IN PARTNERSHIP WITH:
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Institut national de recherche pour l'agriculture, l'alimentation et l'environnement

Université de Montpellier

Activity Report 2019

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

Table of contents

Project-Team GRAPHIK

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Keywords:

Computer Science and Digital Science:

A3.1.1. - Modeling, representation
A3.2.1. - Knowledge bases
A3.2.3. - Inference
A3.2.5. - Ontologies
A7.2. - Logic in Computer Science
A9.1. - Knowledge
A9.6. - Decision support
A9.7. - AI algorithmics
A9.8. - Reasoning

Other Research Topics and Application Domains:

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. A large part of our work is strongly related to *data management* and *database theory*.

We develop logical languages, which mainly correspond to fragments of first-order 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 (formalizing practical issues and solving them with our techniques, which also feeds back into theoretical work).

2.3. Main Challenges

GraphIK focuses on some of the main challenges in KR:

- ontological query answering: querying large, complex or heterogeneous datasets, provided with an ontological layer;
- reasoning with rule-based languages;
- reasoning in presence of inconsistency and
- decision making.

2.4. Scientific Directions

Our research work is currently organized into two research lines, both with theoretical and applied sides:

1. **Ontology-mediated query answering (OMQA)**. Modern information systems are structured around an ontology, which provides a high-level vocabulary, as well as knowledge relevant to the target domain, and enables a uniform access to possibly heterogeneous data sources. As many complex tasks can be recast in terms of query answering, the question of querying data while taking into account inferences enabled by ontological knowledge has become a fundamental issue. This gives rise to the notion of a knowledge base, composed of an ontology and a factbase, both described using a KR language. The factbase can be seen as an abstraction of several data sources, and may actually remain virtual. The topical ontology-mediated query answering (OMQA) problem asks for all answers to queries that are logically entailed by the given knowledge base.
2. **Reasoning with imperfect knowledge and decision support**. To solve real-world problems we often need to consider features that cannot be expressed purely (or naturally) in classical logic. Indeed, information is often "imperfect": it can be partially contradictory, vague or uncertain, etc. These last years, we mostly considered reasoning in presence of conflicts, where contradictory information may come from the data or from the ontology. This requires to define appropriate semantics, able to provide meaningful answers to queries while taming the computational complexity increase. Reasoning becomes more complex from a conceptual viewpoint as well, hence how to explain results to an end-user is also an important issue. Such questions are natural extensions to those studied in the first axis. On the other hand, the work of this axis is also motivated by applications provided by our INRA partners, where the knowledge to be represented intrinsically features several viewpoints and involves different stakeholders with divergent priorities, while a decision has to be made. Beyond the representation of conflictual knowledge itself, this raises arbitration issues. The aim here is to support decision making by tools that help eliciting and representing relevant knowledge, including the stakeholders' preferences and motivations, compute syntheses of compatible options, and propose justified decisions.

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.

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 are 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 (which typically expresses domain knowledge), heterogeneous data sources (provided with their own vocabulary and querying capabilities), and mappings that relate these data sources to the ontological vocabulary. Ontologies play a central role as they act both as a mediation layer that glue together pieces of knowledge extracted from data sources, and as an inference layer that allow to draw new knowledge.

Besides pure knowledge representation and reasoning issues, querying such systems raise issues at the crossroad of data and knowledge management. In particular, although mappings have been widely investigated in databases, they need 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

- One of our papers ([15]) has been recognized as a **highlight of the year 2020** of the INRA department CEPIA.
- The SudoQual engine, which was developed in the context of the Qualinca research project (2012-2016), has been reused by ABES (the French National Agency for Academic Libraries) to build Paprika, a professional tool for documentalists, released this year (https://paprika.idref.fr/). SudoQual/Paprika is devoted to data curation in the context of bibliographic databases.

