LogicA team

Logics and Applications

Rennes

Activity Report
2016

1 Team

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2 Overall Objectives

2.1 Overview

Many of our activities which were in the past performed in the physical world and in interaction with other humans, are nowadays carried out in a digital world in interaction with both human and non-human ‘agents’: classic examples are e-commerce, e-voting, e-banking, e-government, etc. This transposition of some of our activities into the digital world already plays an important role in our everyday life. This transposition is expected to develop in the future, which is certainly desirable in order to harmonize the rate at which our society evolves. This large picture exhibits an urgent need for both taming already existing e-activities and assisting the birth of new ones.

Existing e-activities, such as e-voting, e-commerce, e-banking, e-government etc. rely on a combination of numerous technologies either at the physical/hardware level or at the digital/software one. The nature of interaction between different services that form the whole application is very complex and leads to critical issues regarding its quality that the research community together with industry try to resolve.

Among the main issues, we can mention privacy, legal process, correction of the functionalities. Also, the growing development of applications to support e-activities urges the designers to elaborate methodologies that would allow them to exploit adaptability or re-usability of existing services. Whichever issue can be picked, rigorous settings are required in order to make evidence of the correctness, the quality, the robustness, etc. of the existing products. Moreover, some sectors of activity are currently far from being computerized or even computer-assisted: typically, legal processes, abilities to remote control some domestic processes such as closing roller blinds when a storm is forecast, and so on.

All in all, not only existing e-activities need to be coupled with meticulous development methodologies, but also accurate approaches need being set up to design new e-activities that support underdeveloped domains currently operated by hand. To that end, important efforts are required to bring out the capabilities to rigorously analyze or design the functionalities[1] of services in e-activities.

The LogicA project aims at contributing to this will, by focusing on interaction issues in e-activities with a logical-based perspective. The project will develop foundations, transfer to practical applications, and convey the tight coupling between research and education.

One of the most challenging feature in e-activities analysis is the ability to "predict/control" the interaction between the numerous involved entities. These entities can be artificial (software agents, distributed systems components) or human (users). As a first step, the project will focus on artificial entities, which are, ideally, designed to act *autonomously* on the behalf of users, *e.g.* for negotiating in an e-commerce activity. These entities are called *software agents*, and they gather into *multi-agent system (MAS)*.

Since MAS are central objects, they need to be preliminary well understood at a mathematical level. The theories that will support their use in practical applications should give rise to different techniques, ranging from the ability to guarantee and certify before their deployment that they will behave properly (verification) to the ability of automatically generating skeletons of MAS (synthesis) or of coordination mechanisms between MAS (control/orchestration/choregraphy/communication).

Whereas successful logic-based techniques in computer science already exist for verification, synthesis and control, it is not clear yet how to transfer this know-how to the paradigm of MAS where interaction is central. Investigations to formally *reason about* and *infer properties of* interacting agents is currently a very active topic in computer science, which actually originates with, *e.g.* artificial intelligence and game theory. The LogicA project aims at cross-fertilizing logic-based techniques from verification in computer science, synthesis in discrete-event control theory, agency in artificial intelligence, concepts and solution concepts in game theory, and interaction concepts in philosophy. In particular, what typically differentiates the MAS framework from its pairs is the inherent information change/exchange in its dynamics, which gives evidence of, *e.g.* epistemic, strategic and normative features to be taken into account.

[1] in terms of what an application offers to its users

2.2 Key Issues

The LogicA project follows three main research lines.

Epistemic logics and logics of information change When agent interaction issues are concerned, ability to reason about knowledge is central. To this aim, epistemic logic has been extensively studied [FHMV95], and recent extensions that take dynamics into account draw the attention of a growing community of logicians and computer scientists (see for instance the very much cited book [vvK08] and the recent ERC grant on epistemic protocols coordinated by Hans van Ditmarsch (DR CNRS, LORIA). The LogicA project explores variants of epistemic logic that can easily mix with time, in order to reason about information change along time. As mixing knowledge and time easily yields to high complexity and even undecidability [HV89], the challenge is to identify settings where the formalism would enjoy good computational features while being expressive enough to capture useful properties.

