Evaluation of Inria theme
Data and Knowledge Representation and Processing

Project-team mOeX

https://moex.inria.fr/

30/06/2024
This version has been edited for typos and clarification

Project-team title: Evolving knowledge

Scientific leader: Jérôme Euzenat

Research center(s): Grenoble Rhône-Alpes

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

Inria research theme: Data and Knowledge Representation and Processing

Contents

1 Team life

Current composition of the project-team:

Research scientists and faculty members:
- Jérôme David, Associate professor (MCF), Université Grenoble-Alpes
- Jérôme Euzenat, Senior research scientist (DR1), INRIA
- Lucía Gómez Álvarez, Research scientist (CRCN), INRIA

Associate member:
- Manuel Atencia, Associate professor, Universidad de Málaga

Engineers: none.
Post-docs: none.
Ph.D. students:
- Andreas Kalaitzakis (UGA, finishing)
- Linda Gutsche (ENS Ulm, starting)

Administrative assistant:
- Julia di Toro (INRIA, 25%)
- Alexandra Guidi (UGA, 25%)

Personnel at the start of the evaluation period (03/10/2019)

	Inria	CNRS	University	Other	**Total**
DR (1) / Professors	1				**1**
CR (2) / ISFP (3) / Ass. professors			2		**2**
Other permanent researchers					
CPJ (4)					
Permanent engineers (5)					
Temporary engineers (6)					
Post-docs and SRP					
PhD Students	1		2		**3**
Total	**2**		**4**		**6**

(1) "Senior Research Scientist (Directeur de Recherche)"

(2) "Junior Research Scientist (Chargé de Recherche)"

(3) "Junior Research Scientist under contract (Inria Starting Faculty Position)"

(4) "Junior professor under contract (Young Professor Chair)"

(5) "Civil servant (CNRS, Inria, university, ...)"

(6) "Associated with a contract (Ingénieur Expert, Ingénieur ADT, . . .)"

Personnel at the time of the evaluation (30/06/2024)

	Inria	CNRS	University	Other	**Total**
DR / Professors	1				**1**
CR / ISFP / Assistant professors	1		1		2
Other permanent researchers					
CPJ					
Permanent engineers					
Temporary engineers					
Post-docs					
PhD Students			1		**1**
Total	2		2		4

Changes in the scientific staff

DR / Professors / Others CR / ISFP / Assistant Professors	Inria	CNRS	University	Other	**Total**
Arrivals	1				**1**
Departures			1		**1**

Comments:

- Since August 2021, Manuel Atencia Arcas has been in sabbatical at Universidad de Málaga (Spain). He has continued to participate to the team activities, especially the supervision of PhD students and the writing of papers. This involvement has decreased over time.
- Since January 2024, Lucía Gómez Álvarez has joined the team as a chargée de recherches.
- We benefited from the post-doctoral stay of Helga Lendrin as a social science researcher for 18 months. We worked with her on *Class?* (see §6.2) and links between cultural evolution and Gilbert Simondon's theory of technical objects. Nothing has been published yet.

Last enlistments in the project-team

- Lucía Gómez Álvarez, CRCN 2024 (joined January)

Current position of former project-team members

- Manuel Atencia Arcas, Associate professor (UGA) 2013-2021, currently Associate professor at Universidad de Málaga (Spain)
- Khadija Jradeh, PhD student 2018-2022, currently post-doctoral researcher at IRIT, Toulouse (FR)
- Nacira Abbas, PhD student (Nancy) 2019-2013, currently post-doctoral researcher at LIG, Grenoble (FR)
- Line van den Berg, PhD student 2018-2021, deceased while post-doctoral researcher at University of Bern (CH)
- Yasser Bourahla, PhD student 2019-2023, currently engineer at a non disclosed company (FR)

Team organization and animation

As can be noted the team is very small. Hence on a daily basis we are able to work relatively closely. We did our best, after COVID lockouts, to avoid resorting too much to home-working.

For long, we did not feel the need to held team meetings, but we reinstalled biweekly team meetings in which each team members discuss their progress since 2020. We also have an internal blog in which anyone can report on research problems, methodological questions, thoughts, conference reports, reading reviews etc. It is not as successful as it could be: members are too shy or too busy to fully use it.

Concerning 'scientific integrity', team members are assumed to behave according to (ethical, deontological, regulatory and community) rules. PhD students are trained by the doctoral school. Our blog discusses issues such as 'On our experimental practice', 'Narrative' (about how research narrative can lead to twist finding reports), 'In which journal to publish?', 'Article processing charges at INRIA'. We also refer the reader to the discussion of Reproducibility below (§4.1).

We have very little grasp on career advancement for permanent members (hence I do not see why we are asked in this report to comment on that). Members are encouraged to take responsibility and autonomy as well as to put themselves in a position to be promoted (HDR). This may be the reason why we expect this fall, that one associate professor becomes full professor and that a former post-doctoral member join us back as full professor.

The mOeX team is part of the Laboratoire d'Informatique de Grenoble (which is a CNRS unit with UGA, CNRS, INRIA and Grenoble INP as supervisory organisms). This involves various administrative tasks (Jérôme Euzenat participates to the team leader meetings, Jérôme David and Manuel Atencia are elected members of the laboratory council) and brings some benefits such as faculty workforce.

This also constrains the team to be considered as part of a Zone à Régime Restrictif which is a heavy supplementary burden, that we estimate unjustified (all our work is public). This constraint comes with no compensation.

Training and transfer of knowledge to non-permanent staff

We are definitely a research-oriented team, hence we chiefly train to research. PhD student professional training is taken in charge by the doctoral school with an offer relying on more competent experts. Additionally, INRIA offers continuous training on which members, permanent or non permanent, including PhD students, may rely.

Diversity

We do not have a specific policy towards diversity, our main criteria are competence and motivation.

We have trained PhD students of two different genders (3 women and 1 man, and one of each ongoing) during the period (actually the whole project length) and now the permanent staff is two to one. Among our interns, see web page, the ratio was 11 to 10. Line van den Berg participated in the 'women in logic' workshop [28].

So in terms of gender, diversity is balanced, at least with respect to our output. It has been improved with respect to permanent staff. But our score can only modestly contribute to statistics.

The permanent staff is two French persons and a Spanish one. We have trained PhD students of various nationalities (Lebanese, Algerian*2, French-Greek, Dutch, French). We have no statistics for interns but can see Algerian, Chinese, Tunisian, Albanian, Romanian, German, Italian, and Lebanese.

We do not have numbers in terms of sexual-orientation.

Other comments

None at that stage.

2 Research goals and results

2.1 Keywords

Knowledge representation — Semantic web — Linked data — Data interlinking — Cultural knowledge evolution — Multi agent simulation — Dynamic epistemic logic — Belief revision

2.2 Context and overall goals of the research project

mOeX deals with the evolution of knowledge in autonomous agents. Such agents may encompass human beings, robots, software agents, artificial intelligence systems. They may hold different knowledge and beliefs, represented in different ways. Hence they do not necessarily transfer knowledge directly.

In such a context, it is important to understand how knowledge can be communicated among agents and how this local agent interaction can lead to the global evolution of the society's knowledge. This may be used for the development and the integration of artificial systems beneficial to the society. For instance, establishing how robots introduced in a particular context may adapt and be accepted, how beliefs influence the propagation of opinions in a society, or how to link data spread on the semantic web.

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

We aim at acquiring a precise understanding of knowledge evolution through the consideration of a wide range of situations, representations and adaptation operators.

The ambition of the mOeX project is to answer, in particular, the following questions:

– How do agent populations adapt their knowledge representation to their environment and to other populations?
– How must this knowledge evolve when the environment changes and new populations are encountered?
– How can agents preserve knowledge diversity and is this diversity beneficial?