6. New Software and Platforms

6.1. Docamex

KEYWORD: Ontologies

SCIENTIFIC DESCRIPTION: In many agri-food companies, food quality is often managed using expertise gained through experience. Overall quality enhancement may come from sharing collective expertise. In this paper, we describe the design and implementation of a complete methodology allowing an expert knowledge base to be created and used to recommend the technical action to take to maintain food quality. We present its functional specifications, defined in cooperation with several industrial partners and technical centres over the course of several projects carried out in recent years. We propose a systematic methodology for collecting the knowledge on a given food process, from the design of a questionnaire to the synthesis of the information from completed questionnaires using a mind map approach. We then propose an original core ontology for structuring knowledge as possible causal relationships between situations of interest. We describe how mind map files generated by mind map tools are automatically imported into a conceptual graph knowledge base, before being validated and finally automatically processed in a graph-based visual tool. A specific end-user interface has been designed to ensure that end-user experts in agri-food companies can use the tool in a convenient way. Finally, our approach is compared with current research.

FUNCTIONAL DESCRIPTION: Docamex is a software dedicated to expert knowledge capitalization and visualization.

NEWS OF THE YEAR: Reliability score implemented.

- Participants: Jérôme Fortin and Patrice Buche
- Contact: Jérôme Fortin
- Publication: Expertise-based decision support for managing food quality in agri-food companies

6.2. 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: 2019: new website and completely revised user documentation, following the release of version V3 (in 2018), which required heavy refactoring to benefit from NetBeans plugin-extensible platform architecture and graphical libraries (total replacement of the graphical editors).

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

6.3. Damn

Defeasible reasoning tool for multi-agent collaboration

KEYWORDS: Knowledge representation - Logic programming

FUNCTIONAL DESCRIPTION: Damn 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.

NEWS OF THE YEAR: The HCI has been finalised: multi-users functionalities have been added (login, agents added, etc.).

- Contact: Madalina Croitoru
- URL: https://hamhec.github.io/damn/home

7. New Results

7.1. Ontology-Mediated Query Answering

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

Ontolology-mediated query answering (OMQA) is the issue of querying data while taking into account inferences enabled by ontological knowledge. From an abstract viewpoint, this gives rise to *knowledge bases*, composed of an ontology and a factbase (in database terms: a database instance under incomplete data assumption). Answers to queries are logically entailed from the knowledge base.

This year, we obtained two kinds of results: *theoretical results* on fundamental issues raised by OMQA, and *practical algorithms* for OMQA on key-value stores and RDF integration systems.

7.1.1. Fundamental issues on OMQA with existential rules

Existential rules (a.k.a. datalog+, as this framework generalizes the deductive database language datalog) have emerged as a new ontological language in the OMQA context. 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, known as the *chase* in database theory, 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 is divided into two steps: first, the query is *rewritten* using the rules into a first-order query (typically a union of conjunctive queries, but it can be a more compact form) or into a datalog query; then the rewritten query is evaluated against the factbase (again, as in a classical database system). Depending on the considered class of existential rules, the chase and/or query rewriting may terminate or not.

7.1.1.1. Decidability of chase termination for linear existential rules.

Several chase variants have long been studied in database theory. These chase variants yield logically equivalent results, but differ in their ability to detect redundancies possibly caused by the introduction of unknown individuals (nulls, blank nodes). Given a chase variant, the 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 database inclusion dependencies. We showed the decidability of the chase termination problem on linear rules for three main chase variants, namely skolem (a.k.a. semi-oblivious), restricted (a.k.a. standard) and core chase. The restricted chase is the most used in practice, however its study is notoriously tricky 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 our results, we introduced a novel approach based on so-called derivation trees and a single notion of forbidden pattern. The simplicity of these structures make them subject to implementation. Besides the theoretical interest of a unified approach and new proofs, we provided the first positive decidability results (and complexity upper bounds) 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?

- *ICDT 2019 [29]. In collaboration with Michael Thomazo (Inria VALDA).*

7.1.1.2. Boundedness: Enforcing both chase termination and first-order rewritability.

We carried out the first studies on the boundedness problem for existential rules. This problem asks whether a given set of existential rules is bounded, i.e., whether there is a predefined bound on the "depth" of the chase independently from any factbase (for breadth-first chase versions, the depth corresponds to the number of breadth-first steps). It has been deeply studied in the context of datalog, where it is key to query optimization, although boundedness is undecidable in general. For datalog rules, boundedness is equivalent to a desirable property, namely first-order rewritability: a set of rules is called first-order rewritable if any conjunctive query can be rewritten into a union of conjunctive queries, whose evaluation on any factbase yields the expected answers (i.e., the relevant part of the ontology can be compiled into the rewritten query, which allows to reduce query answering to a simple query evaluation task). This equivalence does not hold for existential rules. Moreover, the notion of boundedness has to be parametrized by the chase variant, as they all behave differently with respect to termination. Beside potential practical use, the notion of boundedness is closely related to an interesting theoretical question on existential rules: what are the relationships between chase termination and first-order query rewritability? With respect to this question, we obtained the following salient result: for the oblivious and skolem (semi-oblivious) chase variants, a set of existential rules is bounded if and only if it ensures both chase termination for any factbase and first-order rewritability for any conjunctive query.

