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Activity Report 2018

Project-Team GRAPHIK

GRAPHs for Inferences and Knowledge representation

IN COLLABORATION WITH: Laboratoire d'informatique, de robotique et de microélectronique de Montpellier (LIRMM)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Data and Knowledge Representation and Processing

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Project-Team GRAPHIK

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A9.8. - Reasoning

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B3.1. - Sustainable development
B9.5.6. - Data science
B9.7.2. - Open data

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2. Overall Objectives

2.1. Logic and Graph-based KR

The main research domain of GraphIK is Knowledge Representation and Reasoning (KR), which studies paradigms and formalisms for representing knowledge and reasoning on these representations. We follow a logic-oriented approach: the different kinds of knowledge have a logical semantics and reasoning mechanisms correspond to inferences in this logic.

However, we also use graphs and hypergraphs (in the graph-theoretic sense) as basic objects. Indeed, we view labelled graphs as an *abstract representation* of knowledge that can be expressed in many KR languages: different kinds of conceptual graphs —historically our main focus—, the Semantic Web language RDFS, expressive rules equivalent to so-called tuple-generating-dependencies in databases, some description logics dedicated to query answering, etc. For these languages, reasoning can be based on the structure of objects (thus on graph-theoretic notions) while being sound and complete with respect to entailment in the associated logical fragments. An important issue is to study *trade-offs* between the expressivity and computational tractability of (sound and complete) reasoning in these languages.

2.2. From Theory to Applications, and Vice-versa

We study logic- and graph-based KR formalisms from three perspectives:

- theoretical (structural properties, expressiveness, translations between languages, problem complexity, algorithm design),
- software (developing tools to implement theoretical results),
- applications (which also feed back into theoretical work).

2.3. Main Challenges

GraphIK focuses on some of the main challenges in KR:

- ontological query answering, *i.e.*, query answering taking an ontology into account, and able to process large datasets;
- reasoning with rule-based languages;
- reasoning in presence of inconsistency and
- decision making.

2.4. Scientific Directions

GraphIK has three main scientific directions:

1. **decidability, complexity and algorithms** for problems in languages corresponding to first-order logic fragments;
2. the addition of expressive and **non-classical features** (to the first-order logic languages studied in the first direction) with a good expressivity/efficiency trade-off;
3. the integration of theoretical tools to **real knowledge-based systems**.

From an applicative viewpoint, two themes are currently privileged:

- knowledge representation and reasoning for agronomy, oriented towards knowledge-based systems to aid decision-making for the quality control in food processing.
- knowledge representation and reasoning for data journalism, oriented towards efficient ontology-mediated query answering of heterogeneous information sources.

3. Research Program

3.1. Logic-based Knowledge Representation and Reasoning

We follow the mainstream *logic-based* approach to knowledge representation (KR). First-order logic (FOL) is the reference logic in KR and most formalisms in this area can be translated into fragments (i.e., particular subsets) of FOL. This is in particular the case for description logics and existential rules, two well-known KR formalisms studied in the team.

A large part of research in this domain can be seen as studying the *trade-off* between the expressivity of languages and the complexity of (sound and complete) reasoning in these languages. The fundamental problem in KR languages is entailment checking: is a given piece of knowledge entailed by other pieces of knowledge, for instance from a knowledge base (KB)? Another important problem is *consistency* checking: is a set of knowledge pieces (for instance the knowledge base itself) consistent, i.e., is it sure that nothing absurd can be entailed from it? The *ontology-mediated query answering* problem is a topical problem (see Section 3.3). It asks for the set of answers to a query in the KB. In the case of Boolean queries (i.e., queries with a yes/no answer), it can be recast as entailment checking.

3.2. Graph-based Knowledge Representation and Reasoning

Besides logical foundations, we are interested in KR formalisms that comply, or aim at complying with the following requirements: to have good *computational* properties and to allow users of knowledge-based systems to have a maximal *understanding and control* over each step of the knowledge base building process and use.

These two requirements are the core motivations for our graph-based approach to KR. We view labelled graphs as an *abstract representation* of knowledge that can be expressed in many KR languages (different kinds of conceptual graphs —historically our main focus— the Semantic Web language RDF (Resource Description Framework), its extension RDFS (RDF Schema), expressive rules equivalent to the so-called tuple-generating-dependencies in databases, some description logics dedicated to query answering, etc.). For these languages, reasoning can be based on the structure of objects, thus based on graph-theoretic notions, while staying logically founded.

More precisely, our basic objects are labelled graphs (or hypergraphs) representing entities and relationships between these entities. These graphs have a natural translation in first-order logic. Our basic reasoning tool is graph homomorphism. The fundamental property is that graph homomorphism is sound and complete with respect to logical entailment *i.e.*, given two (labelled) graphs G and H, there is a homomorphism from G to H *if and only if* the formula assigned to G is entailed by the formula assigned to H. In other words, logical reasoning on these graphs can be performed by graph mechanisms. These knowledge constructs and the associated reasoning mechanisms can be extended (to represent rules for instance) while keeping this fundamental correspondence between graphs and logics.

3.3. Ontology-Mediated Query Answering

Querying knowledge bases has become a central problem in knowledge representation and in databases. A knowledge base (KB) is classically composed of a terminological part (metadata, ontology) and an assertional part (facts, data). Queries are supposed to be at least as expressive as the basic queries in databases, i.e., conjunctive queries, which can be seen as existentially closed conjunctions of atoms or as labelled graphs.

The challenge is to define good trade-offs between the expressivity of the ontological language and the complexity of querying data in presence of ontological knowledge. Description logics have been so far the prominent family of formalisms for representing and reasoning with ontological knowledge. However, classical description logics were not designed for efficient data querying. On the other hand, database languages are able to process complex queries on huge databases, but without taking the ontology into account. There is thus a need for new languages and mechanisms, able to cope with the ever growing size of knowledge bases in the Semantic Web or in scientific domains.