We study these problems chiefly in a well-controlled computer science context using, so far, symbolic knowledge representation. This requires the dialog between different approaches such as cultural evolution, multi-agent simulation, logical modelling, or opinion dynamics.

We consider knowledge as a 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.

The current focus on symbolic knowledge is justified by its prominent use in explicit communication. However, it is expected that obtained results apply more widely.

The activity of the mOeX team during the covered period developed in two axes:

Data interlinking with link keys (§2.3) drawing on our previous work on the semantic web, and specifically ontology matching [2], attempts at dealing with different representations of the same entities within data sets published as RDF.

Cultural knowledge evolution (§2.4) investigates the evolution of knowledge within a society of agents.

In addition, we have orthogonal activities related to reproducibility (§4.1) and mediation (§6.2).

2.3 Research axis 1: Data interlinking with link keys

Personnel

Manuel Atencia, Jérôme David, Jérôme Euzenat, Khadija Jradeh, Nacira Abbas,

Project-team positioning

Vast amounts of RDF data are made available on the web by various institutions providing overlapping information. To be fully exploited, different representations of the same object across various data sets, often using different ontologies, have to be identified. When different vocabularies are used for describing data, it is necessary to identify the concepts they define. This task is called ontology matching and its result is an alignment A, i.e. a set of correspondences $\langle e, r, e' \rangle$ relating entities e and e' of two different ontologies by a particular relation r (which may be equivalence, subsumption, disjointness, etc.) [Euzenat and Shvaiko, 2013].

At the data level, data interlinking is the process of generating links identifying the same resource described in two data sets. Parallel to ontology matching, from two datasets (d and d') it generates a link set made of pairs of resource identifier.

This problem has been addressed in various ways [Nentwig et al., 2017][2] ranging from approximate similarity-based methods to exact logic-based methods. Among the latter, a proofed approach is based on variations of database keys [Atencia et al., 2014a].

We have introduced link keys [Euzenat and Shvaiko, 2013][6, 2] which extend database keys in a way which is more adapted to RDF and deals with two data sets instead of a single relation. An example of a link key expression is:

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

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. More precisely, a link key is a structure $\langle K^{eq}, K^{in}, C \rangle$ such that:

– K^{eq} and K^{in} are sets of pairs of property expressions;
– C is a pair of class expressions (or a correspondence).

Such a link key holds if and only if for any pair of resources belonging to the classes in correspondence such that the values of their property in K^{eq} are pairwise equal and the values of those in K^{in} pairwise intersect, the resources are the same. Link keys are more general than pair of keys related by an alignment [6]. They can then be used for finding the same individuals across two data sets and generating the corresponding owl:sameAs links. Link keys take into account the non functionality of RDF data and have to deal with non literal values. In particular, they may use arbitrary properties and class expressions. This renders their discovery and use difficult.

Scientific achievements

2.3.1 Link key extraction with pattern structures

A first method has been designed to extract and select link keys from two classes which deals with multiple values but not object values [Atencia et al., 2014b]. Moreover, the extraction step has been rephrased in relational concept analysis (RCA [Rouane-Hacene et al., 2013]), an extension of formal concept analysis (FCA [Ganter and Wille, 1999]) taking relations between concepts into account. We showed that a new expression of this problem is able to extract the optimal link keys even in the presence of cyclic dependencies [Atencia et al., 2020] and it does not require information about the alignments of the ontologies.

We also used pattern structures, an extension of formal concept analysis (FCA) with ordered structures, to reformulate the simple link key extraction problem. The strategies used to automatically discover link keys are not able to select the pair of classes on which the link key candidate applies. Indeed, a link key may be relevant for some pair of classes and not relevant for another. Then, discovering link keys for one pair of classes at a time may be computationally expensive if all pairs have to be considered. To overcome this limitation, we have introduced a specific and original pattern structure in which link keys can be discovered in one pass while specifying the pair of classes associated with each link key, focusing on the discovery process and allowing more flexibility [17].

This approach has been implemented in the linkex tool (§4.4).

2.3.2 Strategies for identifying high-quality link keys

Link keys correspond to closed sets of a specific Galois connection and can be discovered thanks to a concept analysis algorithm (FCA, RCA or pattern structure). Given a pattern concept lattice whose intents are link key candidates, we aim at identifying the most relevant candidates with respect to adapted quality measures. To achieve this task, we introduced the Sandwich algorithm which is based on a combination of dual bottom-up and top-down strategies for traversing the pattern concept lattice [14]. The output of the Sandwich algorithm is a partially ordered set of the most relevant link key candidates.

Different link key candidates can generate sets of identity links between individuals that can be considered as equal when they are regarded as partitions of the identity relation and thus involving a kind of redundancy. We have studied such a redundancy through partition pattern structures [13, 15]. In the partition pattern structure concept lattice, every concept has an extent representing a link key candidate and an intent representing a partition of instances into sets of equivalent instances. Experiments showed that redundancy of link key candidates while not significant when based on identity of partitions appears to be much more significant when based on similarity [5].

2.3.3 Fixed-point semantics for relational concept analysis

We have used relational concept analysis (RCA) to extract link keys (§2.3.1). This led us to notice that when there exist circular dependencies between objects, it extracts a unique stable concept lattice family grounded on the initial formal contexts. However, other stable families may exist whose structure depends on the same relational context. These may be useful in applications that need to extract a richer structure than the minimal grounded one.

We first considered this issue in a reduced version of RCA, which only retains the relational structure. We redefined the semantics of RCA in terms of concept lattice families closed by a fixed-point operation induced by this relational structure. We showed that these families admit a least and greatest fixed point and that the well-grounded RCA semantics is characterised by the least fixed point [22]. We then characterised the interesting lattices as the self-supported fixed points. We provided an algorithm to compute the greatest fixed point (dual to the RCA algorithm) and discussed strategies to extract all self-supported fixed points [40]. We then showed that this approach also applies to RCA in general. The space of possible fixed points was further characterised as a complete lattice and the effect of various functions traversing them studied [40].

2.3.4 Tableau methods for reasoning with link keys in description logics

Link keys can be thought of as axioms in a description logic. As such, they can contribute to infer ABox axioms, such as links, other link keys or terminological axioms. This has important practical applications such as link key inference and link key consistency and redundancy checking.

We previously extended the tableau method designed for the ALC description logic to support reasoning with link keys in ALC and proved that this extended method terminates, is sound, complete, and that its complexity is 2ExpTime [3]. We have also designed a worst-case optimal tableau algorithm, based on compressed tableau and directed by rule application, for reasoning in the description logic ALC with individuals and link keys. This algorithm is sound, complete, and has exponential complexity. A proof of concept for this algorithm has been implemented and evaluations were carried out. We have also defined a compressed tableau for reasoning in the description logic ALC extended with link keys and inverse roles. This provides a solid basis for designing a worst-case optimal algorithm for reasoning in the description logic ALCI+LK [3].

2.3.5 Integrating link key extraction and reasoning

In addition, we proposed and evaluated different strategies to integrate reasoning with link keys in the data interlinking pipeline. In particular, it is possible to use the reasoner, during link key extraction, to discard link keys introducing inconsistencies.

Collaborations

We collaborated with our partners from the Elker project on data interlinking but most specifically on link keys:
- Amedeo Napoli, Miguel Couceiro, Alexandre Bazin, Nacira Abbas (Orpailleur, Nancy)
- Chan Le Duc, Myriam Lamolle, Jérémy Lhez (LIASD, Univ Paris 8)
- Marie-Christine Rousset (LIG, Grenoble)

We also collaborated within the CNRS PEPS RegleX-LD on the extraction of link keys based on complex alignments with:
- Cássia Trojahn dos Santos, Élodie Thiéblin (IRIT, Toulouse)
- Fatiha Saïs, Nathalie Pernelle (LRI, Orsay)
- Liliana Ibanescu (INRA, Paris)

This allowed to start a collaboration.