- *IJCAI 2019 [22]. In collaboration with Pierre Bourhis (Inria SPIRALS) and Sophie Tison (Inria LINKS).*

7.1.2. Practical Algorithms for OMQA on key-value stores and RDF integration systems

7.1.2.1. Ontology-mediated query answering on top of key-value stores.

Ontology-mediated query answering was mainly investigated so far based on the assumption that data conforms to relational structures (we include here RDF) and that the paradigm can be deployed on top of relational databases with conjunctive queries at the core (e.g., in SQL or SPARQL). However, this is not the prominent way on which data is today stored and exchanged, especially in the Web. Whether OMQA can be developed for non-relational structures, like those shared by increasingly popular NOSQL languages sustaining Big-Data analytics, has just begun to be investigated. Since 2016, we have been studying OMQA for key-values stores, which are systems providing fast and scalable access to JSON records. We proposed a rule language to express domain knowledge, with rules being directly applicable to key-value stores, without any

translation of JSON into another data model (results published at AAAI 2016 and IJCAI 2017). In 2018-2019, we implemented a prototype for MongoDB, with a restricted part of this rule language (featuring key inclusions and mandatory keys) and tree-pattern queries, and devised optimization techniques based on parallellizing query rewriting and query answering. This work is pursued within a starting PhD thesis (Olivier Rodriguez).

- *Rule-ML 2019 [31]. In collaboration with Reza Akbarinia (Inria ZENITH).*

7.1.2.2. Ontology-mediated query answering in RDF integration systems

Within the iCODA project devoted to data journalism and the co-supervision of Maxime Buron's PhD thesis, we are considering the so-called Ontology-Based Data Access framework, which is composed of three components: the data level, the ontological level and mappings that relate data to facts described in the vocabulary of the ontology. Our framework more precisely considers heterogeneous data sources integrated through mappings into a (possibly virtual) RDF graph, provided with an RDFS ontology and RDFS entailment rules. The innovative aspects with respect to the state of the art are (i) SPARQL queries that extend classical conjunctive queries by the ability of querying data and ontological triples together, and (ii) Global-Local-As-View (GLAV) mappings, which can be seen as source-to-target existential rules. GLAV mappings enable the creation of unknown entities (blank nodes), which increases the amount of information accessible through the integration system. In particular, they allow one to palliate missing data values, by stating the existence of data whose values are not known in the sources. We devised, implemented and experimentally compared several query answering techniques in this setting.

- *ESWC 2019 [23], technical report [36] basis of a paper accepted to EDBT 2020. In collaboration with Maxime Buron and Ioana Manolescu (Inria CEDAR), and François Goasdoué (IRISA).*

7.2. Reasoning with conflicts and decision support

Participants: Pierre Bisquert, Patrice Buche, Michel Chein, Madalina Croitoru, Jérôme Fortin, Alain Gutierrez, Abdelraouf Hecham, Martin Jedwabny, Michel Leclère, Rallou Thomopoulos, Bruno Yun.

The work carried out during this year can be structured into two main research directions: *structured logic-based argumentation* and *collective decision making*.

7.2.1. Structured argumentation

To solve real-world problems we sometimes need to consider features that cannot be expressed purely (or naturally) in classical logic. Indeed, real world information is often "imperfect": it can be partially contradictory, vague or uncertain, etc. During the evaluation period, we mostly considered reasoning in presence of conflicts. To handle this issue, as a reasoning method robust to contradiction, we have used structured argumentation, where arguments have an internal logical structure representing an inference step (i.e. some premises inducing a conclusion). In this context, arguments and their interaction are typically generated from an inconsistent knowledge base. Such arguments are in contrast to those employed in abstract argumentation where they are considered a black box (usually provided as input to a problem and not computed).

