INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Dahu

Verification in Database

Saclay - Île-de-France

Theme : Knowledge and Data Representation and Management

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Dahu is a common project with LSV and ENS de Cachan. The team was created on January the 1st, 2008.

1. Team

Research Scientist

Serge Abiteboul [Research Director (DR), HdR]
Stéphane Demri [Research Director (DR) CNRS, HdR]
Florent Jacquemard [Research assistant (CR), Inria]
Luc Segoufin [Team leader, Research Director (DR), Inria, HdR]

Faculty Member

Cristina Sirangelo [ENS Cachan]

PhD Student

Diego Figueira [Cordi]
Thomas Place [Allocation couplée]
Camille Vacher [Allocation couplée]

Post-Doctoral Fellow

Balder ten Cate [Webdam, from April to September]
Yannis Katsis [Webdam, since October]

Visiting Scientist

Anuj Dawar [In Dahu from January to August. Professor, Cambridge, UK]
Nicole Schweikardt [In Dahu in April and May. Professor, Frankfurt, Germany]
Victor Vianu [In Dahu from mid June to mid September. Professor, UC San Diego, USA]
Amélie Gheerbrant [In Dahu from May to September. PhD student at University of Amsterdam]
Gaëlle Fontaine [In Dahu in July and September. Ph.D student at University of Amsterdam]
Bruno Marnette [In Dahu in July and August. PhD student at Oxford University]
Szymon Toruńczyk [In Dahu since October. PhD student at Warsaw University]

Administrative Assistant

Marie Dominguès [Secretary (SAR) Inria, until September]
Isabelle Biercewicz [Secretary (SAR) Inria, since September]

2. Overall Objectives

2.1. Overall Objectives

For more information see http://www.lsv.ens-cachan.fr/axes/DAHU/dahu.php.

The need to access and exchange data on the Web has led to database management systems (DBMS) that are increasingly distributed and autonomous. Data extraction and querying on the Web is harder than in classical DBMS, because such data is heterogeneous, redundant, inconsistent and subject to frequent modifications. DBMS thus need to be able to detect errors, to analyze them and to correct them. Moreover, increasingly complex Web applications and services rely on DBMS, and their reliability is crucial. This creates a need for tools for specifying DBMS in a high-level manner that is easier to understand, while also facilitating verification of critical properties.

The study of such specification and verification techniques is the main goal of Dahu.

3. Scientific Foundations

3.1. Scientific Foundations

Dahu has strong connections with the Gemo project and the Cassis project.

Dahu aims at developing mechanisms for high-level specifications of systems built around DBMS, that are easy to understand while also facilitating verification of critical properties. This requires developing tools that are suitable for reasoning about systems that manipulate data. Some tools for specifying and reasoning about data have already been studied independently by the database community and by the verification community, with various motivations. However, this work is still in its infancy and needs to be further developed and unified.

Most current proposals for reasoning about DBMS over XML documents are based on tree automata, taking advantage of the tree structure of XML documents. For this reason, the Dahu team is studying a variety of tree automata. This ranges from restrictions of "classical" tree automata in order to understand their expressive power, to extensions of tree automata in order to understand how to incorporate the manipulation of data.

Moreover, Dahu is also interested in logical frameworks that explicitly refer to data. Such logical frameworks can be used as high level declarative languages for specifying integrity constraints, format change during data exchange, web service functionalities and so on. Moreover, the same logical frameworks can be used to express the critical properties we wish to verify.

In order to achieve its goals, Dahu brings together world-class expertise in both databases and verification.

4. Application Domains

4.1. Application Domains

Databases are pervasive across many application fields. Indeed, most human activities today require some form of data management. In particular, all applications involving the processing of large amounts of data require the use of a database. Increasingly complex Web applications and services also rely on DBMS, and their correctness and robustness is crucial.

We believe that the automated solutions that Dahu aims to develop for verifying such systems will be useful in this context.