External support

This work benefited from the support of:
- The ANR Elker project (§7).
- We also participated in a small CNRS (PEPS) RegleX-LD action (§7).

Self-assessment

Our previous four-years plan can be considered completed as below:
1. Continuing the work on link key extraction by extracting more expressive link keys and better evaluation measures;
2. Continuing the work on reasoning with link keys by considering more expressive ontology languages and achieving an actual implementation;
3. Connecting extraction and reasoning by exploiting the reasoning capability during extraction;

4. Applying this work in real-world cases, the most likely candidate being libraries.

The work of link keys has reached its main objectives.

A variety of key extraction techniques have been designed and tested during the period (§2.3.1, 2.3.2). They are also well connected. Moreover, this led to the full definition of the semantics of relational concept analysis (RCA) which is an achievement on its own right (§2.3.3).

Similarly, the work on reasoning with link keys has reached completion and saw the design, analysis and development of two different reasoners (§2.3.4). This has been less successful so far in terms of outstanding publications. The connection between extracting and reasoning has also provided very interesting but unpublished results (§2.3.5).

The application part has been less successful: our work was tested on benchmarks and not real case application. This was mostly due to lack of time and resources, as well as the fact that it was not the topic of one researcher in particular, but spread among the Elker project.

2.4 Research axis 2: Cultural knowledge evolution

Personnel

Manuel Atencia, Jérôme Euzenat, Line van den Berg, Yasser Bourahla, Andrea Kalaitzakis, Helga Lendrin

Project-team positioning

Cultural evolution applies a generalised version of the theory of evolution to culture. It considers how culture spreads and evolves within human societies [Mesoudi, 2011]. In computer science, cultural evolution experiments are performed through multi-agent simulation: a society of agents adapts its culture through a precisely defined protocol: agents perform repeatedly and randomly a specific task, called game, and their evolution is monitored. This aims at discovering experimentally the states that agents reach and the properties of these states.

Experimental cultural evolution has been successfully and convincingly applied to the evolution of natural languages [Steels, 2012]. Agents play *language games* and adjust their vocabulary and grammar as soon as they are not able to communicate properly, i.e. they misuse a term or they do not behave in the expected way. It showed its capacity to model various such games in a systematic framework and to provide convincing explanations of linguistic phenomena.

We adapt this experimental strategy to knowledge representation [19]. Agents use their, shared or private, knowledge to play games and, in case of failure, they use adaptation operators to modify this knowledge. We monitor the evolution of agent knowledge with respect to their ability to perform the game (success rate) and with respect to the properties satisfied by the resulting knowledge itself. Such properties may, for instance, be:

– Agents converge to a common knowledge representation (a convergence property).
– Agents converge towards different but compatible (logically consistent) knowledge (a logical epistemic property), or towards closer knowledge (a metric epistemic property).
– That under the threat of a changing environment, agents that have operators that preserve diverse knowledge recover faster from the changes than those that have operators that converge towards a single representation (a differential property under environment change).

Our goal is to determine which operators are suitable for achieving desired properties in the context of a particular game.

Simulation of cultural evolution has been investigated [Axelrod, 1997, Wang and Gasser, 2002, Steels, 2012], albeit not from the standpoint of knowledge. On the link between belief propagation, very few work had been carried out beyond [Schwind et al., 2015] which relies on direct belief communication.

Scientific achievements

2.4.1 Evolving learned ontologies

So far our experiments in cultural knowledge evolution dealt with adapting alignments. However, agent knowledge is primarily represented in their ontologies which may also be adapted. In order to study ontology evolution, we designed a two-stage experiment in which: (1) agents learn ontologies based on examples of decision making, and (2) then they interactively compare their decisions on different objects and adapt their ontologies when they disagree.

This framework may be instantiated in many ways. We used decision tree induction as learning method and an approximation of ontology accuracy to guide adaptation.

In this scenario, fundamental questions arise: Do agents achieve successful interaction (increasingly consensual decisions)? Can this process improve knowledge correctness? Do all agents end up with the same ontology? We showed that agents indeed reduce interaction failure, most of the time they improve the accuracy of their knowledge about the environment, and they do not necessarily opt for the same ontology [19, 1].

2.4.2 Knowledge transmission across agent generations

In cultural evolution, transmission is achieved in different ways [Mesoudi, 2011]: vertical transmission, in which culture spreads, like genes, from parents to siblings, oblique transmission, in which it spreads, like by education, from agents from the generation of parents to agent of the next generation, and horizontal transmission, in which it spreads among all members of a population.

Knowledge transmission occurring between agents of the same generation, as described above (§2.4.1), is considered as horizontal transmission. Other work has shown that variation generated through vertical, or inter-generation, transmission allows agents to exceed that level [Acerbi and Parisi, 2006]. Such results have been obtained under the drastic selection of (less than 20%) agents allowed to transmit their knowledge or introducing artificial noise during transmission.

In order to study the impact of such measures on the quality of transmitted knowledge, we combined the settings of these two previous work and relaxed these assumptions (no strong selection of teachers, no fully correct seed, no introduction of artificial noise). Under this setting, we confirmed that vertical transmission improves on horizontal transmission even without drastic selection and oriented learning.

We also showed that horizontal transmission is able to compensate for the lack of parent selection if it is maintained for long enough [20]. We also confirmed that that this setting was able to preserve knowledge diversity, although it decreases [1].

2.4.3 Measuring and controlling knowledge diversity

Assessing knowledge diversity may be useful for many purposes. In particular, it is necessary to measure diversity in order to understand how it arises or is preserved (see

§2.4.2). It is also necessary to control it in order to measure its effects. We have considered measuring knowledge diversity using two components: (a) a diversity measure taking advantage of (b) a knowledge difference measure. We have proposed general principles for such components and compared various candidates [21]. The most satisfying solutions are entropy-based measures [Leinster, 2021]. We designed and implemented algorithms using these measures to generate populations of agents with controlled levels of knowledge diversity.

2.4.4 Pluripotent agents

The work on cultural knowledge evolution reported above concentrated on agents performing a single task. This is not a natural condition, thus we are developing agents able to carry out several tasks and to adapt their knowledge with the same protocol. We introduced multi-tasking agents that interact over a limited set of tasks that depend on different properties. By varying the number of tasks assigned to each agent and the number of common properties across these tasks, we found that agents transfer knowledge from one task to another [24]. In addition, we showed that agents with limited memory will specialise on a subset of tasks, whose number depends on available memory. But, counter-intuitively, our experiments demonstrate that multi-task agents are not necessarily less accurate than specialised one.

We limited agent memory size in order to avoid multi-tasking agents to learn all tasks in the long term. Agents with limited memory specialise on a subset of tasks, whose number depends on available memory. However, it seems that maximising task accuracy and achieving consensus are mutually exclusive. Agents can either specialise to the detriment of their interoperability, or learn to agree but fail to specialise [32].

2.4.5 Value-sensitive cultural evolution

Cultural values are cognitive representations of general objectives, such as independence or mastery, that people use to distinguish whether something is 'good' or 'bad'. More specifically, people may use their values to evaluate alternatives and pick the most compatible one. We consider values as grounding agent behaviour in cultural knowledge evolution, and more specifically in the way they evolve their ontologies. We used the cultural values of independence, novelty, authority and mastery to influence the choice of which agent adapts in a population of agents sharing the same values. From a weighted aggregation of how much agents adhere to these values, they determine which one adapts its knowledge when two agents disagree, e.g. novelty will give more change to rare knowledge, though mastery will promote knowledge that has proved efficient. Results [46] show that agents do not improve the accuracy of their knowledge without using the mastery value (akin the success bias in social learning [1]). Under certain conditions, independence causes the agents to converge to successful interactions faster, and novelty increases knowledge diversity, but both effects come with a large reduction in accuracy. We did not find any significant effects of authority.