More precisely, this year, we mainly worked on two issues: the first one concerns the question of scrutinizing a structured argument, i.e. checking both the validity ("is the conclusion induced by the premisses?") and its soundness ("is the argument valid and are its premisses true?"). This is interesting in the context of collective decision making, where participants utter arguments that can be assessed. The second one relates to the computational complexity of generating arguments from a knowledge base. Indeed, it can potentially produce a huge number of arguments, which impedes the usability of argumentation for big knowledge bases.

7.2.1.1. Formalizing argument schemes and fallacies

More precisely, we have presented a logical framework allowing us to express assessment of facts and arguments together with a proof system to answer these questions. Our motivation was to clarify the notion of validity in the context of logic-based arguments along different aspects (such as the formulas used and the inference scheme). Originality lies in the possibility for the user to design their own argument schemes, i.e. specific inference patterns (e.g. expert argument, analogy argument). We showed that classical inference obtains when arguments are based on classical schemes (e.g. Hilbert axioms). We went beyond classical logic by distinguishing "proven" formulas from "uncontroversial" ones (whose negation is not proven) and provided a definition of a fallacious argument in this context.

- *LPNMR 2019 [20]. In collaboration with Florence Dupin de Saint-Cyr and Philippe Besnard (IRIT).*

7.2.1.2. Optimising argumentation frameworks

Another problem addressed was the large number of logical arguments that can be potentially constructed from a knowledge base. To address this problem we have proposed a compact representation of the structured argumentation system under the form of hypergraphs and implemented it in the NAKED prototype. The tool allows to import a knowledge base (expressed in the existential rule framework), generate, visualise and export the corresponding argumentation hypergraph. These functions, paired with the aim of improving the extension computation efficiency, make this software an interesting tool for non-computer science experts, such as people working in the agronomy domain.

- *AAMAS 2019 [33]. In collaboration with Srdjan Vesic (CRIL).*

7.2.2. Collective decision making

In this setting we have focused towards the deliberation and voting techniques. We have investigated how deliberation can help generate or impact the structure of preferences underlying the voting process. We have implemented the PAPOW prototype [27] that allows for filtering of voters depending on their individual characteristics.

7.2.2.1. Argumentation as a tool to generate new preferences

We have investigated how argumentation can solve the Condorcet paradox by using the notion of extension (maxi-consistent sets of arguments) in order to compute new preferences. Our research hypothesis is that a decision made by a group of participants understanding the qualitative rationale (expressed by arguments) behind each other's preferences has better chances to be accepted and used in practice. Accordingly, we proposed a novel qualitative procedure which combines argumentation with computational social choice for modeling the collective decision-making problem. We showed that this qualitative approach produces structured preferences that can overcome major deficiencies that were exhibited in the social choice literature and affect most of the major voting rules. More precisely, we have dealt with the Condorcet Paradox and the properties of monotonicity and homogeneity, which are unsatisfiable by many voting rules.

- *PRAI 2019 [14]. In collaboration with Christos Kaklamanis and Nikos Karanikolas (CTI, Greece).*

7.2.2.2. Argumentation as a tool to modify individual preferences

The previous approach implies that voters are replaced by the extensions which, while it allows to circumvent the Condorcet Paradox, might prove difficult to implement as it disregards the notion of (voters') majority. Hence, we proposed a decision-making procedure based on argumentation and preference aggregation which permits us to explore the effect of reasoning and deliberation along with voting for the decision process. We represented the deliberation phase by defining a new voting argumentation framework, that uses vote and generic arguments, and its acceptability semantics based on the notion of pairwise comparisons between alternatives. We proved for these semantics some theoretical results regarding well-known properties from argumentation and social choice theory.

Moreover, we also studied the notion of unshared features (i.e., alternatives' criteria that constitute justifications of preferences for some agents but not for others) and showed under which conditions it is possible to reach a Condorcet consensus. We provided a deliberation protocol that ensures that, after its completion, the number of unshared features of the decision problem can only be reduced, which would tend to show that deliberation allows to lower the risk of Condorcet Paradox.