Strategic reasoning and automata-theoretic approaches Modeling strategic abilities is central for reasoning about MAS. We plan to carry on with logical formalism that were already proved or are currently foreseen as powerful approaches in many exciting domains, including software tools for information system security, robot teams with sophisticated adaptive strategies, and automatic players capable of beating expert human adversary, just to cite a few. All these examples share the challenge of developing novel theories and tools for agent-based reasoning that take into account the likely behavior of "adversaries".

The natural setting for strategic reasoning is not surprisingly the one of multi-player games with imperfect information. Although discouraging results from the literature shows that three-player games with safety objectives are undecidable [PRA01], there are however promising results which show that some classes may be manageable. Basically, undecidability comes from the ability for some players to form a coalition: the resulting binary indistinguishability relation of the coalition would correspond to the intersection of the relations of its respective members. Now, it is well-known that intersection of binary relations yields more complex relations that may exit decidable classes (e.g. for membership or emptiness), like e.g., rational relations. Note that such phenomenon cannot arise in two-player games where safety objectives can be solved by a simple (although costly) power-set construction [Rei84]. Also, undecidability becomes even "stronger" when dealing with more realistic objectives for epistemic properties, such as seeking a strategy of agent A such eventuallty "agent B does know Property P until agent C knows it".

The LogicA group contributes in the development of logics that make a trade-off between expressiveness and decidability/tractability.

[FHMV95] R. Fagin, J. Halpern, Y. Moses, M. Vardi, *Reasoning about knowledge*, MIT Press, 1995.

[vvK08] H. van Ditmarsch, W. van der Hoek, B. Kooi, *Dynamic Epistemic Logic*, Springer, Dordecht, 2008.

[HV89] J. Y. Halpern, M. Y. Vardi, "The complexity of reasoning about knowledge and time. 1. Lower bounds", *Journal of Computer and System Sciences 38*, 1, 1989, p. 195–237.

[PRA01] G. Peterson, J. Reif, S. Azhar, "Lower bounds for multiplayer noncooperative games of incomplete information", *Computers & Mathematics with Applications 41*, 7, 2001, p. 957–992.

[Rei84] J. H. Reif, "The complexity of two-player games of incomplete information", *Journal of computer and system sciences 29*, 2, 1984, p. 274–301.

Formal approaches for the design of attack trees Whether it is physical security, environmental security, or information technology environments, ensuring security requires preliminary investigations to identify and evaluate risks that threaten the system under consideration. This is what the *risk analysis* [ISO05,ISO13,Sch07] discipline is about.

While many approaches to risk assessment and analysis exist, and the methodologies differ from country to country, from industry to academia, and from organization to organization, some security modelling approaches applied in risk analysis are being adopted across these boundaries. For example, the 2008 NATO Improving Common Security Risk Analysis report [RR08] and the 2013 OWASP CISO Application Security Guide [OWA13] recommend the use of *attack trees* to handle the threat assessment task. DARPA has applied attack trees in their Information Assurance live experiments [Lev03,KB01]. Recently, an excellent state-of-art survey by Kordy et al. [KPCS14] has shown that attack trees have been extensively studied by the scientific community and are widely accepted within the industry.

Indeed, attack trees [Sch99] provide a systematic way of describing the vulnerability of a system, taking various types of attacks into account. Strengths of attack trees combine two aspects: first, an *intuitive representation of possible attacks* and second, *formal mathematical frameworks for analyzing them* in a qualitative or a quantitative manner [MO06,KMRS14].

This research line contributes to the development of mathematical foundations for attack trees and of a tool to assist security experts in their design.

[ISO05] ISO, Geneva, Switzerland, *Norm ISO/IEC 27002 - Information Technology - Security Techniques - Code of Practice for Information Security Management*, edition ISO/IEC 27002:2005, 2005, Section 9.