This problem is related to two other problems identified as fundamental in KR:

- *Query-answering with incomplete information.* Incomplete information means that it might be unknown whether a given assertion is true or false. Databases classically make the so-called closed-world assumption: every fact that cannot be retrieved or inferred from the base is assumed to be false. Knowledge bases classically make the open-world assumption: if something cannot be inferred from the base, and neither can its negation, then its truth status is unknown. The need of coping with incomplete information is a distinctive feature of querying knowledge bases with respect to querying classical databases (however, as explained above, this distinction tends to disappear). The presence of incomplete information makes the query answering task much more difficult.
- *Reasoning with rules.* Researching types of rules and adequate manners to process them is a mainstream topic in the Semantic Web, and, more generally a crucial issue for knowledge-based systems. For several years, we have been studying rules, both in their logical and their graph form, which are syntactically very simple but also very expressive. These rules, known as existential rules or Datalog$+$, can be seen as an abstraction of ontological knowledge expressed in the main languages used in the context of KB querying.

A problem generalizing the above described problems, and particularly relevant in the context of multiple data/metadata sources, is *querying hybrid knowledge bases*. In a hybrid knowledge base, each component may have its own formalism and its own reasoning mechanisms. There may be a common ontology shared by all components, or each component may have its own ontology, with mappings being defined among the ontologies. The question is what kind of interactions between these components and/or what limitations on the languages preserve the decidability of basic problems and if so, a “reasonable” complexity. Note that there are strong connections with the issue of data integration in databases.

3.4. Inconsistency and Decision Making

While classical FOL is the kernel of many KR languages, to solve real-world problems we often need to consider features that cannot be expressed purely (or not naturally) in classical logic. The logic and graph-based formalisms used for previous points have thus to be extended with such features. The following requirements have been identified from scenarios in decision making, privileging the agronomy domain:

- to cope with inconsistency;
- to cope with defeasible knowledge;
- to take into account different and potentially conflicting viewpoints;
- to integrate decision notions (priorities, gravity, risk, benefit).

Although the solutions we develop require to be validated on the applications that motivated them, we also want them to be sufficiently generic to be applied in other contexts. One angle of attack (but not the only possible one) consists in increasing the expressivity of our core languages, while trying to preserve their essential combinatorial properties, so that algorithmic optimizations can be transferred to these extensions.

4. Application Domains

4.1. Agronomy

Agronomy is a strong expertise domain in the area of Montpellier. Some members of GraphIK INRA researchers (computer scientists). We closely collaborate with the Montpellier research laboratory IATE, a join unit of INRA and other organisms. A major issue for INRA and more specifically IATE applications is modeling agrifood chains (i.e., the chain of all processes leading from the plants to the final products, including waste treatment). This modeling has several objectives. It provides better understanding of the processes from begin to end, which aids in decision making, with the aim of improving the quality of the products and decreasing the environmental impact. It also facilitates knowledge sharing between researchers, as well as the capitalization of expert knowledge and "know how". This last point is particularly important in areas strongly related to local know how (like in cheese or wine making), where knowledge is transmitted by experience, with the risk of non-sustainability of the specific skills. An agrifood chain analysis is a highly complex procedure since it relies on numerous criteria of various types: environmental, economical, functional, sanitary, etc. Quality objectives involve different stakeholders, technicians, managers, professional organizations, end-users, public organizations, etc. Since the goals of the implied stakeholders may be divergent dedicated knowledge and representation techniques are to be employed.

4.2. Data Journalism

One of today's major issues in data science is to design techniques and algorithms that allow analysts to efficiently infer useful information and knowledge by inspecting heterogeneous information sources, from structured data to unstructured content. We take data journalism as an emblematic use-case, which stands at the crossroad of multiple research fields: content analysis, data management, knowledge representation and reasoning, visualization and human-machine interaction. We are particularly interested in issues raised by the design of data and knowledge management systems that will support data journalism. These systems include an ontology that typically expresses domain knowledge, heterogeneous data sources, and mappings that relate these data sources expressed with their own vocabulary and querying capabilities, to a (possibly virtual) factbase expressed using the ontological vocabulary. Ontologies play a central role as they act both as a mediation layer that glue together pieces of knowledge extracted from heterogeneous data sources, and as an inference layer that allow to draw new knowledge. In the context of data journalism, those ontologies require challenging features that we need to take into account:

- the wide range of topics addressed in journalism requires a rich top-level ontology, though very specific ontologies might be required to handle specific knowledge (e.g. detailed knowledge on finance to handle the panama papers).
- in data journalism, each piece of knowledge requires different timestamps (temporal information represented within the data, for instance when an event effectively takes place, and temporal information about the data itself, for instance when this event is recorded / validated in the system). Temporal relations (such as Allen's) can be used to express constraints between timestamps and ensure the consistency of the (virtual) knowledge base.
- in data journalism, each piece of knowledge has an identified source. The analysis of conflicting knowledge in the (virtual) knowledge base has to take the source fiability into account.

Besides pure knowledge representation and reasoning issues, querying such systems raise issues at the crossroad of data and knowledge management. In particular, the notion of mappings has to be revisited in the light of the reasoning capabilities enabled by the ontology. More generally, the consistency and the efficiency of the system cannot be ensured by considering the components of the system in isolation (i.e., the ontology, data sources and mappings), but require to study the interactions between these components and to consider the system as a whole.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Highlights

- A new ANR project led by GraphIK on *Complex ontological Queries over Federated and heterogeneous Data (CQFD)* has been accepted. This project, starting in January 2019, is on a core issue for GraphIK and gathers main national teams on this subject. The consortium has a long standing history of research collaboration and the current project will build upon these results.

5.1.2. Awards

The work of two PhD students of our group was recognized by international event awards:

- Stathis Delivorias and co-authors were awarded the best paper award at the International Joint Conference on Rules and Reasoning (RuleML+RR 2018) for the paper entitled “On the k-Boundedness for Existential Rules”
- Bruno Yun participated to the 3rd Summer School on Argumentation (SSA 2018): Computational and Linguistic Perspectives, and got the best student paper prize for his presentation entitled “How can you Mend a Broken Inconsistent KB in Existential Rules Using Argumentation?” (no formal proceedings available).

