Issue on Semantic Technologies and Interoperability in the Build Environment, *9*, 6, IOS Press, 2018, [hal:hal-01953272].

Edition of Books or Proceedings

[27] K. Adrian, J. Euzenat, D. Gromann, E. Jiménez-Ruiz, M. Schorlemmer, V. Tamma (editors), Proc. 2^{nd} JOWO workshop on Interaction-Based Knowledge Sharing (WINKS), Graz (AT), 2019.

[28] K. Adrian, J. Euzenat, D. Gromann (editors), Proc. 1st JOMO workshop on Interaction-Based Knowledge Sharing (WINKS), Bozen-Bolzano, Italy, No commercial editor., 2018, 1–42p., [hal:hal-01951964].

[29] J. Euzenat, F. Schwarzentruber (editors), Actes de la Conférence Nationale en Intelligence Artificielle et des Rencontres Jeunes Chercheurs en Intelligence Artificielle (CNIA+RJCIA), AFIA, Nancy, France, No commercial editor., 2018, 1–133p., [hal:hal-01838695].

[30] P. Shvaiko, J. Euzenat, E. Jiménez-Ruiz, M. Cheatham, O. Hassanzadeh, R. Ichise (editors), Proceedings of the 11th International Workshop on Ontology Matching (OM-2016), Kobe, Japan, No commercial editor., 2016, 1–252p. shvaiko2016b, [hal:hal-01421835].

[31] P. Shvaiko, J. Euzenat, E. Jiménez-Ruiz, M. Cheatham, O. Hassanzadeh (editors), Proceedings of The Tenth International Workshop on Ontology Matching (OM-2015), No commercial editor., 2016, 1–239p. shvaiko2016a, [hal:hal-01254905].

[32] P. Shvaiko, J. Euzenat, E. Jiménez-Ruiz, M. Cheatham, O. Hassanzadeh (editors), OM-2017: Proceedings of the Twelfth International Workshop on Ontology Matching, Wien, Austria, No commercial editor., 2017, 1–233p. shvaiko2017a, [hal:hal-01674668].

[33] P. Shvaiko, J. Euzenat, E. Jiménez-Ruiz, M. Cheatham, O. Hassanzadeh (editors), Ontology Matching: OM-2018: Proceedings of the ISWC Workshop, Monterey, United States, No commercial editor., 2018, 1–227p., [hal:hal-01964687].

Research Reports

[34] M. Atencia, J. Euzenat, C. Le Duc, K. Jradeh, Reasoning for the description logic ALC with link keys, *Research report*, Laboratoire d'Informatique de Grenoble ; INRIA Grenoble Rhône-Alpes ; Université Paris 8, April 2019, [hal:hal-02090087].

[35] A. Sanchez, T. Lesnikova, J. David, J. Euzenat, Instance-level matching, *Contract*, Lindicle, September 2016, sanchez2016a, [hal:hal-01382105].

Miscellaneous

[36] M. Cheatham, I. Cruz, J. Euzenat, C. Pesquita, Special issue on ontology and linked data matching, 2017, Editorial, Semantic web journal 8(2):183-184, [doi:10.3233/SW-160251], [hal:hal-01661138].

[37] P. Pauwels, M. Poveda Villalón, A. Sicilia, J. Euzenat, Semantic technologies and interoperability in the built environment, IOS Press, 2018, Editorial, Semantic web journal 9(6):731-734, [doi:10.3233/SW-180321], [hal:hal-01951968].

[38] J. Vizzini, Data interlinking with relational concept analysis, Mémoire, Université Grenoble Alpes, June 2017, Master's thesis, Université Grenoble Alpes, Grenoble (FR) - vizzini2017a, [hal:hal-01661184].

Additional references

[R1] M. Anslow and M. Rovatsos. Aligning experientially grounded ontologies using language games. In *Proc. 4th international workshop on graph structure for knowledge representation, Buenos Aires (AR)*, pages 15–31, 2015.

[R2] M. Atencia, J. David, and J. Euzenat. Data interlinking through robust linkkey extraction. In *Proc. 21st ECAI, Praha (CZ)*, pages 15–20, 2014.

[R3] M. Atencia, J. David, and F. Scharffe. Keys and pseudo-keys detection for web datasets cleansing and interlinking. In *Proc. 18th EKAW, Galway (IE)*, pages 144–153, 2012.

[R4] M. Atencia and M. Schorlemmer. An interaction-based approach to semantic alignment. *Journal of web semantics*, 13(1):131–147, 2012.

[R5] R. Axelrod. The dissemination of culture: a model with local convergence and global polarization. *Journal of conflict resolution*, 41(2):203–226, 1997.

[R6] P. Chocron and M. Schorlemmer. Attuning ontology alignments to semantically heterogeneous multi-agent interactions. In *Proc. 22nd ECAI, The Hague (NL)*, pages 871–879, 2016.

[R7] P. Chocron and M. Schorlemmer. Vocabulary alignment in openly specified interactions. In *Proc. 16th AAMAS, Saõ Paolo (BR)*, pages 1064–1072, 2017.

[R8] J. David, J. Euzenat, F. Scharffe, and C. Trojahn. The Alignment API 4.0. *Semantic web journal*, 2(1):3–10, 2011.

[R9] J. Euzenat. First experiments in cultural alignment repair (extended version). In *Proc. ESWC 2014 satellite events revised selected papers*, number 8798 in Lecture notes in computer science, pages 115–130, 2014.

[R10] A. Ferrara, A. Nikolov, and F. Scharffe. Data linking for the semantic web. *International journal of semantic web and information systems*, 7(3):46–76, 2011.

[R11] B. Ganter and R. Wille. *Formal concept analysis: mathematical foundations*. Springer, 1999.

[R12] A. Hogan, A. Zimmermann, J. Umbrich, A. Polleres, and S. Decker. Scalable and distributed methods for entity matching, consolidation and disambiguation over linked data corpora. *Journal of web semantics*, 10:76–110, 2012.

[R13] A. Mesoudi, A. Whiten, and K. Laland. Towards a unified science of cultural evolution. *Behavioral and brain sciences*, 29(4):329–383, 2006.

[R14] M. Nentwig, M. Hartung, A.-C. Ngonga Ngomo, and E. Rahm. A survey of current link discovery frameworks. *Semantic web journal*, 8(3):419–436, 2017.

[R15] A.-C. Ngonga Ngomo and S. Auer. LIMES: A time-efficient approach for large-scale link discovery on the web of data. In *Proc. 22nd IJCAI), Barcelona (ES)*, pages 2312–2317, 2011.

[R16] M. Rouane Hacene, M. Huchard, A. Napoli, and P. Valtchev. Relational concept analysis: mining concept lattices from multi-relational data. *Annals of mathematics and artificial intelligence*, 67(1):81–108, 2013.

[R17] F. Saïs, N. Pernelle, and M.-C. Rousset. L2R: A logical method for reference reconciliation. In *Proc. 22nd AAAI, Vancouver (CA)*, pages 329–334. AAAI Press, 2007.

[R18] L. Steels, editor. *Experiments in cultural language evolution*. John Benjamins, Amsterdam (NL), 2012.

[R19] F. Suchanek, S. Abiteboul, and P. Senellart. PARIS: Probabilistic Alignment of Relations, Instances, and Schema. *PVLDB*, 5(3):157–168, 2012.