2.4.6 Intrinsic motivation, curiosity and creativity

In cultural knowledge evolution simulations, agent knowledge might be confined to specific areas because the tasks that they perform do not require them to explore more. We considered how agents may be provided with the intrinsic motivation to explore and how this affects their knowledge. Three different kinds of motivation were investigated: curiosity (the will to explore the unknown), creativity (the will to act differently) and non-exploration (the will to not explore new things). Moreover, intrinsic motivation was modelled directly or learned through reinforcement learning. Finally, agents either explored on their own or picked specific interaction partner(s). We have shown that such settings may have a significant effect on the agent knowledge [47]. Contrary to the expectations and other studies, this did not lead to an increase in knowledge completeness. Out of all intrinsic motivations, curiosity had the highest accuracy and completeness. Models with reinforcement learning performed similarly as direct models. As expected, intrinsic motivation led to faster convergence of the agents' knowledge, especially with social agents. Heterogeneously motivated agents had a higher accuracy and completeness than homogeneously motivated agents only in specific cases.

2.4.7 Opinion dynamics and belief propagation

Opinion dynamics models how social organisation and interactions determine opinions. Belief propagation also studies how logical beliefs propagate within a network. However, it is expected that opinions and beliefs do not evolve independently. Yet, there is hardly any attempt to connect them. Doing so may contribute answering questions such as: How public opinion constrains beliefs and how beliefs shape opinions? How conspiracy theories can spread, in spite of, or supported by, beliefs?

In order to elucidate this connection, we put forth a model in which opinions and beliefs, besides these two social operations, are also connected by two 'cognitive' operations: opinion formation from beliefs and belief alignment with opinions. They aim at reducing the cognitive dissonance between beliefs and opinions adopted from the social propagation. The four resulting operations are very flexible in their implementations. We used the DeGroot opinion dynamic model and belief revision game (BRG, [Schwind et al., 2015]) operations for the social operations. We based the cognitive operations on cultural values held by the agents. The value-based mechanism is balanced with the inertia, or propensity to avoid change, of agents. They allow for modelling various types of agents (favouring opinions, favouring beliefs, eager to change, resisting to change, etc.).

We showed that the outcome of the propagation processes depends on graph topology, initial opinions and beliefs as in classical opinion dynamics and belief revision games. In addition, we show that both opinions influence beliefs and beliefs influence opinions and that outlier beliefs do not spread more but have an influence on the final beliefs.

2.4.8 Modelling cultural evolution in dynamic epistemic logic

Ontology alignments enable agents to communicate while preserving heterogeneity in their knowledge. Alignments may not be provided as input and should be able to evolve when communication fails or when new information contradicting the alignment is acquired. The Alignment Repair Game (ARG) has been proposed for agents to simultaneously communicate and repair their alignments through adaptation operators when communication failures occur [Euzenat, 2017]. ARG was evaluated experimentally and the experiments showed that agents converge towards successful communication and improve their alignments. However, the logical properties of such operators, i.e. whether they are formally correct, complete or redundant, could not be established by experiments. We introduced Dynamic Epistemic Ontology Logic (DEOL) to answer these questions [25, 10]. It allows us (1) to express the ontologies and alignments used, (2) to model the ARG adaptation operators through announcements and conservative upgrades and

(3) to formally establish the correctness, partial redundancy and incompleteness of the adaptation operators in ARG.

These results have raised interesting issues about how closely a multi-agent process should be modelled logically (indeed, it is possible to make agents closer to the logic or try to have a logical model closer to the agents). They also open the perspective to model cultural (knowledge) evolution as a whole with dynamic epistemic logics [4].

2.4.9 Awareness and forgetting in dynamic epistemic logic

In the DEOL modelling, agents are aware of the vocabulary that the other agents may use (we call this Public signature awareness). However, assuming that agents are fully aware of each other's signatures prevents them from adapting their vocabularies to newly gained information, from the environment or learned through agent communication. Therefore this is not realistic for open multi-agent systems. We have proposed a novel way to model awareness with partial valuations functions and weakly reflexive relations [26, 11]. Partial Dynamic Epistemic Logic allows agents to use their own vocabularies to reason and talk about the world. We added dynamic modalities for raising public and private awareness in which a distinction is made between becoming aware of a proposition and learning its truth value. As a result, the semantics introduced can be used to model agent interaction without the public signature awareness assumption. We also investigated associated forgetting operators [26].

Collaborations

For this work we had strong collaborations with:
- The Tyrex INRIA team (Luisa Werner, Nabil Layaïda, Pierre Genevès) and Yves Demazeau (LIG) within the ANR MIAI Chair;
- The team of Koji Hasebe at the University of Tsukuba on Opinion dynamics and belief propagation (see 2.4.7).

External support

This activity benefited from the support of:
- the ANR MIAI Chair on Knowledge communication and evolution (§7);
- One travel grant from the ANR-Region Kaleos project between University Grenoble-Alpes and University of Tsukuba;
- One invited professor grant from INRIA for Koji Hasebe.

Self-assessment

Our previous four years plan was the following:
1. Increasing the variety of phenomena evolved in experiments, in particular, evolving ontologies.
2. Developing the population approach and investigating vertical transmission and synchronisation of knowledge.
3. Dealing with evolution in the face of disruptive events and considering whether diversity is an advantage in this context.
4. Considering mechanisms to embed adaptation constraints in machine learning algorithms and their results.
5. Investigating further the connection between this work and generalised evolution.
6. Developing a full theoretical and general model of cultural knowledge evolution (with dynamic epistemic logics or other formalisms).

7. Finally, developing a semantic experiment notebook allowing to describe experiments in a computer-interpretable way.

We addressed most of our objectives and more. In particular, one non explicit objective was, after publishing our work in artificial intelligence [Euzenat, 2017], to have it accepted in the agent community [25, 19, 10, 20].

The protocol defined for evolving ontologies (1. §2.4.1) has proved particularly interesting and it has been used in various different work (§2.4.4, 2.4.5 and 2.4.6). Although the population approach has not been developed, yet the generation approach (vertical transmission) has provided outstanding results (2. §2.4.2).

In terms of diversity measure and implementation (3. §2.4.3) we have made an interesting and useful contribution. Definitive evidence of the impact of diversity on resilience to face disruptive events, remains to be established.

The work on dynamic epistemic logic modelling of cultural evolution has also provided outstanding results (6. §2.4.8 and 2.4.9). We plan to continue it further with different approaches (see §3.4 and 3.5).

In addition, we made a lot of progress with respect to the standardisation of our experimental practice (7. see §4.1 below). It works. However the semantic part has not been developed. This was subject to finding a larger initiative to be involved in and this still is.

Considering adaptation constraints in learning-based agents has progressed within the Tyrex team who covered this subject within the MIAI chair. It has developed work on neuro-symbolic graph neural networks, but not to the point to address the influence of cultural constraints (4.).

Finally, we did not made progress on the relation of cultural knowledge evolution and generalised evolution theories (5.).

Overall, our work on cultural knowledge evolution has progressed very well. But much more remains to be done so they will be pursued.

2.5 Evolution of research directions during the evaluation period

The objectives from the previous evaluation have been reported in the self-assessments of both axes.

We have followed the activities that we planned to do at the last evaluation. However, the activity intensity felt somewhat below our (arguably high) expectations. This was related to two main factors: the COVID pandemics and the difficulty to recruit students. Ideally we had in mind that the MIAI chair would help us to recruits massively (one doctoral student per topic, one engineer and one post-doctoral student). This did not occur, mostly due to the lack of adequate candidates.

However, we managed to advance all of them but one (connection with generalised evolution) which remains in standby.

The only notable evolution of research direction is, the surge, in 2023, of a new topic related to propagation of beliefs and the relation with opinions (which may also be equated with dynamic logic announcements, §2.4.7).