BEST PAPER AWARD:

[23]
S. DELIVORIAS, M. LECLÈRE, M.-L. MUGNIER, F. ULLIANA. *On the k-Boundedness for Existential Rules*, in "RuleML+RR: Rules and Reasoning", Luxembourg, Luxembourg, September 2018, vol. LNCS, n^o 11092, pp. 48-64, https://arxiv.org/abs/1810.09304 [*DOI :* 10.1007/978-3-319-99906-7_4], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01921140

6. New Software and Platforms

6.1. Cogui

KEYWORDS: Knowledge database - Ontologies - GUI (Graphical User Interface)
SCIENTIFIC DESCRIPTION: Cogui is a visual tool for building and verifying graphical knowledge bases (KB). Knowledge bases are represented under graphical form (close to conceptual graphs). There is a complete correspondence with the logical existential rule (or Datalog+) framework.
FUNCTIONAL DESCRIPTION: Cogui is a freeware written in Java. It allows to graphically create a KB, to handle its structure and content, and to control it. Currently, it supports Conceptual Graphs and import/export in RDFS and Datalog+. Wizards allow to analyze and check facts with respect to some constraints, as well as to query them while taking into account inferences enabled by the ontology.

RELEASE FUNCTIONAL DESCRIPTION: Plugin-extensible architecture, multi-project management, automatic construction of a web documentation of the ontology, adoption of semantic web conventions (IRIs and namespaces), integration of some Graal functionalities (homomorphisms and OWL 2 import), improvement of the import/export between Cogui knowledge bases and Graal dlgp format.
NEWS OF THE YEAR: Release of a new version (V3) resulting from heavy refactoring to benefit from NetBeans plugin-extensible platform architecture and graphical libraries (total replacement of the graphical editors).

This new version requires to completely revise the user documentation, which is in progress.

- Participants: Alain Gutierrez, Michel Chein, Marie-Laure Mugnier, Michel Leclère and Madalina Croitoru
- Partner: LIRMM
- Contact: Michel Chein
- URL: http://www.lirmm.fr/cogui/

6.2. DAGGER

KEYWORDS: Graph algorithmics - Logic programming
FUNCTIONAL DESCRIPTION: We introduce DAGGER: a generator for logic based argumentation frameworks instantiated from inconsistent knowledge bases expressed using Datalog. The tool allows to import a knowledge base in DLGP format and the generation and visualisation of the corresponding argumentation graph. Furthermore, the argumentation framework can also be exported in the Aspartix format.

- Contact: Madalina Croitoru
- URL: http://www.lirmm.fr/~yun/tools.html

6.3. Eldr

Existential Logic for Defeasible Reasoning
KEYWORDS: Knowledge representation - Logic programming
FUNCTIONAL DESCRIPTION: Eldr is an open source defeasible reasoning tool that allows the use of different semantics (ambiguity blocking/propagating with or without team defeat) in order to reason with incoherent or inconsistent knowledge. It allows the reasoning about preferences and their justification between different agents with a final aim of producing justified preferences on different outcomes (alternatives). These preferences are then used with a voting module (given certain voting strategy) to break ties and establish the chosen alternative. It is applied within the GLOPACK and NOAW projects.

- Contact: Madalina Croitoru
- URL: https://github.com/hamhec/graal-elder

6.4. GRAAL

KEYWORDS: Knowledge database - Ontologies - Querying - Data management
SCIENTIFIC DESCRIPTION: Graal is a Java toolkit dedicated to querying knowledge bases within the framework of existential rules, aka Datalog+/-.
FUNCTIONAL DESCRIPTION: Graal has been designed in a modular way, in order to facilitate software reuse and extension. It should make it easy to test new scenarios and techniques, in particular by combining algorithms. The main features of Graal are currently the following: (1) a data layer that provides generic interfaces to store various kinds of data and query them with (union of) conjunctive queries, currently: MySQL, PostgreSQL, Sqlite, in memory graph and linked list structures, (2) an ontological layer, where an ontology is a set of existential rules, (3) a knowledge base layer, where a knowledge base is composed of a fact base (abstraction of the data via generic interfaces) and an ontology, (4) algorithms to process ontology-mediated queries, based on query rewriting and/or forward chaining (or chase), (5) a rule analyzer, which performs a syntactic and structural analysis of an existential rule set, (6) several IO formats, including imports from OWL 2.

RELEASE FUNCTIONAL DESCRIPTION: Version 1.3.0 (2017) fixes some bugs, makes the dlgp parser more flexible (dlgp being our serialization format for existential rules) and improves the efficiency of the forward chaining (chase) algorithms.

Version 1.3.1 (2018) provides minor optimizations and small bug fixes.
NEWS OF THE YEAR: 2018: Version 1.3.1, with small bug fixes and minor improvements. Several new functionalities were developed by internships in 2018 but the code is not integrated to Graal yet. 2017: New stable version (1.3.0) realised. Moreover, Graal website has been deeply restructured and enriched with new tools, available online or for download, and documentation including tutorials, examples of use, and technical documentation about all Graal modules.

- Participants: Marie-Laure Mugnier, Clément Sipieter, Jean-François Baget, Mélanie König, Michel Leclère and Swan Rocher
- Contact: Marie-Laure Mugnier
- Publications: Graal: A Toolkit for Query Answering with Existential Rules - Datalog+, RuleML and OWL 2: Formats and Translations for Existential Rules
- URL: https://github.com/graphik-team

7. New Results

7.1. Ontology Mediated Query Answering

Participants: Jean-François Baget, Meghyn Bienvenu, Efstathios Delivorias, Michel Leclère, Marie-Laure Mugnier, Federico Ulliana.

Ontolology-mediated query answering (OMQA) is the issue of querying data while taking into account inferences enabled by ontological knowledge. This gives rise to *knowledge bases*, composed of a factbase (in database terms: an instance that contains incomplete data) and an ontology. Answers to queries are logically entailed from the knowledge base. Two families of formalisms for representing and reasoning with the ontological component have been considered in this context: *description logics* (DLs) and *existential rules* (aka Datalog+, or tuple-generating dependencies in database theory). Both frameworks correspond to fragments of first-order logic, which are incomparable in general but closely related in the context of OMQA: indeed, most DLs considered for OMQA, known as lighthweight DLs, are naturally translated into specific classes of existential rules. Importantly, the foundational work carried by the knowledge representation community led to the definition of several W3C standards for Semantic Web languages, namely the family of OWL 2 ontology languages, which can be used in combination with the RDF(S) Semantic Web language. This paradigm is also supported by commercial systems, such as Oracle.

