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2025 *Activity Report*

RESEARCH CENTRE: **Inria Centre at Université Grenoble Alpes**
IN PARTNERSHIP WITH: **Université de Grenoble Alpes**

Project-Team

MOEX

Evolving Knowledge

In collaboration with Laboratoire d'Informatique de Grenoble (LIG)

Project-Team MOEX

Creation of the Project-Team: 2017 November 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A3.2. – Knowledge

A3.2.1. – Knowledge bases

A3.2.2. – Knowledge extraction, cleaning

A3.2.3. – Inference

A3.2.4. – Semantic Web

A3.2.5. – Ontologies

A3.2.6. – Linked data

A3.3.2. – Data mining

A3.5. – Social networks

A6.1.3. – Discrete Modeling (multi-agent, people centered)

A7.2. – Logic in Computer Science

A9. – Artificial intelligence

A9.1. – Knowledge

A9.2.3. – Reinforcement learning

A9.8. – Reasoning

A9.9. – Distributed AI, Multi-agent

A9.15. – Symbolic AI

Other research topics and application domains

B8.5. – Smart society

B9. – Society and Knowledge

B9.5.1. – Computer science

B9.6.5. – Sociology

B9.6.14. – Anthropology, ethnology

B9.7.2. – Open data

B9.8. – Reproducibility

Contents

1 Team members, visitors, external collaborators

Research Scientists

- Jérôme Euzenat [Team leader, INRIA, Senior Researcher, HDR]
- Lucía Gómez Álvarez [INRIA, Researcher]

Faculty Members

- Jérôme David [UGA, Professor, HDR]
- Cássia Trojahn [UGA, Professor, HDR]

PhD Students

- Linda Gutsche [UGA]
- Richard Trezeux [UGA]
- Roxane Vanden Bossche [UGA, from Sep 2025]

Interns and Apprentices

- Adrien Bonnardel [UGA, Intern, until Jun 2025]
- Hiro Kataoka [INRIA, Intern, from Feb 2025 until Jul 2025]
- Aksel Perrigault [UGA, Intern, until Jul 2025]
- Roxane Vanden Bossche [INRIA, Intern, from Apr 2025 until Aug 2025]

Administrative Assistant

- Julia Di Toro [INRIA]

Visiting Scientists

- Koji Hasebe [University of Tsukuba, from Sep 2025 until Oct 2025]
- Hiro Kataoka [UGA, until Jan 2025, MIAI]
- Piotr Ostropolski-Nalewaja [University of Wrocław, from Jun 2025 until Jun 2025]

External Collaborator

- Manuel Atencia [Universidad de Málaga]

2 Overall objectives

mOeX addresses the evolution of knowledge representations in individuals and populations. 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 them chiefly in a well-controlled computer science context.

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 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.

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

In addition, we still investigate RDF data interlinking with link keys, a way to link entities from different data sets.

3 Research program

3.1 Knowledge and belief representation semantics

We work with knowledge and beliefs represented in computers. In principle, the difference between them is based on their epistemological status: knowledge is true belief. But they can both be expressed in the same knowledge representation languages (like description logics, conceptual graphs and object-based languages). Their semantics is usually defined within model theory initially developed for logics.

We consider a language L as a set of syntactically defined expressions (often inductively defined by applying constructors over other expressions). A representation ($o \subseteq L$) is a set of such expressions. It may also be called an ontology. An interpretation function (I) is inductively defined over the structure of the language to a structure called the domain of interpretation (D). This expresses the construction of the "meaning" of an expression in function of that of its components. A formula is satisfied by an interpretation if it fulfills a condition (in general being interpreted over a particular subset of the domain). A model of a set of expressions is an interpretation satisfying all the expressions. A set of expressions is said consistent if it has at least one model, inconsistent otherwise. An expression (δ) is then a consequence of a set of expressions (o) if it is satisfied by all of their models (noted $o \models \delta$).

The languages designed for the semantic web (RDF and OWL) follow that approach. RDF is a knowledge representation language dedicated to the description of resources; OWL is designed for expressing ontologies: it describes concepts and relations that can be used within RDF.

A computer must determine if a particular expression (taken as a query, for instance) is the consequence of a set of axioms (a knowledge base). For that purpose, it uses programs, called provers, that can be based on the processing of a set of inference rules, on the construction of models or on procedural programming. These programs are able to deduce theorems (noted $o \vdash \delta$). They are said to be sound if they only find theorems which are indeed consequences and to be complete if they find all the consequences as theorems.

3.2 Standpoint logics and alignments

Both within human and artificial agent communities, diversity in world representations is to be expected. 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.) [4].

Standpoint logics are a way to model heterogeneous knowledge held by different agents. Standpoint logics [21] are first-order multi-modal logics 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 epistemic logics. Standpoint logics facilitate 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 standpoint logics 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. We plan to investigate theoretical models of standpoint knowledge evolution, using notions of belief revision and building on our previous work modelling cultural evolution with dynamic epistemic logic.

3.3 Data interlinking with link keys

Vast amounts of RDF data are made available on the web by various institutions providing overlapping information. 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 identifiers.

We have introduced link keys [4, 1] 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 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.

3.4 Experimental cultural knowledge evolution

Cultural evolution applies a generalised version of the theory of evolution to culture. It considers how culture spreads and evolves within human societies [22]. 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.

We adapt the experimental strategy, developed for cultural language evolution [23], to knowledge representation [2]. 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 different games.

4 Application domains

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 potential impact in the long term in fields such as digital twins, social network analysis or social robotics in which the knowledge acquired by autonomous agents will have to be shared and adapted to changing situations.