5. New Results

5.1. XML specification and verification

Participants: Serge Abiteboul, Diego Figueira, Luc Segoufin, Cristina Sirangelo.

In general Dahu aims at making systems with data safer and more reliable. This means providing suitable models together with a toolbox for helping in the design and implementation of such systems.

We have tackled this year several specific scenarios: models for describing and verifying incomplete information, models for exchanging data, models for distributed XML repository, decision procedure around the query language XPath and static analysis of dynamic XML systems.

XPath is arguably the most widely used XML query language as it is implemented in XSLT and XQuery and it is used as a constituent part of several specification and update languages. Hence in order to perform static analysis on a system manipulating XML data it is important to master the static analysis for XPath. Most of the important static analysis problems reduce to satisfiability checking: does a given query return a non-empty answer on some data. In general the satisfiability of XPath is undecidable, however important fragments can be shown to be decidable. In [26] we have shown that when restricting the navigational axis of XPath to the child and descendant relation then satisfiability can be decided in ExpTime. In [27] we have shown that for many other natural fragments of XPath satisfiability is, if decidable, not primitive recursive.

Active XML is a high-level specification language tailored to data-intensive, distributed, dynamic Web services. Active XML is based on XML documents with embedded function calls. The state of a document evolves depending on the result of internal function calls (local computations) or external ones (interactions with users or other services). Function calls return documents that may be active, so may activate new subtasks. In [13], [12], we studied the verification of temporal properties of runs of Active XML systems, specified in a tree-pattern based temporal logic, Tree-LTL, that allows expressing a rich class of semantic properties of the application. The main results establish the boundary of decidability and the complexity of automatic verification of Tree-LTL properties.

Towards a data-centric workflow approach, we introduced in [19] an *artifact model* to capture data and workflow management activities in distributed settings. As above, the model is built on Active XML. We argue that the model captures the essential features of service calls and the essential features of business artifacts as described informally by Nigam and Caswell in 2003. We also briefly consider the *monitoring* of distributed systems and the *verification* of temporal properties for them.

A distributed XML document is an XML document that spans several machines or Web repositories. We assume that a distribution design of the document tree is given, providing an XML tree some of whose leaves are "docking points", to which XML subtrees can be attached. These subtrees may be provided and controlled by peers at remote locations, or may correspond to the result of function calls, e.g., Web services. If a global type τ, e.g. a DTD, is specified for a distributed document T, it would be most desirable to be able to break this type into a collection of local types, called a local typing, such that the document satisfies τ if and only if each peer (or function) satisfies its local type. In [21], we lay out the fundamentals of a theory of local typing and provide formal definitions for several variants of locality.

Data exchange between different independent applications has been a central database application since the early development of database systems, and sees now a renewed interest with XML – originally designed as an exchange language. The general problem is how to transfer data from a source database to a target database, structured according to different schemas, knowing a mapping relation between the two schemas. In the literature two main semantics of data exchange existed: one based on the Open World Assumption (OWA), and another one based on the Closed World Assumption (CWA) on target instances. We have studied the effect of introducing an explicit CWA/OWA annotation on target attributes of schema mappings, and we have formalized a corresponding mixed CWA/OWA semantics of data exchange. We have studied the complexity of answering queries over the set of all possible target solutions by establishing a complexity characterization based on the number of open attributes in schema mappings. We have also studied one of the main schema mapping operations, schema composition, for annotated schema mappings. We have shown that large classes of CWA schema mappings enjoy closure under composition. These results are surveyed in [31].

XML key applications on the Web, such as data integration and exchange, make the presence of incomplete information unavoidable in XML data, due to the incompatibility of schemas and constraints among different sites. In [23] we have developed a general model of incomplete information in XML which, in analogy with its relational counterpart, is centered on the notion of null to represent missing information. However the structure of XML documents is much more involved than that of relational databases, and missing information may occur not only in attribute values, but also in the tree structure of the documents. We have considered several models of incomplete information in XML and we have investigated how different features characterizing these models affect the complexity of some relevant computational problems. Among these, the problem of checking consistency of an incomplete representation and answering queries over it. As a result we have traced a boudary between tractabilty and intractability of these problems. In particular this study allowed us to find a robust class of incomplete documents and queries that make query answering tractable.