Techniques for query answering under existential rules mostly rely on the two classical ways of processing rules, namely forward chaining and backward chaining. In forward chaining (also known as the *chase* in databases), the rules are applied to enrich the factbase and query answering can then be solved by evaluating the query against the *saturated* factbase (as in a classical database system, i.e., with forgetting the ontological knowledge). The backward chaining process can be divided into two steps: first, the query is *rewritten* using the rules into a first-order query (typically a union of conjunctive queries, but possibly a more compact form); then the rewritten query is evaluated against the factbase (again, as in a classical database system). Some classes of existential rules and lightweight description logics ensure the termination of the chase and/or query rewriting, but not all.

7.1.1. Revisiting the Chase

The interest for existential rules in the OMQA context brought again to light a fundamental tool in database theory, namely the chase. Several chase variants are known: they all yield logically equivalent results, but differ on how they handle redundancies possibly caused by the introduction of unknown individuals (often called nulls). Briefly, detecting redundancies leads to smaller saturated factbases, and prevents some infinite chase sequences, but it is costly. Given a chase variant, the (all-instances) chase termination problem takes as input a set of existential rules and asks if this set of rules ensures the termination of the chase for any factbase. It is well-known that this problem is undecidable for all known chase variants.

Hence, a crucial issue is whether chase termination becomes decidable for some known subclasses of existential rules. We considered *linear* existential rules, a simple yet important subclass of existential rules that generalizes inclusion dependencies. We showed the decidability of the (all-instances) chase termination problem on linear rules for three main chase variants, namely *semi-oblivious*, *restricted* and *core* chase. The restricted chase is the most used variant of the chase, however it is notoriously tricky to study because the order in which rule applications are performed matters. Indeed, for the same factbase, some restricted chase sequences may terminate, while others may not. To obtain these results, we introduced a novel approach based on so-called derivation trees and a single notion of forbidden pattern. Besides the theoretical interest of an unified approach and new proofs, we provided the first positive decidability results concerning the termination of the restricted chase, proving that chase termination on linear existential rules is decidable for both versions of the problem: Does *every* chase sequence terminate? Does *some* chase sequence terminate? [37] [27] (also to appear at ICDT 2019).

As part of Stathis Delivorias' PhD thesis, we considered the related problem of *boundedness*, which asks if a given set of existential rules is bounded, i.e., whether there is a predefined upper bound on the depth of the chase, independently from any factbase. This problem is already undecidable in the specific case of datalog rules (whose head has no existential variables). However, knowing that a set of rules is bounded for some chase variant does not help much in practice if the bound is unknown. Hence, we investigated the decidability of the k-boundedness problem, which asks whether a given set of rules is bounded by an integer k. We proved that k-boundedness is decidable for three main chase variants, namely the oblivious, semi-oblivious and restricted chase [23].

We investigated the combination of existential rules and answer set programming. The combination of the two formalisms requires to extend existential rules with nonmonotonic negation and to extend ASP with existential variables. To this aim, we introduced the syntax and semantics of existential non-monotonic rules using skolemization which join together the two frameworks. Building on our previous work published at ECAI and NMR, we presented syntactic conditions that ensure the termination of the chase for existential rules and discussed extension of these results in the nonmonotonic case [13].

7.1.2. Complexity of Ontology-Mediated Query Rewriting

Extending our previous work published at LICS, we carried out a systematic study on two fundamental problems in ontology-mediated query answering, in the context of the description logic OWL 2 QL. This dialect of the W3C standard ontology language OWL 2 is aimed towards efficient query answering on large data and ensures that every conjunctive ontology-mediated-query (OMQ) is rewritable into a first-order query. The first problem is the *succintness* of first-order rewritings of OMQs, which consists in understanding how difficult it is to built rewritings for queries in some OMQ class, and in particular to determine whether OMQs in the class have polynomial-size rewritings. The second problem is the *complexity* of OMQ answering. We classified OMQs according to the shape of their conjunctive queries (treewidth, the number of leaves) and the existential depth of their ontologies. For each of these classes, we determined the combined complexity of OMQ answering, and whether all OMQs in the class have polynomial-size first-order, positive existential and nonrecursive datalog rewritings. We obtained the succinctness results using hypergraph programs, a new computational model for Boolean functions, which makes it possible to connect the size of OMQ rewritings and circuit complexity [14].

7.1.3. Ontology-Based Data Access

In the above settings, data is supposed to be stored in a factbase built on the same vocabulary as the ontology. We now consider a more general setting, often called *Ontology-Based Data Access (OBDA)*, in which data is stored in one or several databases, which were generally built independently from the ontology. Hence, the ontological level acts as a mediating level, and a new component, namely *mappings*, allows to transfer the answers to queries over the data into facts expressed in the ontology vocabulary. Mappings may be triggered to actually materialize the factbase, but such materialization may be not possible nor desirable, in which case the factbase remains virtual.

OBDA is the core setting we consider in the Inria Project Lab iCODA on data journalism (https://project.inria.fr/icoda/). As part of Maxime Buron's PhD thesis (co-supervision shared between CEDAR and GraphIK teams), we investigate several frameworks and query answering techniques in the OBDA setting. We consider the Semantic Web language RDFS to express the (possibly virtual) factbase and the core ontology, RDF rules that include classical RDF entailment rules but possibly richer ontological knowledge, expressive mappings (namely global-local-as-view mappings, whereas most existing work in the area is restricted to global-as-view mappings), and queries which, in the spirit of RDF, can interrogate both the ontology and the data at the same time. In particular, we proposed a new way of answering queries by a reduction to database query rewriting with views [21]. Software development and experiments are under progress.

We also pursued our work on inconsistency-tolerant query answering, revisiting existing complexity results obtained for OMQA in the wider context of OBDA, i.e., considering mappings. We formalized the problem and performed a detailed analysis of the data complexity of inconsistency-tolerant OBDA for ontologies formulated in data-tractable description logics, considering different semantics, notions of repairs and classes of GAV mappings. Our results imply that adding plain GAV mappings to the OMQA framework does not affect data complexity of inconsistency-tolerant query answering, but considering mappings with negated atoms leads to higher complexity [20].