Our work on data interlinking aims at application to linked data offered in RDF on the web. It is applied to open science topics such as bibliographic search and dataset matching.

5 Highlights of the year

This years have seen the publication of the semantics of the full relational concept analysis method [7].

6 Latest software developments, platforms, open data

6.1 Latest software developments

6.1.1 Lazylav

Name: Lazy lavender

Keywords: Reproducibility, Multi-agent, Simulation

Scientific Description: Lazy lavender aims at supporting mOeX's research on simulating knowledge evolution. It is not a general purpose simulator. However, it features some methodological innovations in term of facilitating publication, recording, and replaying of experiments.

Functional Description: Lazy Lavender is a simulation environment for cultural knowledge evolution, i.e. running randomised experiments with agent adjusting their knowledge while attempting to communicate. It can generate detailed reports and data from the experiments and directions to repeat them.

Release Contributions: Lazy lavender is continuously evolving and does not feature stable releases.

Instead, git hashes are used to determine which version is used in a simulation.

URL: `https://gitlab.inria.fr/moex/lazylav/`

Publications: hal-03426130, hal-01661140, hal-01661139, hal-01180916, hal-03939919, hal-03905183

Contact: Jerome Euzenat

Participants: Jerome Euzenat, 7 anonymous participants

6.1.2 Alignment API

Keywords: Ontologies, Alignment, Ontology engineering, Knowledge representation

Scientific Description: The API itself is a Java description of tools for accessing the common format. It defines five main interfaces (OntologyNetwork, Alignment, Cell, Relation and Evaluator).

We provide an implementation for this API which can be used for producing transformations, rules or bridge axioms independently from the algorithm that produced the alignment. It features: - a base implementation of the interfaces with all useful facilities, - a library of sample matchers, - a library of renderers (XSLT, RDF, SKOS, SWRL, OWL, C-OWL, SPARQL), - a library of evaluators (various generalisation of precision/recall, precision/recall graphs), - a flexible test generation framework that allows for generating evaluation data sets, - a library of wrappers for several ontology APIs , - a parser for the format.

The API implementation provides an extended language for expressive alignments (EDOAL). EDOAL supports many types of restrictions inspired from description logics as well as link keys. It is fully supported for parsing and serialising in XML. It also provides other serialisers, to OWL and SPARQL queries in particular.

To instanciate the API, it is sufficient to refine the base implementation by providing the align() method. Doing so, the new implementation will benefit from all the services already implemented.

Functional Description: Using ontologies is the privileged way to achieve interoperability among heterogeneous systems within the Semantic web. However, as the ontologies underlying two systems are not necessarily compatible, they may in turn need to be reconciled. Ontology reconciliation requires most of the time to find the correspondences between entities (e.g. classes, objects, properties) occurring in the ontologies. We call a set of such correspondences an alignment.

Release Contributions: See release notes.

The Alignment API is now hosted by gitlab and versioned with git.

The Alignment API compiles in Java 11 (jars are still compiled in Java 8).

URL: `https://moex.gitlabpages.inria.fr/alignapi/`

Publications: hal-00825931, hal-00781018

Contact: Jerome Euzenat

Participants: Jérôme David, 6 anonymous participants

6.1.3 LinkEx

Keywords: LOD - Linked open data, Data interlinking, Formal concept analysis

Functional Description: LinkEx implements link key candidate extraction with our initial algorithms, formal concept analysis or pattern structures. It can extract link key expressions with inverse and composed properties and generate compound link keys. Extracted link key expressions may be evaluated using various measures, including our discriminability and coverage. It can also evaluate them according to an input link sample. The set of candidates can be rendered within the Alignment API's EDOAL language or in dot.

URL: `https://gitlab.inria.fr/moex/linkex`

Publications: hal-02168775, hal-01179166

Contact: Jérôme David

Participant: Jérôme David

6.2 Open data

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 specifications to rerun experiments but these have to be repurposed.

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 experiments are published in papers, they are also published in Zenodo. These are important steps towards accountability, portability, reproducibility and long term storage.

Semantically describing experiments would provide more benefits. 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 (§6.1.1) also works with other simulators, developed in different languages (§7.1.3 and 7.1.4).

7 New results

7.1 Cultural knowledge evolution

7.1.1 Ontology/knowledge evolution

Participants: Jérôme David *(Correspondent)*.

Evolving an ontology involves re-learning, re-enriching and re-validating knowledge in the face of changes to the domain, and techniques applied for them can be adapted to ontology evolution. The possibilistic approach to axiom scoring has been applied over complete and large datasets in ontology learning. We adapted the possibilistic approach to axiom scoring to the context of RDF data streams for ontology evolution, a scenario which forcefully deals with incomplete and time-dependent data [6]. Possibilistic axiom scoring is used in two distinct scenarios: (1) With previously known property axioms, allowing for the exploration of the effectiveness of the approach in a scenario in which no incorrect data was present; and (2) in an evolving knowledge scenario, in which neither the properties nor the axioms were known and the dataset was obtained from publicly available sources, possibly both incomplete and with errors. Results show the effectiveness of the approach in accepting/rejecting axioms for the ontology's properties. The different approaches to possibility and necessity proposed in literature were recontextualised in terms of their bias towards selective confirmations or counterexamples – showing that some axioms benefit from a more lenient approach, while others present a lower risk of introducing inconsistencies by having harsher acceptance conditions.

7.1.2 A new semantics for the logic of doxastic attitudes

Participants: Jérôme Euzenat, Lucía Gómez Álvarez, Linda Gutsche *(Correspondent)*.