- *ICAART 2019 [28]. In collaboration with Christos Kaklamanis and Nikos Karanikolas (CTI, Greece). PRIMA 2019 [21].*

7.2.3. Discovering and qualifying authority links

We finalized this year the description of the engine SudoQual, devoted to the evaluation of link quality in document bases, developed in collaboration with ABES, the French National Agency for Academic Libraries (http://www.abes.fr), in the context of ANR Qualinca research project (2012-2016) (https://www.lirmm.fr/qualinca/). We presented the methodology and general algorithms used to discover and qualify so-called authority links (which are coreference links between entities mentioned in descriptions of documents and entities described in referential bases). Moreover, ABES has put in production this year a professional tool for documentalists, called Paprika (https://paprika.idref.fr/), whose kernel is the SudoQual engine.

- *KCAP 2019 [25].*

7.3. Miscellaneous: Automated design of biological devices

Participants: Michel Leclère, Guillaume Perution Kihli, Federico Ulliana.

We mention here results obtained in a collaboration with a team of biologists from the Center for Structural Biochemistry (CBS, Montpellier) on the logical computing capabilities of living organisms. More precisely, this joint work focuses on the development of a framework dedicated to the design of so-called Recombinase-based devices, whose behavior is specified as Boolean functions. We looked at the case of single-cell devices, whose expressivity limits, that is, the Boolean functions they can implement without distributing the Boolean function in several parts, are still unknown. While it is easy to determine which Boolean function is implemented by a device, the converse problem of automatically designing a device implementing a given Boolean function is a difficult task for which no automatic method exists. To tackle this problem, we experimented in the past years a combinatorial approach consisting in exhaustively generating all devices up to a given size, then determining the Boolean function they implement. A generating program and a database for these devices were developed. This year, we achieved the first formal study of this problem, which we believe can serve as foundations for the development of new biological design solutions. A set of minimality properties naturally emerged from our study, which led us to define the notion of canonical and representative devices, by which infinitely large classes of design solutions can be finitely expressed. These results strengthen the reliability of the approach and show that our program generates all representative canonical devices. Finally, our results also indicate some interesting expressivity limits for single-cell devices. Indeed, the generation process showed that 8% among all 4-input Boolean functions cannot be implemented. We also formally proved that single-cell devices cannot implement some n-input Boolean functions, for every $n \geq 7$.

- *TPNC 2019 [30]. In collaboration with Jérôme Bonnet and Sarah Guiziou (CBS).*

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 are usually acquired over a long time. This know-how is today mainly transmitted by apprenticeship and a concrete risk of knowledge forgetting is raised by the evolution of practices in the sector. The main goal of the project is to develop a new approach for expert knowledge elicitation and capitalization, and a dedicated software for decision making. The novel part of the decision making tool consists 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 starting PhD thesis (Elie Najm) will investigate knowledge representation and reasoning for agro-ecological systems, in collaboration with the research laboratory UMR SYSTEM (Tropical and mediterranean cropping system functioning and management).
https://www.hdigitag.fr/en/

8.1.5. Vitamin (Méta-programme Did'It 2017-2018)

Participant: Rallou Thomopoulos.

The goal is to get a better understanding of factors influencing individuals in their transition to stop or reduce their animal product consumption. We use comprehensive individual interviews, questionnaires as well as diverse modelling techniques (mainly multi-agents & argumentation systems) to collect and analyse this topic. We develop agent-based models integrating argumentation systems about vegetarian transitions, at the long and short term. We have proposed a generic framework implemented in the GAMA platform allowing to explicitly represent exchanges of arguments between actors in the context of an opinion dynamic model. More precisely, we propose to formalize the inner attitude towards an opinion of each agent as an argumentation graph and give them the possibility to share arguments with other agents. The application to food choices allows studying the possible evolution of the vegetarian diet.
https://www.researchgate.net/project/VITAMIN-VegetarIan-Transition-Argument-ModellINg

8.1.6. Informal National Partners

We continue to work informally with the following partners:

- Pierre Bourhis (SPIRALS Inria team) and Sophie Tison (LINKS Inria team) Ontology-Mediated Query Answering [22].
- Michael Thomazo (VALDA Inria team) on Ontology-Mediated Query Answering [29].
- Jérôme Bonnet and Sarah Guiziou, from the Center for Structural Biochemistry of Montpellier (CBS), on the encoding of Boolean functions in biological systems [30]
- Srdjan Vesic (CRIL) on logical argumentation systems. In particular, Srdjan Vesic was a co-supervisor of Bruno Yun's PhD thesis, defended in July 2019 [33].
- Jean-Claude Léon (IMAGINE Inria team) on the development of an ontology-mediated query answering system applied to the field of CAD (Computer Aided Design).
- Slawek Staworko (LINKS Inria team) on data cleaning and argumentation techniques for repairing.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