Note that the latter work can also be seen as a contribution to maxi-consistent reasoning (see Section 7.2.2).

7.2. Reasoning with Inconsistency

Participants: Meghyn Bienvenu, Pierre Bisquert, Patrice Buche, Abdelraouf Hecham, Madalina Croitoru, Jérôme Fortin, Rallou Thomopoulos, Bruno Yun.

When reasoning about inconsistent logical KBs, one has to deploy reasoning mechanisms that do not follow the classical logical inference. This is due to the fact that, in classical logic, falsum implies everything. Alternative reasoning techniques are therefore needed in order to make sense of such KBs. In this section we present our results using two main classes of such techniques: defeasible reasoning and maxi-consistent reasoning.

7.2.1. Defeasible Reasoning

Defeasible reasoning is used to evaluate claims or statements in an inconsistent setting where the rules encoding the ontological knowledge may contradict each other. Unfortunately, there is no universally valid way to reason defeasibly. An inherent characteristic of defeasible reasoning is its systematic reliance on a set of intuitions and rules of thumb, which have been long debated between logicians. For example, could an information derived from a contested claim be used to contest another claim (i.e., ambiguity handling)? Could "chains" of reasoning for the same claim be combined to defend against challenging statements (i.e., team defeat)? Is circular reasoning allowed? Etc. We got interested in the task of a data engineer looking to select what existing tool to use to perform defeasible reasoning. To this end we proposed the first benchmark in the literature for first-order logic defeasible reasoning tools profiling and showed how to use the proposed benchmark in order to categorize existing tools based on their semantics (e.g. ambiguity handling), logical language (e.g. existential rules) and expressiveness (e.g. priorities) [25]. Furthermore, we proposed a new logical formalism called Statement Graphs (SGs) that captures the state-of-the-art defeasible reasoning features via a flexible labelling function [24].

7.2.2. Maxi-Consistent Reasoning

We now consider reasoning with inconsistent knowledge bases, when making the assumption that the ontological knowledge (here expressed by rules) is reliable, hence inconsistencies come from the data (or factbase), which may contradict ontological knowledge. We consider maximally consistent subsets of the factbase as the basis for inference (in short, "maxi-consistent" reasoning).

Repair semantics. One of the main challenges of reasoning with inconsistency is handling the inherent inconsistency that might occur amongst independently built data sources partially describing the same knowledge of interest. Inconsistency-tolerant semantics consider all maximally consistent subsets of a factbase, called repairs, that they manipulate using a modifier of these repairs (e.g. saturating them by the rules) and an inference strategy (e.g. answers have to be found in all repairs). However, using all repairs might be inappropriate for certain applications that would rather focus on particular data sources. For instance, when considering more reliable sources (i.e., sensor information, provenance data etc.) one could focus on repairs using mostly facts from such sources. When there is no given preference order on sources, we propose to use an intrinsic preference on facts based on their participation in inconsistencies, which generates a preference of repairs (i.e., those that contain less controversial facts are preferred). This led us to define a novel framework that takes into consideration the inconsistency on the facts and restricts the set of repairs to the "best" with respect to inconsistency values. We showed the significance and the practical interest of our approach using the real data collected in the framework of the Pack4Fresh project for reducing food wastes. During this project, we collected data using an online poll from a set of professionals of the food industry, including wholesalers, quality managers, floorwalkers and warehouse managers, about food packagings and their characteristics. The framework was able to rank the repairs efficiently and the results were then analysed and evaluated by experts from the packaging industry [35].

Argumentation. Argumentation is a reasoning under inconsistency technique, that allows to build arguments and attacks over an inconsistent data. The arguments represent the various inferences one can make. The attacks capture the inconsistency between the different pieces of knowledge. The set of arguments and the corresponding set of attacks is referred to as an argumentation framework (AF). AFs are visually represented using a directed graph where the nodes represent the arguments and the directed edges the attacks between the arguments. Classically, reasoning with argumentation systems consists of finding the maximal sets of arguments that (1) are not attacking each other and (2) defend themselves (as a group) from all incoming attacks. Such sets are called extensions.

Argumentation as a reasoning method over logic knowledge bases has the added value of providing better explanations to users than classical methods. However, one drawback of logic based argumentation frameworks is the large number of arguments generated. We provided a methodology for filtering semantically redundant arguments adapted for knowledge bases without rules or knowledge bases with rules. In the first case of knowledge bases without rules, we use the observation that free facts (i.e., facts that are not touched by any negative constraints) induce an exponential growth on the argumentation graph without any impact on its underlying structure. Therefore, we first generate the argumentation graph corresponding to the knowledge base without the free facts and then redo the whole graph including the arguments of the free facts in an efficient manner. In the second case, of the knowledge bases with rules, we introduce a new structure for the arguments and the attacks. In this new structure, we have significantly less arguments [28] (extended in [31]).

Furthermore, we provided a tool called Dagger that allows a knowledge engineer to (1) input a KB in a commonly used format and then (2) generate, (3) visualise or (4) export the argumentation graph [30]. Using the tool we were able to provide the first benchmark of logic based argumentation graphs in the litterature [32].

An alternative to the extension based semantics explained above are the ranking based semantics used mainly in the case where arguments are seen as abstract entities (and not necessarily logic derivation). There is a difference in the output format between these two approaches: when using a ranking based semantics, the output is a ranking on the arguments; in the case of extension based semantics, the output is a set of extensions. While the ranking and the scores (which are present in many ranking based semantics) allow to better assess the acceptability degree of each individual argument, the question "what are the different points of view of the argumentation framework?" stays unanswered when using a ranking based semantics. We have proposed a modular framework that is generic enough to be able to accommodate various application scenarios. In this case, one important property of the framework lies in its versatility and its capacity to yield different results according to various instantiations [33].

7.3. Decision Support Systems Applied to Agronomy

Participants: Pierre Bisquert, Patrice Buche, Abdelraouf Hecham, Madalina Croitoru, Jérôme Fortin, Rallou Thomopoulos, Bruno Yun.

High-level decision-making needs to take into account the often-conflicting interests of different stakeholders with the goal of finding solutions to provide trade-offs and build consensus towards the adoption of so-called win-win solutions. In order to enrich the deliberation process we have proposed several complementary approaches that combine various methods for an unified approach towards decision making. This has been applied in practical domains as explained below.