When representing an agent's beliefs with a belief base, a distinction can be made between beliefs explicitly contained in the belief base and those that can be derived from it. The logic of doxastic attitudes models this distinction in epistemic logic through modal operators for explicit and implicit beliefs, and a semantics based on the notion of belief bases. We extended this framework to allow agents to hold explicit beliefs about other agents' implicit beliefs and suggested an alternative semantics that can model agents with imperfect reasoning. We proved that the new semantics, when restricted to agents that can derive from a set of formulas all that it logically entails, is indeed equivalent to the original one.

7.1.3 Learning general adaptation strategies for cultural knowledge evolution

Participants: Jérôme David, Jérôme Euzenat, Richard Trézeux *(Correspondent)*.

Computational cultural evolution aims to model how agents develop a common culture through local interactions (see §3.4). It is achieved through specific games in which agents take turns to make decisions in a specific environment according to their knowledge. Interactions may succeed or fail, in which cases agents adapt their knowledge. Previous work on computational cultural evolution observes the effect of static adaptation operators [2]. Our recent work uses reinforcement learning to learn to adapt agent's decisions. But because decisions are directly selected, learned policies depend on the environment. Hence, they do not perform well in different environments. We aim at learning environment-independent policies to play a specific game type. For that purpose, we designed agents that use reinforcement learning to learn policies combining different knowledge adaptation operators, instead of learning how to make decisions. Decisions are thus guided by a symbolic knowledge base updated with the learned policy, but rewards go to the policy operators. Thus, these adaptation policies depend, through the operators, on the knowledge structure rather than the specific content of the environment. Results show that these policies allow agents to efficiently complete the games and remain effective across different environments.

7.1.4 Opinion and belief propagation increases echo chambers

Participants: Jérôme Euzenat *(Correspondent)*, Koji Hasebe, Hiro Kataoka.

Echo chambers, the state in which agents are split into groups sharing the same opinion, is a well-known phenomenon in social networks. Opinion dynamics models have been proposed to explain how the phenomenon occurs through agents revising their opinions. However, social network users also exchange beliefs supporting their opinions. This has not been taken into account. We have extended an existing opinion dynamics model by allowing agents to exchange and update both beliefs and opinions. The process of updating beliefs is described based on the classical belief revision theory. Beliefs and opinions can influence each other guided by values that agents share. We compared opinion propagation with respect to belief influence. Simulation results show that connecting beliefs and opinions increases the number of echo chambers [14].

7.2 Standpoint logics

7.2.1 Reasoning in standpoint first order logic

Participants: Lucía Gómez Álvarez *(Correspondent)*.

Standpoint extensions of knowledge representation formalisms have been recently introduced to incorporate multi-perspective modelling and reasoning capabilities (see §3.2). In such modal extensions, the integration of conceptual modelling and perspective annotations can be more or less tight, with monodic standpoint extensions striking a good balance as they enable advanced modelling while preserving good reasoning complexities. We have considered the extension of C2 – the counting two-variable fragment of first-order logic – by monodic standpoints [12]. At the core of this work was a polytime translation of formulae in standpoint logic into standpoint-free C2, which required elaborate model-theoretic arguments. By virtue of this translation, the NEXPTIME-complete complexity of checking satisfiability in C2 carried over to our formalism. As this work subsumed monodic S5 over C2, the results also significantly advanced the state of the art in research on first-order modal logics. As a practical consequence, the very expressive description logics SHOIQBs and SROIQBs, which subsume the popular W3C-standardized OWL 1 and OWL 2 ontology languages, were shown to allow for monodic standpoint extensions without any increase of standard reasoning complexity. We proved that NEXPTIME-hardness already occurred in much less expressive DLs as long as they featured both nominals and monodic standpoints. We also showed that, with inverses, functionality, and nominals present, minimally lifting the monodicity restriction led to undecidability.

7.2.2 SAT meets tableaux for standpoint linear temporal logic

Participants: Lucía Gómez Álvarez *(Correspondent)*.

Many complex scenarios require the coordination of agents possessing different points of view, and thus may involve reasoning across both conflicting perspectives and temporal dynamics. To address this need, standpoint linear temporal logic (SLTL) provides a framework combining standpoint logic (SL, see §3.2) with linear temporal logic (LTL), a well-established formalism for specifying temporal properties of systems and processes. In this work, we took a significant step beyond the previous theoretical work on SLTL and provided automated reasoning support for the logic. We did this by introducing a SAT-based approach for checking the satisfiability of SLTL formulae. This consisted of producing a SAT encoding that emulates the behaviour of a tableau algorithm for SLTL up to a depth k in an incremental fashion, in what is known as bounded satisfiability checking. Our algorithm was implemented as an extension of the BLACK satisfiability checker, a state-of-the-art SAT-based LTL solver. In order to evaluate the feasibility of the approach, we introduced the first benchmark set for SLTL, which included a diverse and scalable collection of formulae designed to evaluate solver performance and scalability.

7.2.3 Belief revision for standpoint logic

Participants: Jérôme Euzenat, Lucía Gómez Álvarez, Roxane Vanden Bossche *(Correspondent)*.

We have started adapting belief revision to standpoint logic (see §3.2). We introduce four dynamic operators inspired from the equivalent operators of dynamic epistemic logic: Public announcements for standpoint logic, private announcements for standpoint logic, simple radical update for standpoint logic, and memoryless radical update for standpoint logic. Those new operators are compatible with standpoint structures, the semantic structures of Standpoint Logic. We show that extending standpoint logic with public and private announcements preserves the NP-completeness of its satisfiability problem.