Incomplete information can also be represented using probabilities. In addition to ordinary XML documents, a p-documents have distributional nodes that specify the possible worlds and their probabilistic distribution. Particular families of p-documents are determined by the types of distributional nodes that can be used as well as by the structural constraints on the placement of those nodes in a p-document. Some of the resulting families provide natural extensions and combinations of previously studied probabilistic XML models. The expressive

power of families of p-documents has been investigated in [15]. The evaluation of aggregate functions such as count, sum, avg, for probabilistic XML is the topic of [20]

5.2. Automata and logics for data words and data trees

Participants: Stéphane Demri, Diego Figueira, Luc Segoufin.

Dahu aim as providing tools for specifying and verifying systems with data. This means finding a suitable logical framework for specifying such systems. A logical framework is suitable if it is expressible enough for modeling the operations of interest. Of course, for the logical framework to be useful, it must come with techniques and tools for reasoning about it, in particular it should be decidable. This can be achieved by compiling the model into some form of decidable automata manipulating data. In the presence of data, the design of appropriate classes of logic and automata with interesting complexities is an on-going research task.

Most of our new results in this direction concerns data words and data trees. Those are words and trees where each position contains a data value together with the classical label. Data words and data trees can model many systems with data with a focus on one variable flow. Data trees can also model XML data.

We have studied several extensions of the classical model of logic and automata with features that could be used for manipulating data. This is done either by using registers or memory explicitly in the model or by restricting the transitions of the automata with constraints that can involve data comparisons. Several models have been considered.

As query languages such as XPath and XML schema are closely related to the two variable fragment of first-order logic, we have studied this fragment over data trees. In [16] it is shown that satisfiability for two-variable first-order logic is decidable if the tree structure can be accessed only through the child and the next sibling predicates and the access to data values is restricted to equality tests. From this main result, decidability of satisfiability and containment for a data-aware fragment of XPath and of the implication problem for unary key and inclusion constraints is concluded.

As another line of investigation, we studied a bottom-up model of computation that can test for data equality of distant nodes on different branches of the tree [26]. This model captures XPath with downward and child axes, and has an incomparable expressive power with respect to the previous mentioned approach. The model is decidable in ExpTime.

We have analyzed the computational complexity of the covering and boundedness problems for branching vector addition systems [25]. Branching vector addition systems (BVAS) form a new computational model that is used for instance in computational linguistics and for the verification of cryptographical protocols. This model has tight relationships with data logics intepreted over data trees. Recently, Verma and Goubault-Larrecq (EPI SECSI, LSV) have shown that the covering and boundedness problems for BVAS are decidable. In this work, we have extended and refined the standard proofs for vector addition systems (equivalent to Petri nets) by Rackoff (TCS, 1978) and Lipton (TR, 1976) in order to establish that the covering and boundedness problems for BVAS are 2EXPTIME-complete.

In the article [17], we have studied decidability and complexity issues for fragments of LTL with Presburger constraints obtained by restricting the syntactic resources of the formulae while preserving the strength of the logical operators. It is shown that model-checking and satisfiability problems for the fragments of LTL with difference constraints restricted to two variables and distance one and to one variable and distance two are highly undecidable, enlarging significantly the class of known undecidable fragments. On the positive side, we prove that the fragment restricted to one variable and to distance one augmented with propositional variables is PSPACE-complete.

In [34] we illustrate two aspects of automata theory related to linear-time temporal logic LTL used for the verification of computer systems. A translation from LTL formulae to Büchi automata is presented with the aim to design an elementary translation which is reasonably efficient and produces small automata. Secondly, we recall how temporal operators can be defined from regular languages and we show why adding even a single operator definable by a context-free language can lead to undecidability.