First, in [17] we presented a systematic method to assess possible options, based on the complementarity of argumentation modeling and system dynamics (SD) simulation, in conjunction with field experimentation. Taking advantage of the argument analysis, SD simulations are used to: 1) compare different cultural strategies available to farmers in current operating, market and regulatory conditions; 2) propose plausible what-if scenarios anticipating technological progress, and exploring the impact of adopting potential incentives and dissuasive regulatory measures.

Second, voting theory has been applied at the service of decision making. We employed Computational Social Choice (CSC) and Argumentation Framework (AF) as a combination to propose socially fair decisions which take into account both (1) the involved agents' preferences and (2) the justifications behind these preferences. Furthermore we implemented a software tool for decision-making which is composed of two main systems, i.e., the social choice system and the deliberation system [16]. This work was evaluated in practice [18]. Note that the use of argumentation in practice, when not considering fully formalised domains is very challenging. This specifically concerns decision support systems as shown in [34] where we focused on the following research question: "How to define an attack relation for argumentative decision making in socio-economic systems?" To address this question we proposed three kinds of attacks that could be defined in the context of a specific application (packaging selection) and studied how the non-computer-science experts evaluated, against a given set of decision tasks, each of these attacks.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. CQFD (ANR PRC, Jan. 2019-Dec. 2022)

Participants: Jean-François Baget, Michel Leclère, Marie-Laure Mugnier, Federico Ulliana.

CQFD (Complex ontological Queries over Federated heterogeneous Data), coordinated by Federico Ulliana (GraphIK), involves participants from Inria Saclay (CEDAR team), Inria Paris (VALDA team), Inria Nord Europe (SPIRALS team), IRISA, LIG, LTCI, and LaBRI. The aim of this project is tackle two crucial challenges in OMQA (Ontology Mediated Query Answering), namely, heterogeneity, that is, the possibility to deal with multiple types of data-sources and database management systems, and federation, that is, the possibility of cross-querying a collection of heterogeneous datasources. By featuring 8 different partners in France, this project aims at consolidating a national community of researchers around the OMQA issue.

8.1.2. ICODA (Inria Project Lab, 2017-2021)

Participants: Jean-François Baget, Michel Chein, Marie-Laure Mugnier.

The iCODA project (Knowledge-mediated Content and Data Interactive Analytics—The case of data journalism), coordinated by Guillaume Gravier and Laurent Amsaleg (LINKMEDIA), takes together four Inria teams: LINKMEDIA, CEDAR, ILDA and GraphIK, as well as three press partners: Ouest France, Le Monde (les décodeurs) and AFP.

Taking data journalism as an emblematic use-case, the goal of the project is to develop the scientific and technological foundations for knowledge-mediated user-in-the-loop big data analytics jointly exploiting data and content, and to demonstrate the effectiveness of the approach in realistic, high-visibility use-cases.
https://project.inria.fr/icoda/

8.1.3. Docamex (CASDAR project, 2017-2020)

Participants: Patrice Buche, Madalina Croitoru, Jérôme Fortin, Clément Sipieter.

DOCaMEx (Développement de prOgiciels de Capitalisation et de Mobilisation du savoir-faire et de l'Expérience fromagers en filière valorisant leur terroir), let by CFTC (centre technique des fromages de Franche-Comté) involves 7 research units (including IATE and LIRMM), 8 technical centers and 3 dairy product schools. It represents five cheese-making chains (Comté, Reblochon, Emmental de Savoie, Salers, Cantal).

Traditional cheese making requires a lot of knowledge, expertise, and experience, which is usually acquired over a long time. This knowledge is today mainly transmitted by apprenticeship and a concrete risk of knowledge forgetting is raised by the evolution of practices in the sector. Using new methods for expert knowledge capitalization the main goal of the project is to develop a new approach for expert knowledge elicitation and a dedicated software for decision making. The novel part of the decision making tool will consist in the representation power and reasoning efficiency in the context of the logic used to describe the domain knowledge.
http://www.rmtfromagesdeterroirs.com/projets-de-r-et-d/docamex/

8.1.4. Convergence Institute #DigitAg (2017-2023)

Participants: Patrice Buche, Madalina Croitoru, Marie-Laure Mugnier, Rallou Thomopoulos, Federico Ulliana.

Located in Montpellier, #DigitAg (for Digital Agriculture) gathers 17 founding members: research institutes, including Inria, the University of Montpellier and higher-education institutes in agronomy, transfer structures and companies. Its objective is to support the development of digital agriculture. GraphIK is involved in this project on the issues of designing data and knowledge management systems adapted to agricultural information systems, and of developing methods for integrating different types of information and knowledge (generated from data, experts, models). A collaboration is starting with the research laboratory UMR SYSTEM (Tropical and mediterranean cropping system functioning and management) on knowledge representation and reasoning for agro-ecological systems.
https://www.hdigitag.fr/en/

8.1.5. Informal National Partners

We continue to work informally with the following partners:

- Michael Thomazo (VALDA Inria team) on Ontology-Mediated Query Answering [37], [27].
- Jérôme Bonnet and Sarah Gouiziou, from the Center for Structural Biochemistry of Montpellier (CBS), on the encoding of Boolean functions in biological systems [15].
- Jean-Claude Léon (IMAGINE Inria team) on the developement of an ontology-mediated query answering system applied to the field of CAD (Computer Aided Design).
- Srdjan Vesic (CRIL) on logical argumentation systems [35], [28], [30], [31], [32] . In particular, Srdjan Vesic is a co-supervisor of Bruno Yun PhD thesis, started in Sept 2016.

8.2. European Initiatives

8.2.1. NoAW (H2020, Oct. 2016-Sept. 2020)

Participants: Patrice Buche, Pierre Bisquert, Madalina Croitoru, Nikolaos Karanikolas, Rallou Thomopoulos.