7.3 Link keys and ontology matching

7.3.1 Expressive ontology alignments

Participants: Cássia Trojahn *(Correspondent)*.

Complex ontology matching generates alignments whose correspondences feature logical constructors or transformation functions of literal values. The complexity in this task lies not only in finding multiple entities to map, but also in writing the right logical constructors to combine them in the right way. We have been working on the generation of expressive correspondences between large ontologies using ontology modularisation strategies and large language models. This involves as well proposing a new metric for evaluating such correspondences with the help of reference alignments [15]. It has been used in the OAEI campaigns with the participation of the CMatch (Complex Matcher) system [16] and leading the Complex Track [8].

7.3.2 Link key discovery with graph embeddings

Participants: Jérôme David, Cássia Trojahn *(Correspondent)*.

Entity matching automates the discovery of identity links between entities within different Knowledge Graphs (KGs). Link keys are crucial for entity matching, serving as rules allowing to identify identity links across different KGs, possibly described using different ontologies. However, the approach for extracting link keys struggles to scale on large KGs. While embedding-based methods efficiently handle large KGs they lack explainability. We proposed a novel hybrid approach to guarantee the scalability link key extraction approach and improve the explainability of embedding-based entity matching methods [13]. First, embedding-based approaches are used to sample the KGs based on the identity links they generate, thereby reducing the search space to relevant sub-graphs for link key extraction. Second, rules (in the form of link keys) are extracted to explain the generation of identity links by the embedding-based methods. Experimental results demonstrate that the proposed approach allows link key extraction to scale on large KGs, preserving the quality of the extracted link keys. Additionally, it shows that link keys can improve the explainability of the identity links generated by embedding-methods, allowing for the regeneration of 77% of the identity links produced for a specific entity matching task, thereby providing an approximation of the reasons behind their generation.

7.3.3 Compressing concept lattices by clustering

Participants: Jérôme David *(Correspondent)*.

A concept lattice provides a model of a dataset that can be navigated and explored by an analyst in an interactive way, except when the concept lattice is too large. Such a problem can be overcome by building a representation of the whole concept lattice of reasonable size that can be interpreted by the analyst. Relying on previous work about link key discovery (see §3.3), we have redesigned an approach based on Formal Concept Analysis and Agglomerative Hierarchical Clustering (AHC) applied to a set of concepts for building a representative set of clusters [9]. Accordingly, we proposed an AHC algorithm that (a) efficiently computes this representative set, and (b) respects the ordinal structure of the original concept lattice. Experiments performed over real datasets show the effectiveness of the approach.

7.3.4 Fixed-point semantics for relational concept analysis

Participants: Jérôme Euzenat *(Correspondent)*.

We have used relational concept analysis (RCA) to extract link keys. This led us to notice that, when there exist circular dependencies between objects, RCA 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 extended our previous work on this issue by extending results to the full relational concept analysis, providing a definitive formal semantics to it [7]. We redefined the semantics of RCA in terms of concept lattice families induced by this relational structure. We showed that the concept lattice families closed by a pair of fixed-point operations admit a least and greatest fixed point and that the RCA semantics is characterised by the least fixed point. 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.

7.3.5 Agents and large language models for open data discovery

Participants: Cássia Trojahn *(Correspondent)*.

Open science has broadened access to scientific datasets. However, identifying relevant ones to specific user needs remains challenging due to its volume, diversity and poor metadata. We proposed to combine semantically enriched open dataset metadata with LLM-based agents that interpret natural language queries to manage the gap between users' needs and dataset descriptions, and to support the retrieval of relevant datasets

[18]. This enables the extraction and refinement of user needs, as well as the generation of justifications for the retrieved results. To assess the performance of the proposed system, an evaluation was conducted across multiple earth observation data request scenarios [10].

7.3.6 Semantic representation of memory concepts

Participants: Cássia Trojahn *(Correspondent)*.

Different disciplines have been studying human memory and related issues for thousands of years. However, the definitions of the concepts relating to memory vary depending on the discipline or theory. In order to conciliate these variations and ambiguities, a solution is to formally define the concepts studied through ontologies. We have developed Mem'Onto, a memory ontology which gathers concepts related to memory, based on Tulving's SPI model [11]. This theory corresponds to a model of memory organisation and brings together various central elements of memory according to Tulving, whether in memory systems (e.g. episodic memory, semantic memory, procedural memory), in mnesic processes (e.g. encoding, storage, retrieval) or in the level of consciousness of these subsystems during retrieval (implicit and explicit). Mem'Onto is adapted from an existing ontology, CoTOn, a Cognitive Theory Ontology designed from a working memory use case.

8 Partnerships and cooperations

Participants: Jérôme David, Jérôme Euzenat, Lucía Gómez Álvarez, Linda Gutsche, Cássia Trojahn, Roxane Vanden Bossche.

8.1 International initiatives

8.1.1 Inria associate team not involved in an IIL or an international program

Title: Fukuro

Partner Institution(s): University of Tsukuba, Japan

Date/Duration: 2025–2028

Additionnal info/keywords: The Fukuro associate team joins the mOeX team and the multi-agent systems team of the University of Tsukuba (JP). Our goal is to study belief propagation with opinion dynamic techniques (see §7.1.4).

8.1.2 Participation in other International Programs

Title: Echo Chambers in Hybrid Opinion-knowledge interactions (Echo)

Partner Institution(s): University of Tsukuba, Japan

Date/Duration: 2025

Additionnal info/keywords: Project of the NTU-UGA-UT Trilateral Center which aims to analyse how echo chambers can be raised in relation with beliefs-opinions interactions (see §7.1.4).