3 Objectives for the next four years

mOeX aims at deepening the work on cultural knowledge evolution (§2.4). We review here the main directions that we plan to take in the next four years.

3.1 Link keys

We do not plan to further work extensively on link keys (§2.3). There are still some work submitted, in particular the work on RCA semantics. There is no student working on it.

3.2 Cultural knowledge evolution: diversity, population and motivation

Beyond transmission, cultural evolution relies on variation and selection: the former provides the opportunity to explore different cultures; the latter tends to reduce these. Diversity, the coexistence of different knowledge representation in the same society, is affected by both. Although genetics provides a small set of options for these operations, cultural evolution offers far more variety.

In the past period, we started to deals with some of these issues: value-sensitive knowledge evolution (§2.4.5), intrinsic motivation (§2.4.6) and controlling knowledge diversity (§2.4.3). This provided interesting results, but we aim at exploring them more in depth.

This will be achieved by designing corresponding mechanisms and studying them experimentally and/or theoretically, allowing us to address the following questions:

- How can, direct or indirect, intrinsic motivation to improve knowledge be implemented?
- What benefits does it bring? Does it increase or decrease diversity?
- Can agent values drive their motivation? Can it guide the way knowledge is adapted?
- Does diversity increases resilience in front of disruptive events?

Finally, we plan to connect this work with the work on belief propagation (§2.4.7), considering the effects of transmission.

3.3 Extension to non-symbolic knowledge

So far, we only considered symbolic knowledge representation. We want to extend this work to non-symbolic knowledge representations.

We plan to mix, on the one hand, 'symbolic' agents that represent their knowledge using ontologies, logical reasoning and adaptation/revision operators based on consistency, and on the other hand, 'subsymbolic' agents in which knowledge is represented with probability densities, prediction mechanisms are based on the associated neural structure and adaptation is performed by retropropagation.

We expect that the introduction of different mechanisms for acquiring and representing knowledge increases its diversity. In addition, we aim at determining whether this combination always leads to fruitful communication and whether the quality of he knowledge is improved. This raises the problem of assessing non-symbolic knowledge: its intrinsic quality, different from accuracy, and its diversity. This work will allow us to study possible transfers of knowledge, as well as helping to make subsymbolic systems easier to explain.

3.4 Theoretical models of cultural knowledge evolution

Cultural knowledge evolution may be generally though of as agents revising their beliefs when something tells them that they may not be correct. So far, we have adopted a bottom-up approach to model them in logic, starting from a particular type of games (§2.4.8). We want to take a top-down approach to model cultural evolution generally.

For this, we plan to draw on both dynamic epistemic logic (DEL) [Baltag and Smets, 2008] and belief revision [Fermé and Hansson, 2018]. In particular, we will investigate in more depth the relationships between the DEL semantics of belief upgrade [Baltag and Smets, 2008] and that of iterated belief revision. This would also allows us to connect our work on belief propagation (§2.4.7) with BeliefFlows [Schwind et al., 2024].

3.5 Standpoint logics

We have provided a Standpoint Logic (SL [Gómez Álvarez and Rudolph, 2021]) as a way to model heterogeneous knowledge held by different agents. SL is a first-order multimodal logic allowing agents to establish individual standpoints, which involve specifying constraints and relations. It is close to epistemic logic, but its simplified semantics allows it to support more expressive underlying languages (usual in ontologies and knowledge bases) at the expense of the full-fledged modality nesting of usual Kripke semantics. SL facilitates combining standpoints and establishing alignments between them.

This research line has two main objectives: Firstly, we aim to establish Standpoint Logic as a robust framework in knowledge representation. Key reasoning tasks in SL include deriving global knowledge, determining standpoint-relative knowledge, and contrasting knowledge inferred from different standpoints. Secondly, while current standpoint representations capture static viewpoints, we will address the evolution of standpoints. This has connections with the previous topic as SL is a kind of epistemic logic.

3.6 Link with SSH studies of cultural evolution (towards artificial cultural evolution)

Confronting our work with social sciences and the humanities was not part of our initial goals. However, we decided to change this in order to integrate our work in a broader view and gain more impact.

One of the difficulty that we are facing is the lack of integrated community on the topic of cultural knowledge evolution. Typically researchers on cultural evolution (in general) have been spread around fields such as ethology, anthropology, robotics and many more [Mesoudi, 2011]. One illustration of this is that the efforts of the Cultural Evolution Society (CES) to set up a journal have failed.

One of our objectives is to be more connected to people involved on this domain at large. We benefited from the stay of Helga Lendrin in mOeX. However the best solution would be to collaborate with structured teams in that domain. We have actively participated to the last CES conference and will again join the next one.

We aim at promoting some artificial cultural evolution (like there is artificial intelligence). Such a research field would cover simulating cultural evolution, as it has already been done [Acerbi and Parisi, 2006, Steels, 2012] and considering how machines and humans can evolve cultures together. This is related to recent efforts to consider the impact of computers and AI on human culture evolution [Brinkmann et al., 2023].

4 Knowledge dissemination

4.1 Open science and data management plan

Since the team is involved into experimental work, we are strongly concerned by its reproducibility. We used to describe our experiments and publish our data in INRIA's gforge repository. However, after the decision to close it, we decided to develop our own at https://sake.re to which we moved all previous experiments. Thanks to INRIA support teams, old URLs have been redirected, but not all experiments have yet been repurposed to be exposed as Jupyter notebooks. We also developed the ability to automatically generate Docker container specification to rerun experiments but these have to be repurposed for accommodating Jupyter.

We have developed a git-based methodology for describing experiments before performing them, committing their results and their analysis through Jupyter notebooks. Experiments can be reproduced by checking out exact software versions and running the same parameters. They are also easily repurposed with different parameters. When experiment are published in papers, they are also published in Zenodo. These are an important step towards accountability, portability, reproducibility and long term storage.

Some neglected benefits of semantically describing experiments provide more arguments in favour of scientific knowledge graphs [23]. Beyond being searchable through flat metadata, a knowledge graph of experiment descriptions may be able to provide answers to scientific and methodological questions. This includes identifying non experimented conditions or retrieving specific techniques used in experiments. In turn, this is useful for researchers as this information can be used for re-purposing experiments, checking claimed results or performing meta-analyses.

As all our production, results once published are available under creative commons CC-BY 4.0 License. They do not include personal data, beyond the name of the authors.

We had the pleasure to see that this strategy initially developed around our *Lazy lavender* framework (§4.4) also works with other simulators, developed in different languages (§2.4.7).

This activity led to further experiments and publications related to reproducibility [29] and exploitability [23].

4.2 Publications

	2020	2021	2022	2023	2024	**Total**
PhD Theses		1	1	1		**3**
H.D.R. (*)				1		**1**
Journals	3	2		2	1	**8**
Conference proceedings (**)	2	4	2	1	1	**10**
Workshop proceedings (**)	3	1	4	1		**9**
Short papers and posters		1		1		**2**
Book chapters	2	1				**3**
Books (written)						
Books and proceedings (edited)	1	1	1	1		**4**
Patents						
General audience papers			1			**1**
Technical reports				1		**1**

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

Major journals in the field and, in parentheses, the number of papers coauthored by members of the project-team published during the evaluation period:

– *Semantic web journal* (2)
– *Journal of web semantics* (0)
* *Artificial intelligence* (1)
* *Journal of artificial intelligence research* (0)
+ *JAAMAS* (1)
+ *JASSS* (0)

Major conferences in the field and, in parentheses, the number of papers coauthored by members of the project-team published during the evaluation period:

– *International semantic web conference* (0)
* *International joint conference on artificial intelligence* (0)
* *European conference on artificial intelligence* (0)
* *International conference on autonomous agents and multi-agent systems* (3)
+ *AAAI conference on artificial intelligence* (1)
+ *International conference on knowledge representation and reasoning* (0)

We did not change these lists since last time (+ means that this is a conference that we are adding; - is an item that was in last evaluation and that we will retract due to to our lesser activity on semantic web).