5.3. Automata theory

Participants: Florent Jacquemard, Thomas Place, Luc Segoufin, Camille Vacher.

The links between models for XML and regular tree languages has been advocated in many places. Tree automata seem to be playing for semi-structured data and XML the role of the relational algebra for relational databases. As XML is central in our research we also study tree automata and regular tree languages.

A first line of research concerns the expressive power of various subclasses of regular tree languages. It is usually admitted that a fragment is completely understood, in term of expressive power, when one has a *decidable characterization* of it. That is an algorithm that given a regular tree language, presented say as a tree automata, tests whether it belongs to the class being investigated or not. This question is an active research topic that turns out to be quite challenging. A regular tree language L is said to be locally testable if membership of a tree into L depends only on the presence or absence of some neighborhoods in the tree. In [32] we have shown that it is decidable whether a regular tree language is locally testable.

We have also considered superclasses of regular tree languages, described by tree automata with features which extend strictly standard tree automata. This is the case of Rigid Tree Automata (RTA), an extension of standard bottom-up tree automata with distinguished states called rigid. Rigid states define a restriction on the computation of RTA on trees: RTA tests for equality of subtrees reaching the same rigid state. In [30], we have studied the expressiveness of these automata and properties like determinism, pumping lemma, Boolean closure, and several decision problems. Our main result is the decidability of whether a given tree belongs to the rewrite closure of a RTA language under a restricted family of term rewriting systems, whereas this closure is not a RTA language.

We have obtained some other results concerning the transformation of tree automata languages under various kind of rewriting systems. In [28], we show that the transformation of a tree automata language obtained by application shallow rewrite rules following an innermost strategy (such strategy corresponds to the *call by value* computation of programming languages) can be recognized by a tree automaton with equality and disequality constraints between brothers. This latter class of automata is another strict extension of tree automata, with the ability to perform some tests of isomorphism between subtree during computations. We have also considered the property of unique normalization (UN), which states that, starting from any tree and applying arbitrarily transformations defined by a given set of rewrite rules, one can reach at most one normal form (one tree which cannot be transformed). Using tree automata techniques, we have studied in [29] the decidability of this property for classes of rewrite rules defined by syntactic restrictions such as linearity (variables can occur only once in each side of the rules), flatness (sides of the rules have depth at most one) and shallowness (variables occur at depth at most one in the rules).

6. Other Grants and Activities

6.1. National collaborations

Dahu is currently participating in two ANR projects:

ENUM is a research project supported by the ANR blanche on algorithmic and complexity problems raised by enumerating solutions of a query. The goal is to provide formal methods to understand and compare the complexity of enumerations problems. The partners are University of Paris-7 (with Arnaud Durand), the project-team Mostrare at INRIA-Lille (with Joachim Niehren), the university of Caen (with Etienne Grandjean) and the university of Marseille (with Nadia Creignou). Dahu is involved in the ANR as part of the Paris-7 node.

Averiss is a research project supported by the ANR SETIN (ANR-06-SETI-001-02, 2007-2009) on the development of new techniques for automatic software verification taking into account complex features of modern programming languages, including infinite data domains and procedure calls. The partners are LIAFA, University of Paris-7 (with Ahmed Bouajjani), LABRI, Bordeaux (with Igor Walukiewicz) and LSV, ENS Cachan (with Philippe Schnoebelen). Dahu is involved in this project as part of the LSV node.