8.2 International research visitors

8.2.1 Visits of international scientists

Other international visits to the team

Piotr Ostropolski-Nalewaja

Status Assistant professor

Institution of origin: University of Wrocław

Country: Poland

Dates: 2025-06-02 – 2025-06-30

Context of the visit: This visit was held in the context of the collaboration on Bridging KR Paradigms: Existential Rules and Standpoint Logics. During the stay there were significant advances on our work on fully modalised Standpoint Description Logics.

Mobility program/type of mobility: research stay (INRIA Grenoble invited professor)

Koji Hasebe

Status Assistant professor

Institution of origin: University of Tsukuba

Country: Japan

Dates: 2024-09-12 – 2024-10-16

Context of the visit: Work on opinion dynamics and belief propagation (see §7.1.4).

Mobility program/type of mobility: research stay (NTU-UGA-UT Trilateral Center)

Hiro Kataoka

Status Intern

Institution of origin: University of Tsukuba

Country: Japan

Dates: 2025-01-01 – 2025-07-18

Context of the visit: Work on opinion dynamics and belief propagation, especially the work on echo chamber occurence (see §7.1.4).

Mobility program/type of mobility: research stay (in parallel to study)

8.2.2 Visits to international teams

Research stays abroad

Jérôme David

Visited institution: University of Tsukuba

Country: Japan

Dates: 2025-07-15 – 2025-08-04

Context of the visit: Study of diversity in the context of opinion dynamics and belief propagation (see §7.1.4).

Mobility program/type of mobility: research stay (NTU-UGA-UT Trilateral Center)

Lucía Gómez Álvarez

Visited institution: Technische Universität Dresden

Country: Germany

Dates: 2024-08-18 – 2024-08-22

Context of the visit: This visit was held in the context of the collaboration on fully modalised Standpoint Description Logics, with Sebastian Rudolph and Piotr Ostropolski-Nalewaja (see §7.2.1)

Mobility program/type of mobility: research stay

Lucía Gómez Álvarez

Visited institution: Free University of Bolzano

Country: Italy

Dates: 2025-09-08 – 2025-09-12

Context of the visit: This visit was held in the context of the collaboration on Temporal Standpoint Logics with Nicola Gigante and Tim Lyon (see §7.2.2).

Mobility program/type of mobility: research stay

Jérôme Euzenat

Visited institution: University of Tsukuba

Country: Japan

Dates: 2025-12-01 – 2025-12-12

Context of the visit: Pursued the work on joint belief opinion propagation and their effects on the creation of echo chambers. Supervision of students in double diploma UGA-Tsukuba (see §7.1.4)

Mobility program/type of mobility: research stay (NTU-UGA-UT Trilateral Center)

9 Dissemination

Participants: Jérôme David, Jérôme Euzenat, Lucía Gómez Álvarez, Linda Gutsche, Cássia Trojahn, Roxane Vanden Bossche.

9.1 Promoting scientific activities

9.1.1 Scientific events: organisation

General chair, scientific chair

- Lucía Gómez Álvarez had been chair of the "Interdisciplinary school on applied ontology (ISAO)", Catania (IT), 2025.

Member of the organizing committees

- Cássia Trojahn and Jérôme Euzenat had been organisers of the 20th Ontology matching workshop of the 25th ISWC, Nara (JP), 2025 (with Pavel Shvaiko, Ernesto Jiménez Ruiz, and Oktie Hassanzadeh) [19]

9.1.2 Scientific events: selection

Member of the conference program committees

- Cássia Trojahn and Jérôme Euzenat had been senior programme committee members of the "International conference on formal ontologies for information systems (FOIS)", Lucía Gómez Álvarez had been programme committee member.
- Cássia Trojahn had been programme committee member of the "International world-wide web conference (WWW)".
- Jérôme Euzenat had been programme committee member of the "International Joint Conference on Artificial Intelligence (IJCAI)"
- Jérôme Euzenat had been programme committee member of the "European Conference on Artificial Intelligence (ECAI)"
- Jérôme Euzenat and Cássia Trojahn had been programme committee member of the "International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS)".
- Lucía Gómez Álvarez had been programme committee member of the International Conference on Principles of Knowledge Representation and Reasoning (KR).
- Lucía Gómez Álvarez had been programme committee member of the "AAAI Conference on Artificial Intelligence (AAAI)".
- Lucía Gómez Álvarez had been programme committee member of the "European conference on logics in artificial intelligence (JELIA)".
- Cássia Trojahn and Jérôme David had been programme committee member of the "International semantic web conference (ISWC)".
- Cássia Trojahn had been senior programme committee member and Jérôme David programme committee member of the "European semantic web conference (ESWC)".
- Cássia Trojahn had been programme committee member of the "International conference on knowledge capture (KCap)".
- Jérôme David had been programme committee member of "Extraction et gestion des connaissances (EGC)".
- Cássia Trojahn had been programme committee member of "Ingénierie des connaissances (IC)".

9.1.3 Journal

Member of the editorial boards

- Jérôme Euzenat is member of the editorial board of *Journal of web semantics* (area editor) and the *Semantic web journal*.
- Cássia Trojahn is member of the editorial board of *Transactions on graph data and knowledge*.