NoAW (No Agricultural Waste) is led by INRA-IATE. Driven by a "near zero-waste" society requirement, the goal of NoAW project is to generate innovative efficient approaches to convert growing agricultural waste issues into eco-efficient bio-based products opportunities with direct benefits for both environment, economy and EU consumer. To achieve this goal, the NoAW concept relies on developing holistic life cycle thinking able to support environmentally responsible R&D innovations on agro-waste conversion at different TRLs, in the light of regional and seasonal specificities, not forgetting risks emerging from circular management of agro-wastes (e.g. contaminants accumulation). GraphIK contributes on two aspects. On the one hand we participate in the annotation effort of knowledge bases (using the @Web tool). On the other hand we further investigate the interplay of argumentation with logically instantiated frameworks and its relation with social choice in the context of decision making.
http://cordis.europa.eu/project/rcn/203384_en.html

8.2.2. GLOPACK (H2020, June. 2018- July. 2022)

Participants: Patrice Buche, Pierre Bisquert, Madalina Croitoru.

GLOPACK is also led by INRA-IATE. It proposes a cutting-edge strategy addressing the technical and societal barriers to spread in our social system, innovative eco-efficient packaging able to reduce food environmental footprint. Focusing on accelerating the transition to a circular economy concept, GLOPACK aims to support users and consumers' access to innovative packaging solutions enabling the reduction and circular management of agro-food, including packaging, wastes. Validation of the solutions including compliance with legal requirements, economic feasibility and environmental impact will push forward the technologies tested and the related decision-making tool to TRL 7 for a rapid and easy market uptake contributing therefore to strengthen European companies' competitiveness in an always more globalised and connected world.
https://glopack2020.eu/.

8.2.3. FoodMC (European COST action, 2016-2020)

Participants: Patrice Buche, Madalina Croitoru, Rallou Thomopoulos.

COST actions aim to develop European cooperation in science and technology. FoodMC (CA 15118) is a cost action on Mathematical and Computer Science Methods for Food Science and Industry. Rallou Thomopoulos is co-leader of this action for France, and member of the action Management Committee, and other members of GraphIK (Patrice Buche, Madalina Croitoru) are participants. The action is organised in four working groups, dealing respectively with the modelling of food products and food processes, modelling for eco-design of food processes, software tools for the food industry, and dissemination and knowledge transfer. http://www6.inra.fr/foodmc

8.2.4. Informal International Partners

- University of Toronto (Canada): collaboration with Sheila McIlraith and her research group on temporal logics [22].
- Birkbeck College, University of London (UK): collaboration with Michael Zacharyaschev, Roman Kontchakov, and Stanislav Kikot on the complexity of ontology-mediated query answering [14].
- Patras University (Greece): collaboration with Nikolaos Karanikolas (formerly postdoc in the team) [16].

8.2.5. International Research Visitors

- David Carral (postdoc, TU Dresden, Germany) visited the group between 19-21 Dec. 2018.
- Joshua Sohn (PhD, DTU, Denmark) visited the group for a month in October 2018.
- Prof. Guillermo Simari (U. Nacional del Sur, Argentina) visited the group for a week in July 2018.

8.2.6. Visits to International Teams

- One-year stay (academic year 2017-2018) of Meghyn Bienvenu at University of Toronto, Computer Science Department, collaboration with Sheila McIlraith and KR group, focusing mainly on program synthesis with linear temporal logic (LTL) specifications, in particular, taking into account environment assumptions and user preferences.
- Marie-Laure Mugnier visited the Knowledge-Based Systems research group at TU Dresden (Markus Kroetzsch), mid July 2018.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

- Co-chair of the Doctoral Consortium for the KR conference, Tempe, Arizona, October 27th 2018. http://reasoning.eas.asu.edu/kr2018/.
- Co-chair of the Tutorial Track for the IJCAI conference, Stockholm, Sweden, 13th July 2018. https://www.ijcai-18.org/.
- Scientific co-chair of the international Workshop "Reasoning on Data" associated with the international conference The Web 2018, April 24, 2018. https://sites.google.com/site/2018rod/
- Co-organization of a one-day meeting of the group "Reasoning on Data", common to GDR MaDICS and IA, October 4, 2018. http://www.lirmm.fr/rod/rod3.html

9.1.1.2. Member of the Conference Program Committees

We are regularly program committee members for the major conferences in AI (i.e., IJCAI, AAAI, ECAI, AAMAS), and more focused conferences and workshops (such as RuleML+RR, Description Logics, COMMA etc.). We also take part in the animation of the national community (JIAF, EGC, IC, BDA). For 2018, we served in the following program committees:

International

- IJCAI / ECAI 2018 (International Conferences on Artificial Intelligence): Senior PC and PC
- AAAI 2018 (AAAI Conference on Artificial Intelligence): Senior PC
- AAMAS 2018 (International Conference on Autonomous Agents and Multiagent Systems): PC
- RuleML+RR 2018 (International Joint Conference on Rules and Reasoning): PC
- Description Logics 2018: PC
- KR 2018 (Knowledge Representation and Reasoning): PC

National

- IC 2018 (Ingénierie des Connaisances) : PC
- EGC 2018 (Conférence sur l'Extraction et Gestion de Connaissances): PC
- JIAF (Journées d'Intelligence Artificielle Fondamentale): PC

9.1.2. Invited Talks

- Invited tutorial, Reasoning on data: the ontology-mediated query answering problem, 6th World Congress and School on Universal Logic (in association with UNILOG 2018), Vichy, 16-20 June, 2018 (Marie-Laure Mugnier)
  https://www.uni-log.org/start6s.html
- Invited Seminar, Answering Conjunctive Regular Path Queries over Existential Rule Knowledge Bases, Quantitative Logics and Automata Seminar, TU Dresden, July 10, 2018 (Marie-Laure Mugnier)
- Invited Talk, L'interrogation de données en présence d'ontologies : Exploiter les connaissances pour mieux tirer parti des données, Journées Nationales du GDR Informatique Mathématiques (IM), April 2018 (Meghyn Bienvenu)
- Invited Talk, Accès aux données médiatisé par des ontologies, Journées plénières du GDR IA, October 2018 (Meghyn Bienvenu)
- Invited Talk, Ontology-Mediated Query Answering and Heterogeneous Data, Séminaire INRA du réseau IN-OVIVE, June 2018 (Federico Ulliana)
- Invited talk, Ontology-mediated query answering: Harnessing knowledge to get more from data, Annual Meeting of GT ALGA (GDR IM), October 2018 (Meghyn Bienvenu)
- Invited talk, Difficultés posées par les prédicats calculés en Ontology Mediated Query Answering, Meeting of GT RoD (GDR IA), October 2018 (Jean-François Baget)

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

The six faculty members teach at all university levels (IUT, Licence, Master). All of them do an average of 200 teaching hours per year. The main courses they are in charge of are: Logics (L), Databases (M, IUT), Web Technologies (IUT), Artificial Intelligence (M), Knowledge Representation and Reasoning (M), Social and Semantic Web (M), Software Engineering (IUT), Human Computer Interaction (IUT). Concerning full-time researchers in 2018, Jean-François Baget gave Master courses (40 h) and Meghyn Bienvenu gave a 3-hour tutorial at the international conference KR 2018 on "Inconsistency-Tolerant Ontology-Mediated Query Answering".