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

Participants: Patrice Buche, Pierre Bisquert, Madalina Croitoru, 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

8.2.1.2. 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/

8.2.2. Collaborations in European Programs, Except FP7 & H2020

8.2.2.1. 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

8.3. International Research Visitors

8.3.1. Visits of International Scientists

Carlos Saez, postdoctoral researcher at the Biomedical Data Science Lab of the ITACA Institute of the Universitat Politècnica de València (UPV, Spain) stayed one week (from 10/12/2019 to 14/12/2019) to work on data quality issues for machine learning techniques and how OBDA and argumentation could help improve the quality of data.

8.3.2. Visits to International Teams

8.3.2.1. Research Stays Abroad

Madalina Croitoru obtained a SICSA Distinguished Visitor Program Funding and stayed at the University of Aberdeen from the 1st of April 2019 to the 31st of May 2019. She worked with Professor Nir Oren on ethical decision making in a multi-agent setting.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

- Marie-Laure Mugnier is co-responsible for a national group (2017-2020), named **Reasoning on Data** (Rod), common to two GDRs (CNRS research groups), namely Artificial Intelligence (formal and algorithmic aspects of Artificial Intelligence) and MaDICS (Big Data, Data Science). The aim of this action is to gather researchers from different domains on the development of knowledge representation and reasoning techniques devoted to data exploitation. http://www.lirmm.fr/rod/
- Rallou Thomopoulos has been co-leader of the trans-unit program **InCom** (Knowledge and Model Integration) of the CEPIA Division of INRA from 2018. She also organised the session on "Digital Issues" in the 2019 annual seminar of INRAE-TRANSFORM research division, and she was co-organizer of a one-day workshop on data-mining for food and bioproduct processing research on the 25th of November 2019.
- Patrice Buche is a coordinator of the **IN-OVIVE** (INtégration de sources/masses de données hétérogènes et Ontologies, dans le domaine des sciences du VIVant et de l'Environnement) network. He also was one of the organisers of the Fifth IN'OVIVE workshop event (https://workshop.inra.fr/in-ovive-2019/), collocated with the IC 2019 conference.

9.1.1.1. General Chair, Scientific Chair

Madalina Croitoru is part of the Steering Committee of ICCS 2020 (25th International Conference of Conceptual Structures).

9.1.2. Scientific Events: Selection

9.1.2.1. Chair of Conference Program Committees

Madalina Croitoru was co-chair of the **Doctoral Consortium at AAMAS 2019** (http://aamas2019.encs.concordia.ca/).

9.1.2.2. Member of the Conference Program Committees

We regularly participate to the program committees of the top conferences in AI and KR (IJCAI, AAAI, ECAI, KR, AAMAS), as PC members or senior PC members. We also regularly participate to the program committees of more focused international conferences and workshops as well as national events.

International

- IJCAI / PRICAI 2020 (29th International Joint Conference on Artificial Intelligence): senior PC and PC
- IJCAI / ECAI 2019 (28th International Joint Conference on Artificial Intelligence): senior PC
- ECAI 2020 (24th European Conference on Artificial Intelligence): senior PC
- AAAI 2019 (33rd AAAI Conference on Artificial Intelligence): PC
- Datalog 2.0 2019: PC
- ISWC 2019 (18th International Semantic Web Conference): PC

National

- CNAI 2019 (Conférence Nationale en Intelligence Artificielle): PC
- IC 2019 (Ingénierie des Connaissances): PC
- EGC 2019 (Extraction et Gestion des Connaissances): PC

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

- International Journal of Metadata, Semantics and Ontologies (IJSMO)
- Revue africaine de la recherche en informatique et mathématiques appliquées (ARIMA)

9.1.3.2. Reviewer - Reviewing Activities

- Artificial Intelligence Journal (AIJ)
- Theory and Practice of Logic Programming (TPLP)
- International Journal of Approximate Reasoning (IJAR)