Reviewer - reviewing activities

- Jérôme David reviewed for *Journal of web semantics*
- Lucía Gómez Álvarez reviewed for *Applied ontology* and *Journal of artificial intelligence research*
- Cassia Trojahn has reviewed for *Transactions on graph data and knowledge*

9.1.4 Invited talks

- Jérôme Euzenat delivered the distinguished lecture of the Institut für Informatik, University of Paderborn (DE), on Cultural knowledge evolution in artificial agent societies, 2025-06-17
- Jérôme Euzenat presented "A cultural evolution approach to knowledge and belief coordination" at the "Workshop on semantics, reasoning & coordination", Saint-Étienne (FR), 2025-09-04
- Lucía Gómez Álvarez gave a presentation on "How to Agree to Disagree: Managing Conceptual Diversity using Standpoint Logic" at the Free University of Bozen-Bolzano (IT), 2025-09-11
- Jérôme Euzenat presented "Knowledge representation is knowledge approximation" at the "Workshop en mémoire d'Hassan Aït-Kaci", Villeurbanne (FR), 2025-09-26

9.1.5 Leadership within the scientific community

- Jérôme David is member of the board of the Extraction and gestion des connaissances (Knowledge extraction and management) conference series.
- Cássia Trojahn is member of the steering committee of the AFIA "Sciences of knowledge engineering" college.
- Jérôme Euzenat is EurAI fellow.

9.1.6 Scientific expertise

- Cássia Trojahn is member of the sectorial scientific commission "Data and model science" of the French research institute for development (IRD)
- Cássia Trojahn has been member of the HCERES evaluation panel of Espace-Dev (IRD Montpellier)
- Cássia Trojahn has been evaluator for eight MSCA Doctoral Network proposals
- Jérôme David had been president of the recruitment committee of Université Grenoble Alpes for the associate professor position 27MCF464, 2025
- Jérôme David had been member of the selection committee for associate professor position (section 26) at Université Grenoble Alpes (SHS department)
- Cássia Trojahn has been evaluator for three project proposals to the ANR 23 and 56 committees

9.1.7 Research administration

- Jérôme David is member of the "Commission du développement technologique" of INRIA Grenoble Rhône-Alpes
- Jérôme Euzenat is member of the COS (Scientific Orientation Committee) of INRIA Grenoble Rhône-Alpes

9.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

9.2.1 Teaching

Responsibilities

- Cássia Trojahn is responsible for the M1 MIASHS - Parcours Informatique et Cognition (UFR SHS/UGA)
- Jérôme David is the representative of IM2AG department for the CMA EFELIA project (Univ. Grenoble Alpes).
- Lucía Gómez Álvarez had been tutorial chair of the 15th "International conference on formal ontologies for information systems (FOIS)", Catania (IT), 2025.

Lectures

- Licence: Cássia Trojahn, Programmation fonctionelle, 42h/y, L1 MIASH, UGA, France
- Licence: Linda Gutsche, Algorithmique et programmation fonctionnelle, 51h/y, L1 informatique & L1 mathématiques, UGA, France
- Licence: Jérôme David, Système et environnement de programmation: principes d'utilisation, 40.5h/y, L1 informatique, UGA, France
- Licence: Jérôme David, Gestion de données relationnelles et applications, 34.5h/y, L1 informatique, UGA, France
- Licence: Roxane Vanden Bossche, Théorie des automates, 27h/y, L2 informatique, UGA, France
- Licence: Cássia Trojahn, Système, 16h/y, L3 MIASH, UGA, France
- Licence: Jérôme Euzenat and Cássia Trojahn, Programmation Logique, 24h/y, L2 MIASHS, UGA, France
- Licence: Linda Gutsche, Modèles de calculs – machines de Turing, 12h/y, L3 informatique, UGA, France
- Licence: Jérôme David, Programmation, 82.5h/y, L3 MI, UGA, France
- Master: Jérôme David, Conception orientée-objet, 30h/y, M1 Informatique, UGA, France
- Master: Cássia Trojahn, Introduction à l'intelligence artificielle, 36h/y, M1 MIASH, UGA, France
- Master: Cássia Trojahn, Génie Logiciel, 36h/y, M1 MIASH, UGA, France
- Master: Cássia Trojahn, IA pour les systèmes complexes, M2 MIASH 36h/y, UGA, France
- Master: Jérôme David, Programmation Objet - Java, 40h/y, M2 CCI, UGA, France

Tutorials

- Jérôme Euzenat gave an online presentation on Ontology evolution at the "Educational series on applied ontology (ESAO), 2025-03-20
- Cássia Trojahn gave two lectures "Ontology matching, standardisation and interoperability" (with Stefan Schultz) and "Knowledge graphs and their interface to Applied Ontology" and one hands-on session on "Ontology matching tools" at ISAO, 2025-09-15–19, Catania (IT)

9.2.2 Supervision

PhD theses

- Linda Gutsche, "Modelling cultural knowledge evolution with dynamic epistemic logics and belief revision", in progress since 2024-09-01 (Jérôme Euzenat and Lucía Gómez Álvarez)
- Richard Trézeux, "Reinforcement learning and knowledge evolution", in progress since 2024-10-01 (Jérôme David and Jérôme Euzenat)
- Roxane Vanden Bossche, "Knowledge evolution in standpoint logic", in progress since 2025-09-01 (Lucía Gómez Álvarez and Jérôme Euzenat)

M2 internships

- Hiro Kataoka, "Exchanging and updating opinions and beliefs reduces echo chambers", co-supervised between Jérôme Euzenat and Koji Hasebe (2e année master recherche «mathématiques et informatique», Université Grenoble Alpes, double diploma with University of Tsukuba)).
- Roxane Vanden Bossche, "Belief revision for Standpoint logics", co-supervised between Lucía Gómez Álvarez and Jérôme Euzenat (2e année Master Parisien de Recherche en Informatique).