[ISO13] ISO, Geneva, Switzerland, *Norm ISO/IEC 27002 2013 - Information Technology - Security Techniques - Code of Practice for Information Security Management*, edition ISO/IEC 27002:2013, 2013, Section 11 "Physical Security Management".

[Sch07] E. E. Schultz, “Risks due to the Convergence of Physical Security and Information Technology Environments”, *Inf. Secur. Tech. Rep. 12*, 2007, p. 80–84.

[RR08] N. Research, T. O. (RTO), “Improving Common Security Risk Analysis”, *research report number AC/323(ISP-049)TP/193*, North Atlantic Treaty Organisation, University of California, Berkeley, 2008.

[OWA13] OWASP, “CISO AppSec Guide: Criteria for Managing Application Security Risks”, 2013.

[Lev03] D. Levin, “Lessons Learned in Using Live Red Teams in IA Experiments”, *in: 3rd DARPA Information Survivability Conference and Exposition (DISCEX-III 2003)*, p. 110–119, 2003.

[KB01] D. L. Kewley, J. F. Bouchard, “DARPA Information Assurance Program dynamic defense experiment summary”, *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on 31*, 4, 2001, p. 331–336.

[KPCS14] B. Kordy, L. Piètre-Cambacédès, P. Schweitzer, “DAG-Based Attack and Defense Modeling: Don’t Miss the Forest for the Attack Trees”, *Computer Science Review*, 2014, DOI: 10.1016/j.cosrev.2014.07.001.

[Sch99] B. Schneier, “Attack Trees”, *Dr. Dobb’s Journal of Software Tools 24*, 12, 1999, p. 21–29, http://www.ddj.com/security/184414879.

[MO06] S. Mauw, M. Oostdijk, “Foundations of Attack Trees”, *in: ICISC’05*, D. Won, S. Kim (editors), *LNCS, 3935*, Springer, p. 186–198, 2006, http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.97.1056.

[KMRS14] B. Kordy, S. Mauw, S. Radomirović, P. Schweitzer, “Attack–Defense Trees”, *Journal of Logic and Computation 24*, 1, 2014, p. 55–87.

3 Scientific Foundations

3.1 Epistemic planning and epistemic protocol synthesis

Participants: Sophie Pinchinat, François Schwarzentruber.

Planning is the process of organizing activities required to achieve a desired goal. In the "classical" planning community [GNT04], planning under uncertainty and with multiple agents is acknowledged to be a real challenge. It has been shown that the Dynamic Epistemic Logic framework [vvK08] is a good setting to address planning for goals that may involve agents' knowledge, and even agents' knowledge about other agents' knowledge, etc. [BA11]. The approach is promising with applications to, e.g., privacy issues stemming from the growing use of social networks (for example, we may want to achieve some task while being sure that some adversary will never come to *know* a sensitive fact/information). We were able to pinpoint a smaller class of instances where the epistemic planning is already undecidable while exhibiting classes where it is decidable [24].

3.2 Grounded semantics for epistemic reasoning

Participants: Tristan Charrier, François Schwarzentruber.

Nowadays, the behavior of artificial agents is mostly described by low-level imperative languages, whereas the use of knowledge programs [FHMV95], which are based on logic, is very little developed and yet could offer high-level descriptions together with clean analysis tools.

But, the semantics of epistemic logic is given in terms of Kripke models and it is unclear how to design Kripke models corresponding to a given application. We defined grounded semantics, that is to say, we defined specific Kripke models for different applicative contexts, that could be camera surveillance, programming drone systems, video games, etc.

We developped a logic for reasoning about knowledge of autonomous cameras [36]. We also developped a framework where visibility constraints between agents and elements of the environment can be desribed [23].

3.3 Strategic reasoning and automata-theoretic approaches

Participants: Sophie Pinchinat, François Schwarzentruber.

Recently, the AI and Formal Methods communities moved closer because of the intrinsic similarity between multi-player games with imperfect information and MAS. Since then, attention has been paid on extensions of game-like settings to objectives intrinsically mixing knowl-

[GNT04] M. Ghallab, D. Nau, P. Traverso, *Automated Planning: Theory & Practice*, Morgan Kaufmann, San Francisco, 2004.