Representative publications for the evaluation period.

– M. Atencia, J. David, J. Euzenat, On the relation between keys and link keys for data interlinking, *Semantic web journal* 12(4):547–567, 2021 [6]
– Y. Bourahla, M. Atencia, J. Euzenat, Knowledge improvement and diversity under interaction-driven adaptation of learned ontologies, Proc. 20th AAMAS, pp242–250, 2021 [19]
– Y. Bourahla, M. Atencia, J. Euzenat, Knowledge transmission and improvement across generations do not need strong selection, Proc. 21st AAMAS, pp163–171, [20]
– L. van den Berg, M. Atencia, J. Euzenat, A logical model for the ontology alignment repair game, *Autonomous Agents and Multi-Agent Systems* 35(2):1–32, 2021 [10].
– L. van den Berg, M. Atencia, J. Euzenat, Raising awareness without disclosing truth, *Annals of Mathematics and Artificial Intelligence* 91(4):431–464, 2023 [11]

4.3 Teaching

Responsibilities

– Jérôme David was coordinator of the Master "Mathematiques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes, 2019-2024);
– Manuel Atencia was co-responsible of the 2nd year of Master "Mathematiques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes, 2019-2021);
– Manuel Atencia was coordinator of the "Web, Informatique et Connaissance" option of the master M2 "Mathematicques et informatiques appliquées aux sciences humaines et sociales" (Univ. Grenoble Alpes, 2019-2021);

Lectures

Person	Course	Level	Disc.	2019 -2020	2020 -2021	2021 -2022	2022 -2023	2023 -2024
J. David	Algorithmique et programmation par objets	L2	MIASHS	70	70	70	70	70
	Programmation Fonctionelle	L1	MIASHS			19.5		
	Programmation logique	L2	MIASHS				12	
	Système	L3	MIASHS	18	18	18	18	18
	Réseaux	L3	MIASHS					12
	Programmation par objets avancée et structures de données	L3	MIASHS					18
	Systèmes d'exploitation	M1	DCISS				27	18
	Programmation Java 2	M1	MIASHS	30	30	30	30	30
	JavaEE	M2	MIASHS	30	30	30	30	
	Développement Web Mobile	M2	MIASHS	30				
	Web sémantique	M2	MIASHS	3	3	3	3	
	Stage de programmation	M2	MIASHS	10	10	10	10	10
	Soutien programmation	M2	MIASHS					10
M. Atencia	Introduction aux technologies du Web	L3	MIASHS	60	60	84		
	Formats de données du web	M1	MIASHS	30	30	42		
	Introduction à la programmation web	M1	MIASHS	30	42	42		
	Intelligence artificielle	M1	MIASHS	7.5	7.5			
	Web sémantique	M2	MIASHS	27	27	27		
	Semantic web: from XML to OWL	M2	MoSIG	22.5				
J. Euzenat	Semantics of distributed knowledge	M2	MoSIG		22.5	22.5	27	27
	Programmation logique	L2	MIASHS			12	12	12
Y. Bourahla	Algorithmique et programmation Python	L1	PCMM			55		
	Programmation fonctionelle	L2	MIASHS					41
	Programmation logique	L2	MIASHS				12	22
	Langages formels	L2	MIASHS					38
	Syytèmes d'exploitation	L3	MIASHS					12
	Soutien algorithmique	L3	MIASHS					10
	AI for complex systems	M1	MIASHS				42	
	Formats de données du web	M1	MIASHS				42	

The unit is heq TD; L1,2,3=Bachelor 1st, 2nd, 3rd year; M1,2=Master 1st, 2nd year

MIASHS=Mathematics and Informatics Applied to Social Sciences and the Humanities (University Grenoble Alpes)

MOSIG=Master of Science in Informatics, Grenoble (University Grenoble Alpes and Grenoble INP)

DCISS=Double competency: informatics and social sciences (University Grenoble Alpes)

PCMM=Physics, Chemistry, Mechanics, Mathematics (University Grenoble Alpes)

Supervision

Nacira Abbas "Analyse formelle de concepts pour la découverte de clés de liage dans le web des données" [https://www.theses.fr/2023UPASG045] supervised by Jérôme David and Amedeo Napoli (LORIA), since 2018, defended on 2023-10-13

Khadija Jradeh "Optimised tableau algorithms for reasoning in the description logic ALC extended with link keys" [3] supervised by Manuel Atencia and Chan Le Duc (LIMICS, University Paris 13), since 2018, defended on 2022-07-12

Line van den Berg "Knowledge Evolution in Agent Populations" [4] supervised by Manuel Atencia and Jérôme Euzenat, since 2018, defended 2021-10-29

Yasser Bourahla "Multi-agent simulation of cultural ontology evolution through interaction" [1] supervised by Manuel Atencia and Jérôme Euzenat, since 2019, defended on 2023-07-11

Andreas Kalaitzakis "Effects of collaboration and specialisation on agent knowledge evolution" supervised by Jérôme Euzenat, since 2020, in progress

Alban Flandin "The benefits of forgetting knowledge" supervised by Jérôme Euzenat and Yves Demazeau (LIG), since 2020, stopped 2021-09-30

Thesis and habilitation panels

	HDR			PhD		
Person	chair	reviewer	member	chair	reviewer	member
Manuel Atencia						1
Jérôme David					1	
Jérôme Euzenat		1	2	3	3	1

4.4 Software

Alignment API (https://moex.gitlabpages.inria.fr/alignapi/) LGPL 2.1

We have designed a format for expressing ontology alignments in a uniform way allowing anyone to share alignments on the web. The API itself 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 (§2.3) in the EDOAL language and their transformations into SPARQL queries.

The Alignment API is used in the Ontology Alignment Evaluation Initiative data and result processing. As of 2018 it had been also used by more than 60 other teams worldwide[1]. The Alignment API is freely available since December 2003 and has been registered by the software protection agency (APP). It is certainly less used nowadays as Python is gaining traction.

LINKEX (https://gitlab.inria.fr/moex/linkex) GPL 3.0

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 §2.3). 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 key 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://moex.inria.fr/software/lazylav/) CeCILL-C+LGPL 2.1

Lazy lavender is a simulation tool for cultural knowledge evolution, i.e. running randomised experiments with agent adjusting their knowledge while attempting to communicate.

[1] https://moex.gitlabpages.inria.fr/alignapi/impl.html

It has been the basis for most of our cultural evolution experiments (and all those currently available on the https://sake.re site). Students have been able to reuse the implementation of previous implementers (we are at the third generation of developers).

ClassApp (https://gitlab.inria.fr/moex/classapp) GPL 2.0

ClassApp is a Java implementation of the *Class?* game (§6.2). It is composed of a representation library and playing engine and a graphical interface allowing to play against artificial agents.

We are now starting using it for cultural evolution experiments.

KDiv (https://moex.inria.fr/software/kdiv/) MIT

KDiv is a python implementation of our entropy-based knowledge diversity measure (§2.4.3). It is meant as a proof of concept.

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

	Family	Audience	Maintenance	Duration
Alignment API	vehicle	community	lts	21y (2003)
Linkex	research	partners	lts	10y (2014)
Lazy lavender	research	partners	lts	10y (2014)
ClassApp	research	universe	lts	3y (2021)
KDiv	research	team	basic	2y (2022)

We interpret here 'lts' as the maintenance of a stable software: we make no promise that it will evolve, although some of these are actively developed, but we will correct bugs and port it on new languages and library versions.

4.5 Datasets

See §4.1.