Moreover, faculty members have some specific responsibilities in the Computer Science Licence and Master. Madalina Croitoru is the head of Special Conversion Year at IUT (since 2014) and the head of international relations for the computer science department at IUT (since 2018). Federico Ulliana is the head of the curriculum "Data, Knowledge and Natural Language Processing" (DECOL, about 30 students), part of the Master of Computer Science, since 2017.

9.2.2. Involvement in University Structures

Michel Leclere is deputy head of the computer science department of the faculty (since 2015). He is also in charge of the Information Systems of the faculty. Marie-Laure Mugnier is member of the Council of the Scientific Department MIPS (Mathematics Informatics Physics and Systems) of the University of Montpellier (since 2016).

9.2.3. Supervision

PhD defended: Abdelraouf Hecham, Defeasible Reasoning for Existential Rules, University of Montpellier, 9th of July 2018, P. Bisquert and M. Croitoru.

PhD in progress: Stathis Delivorias. Supervisors: Federico Ulliana, Michel Leclère and Marie-Laure Mugnier. "Boundedness and Module extraction in Existential Rules KBs". Started Oct. 2015.

PhD in progress: Bruno Yun. Supervisors: Madalina Croitoru, Rallou Thomopolous, Srdjan Vesic (CRIL). "Decision Making and Ranking Semantics in Logical Argumentation Frameworks". Started October 2016.

PhD in progress: Maxime Buron (CEDAR Inria team). "Efficient reasoning on large heterogeneous graphs",Supervisors: François Gaosdoué (IRISA/CEDAR) Ioana Manolescu (CEDAR), Marie-Laure Mugnier. Started October 2017.

9.2.4. Juries

- Marie Laure Mugnier was a PhD reviewer for Duc Minh TRAN, University of Nice, July 2018.
- Marie Laure Mugnier was a PhD jury member for Jieying CHEN, University Paris Sud, November 2018.
- Meghyn Bienvenu was a PhD jury member for Christos Rantsoudis, University of Toulouse / IRIT, December 2018.

9.3. Popularization

9.3.1. Articles and contents

- M. Chein, Sur la science informatique et son installation à Montpellier, Conf. Association française pour l'avancement des sciences, Montpellier avril 2017 /Bull. Acad. Sc. Lett. Montp., vol. 48, suppl. C1 (2017), p.89-102/
- M. Chein, L'informatique : la science au coeur du numérique , Conf. Académie des Sc ; et Lett. De Montpellier, mai 2017, /Bull. Acad. Sc. Lett. Montp., vol.48 (2017), p.203-214/

9.3.2. Interventions

- M. Chein, Intelligence artificielle : Mythes et Réalités, Médiathèque, La Boissière, mars 2018
- M. Chein, La complexité en Informatique. Complexité spatio-temporelle des programmes, des algorithmes et des problèmes. Pierre Rouge Sciences, Assas, janvier 2018

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[2] J.-F. BAGET, M. LECLÈRE, M.-L. MUGNIER, E. SALVAT. *On Rules with Existential Variables: Walking the Decidability Line*, in "Artificial Intelligence", March 2011, vol. 175, n° 9-10, pp. 1620-1654 [*DOI :* 10.1016/J.ARTINT.2011.03.002], http://hal.inria.fr/lirmm-00587012/en

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[5] M. BIENVENU, S. KIKOT, R. KONTCHAKOV, V. V. PODOLSKII, M. ZAKHARYASCHEV. *Ontology-Mediated Queries: Combined Complexity and Succinctness of Rewritings via Circuit Complexity*, in "Journal of the ACM (JACM)", September 2018, vol. 65, n° 5, pp. 1-51 [*DOI :* 10.1145/3191832], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01892661

[6] M. CHEIN, M.-L. MUGNIER. *Graph-based Knowledge Representation and Reasoning—Computational Foundations of Conceptual Graphs*, Advanced Information and Knowledge Processing, Springer, 2009

[7] V. GUILLARD, P. BUCHE, S. DESTERCKE, N. TAMANI, M. CROITORU, L. MENUT, C. GUILLAUME, N. GONTARD. *A Decision Support System to design modified atmosphere packaging for fresh produce based on a bipolar flexible querying approach*, in "Computers and Electronics in Agriculture", February 2015, vol. 111, pp. 131-139 [*DOI :* 10.1016/J.COMPAG.2014.12.010], https://hal.archives-ouvertes.fr/hal-01104835

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] A. HECHAM. *Defeasible reasoning for existential rules*, Université de Montpellier, July 2018, https://tel.archives-ouvertes.fr/tel-01904558

Articles in International Peer-Reviewed Journals

[12] C. A. ACEVES LARA, V. ATHÈS, P. BUCHE, G. D. VALLE, V. FARINES, F. FONSECA, V. GUILLARD, K. KANSOU, M. KRISTIAWAN, V. MONCLUS, J.-R. MOURET, A. NDIAYE, P. NEVEU, S. PASSOT, C. PÉNICAUD, J.-M. SABLAYROLLES, J.-M. SALMON, R. THOMOPOULOS, I. C. TRÉLÉA. *The virtual food system: Innovative models and experiential feedback in technologies for winemaking, the cereals chain, food packaging and eco-designed starter production*, in "Innovative Food Science and Emerging Technologies", April 2018, vol. 46, pp. 54-64 [*DOI :* 10.1016/J.IFSET.2017.10.006], https://hal-lirmm.ccsd.cnrs.fr/lirmm-01651998

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