6.2. International collaborations

6.2.1. Cooperation within Europe

Dahu is involved into two major grants funded by EU:

FOX FoX is a FET-Open project funded within the FP7 framework. The objective of FoX is to study the fundamental issues necessary in order to make the data management over the internet more efficient and more reliable. The partners of Dahu in FoX are Thomas Schwentick at the university of Dortmund, Mikołaj Bojańczyk at the university of Warsaw, Leonid Libkin at the university of Edinburgh, Georg Gottlob at the university of Oxford, Frank Neven at the university of Hasselt and Maarten Marx at the university of Amsterdam. The project start on May 1st and will last three year. Luc Segoufin is the coordinator of this project.

Webdam Webdam is an ERC "Advanced investigators grants" obtained by Serge Abiteboul. It started in December 2008. The goal is to develop a formal model for Web data management. This model will open new horizons for the development of the Web in a well-principled way, enhancing its functionality, performance, and reliability. Specifically, the goal is to develop a universally accepted formal framework for describing complex and flexible interactingWeb applications featuring notably data exchange, sharing, integration, querying and updating. We also propose to develop formal foundations that will enable peers to concurrently reason about global data management activities, cooperate in solving specific tasks and support services with desired quality of service.

The Webdam project is shared between the Dahu and Gemo project-teams, both from INRIA Saclay.

6.2.2. Cooperation with Tunisia

Dahu is coordinator (on the French side) of a project INRIA-DGRSRT (Tunisian universities) on "automated verification of the conformance of firewall configurations to access-control policies", since January 2008. The other partners of the project are the CASSIS team at INRIA Nancy-Grand-Est and the security team at Sup'Com Tunis. This year, DAHU has hosted in July and August the internship of Nihel Ben Youssef (PhD in Supcom Tunis). This internship has resulted in an implementation and the publication of [24].

6.2.3. Cooperation with North America

Close links also exist with UC San Diego and the database group of Victor Vianu.

7. Dissemination

7.1. Thesis

Claire David, now post-doc in Edinburgh, defended her thesis "Analyse de XML avec données non-bornées" in May 2009 [11]. The thesis was supervised by Luc Segoufin and Anca Muscholl (LaBri).

7.2. Participation in conferences organisation

Luc Segoufin is PC-chair of the Intl. Conf. on Database Theory (ICDT'10) to be held in Lausanne in 2010. Serge Abiteboul was General PC chair of the Very Large Database 2009 Conference.

Several members of the project have participated in program committees:

- S. Demri: International Conference on Mathematical Foundations of Computer Sciences (MFCS), August 2009; International Conference on Automated Reasoning with Analytic Tableaux and Related Methods (TABLEAUX), July 2009; International Symposium on Temporal Representation and Reasoning (TIME), July 2009; Workshop on Methods for Modalities (M4M), November, 2009; Worskshop on " Tableaux as Automata as Logical Decision Procedures", July 2009.
- F. Jacquemard: International Conference on RIsks and Security of Internet and Systems (CRISIS), October 2008.
- L. Segoufin: Computer Science Logic (CSL'09), ACM Principle of Database Systems (PODS'09), Foundations of Software Technology and Theoretical Computer Science (FSTTCS'09), Intl. Conf. on Database Theory (ICDT'10).
- C. Sirangelo: 12th International Conference on Extending Database Technology (EDBT), March 2009.
- B. ten Cate: ACM Principles of Database Systems (PODS 2009), Mathematical Foundations of Computer Science (MFCS 2009), Methods for Modalities (M4M 2009), Advances in Modal Logic (AiML 2010), Workshop on Logic, Language, Information and Computation (WoLLIC 2010), Foundations of Information and Knowledge Systems (FoIKS 2010), Intl. World Wide Web Conference (WWW 2010).

In May 2009 Luc Segoufin organized an international workshop in Cachan on foundation of semistructured documents.

In June 2009, Luc Segoufin organized the annual workshop of the working group "Complexité et Modèle Finis" of the GDR-IM in Cachan.

In August 2009, Serge Abiteboul organized with Pierre Senellart and Alban Galland a workshop on Brainstorming on Foundations of Web Data Management.

In July 2009, Balder ten Cate organized in Cachan a Workshop on Modal Logic.