5 Visibility

5.1 Leadership within the Scientific Community

- Jérôme Euzenat is EurAI fellow.
- Jérôme Euzenat is member of the scientific council of the CNRS GDR on Formal and Algorithmic Aspects of Artificial intelligence (2019-2022) then of the CNRS GDR Raisonnement, Apprentissage et Décision en Intelligence Artificielle (RADIA, 2023-2024).
- Jérôme David is member of the board of the Extraction and gestion des connaissances (Knowledge extraction and management) conference series (2019-2024).

Expertise

- Jérôme Euzenat has been member of the HCERES visiting committee for the CRIL research laboratory (2019).
- Jérôme Euzenat has been evaluation panel member for the Emmy Noether independent junior research groups in the field of artificial intelligence methods of the Deutsche Forschungsgemeinschaft (DFG, 2020)
- Jérôme Euzenat had been member of the Interdisciplinary assessment board for the interdisciplinary and cross-disciplinary research program in Artificial Intelligence of the Spanish Ministry of Universities, 2023.
- Jérôme David has been president of the selection committee for an assistant professor (section 27) at Université Grenoble Alpes (SHS department, 2023)

- Jérôme Euzenat has been member of the selection committee for the associate professor position 27MCF1141 at Université de Lorraine (IUT Saint-Dié, 2023)
- Jérôme David has been member of the selection committee for lecturer position (Polytech'Nantes, 2023)
- Jérôme Euzenat has been evaluator for exchange grants of the European project TAILOR (member of the "connectivity fund scientific board", 2023-2024)
- Manuel Atencia has been part of the committee granting IDEX scholarships for the Master "Mathematiques et informatiques appliquées aux sciences humaines et sociales" (2021);

Organization

- Jérôme Euzenat had been organiser of the Ontology matching workshop 2019-2023 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, Cássia Trojahn dos Santos and Oktie Hassanzadeh) [36, 37, 38, 39]

Responsibilities

- Jérôme Euzenat is member of the COS (Scientific Orientation Committee) of INRIA Grenoble Rhône-Alpes (2021-)
- Jérôme David is member of the "Commission du développement technologique" of INRIA Grenoble Rhône-Alpes (the whole period)
- Jérôme David and Manuel Atencia are member of the LIG laboratory council (-2024)

5.2 Boards and review

- Jérôme Euzenat is member of the editorial board of *Journal of web semantics* (area editor, 2019-), *Journal on data semantics* (associate editor, 2019-2021) and the *Semantic web journal* (2019-).
- Manuel Atencia had been reviewers for *Autonomous agents and multi-agent systems*.
- Jérôme David had been reviewer for *Applied ontology* and *Artificial intelligence*.
- Jérôme Euzenat had been reviewer for *Knowledge and information systems* and *Autonomous agents and multi-agent systems*.

Chair of Conference Program Committees

- Jérôme Euzenat was "sister conference" co-chairperson (with Juanzi Li) of the "International semantic web conference (ISWC)" 2020.
- Jérôme Euzenat, with Isabelle Bloch, Jérôme Lang and François Schwarzentruber have been invited editors of the special issue of "Revue ouverte d'intelligence artificielle" dedicated to selected papers of the French national artificial intelligence conferences 2018, 2019 and 2020 [43, 42]

Programme committees

- Jérôme Euzenat has been programme committee member of the "International Joint Conference on Artificial Intelligence (IJCAI)" 2019, 2020, 2021, 2022, 2023.
- Manuel Atencia and Jérôme David have been programme committee members of the "International Joint Conference on Artificial Intelligence (IJCAI)" 2019.
- Jérôme Euzenat has been programme committee member of the "European Conference on Artificial Intelligence (ECAI)" 2019, 2022, 2023.
- Manuel Atencia has been programme committee member of the "European Conference on Artificial Intelligence (ECAI)" 2019.
- Jérôme Euzenat has been programme committee member of the "International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS)" 2020, 2021, 2022.

– Jérôme Euzenat has been programme committee member of the "Web Conference (www)" 2019, 2020, 2021.
– Manuel Atencia, Jérôme David and Jérôme Euzenat have been programme committee members of the "International semantic web conference (iswc)" 2019.
– Jérôme David has been programme committee member of the "Web Conference (www)" 2019.
– Jérôme Euzenat has been programme committee member of the "International semantic web conference (iswc)" 2023.
– Jérôme David has been programme committee member of the "International semantic web conference (iswc)" 2019, 2020, 2021, 2023.
– Jérôme Euzenat had been programme committee member of the "International conference on formal ontologies for information systems (fois)" 2023.
– Jérôme Euzenat has been programme committee member of the "International conference on knowledge engineering and knowledge management (ekaw)" 2019.
– Jérôme Euzenat had been programme committee member of the "International conference on conceptual structures (iccs)" 2019, 2023.
– Jérôme Euzenat has been programme committee member of the "International conference on semantic systems (Semantics)" 2019.
– Jérôme David has been programme committee member of the "European semantic web conference (eswc)" 2019, 2020, 2021, 2022, 2023.
– Manuel Atencia has been programme committee member of the "European semantic web conference (eswc)" 2020, 2021.
– Jérôme David has been programme committee member of "Extraction et gestion des connaissances (egc)" 2019, 2020, 2021, 2022, 2023.
– Manuel Atencia has been programme committee members of the "Extraction et Gestion des connaissances (egc)" 2019.
– Jérôme David has been programme committee member of "Ingénierie des connaissances (ic)" 2022, 2023.
– Jérôme Euzenat has been programme committee member of the "Journées Françaises d'intelligence artificielle fondamentale (jiaf)" 2019, 2020, 2021, 2022, 2023.

Invited Talks

– "For knowledge", iswc keynote speech, Auckland (nz), 2019-10-29 (Jérôme Euzenat)
– Jérôme David gave a talk on "Several link keys are better than one, or Extracting disjunctions of link key candidates" to the Journées Raisonner sur les Données (RoD). 2020-07-06.
– Line van den Berg gave a Logic and Interactive Rationality Seminar (LIRa, Amsterdam (NL), 2021-03-25) on "Multi-Agent Knowledge Evolution in Dynamic Epistemic Logic".
– Jérôme Euzenat gave an invited talk to the 5ème Journée AFIA-EGC Extraction et gestion des connaissances et intelligence artificielle (Grenoble (FR), 2021-05-18) on "Knowledge evolution: a computational cultural knowledge evolution perspective".
– Line van den Berg gave a Bern Logic Seminar (Bern (CH), 2021-10-14) on "Cultural Knowledge Evolution in Dynamic Epistemic Logic".
– Jérôme Euzenat gave an invited talk to the Ontocommons online workshop: "Ontology commons addressing challenges of the industry 5.0 transition" (Online, 2021-11-02) on "Introduction to ontology matching and alignments".
– Jérôme David gave an invited talk to the Decade workshop (DEcouverte de Connaissances et Apprentissage dans les Données graphEs), Saint-Étienne (FR), 2022-06-28, on "Selection of representative subsets of link key candidates".

– Helga Lendrin talked about the industrialisation process of higher education in sub-Saharan Africa at at University of Paris 1 Master 2 seminar on “digital experimentation in Africa”, 2022-12-02.
– Jérôme Euzenat has been invited to the “Belief revision, argumentation and ontologies (BRAOn)” workshop, Madeira (PT), 2022-03-27-31.
– Jérôme Euzenat gave an invited talk to the International Collaborative Workshop of Ruhr Universität Bochum-Université Grenoble Alpes-University of Tsukuba, online, 2022-12-15, on “Artificial cultural knowledge evolution: agents that share knowledge”.
– Jérôme Euzenat had been invited to the SESAME seminar to give a talk on “Multi-agent simulation of cultural knowledge evolution”, Montpellier (FR), 2023-02-17.
– Jérôme Euzenat participated to the “Autonomous agents on the web” Dagstuhl seminar (Online, 2021-02-14-19) [44] and its in-person version (2023-02-19 – 24) [45].