9.1.4. Invited Talks

- Marie-Laure Mugnier, *Existential Rules: a Study Through Chase Termination, FO-Rewritability and Boundedness*, keynote talk, 3rd International Joint Conference on Rules and Reasoning (RuleML+RR 2019), 2019 http://2019.ruleml-rr.org
- Marie-Laure Mugnier, *Reasoning on Data: Ontology-Based Data Access*, keynote talk, Journées d'Intelligence Artificielle Fondamentale (JIAF 2019), associated with PFIA 2019, 2019 https://www.irit.fr/pfia2019/jiaf/
- Marie-Laure Mugnier, *An introduction to Ontology-Based Data Access*, invited tutorial, Winter School of the 19th Conférence Francophone sur l'Extraction et la Gestion de Connaissances (EGC 2019), 2019 https://egc2019.sciencesconf.org/
- Patrice Buche, *Semantic to the rescue of food industry needs*, invited talk, SEmantic web SeminAr MontpEllier (SESAME), 2019 (https://informatique-mia.inra.fr/sesame)
- Pierre Bisquert, *Argumentation and decision in agronomical problems*, invited talk, Journée Robustesse en traitement de données et en recommandation: méthodes et applications, 2019 https://lfa2019.wp.imt.fr/files/2019/10/Programme13nov2019.pdf

9.1.5. Research Administration

- Marie-Laure Mugnier was the *scientific coordinator* for the evaluation of Inria theme "Data and Knowledge Representation and Processing" and its twelve project-teams (evaluation period: 2016-2019).
- From September 2019 onwards, Madalina Croitoru is *deputy member* of the CNU section 27 (Computer Science).
- Rallou Thomopoulos is an *elected member* of the Scientific Committee of the INRA-CEPIA research division (2016-2020).

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 2019, Jean-François Baget and Pierre Bisquert gave Master courses (40h and 1h30 respectively).

Moreover, some faculty members have specific teaching responsibilities:

- At IUT, Madalina Croitoru was the head of Special Conversion Year (2014-2019) and the head of international relations for the computer science department (2018-mid-2019). In 2019, she was promoted professor and moved to the Science Faculty. From September 2019, she has been in charge of international relations for the Computer Science department at the Science Faculty as well as of the management of industrial master internships (about 100 students each year).
- 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 Leclère has been deputy head of the Computer Science department of the Science Faculty (July 2015 - July 2019). He was also in charge of the Information Systems of the faculty (April 2017 - October 2019)
- 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: Stathis Delivorias, "Chase variants & boundedness". Supervisors: Federico Ulliana, Michel Leclère and Marie-Laure Mugnier. University of Montpellier, September 2019.

PhD defended: Bruno Yun, "Argumentation techniques for existential rules". Supervisors: Madalina Croitoru, Rallou Thomopolous and Srdjan Vesic (CRIL). University of Montpellier, July 2019.

PhD in progress: Elie Najm, "Knowledge Representation and Reasoning for innovating agroecological systems". Supervisors: Marie-Laure Mugnier and Christian Gary (INRA, UMR SYSTEM). Started October 2019.

PhD in progress: Olivier Rodriguez, "Querying key-value store under semantic constraints". Supervisors: Federico Ulliana and Marie-Laure Mugnier. Started February 2019.

PhD in progress: Martin Jedwabny, "Argumentation and ethical decision making". Supervisors: Madalina Croitoru and Pierre Bisquert. Started October 2019.

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

9.2.4. Juries

- Jury member for the HDR of Ivan Varzinczak (Nov. 2019, U. Artois) - Marie-Laure Mugnier
- Jury member for the HDR of Meghyn Bienvenu (Dec. 2019, U. Bordeaux) - Marie-Laure Mugnier
- Jury reviewer for the PhD defense of Gerald Berger (June 2019, TU Vienna, Austria) - Marie-Laure Mugnier
- Jury member for the PhD defense of Frederic Verdier (Dec. 2019, U. Montpellier) - Marie-Laure Mugnier
- Jury member for the PhD defense of Lily Galois (Dec. 2019, U. Lille) - Marie-Laure Mugnier

We do not not mention here participations to juries as supervisors of GraphIK PhD students.

9.3. Popularization

Michel Chein gave two talks on Artificial Intelligence: a public conference in the context of the Academy of the Sciences and Humanities of Montpellier and a radio interview (RCF) - both in March 2019.

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