9.2.3 Juries

- Cássia Trojahn had been panel member and reviewer of the PhD thesis of Issam Khedher, "Intelligence artificielle et multimodalité pour l'observation des territoires – Monitoring urbain" (Université Lumière Lyon 2).
- Cássia Trojahn had been panel member and reviewer of the PhD thesis of Vivien Léonard, "Méthodes explicites et frugales pour la désambiguïsation d'entités nommées dans les microposts francophones" (Université de Tours).
- Cássia Trojahn had been panel member and reviewer of the PhD thesis of Timothy Bell, "Réussite initiale dans les études supérieures: prédiction et représentation graphique des résultats" (Université Côte d'Azur).
- Jérôme Euzenat had been panel member and reviewer of the PhD thesis of Sébastien Guillemin, "Interprétation de données hétérogènes et multivariées" (Université Bourgogne Europe).
- Cássia Trojahn had been panel president of the PhD thesis of Daniela Milon Flores, "OFf-SETT: An Ontology-Driven Framework for Semantic Environmental Trajectories of Territories" (Université Grenoble Alpes)
- Cássia Trojahn had been panel president of the PhD thesis of Nour Elhouda Kired, "Alignement de sources de données disparates à l'aide de grands modèles de langage" (Université de Toulouse)

9.2.4 Educational and pedagogical outreach

- Introduction to the *Class?* game to a tenth graders (2$^{\text{nde}}$ MathC2+) group, Saint-Martin d'Hères (FR), 2025-06-26.

10 Scientific production

10.1 Major publications

[1] M. Atencia, J. David and J. Euzenat. 'On the relation between keys and link keys for data interlinking'. In: *Semantic Web – Interoperability, Usability, Applicability* 12.4 (2021), pp. 547–567. DOI: 10.3233/SW-200414. URL: https://hal.science/hal-03426150 (cit. on p. 7).

[2] Y. Bourahla, M. Atencia and J. Euzenat. 'Knowledge improvement and diversity under interaction-driven adaptation of learned ontologies'. In: AAMAS 2021 - 20th ACM international conference on Autonomous Agents and Multi-Agent Systems. London, United Kingdom, 2021, pp. 242–250. URL: https://hal.archives-ouvertes.fr/hal-03426130 (cit. on pp. 7, 11).

[3] J. Euzenat. 'Interaction-based ontology alignment repair with expansion and relaxation'. In: *Proc. 26th International Joint Conference on Artificial Intelligence (IJCAI), Melbourne (VIC AU)*. 2017, pp. 185–191.

[4] J. Euzenat and P. Shvaiko. *Ontology matching*. en. 2nd. Heidelberg (DE): Springer-Verlag, 2013. 520 pp. URL: http://book.ontologymatching.org (cit. on pp. 6, 7).

10.2 Publications of the year

International journals

[5] J. Breton, M. M. Billami, M. Chevalier, H. T. Nguyen, K. Satoh, C. Trojahn and M. M. Zin. 'Leveraging LLMs for legal terms extraction with limited annotated data'. In: *Artificial Intelligence and Law* (14th Mar. 2025). DOI: 10.1007/s10506-025-09448-8. URL: https://hal.science/hal-05446939.

[6] A. Canito, J. David, J. Corchado and G. Marreiros. 'Ontology evolution from resource description framework streams using possibilistic axiom scoring'. In: *Semantic Web – Interoperability, Usability, Applicability* 17.1 (29th Dec. 2025), pp. 1–33. DOI: 10.1177/22104968251406727. URL: https://hal.science/hal-05463709 (cit. on p. 10).

[7] J. Euzenat. 'The fixed-point semantics of relational concept analysis'. In: *Journal of Artificial Intelligence Research* 83 (23rd June 2025). DOI: 10.1613/jair.1.17882. URL: https://hal.science/hal-05463739 (cit. on pp. 8, 13).

International peer-reviewed conferences

[8] M. Abd Nikooie Pour, E. Blomqvist, P. Giesteira Cotovio, A. Coulet, L. Ferraz, S. Hertling, S. Jain, E. Jiménez-Ruiz, F. Kraus, P. Lambrix, H. Li, Y. Li, X. Liu, P. Monnin, H. Paulheim, C. Pesquita, A. Sharma, P. Shvaiko, M. Silva, G. Sousa, C. Trojahn, J. Vataščinová, B. Yaman, O. Zamazal and L. Zhou. 'Results of the Ontology Alignment Evaluation Initiative 2025'. In: OM 2025 - Ontology Matching 2025. Nara, Japan, 2nd Nov. 2025. URL: https://inria.hal.science/hal-05447839 (cit. on p. 12).

[9] J. Baixeries, A. Bazin, J. David and A. Napoli. 'A proposal for building a compact and tunable representation of a concept lattice based on clustering'. In: *Proceedings of the 2nd international joint conference on conceptual knowledge structures (CONCEPTS)*. CONCEPTS 2025 - 2nd International Joint Conference on Conceptual Knowledge Structures. Cluj-Napoca, Romania: Springer Verlag, 2025, pp. 161–177. DOI: 10.1007/978-3-032-03364-2_10. URL: https://hal.science/hal-05463724 (cit. on p. 13).

[10] A. Dupuy, N. Aussenac-Gilles, C. Baehr and C. Trojahn. 'Interpreting User Needs with LLMs-based Conversational Agents and Knowledge Graphs: An Earth Observation Use Case'. In: 24th ISWC Poster and demo track. Nara, Japan, 2nd Nov. 2025, pp. 265–270. URL: https://hal.science/hal-05448470 (cit. on p. 14).