6 Societal relevance

6.1 Technology transfer and socio-economic impact

mOeX is a small team addressing long-term topics and not targetting short-term applicability.

Our work on data interlinking aims at application to linked data offered in RDF on the web. It has found applications in thesauri and bibliographical data interlinking (see previous evaluation period).

mOeX’s work on cultural knowledge evolution is not directly applied and rather aims at isolating general principles of knowledge evolution.

However, we foresee its long-term potential impact in socio-technical system fields such as social robotics in which the knowledge acquired by autonomous agents will have to be shared and adapted to changing situations.

There are some fears that such systems may not abide to human values and beliefs. Another worry is that too rigid systems may be rejected by potential users. Finally, the race towards short-term optimisation may reduce diversity and be detrimental to long-term resilience.

Evolving such systems with cultural evolution mechanisms may help integrate common values and achieve a smoother integration. Yet we want to understand if the behaviour of artificial systems must be explicitly programmed within such systems (value-based engineering) or if it can be constrained by their very cultural evolution mechanisms (socially negotiated, hence not hard-wired).

Another social implication of our work is the study of belief propagation. For instance, understanding how beliefs propagate may be applied to counter fake news propagation, but may as well be used to ease instillation of ideas, either positive or not. Not understanding it, may be even more disturbing.

6.2 Societal impact

Mediation

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 pupils and students 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?*[2] which allows players to guess the hidden classification of another player.

It has been presented to school classes from year 5 of primary school (fourth graders) to year 11 (tenth graders), albeit it shows features of interest for a wider audience.

We have completed the design of a Small *Class?* game book [41] which offers a progressive curriculum investigating the ins-and-outs of the game. Beyond playing the game, it allows for understanding how to classify, learn decision tree, and find ontology alignment.

We have implemented the first part of the *Class?* game as a computer game[3]. Finally we are starting to use this material in research, for instance for simulating knowledge transmission in agents and people.

List of interventions:

- Introduction of the *Class?* game to a fourth grader (CM1-CM2) class, Montbonnot (FR), 2019-06-25 (Line van den Berg and Jérôme Euzenat)
- Introduction of the *Class?* game to a tenth grader (2^{nde} MathC2+) group, Montbonnot (FR), 2019-06-25 (Line van den Berg and Jérôme Euzenat)
- Introduction of the *Class?* game to seventh and eighth grader (5^{ime} and 4^{ime}) classes within the Fête de la science (Science fair), Montbonnot (FR), 2019-10-10 (Line van den Berg and Jérôme Euzenat)
- Introduction of the *Class?* game to general public within the Fête de la science (Science fair), Montbonnot (FR), 2019-10-12 (Line van den Berg and Jérôme Euzenat)
- Presentation of the *Class?* game to the meeting of the Société Francophone de Classification, Nancy (FR), 2019-09-03–04 (Jérôme Euzenat)
- Introduction by all members of mOeX of the *Class?* game to high-school students (tenth and eleventh graders) within the Fête de la science (Science fair), Montbonnot (FR), 2021-10-05–07.
- Introduction of the *Class?* game to a tenth grader (2nd MathC2+) group, Montbonnot (FR), 2022-06-27.
- Introduction by all members of mOeX of the *Class?* game to ninth graders within the Fête de la science (Science fair), Saint-Martin d'Hères (FR), 2022-10-13
- Presentation of the *Class?* game to the French «info sans ordi (computer science unplugged)» group, Lyon (FR), 2023-10-04
- Introduction of the *Class?* game to a tenth grader (2^{nd} MathC2+) class, Montbonnot (FR), 2023-06-28.
- Introduction of the *Class?* game to tenth grader classes within the Fête de la science (Science fair), Montbonnot (FR), 2023-10-09

General public talks

- Presentation "L'intelligence artificielle en perspective", Université Inter-Âges du Dauphiné (UIAD), Grenoble (FR), 2019-03-06 (Jérôme Euzenat)

7 Funding and collaborations

We note that the budget allocated to teams to function decreases year after year.

[2] https://moex.inria.fr/mediation/class/
[3] https://gitlab.inria.fr/moex/classapp

Hence, research operation relies on external funding coming with multiple administrative constraints (fragmentation, deadline, engagement rules, delays). Such constraints lead to extra burden and the underspending of the allocated grants.

At the moment the mOeX team has no external funding. We plan to apply as soon as a relevant call is open.

National initiatives

ANR Elker

Project name: Elker
Program: ANR-PRC
Title: Extending link keys: extraction and reasoning
Coordinator: LIG (Manuel Atencia)
Other partners: INRIA Lorraine, Université de Vincennes+Université Paris 13
Duration: October 2017–September 2021
Grant: 170k€ for mOeX
Web site: https://project.inria.fr/elker/
Abstract: The goal of Elker is to extend the foundations and algorithms of link keys (see §2.3) in two complementary ways: extracting link keys automatically from datasets and reasoning with link keys.

PEPS RegleX-LD

Project name: RegleX-LD
Program: Projets Exploratoires Premier Soutien (CNRS, INS2I)
Title: Découverte de règles expressives de correspondances complexes et de liage de données
Coordinator: IRIT (Cássia Trojahn)
Other partners: INRA Paris, LRI Orsay, LIG Grenoble
Duration: January 2019 – December 2019
Grant: 10k€ for the whole project
Abstract: RegleX-LD aims at discovering expressive ontology correspondences and data interlinking patterns using unsupervised or weakly supervised methods.

MIAI

Project name: MIAI
Program: ANR-3IA
Title: Multidisciplinary institute in artificial intelligence
Coordinator: Université Grenoble Alpes (Éric Gaussier)
Other partners (in the chair): INRIA Tyrex team, Yves Demazeau (LIG)
Duration: July 2019–December 2023
Grant: 320k€ for the chair (including mOeX and other colleagues)
Web site: https://miai.univ-grenoble-alpes.fr
Abstract: mOeX held the MIAI Knowledge communication and evolution chair which aims at understanding and developing mechanisms for seamlessly improving knowledge (see §2.4). It studies the evolution of knowledge in a society of people and AI systems by applying evolution theory to knowledge representation.

European projects

Tailor

Title: Trustworthy AI through the integration of learning, optimisation and reasoning
Program: H2020-ICT-48-2020
Coordinator: Linköping University (coordinator)
Other partners: CNR, INRIA, University college Cork, KU Leuven... Université Grenoble Alpes... (around 100)
Duration: September 2020–August 2024
Grant: 100k€ for Université Grenoble Alpes
Web site: https://tailor-network.eu/
Abstract: UGA is mostly involved in the work packages concerning trustworthy AI and social AI. mOeX participates in the Tailor network, especially in work package 6 "Social AI: learning and reasoning in social contexts".
Since September 2023, Jérôme Euzenat represents the University Grenoble Alpes within the TAILOR network.

Other funding and visit

- Nacira Abbas (U. Lorraine) visited mOeX between 2019-02-04 and 2019-02-15 in the framework of the Elker project, working on link key extraction with formal concept analysis.
- Hiba Belhadi, PhD student at Université des Sciences et de la Technologie Houari Boumediene (UTHB), Algiers, visited mOeX between 2019-10-15 and 2019-11-15 to work on selecting and matching properties for data interlinking.
- Alda Canito, PhD student at Universidad de Salamanca (Spain), visited mOeX between April and July 2023 and again in October 2023 to work on ontology evolution for predictive maintenance.
- Koji Hasebe (University of Tsukuba) benefited from an INRIA invited professor grant to visit mOeX for one month in July 2023 in the context of our work of opinion dynamics and belief propagation (§2.4.7).
- Jérôme Euzenat visited the multi-agent system team at the University of Tsukuba for one month in October 2023 granted by the PAI Project Kyoukan (20 006913 01 9183) supported by the Région Auvergne Rhône-Alpes. This also contributed to our work of opinion dynamics and belief propagation (§2.4.7).

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