7.3. Participation to symposia, seminars, invitations

Besides the presentations of our papers accepted to international conferences, the members of Dahu made the following keynote talks to international conferences or workshops.

Florent Jacquemard gave an invited presentation on "Rewrite based Verification of XML Updates" during the second Mini-Workshop on Rewriting Techniques, Nagoya, 2009.

Serge Abiteboul gave an invited presentation at Time'09 [19].

Balder ten Cate gave an invited presentation at Invited speaker at the Workshop on Automata and Algorithmic Logic, Stuttgart 2009.

7.4. Scientific Animations

- Stéphane Demri is a member of the steering committee of the Tableaux conference (Intl. Conf. Automated Theorem Proving with Analytic Tableaux and Related Methods).
- Stéphane Demri is member of the publication board of the review "Technique et Science Informatiques" (among 5 members).
- Florent Jacquemard is member of the board (general secretary) of the French Association for Information and Communication Systems (ASTI).
- Balder ten Cate is member of the board (secretary) of the Dutch Organization for Logic and Philosophy of the Exact Sciences (VvL).

7.5. Presentations to a larger public

S. Abiteboul participated to the Téléphone Sonne on France Inter. He published interviews or articles in Science et Vie, Le Nouvel Economiste and L'informaticien. He participated as panelist to the colloquium "Une histoire de DIM, Domaines d'Intérêt Majeur" organized par by the Île-de-France région. He had presentations at the colloquium INRIA "Web et Industrie" in Lille, at "Demain, la République du Web : une utopie ?" at La Cantine, and at "Perspectives IT pour le Codir", of the OLG Clubs, at La Vilette.

7.6. Teaching

As a Maître de conférence Cristina Sirangelo is teaching in the department of computer science of ENS de Cachan. Thomas Place and Camille Vacher are also teaching in this departement as part of their allocation couplée.

In this department Stéphane Demri has been in charge of the second-year students for 2008/2009 and is also "délégué aux thèses" in computer science for the Ecole Doctorale Sciences Pratiques (EDSP), ENS Cachan.

In the Master Parisien de Recherche en Informatique (MPRI), Florent Jacquemard is teaching in the first year (M1), a course on Tree Automata Techniques and Applications and Luc Segoufin is teaching in the first year (M1) a course on advanced complexity.

Serge Abiteboul is teaching the database course, joint between ENS Cachan and ENS Ulm. He teaches distributed data management in the CS Master at Orsay University.

7.7. Thesis jury

Luc Segoufin was a reviewer and member of the jury for the thesis of Guillaume Bagan, Université de Caen and David Duris, Université of Paris 7.

Stéphane Demri was a reviewer for the thesis of Claire David (Université Paris 7) and Sergio Mera (Universidad de Buenos Aires et Université Henri Poincaré, Nancy 1).

Serge Abiteboul was a reviewer for the habilitation of Véronique Cortier (Nancy).

8. Bibliography

Major publications by the team in recent years

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[10] B. TEN CATE, L. SEGOUFIN. *XPath, transitive closure logic, and nested tree walking automata*, in "ACM Symposium on Principles of Database Systems (PODS)", 2008, p. 251-260.

Year Publications

Doctoral Dissertations and Habilitation Theses

[11] C. DAVID. *Analyse de XML avec données non-bornées*, University of Paris VII, 2009, Ph. D. Thesis.

Articles in International Peer-Reviewed Journal

[12] S. ABITEBOUL, L. SEGOUFIN, V. VIANU. *Modeling and Verifying Active XML Artifacts*, in "IEEE Data Eng. Bull.", vol. 32, n^{o} 3, 2009, p. 10-15 US .

[13] S. ABITEBOUL, L. SEGOUFIN, V. VIANU. *Static Analysis of Active XML Services*, in "ACM trans. on Database Systems (TODS)", vol. 34, n^{o} 4, 2009 US .

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