[11] S. Felice, F. Arnould and C. Trojahn dos Santos. 'Towards a semantic representation of memory entities'. In: *Proceedings of the Joint Ontology Workshops (JOWO) held at the 15th International Conference on Formal Ontology in Information Systems (FOIS 2025)*. CAOS: Cognition And OntologieS, Joint Ontology Workshops (JOWO) held at the 15th International Conference on Formal Ontology in Information Systems (FOIS 2025). Catana, Italy, 8th Sept. 2025. URL: https://hal.science/hal-05317397 (cit. on p. 14).

[12] L. Gómez Álvarez and S. Rudolph. 'Putting perspective into OWL [sic]: complexity-neutral standpoint reasoning for ontology languages via monodic S5 over counting two-variable first-order logic'. In: *Proc. KR conference on International Conference on Principles of Knowledge Representation and Reasoning*. KR 2025 - conference on International Conference on Principles of Knowledge Representation and Reasoning. Melbourne, Australia: No commercial editor., 2025, pp. 366–375. URL: https://hal.science/hal-05463692 (cit. on p. 11).

[13] C. K. Jradeh, E. Raoufi, J. David, P. Larmande, F. Scharffe, K. Todorov and C. Trojahn. 'Graph Embeddings Meet Link Keys Discovery for Entity Matching'. In: *WWW '25: Proceedings of the ACM on Web Conference 2025*. WWW '25: The ACM Web Conference 2025. Sydney NSW Australia, Australia: ACM, 22nd Apr. 2025, pp. 3344–3353. DOI: 10.1145/3696410.3714581. URL: https://hal.science/hal-04920958 (cit. on p. 13).

[14] H. Kataoka, J. Euzenat and K. Hasebe. 'Exchanging and updating opinions and beliefs reinforces echo chambers'. In: *Proc. 39th Annual conference of the Japanese society on artificial intelligence (JSAI)*. 39th Annual conference of the Japanese society on artificial intelligence (JSAI). Osaka, Japan: Japanese Society for Artificial Intelligence, 2025, 3K1IS302–3K1IS302. DOI: 10.11517/pjsai.JSAI2025.0_3K1IS302. URL: https://hal.science/hal-05463732 (cit. on p. 11).

[15] G. Santos Sousa, R. Lima and C. Trojahn. 'On Evaluation Metrics for Complex Matching Based on Reference Alignments'. In: *The Semantic Web: 22nd European Semantic Web Conference, ESWC 2025, Proceedings, Part I*. The Semantic Web: 22nd European Semantic Web Conference, ESWC 2025. Vol. 15718. Lecture Notes in Computer Science. Portorož, Slovenia: Springer Nature Switzerland, 1st June 2025, pp. 77–93. DOI: 10.1007/978-3-031-94575-5_5. URL: https://hal.science/hal-05448444 (cit. on p. 12).

[16] G. Santos Sousa, R. Lima and C. Trojahn. 'Results of CMatch in OAEI 2025'. In: *Proceedings of the 20th International Workshop on Ontology Matching co-located with the 24rd International Semantic Web Conference*. 20th International Workshop on Ontology Matching co-located with the 24rd International Semantic Web Conference. Nara, Japan, 2nd Nov. 2025. URL: https://hal.science/hal-05448469 (cit. on p. 12).

National peer-reviewed Conferences

[17] J. Breton, M. B. Billami, M. Chevalier and C. Trojahn. 'Extraction terminologique juridique à faible supervision : une méthode hybride combinant LLM, règles syntaxiques et CamemBERT'. In: *IC 2025 : 36es Journées francophones d'Ingénierie des Connaissances*. 36es Journées francophones d'Ingénierie des Connaissances, IC 2025. IC2025. Dijon, France, 2nd July 2025. URL: https://hal.science/hal-05441298.

Conferences without proceedings

[18] A. Dupuy, N. Aussenac-Gilles, C. Baehr and C. Trojahn. 'Combining LLMs-based Conversational Agents and Ontologies for Open Data Research'. In: 19th Metadata and Semantics Research Conference (MTSR 2025). Thessaloniki, Greece, 17th Dec. 2025. URL: https://hal.science/hal-05448240 (cit. on p. 14).

Edition (books, proceedings, special issue of a journal)

[19] E. Jiménez-Ruiz, O. Hassanzadeh, C. Trojahn dos Santos, S. Hertling, H. Li, P. Shvaiko and J. Euzenat, eds. *Proc. 20th ISWC workshop on ontology matching (OM)*. 20th ISWC workshop on ontology matching (OM). Nara, Japan: No commercial editor., 2025, pp. 1–248. URL: https://hal.science/hal-05463695 (cit. on p. 16).

[20] *Post-actes de la conférence Ingénierie des Connaissances (IC 2021-2022-2023)* 6.1-2 (21st Nov. 2025). DOI: 10.5802/roia.90fr. URL: https://hal.science/hal-05376657.

10.3 Cited publications

[21] L. Gómez Álvarez and S. Rudolph. 'Standpoint Logic: Multi-Perspective Knowledge Representation'. In: *Proc. 12th FOIS*. Bozen-Bolzano (IT), 2021, pp. 3–17 (cit. on p. 6).

[22] A. Mesoudi. *Cultural Evolution: How Darwinian theory can explain human culture and synthesize the social sciences*. University of Chicago Press, Chicago (IL US), 2011 (cit. on p. 7).

[23] L. Steels, ed. *Experiments in cultural language evolution*. John Benjamins, Amsterdam (NL), 2012 (cit. on p. 7).