[vvK08] H. van Ditmarsch, W. van der Hoek, B. Kooi, *Dynamic Epistemic Logic*, Springer, Dordecht, 2008.

[BA11] T. Bolander, M. B. Andersen, "Epistemic planning for single- and multi-agent systems", *Journal of Applied Non-Classical Logics 21*, 1, 2011, p. 9–34.

[FHMV95] R. Fagin, J. Halpern, Y. Moses, M. Vardi, *Reasoning about knowledge*, MIT Press, 1995.

edge and time[2], in order to be able to express, e.g. *opacity properties* in software security such as "Defender has a strategy so that Intruder never knows information I" [59, 57],[DDM10,MY13]. Note that, works on designing logics to feature both knowledge and time has been investigated long ago, with a very natural combination of temporal logics and epistemic logic [HV89,HvdMV04]. Handling these logics (model-checking or synthesis) already proved to be difficult, quickly yielding undecidability [HV89,vdMS99,Dim11]. The critical point lies in the interplay of two "orthogonal" fixed-points modalities when agents' perception ability on the actual system evolution is not bound, e.g. *perfect recall* or *imperfect* (but unbounded) *recall* [vdMS99]; basically, the perception abilities of agents can range from *perfect recall* to *memoryless* and include *imperfect recall.*

The most natural way to incorporate knowledge/agent's perception into logics for strategic reasoning is achieved by adding epistemic modalities into alternating-time logic [vdHW03,Sch04,JÅ06,Dim09]. Still, merging perception and strategic abilities of agents can take different paths, as the two are not independent: the strategic abilities of agents should not overstep their perception abilities, in the sens that strategies should be defined at a level of abstraction at least equal to the level of what agent perceive from the actual situation: for example, if an agent does not recall the past, its strategies should be memoryless. Some pioneer papers put aside, this dependency is now well understood. Many frameworks lead to undecidability [Dim09]. There are however results relying on strong restrictions on the agents' perception (and thus on their strategic abilities), such as the obvious memoryless perception assumption [vdHW03,JÅ06,BJL11], or very particular imperfect recall [Sch04], but The complete understanding of the landscape is not achieved yet.

[2]even if not told this way

[DDM10] J. Dubreil, P. Darondeau, H. Marchand, "Supervisory control for opacity", *Automatic Control, IEEE Transactions on 55*, 5, 2010, p. 1089–1100.

[MY13] J. Mullins, M. Yeddes, "Opacity with Orwellian Observers and Intransitive Non-interference", *arXiv preprint arXiv:1312.6426*, 2013.

[HV89] J. Y. Halpern, M. Y. Vardi, "The complexity of reasoning about knowledge and time. 1. Lower bounds", *Journal of Computer and System Sciences 38*, 1, 1989, p. 195–237.

[HvdMV04] J. Y. Halpern, R. van der Meyden, M. Y. Vardi, "Complete Axiomatizations for Reasoning about Knowledge and Time", *SIAM J. Comput. 33*, 3, 2004, p. 674–703.

[vdMS99] R. van der Meyden, N. V. Shilov, "Model Checking Knowledge and Time in Systems with Perfect Recall (Extended Abstract)", *in: FSTTCS*, C. P. Rangan, V. Raman, R. Ramanujam (editors), *Lecture Notes in Computer Science*, *1738*, Springer, p. 432–445, 1999.

[Dim11] C. Dima, "Non-axiomatizability for the linear temporal logic of knowledge with concrete observability", *J. Log. Comput. 21*, 6, 2011, p. 939–958.

[vdHW03] W. van der Hoek, M. Wooldridge, "Cooperation, knowledge, and time: Alternating-time temporal epistemic logic and its applications", *Studia Logica 75*, 1, 2003, p. 125–157.

[Sch04] P.-Y. Schobbens, "Alternating-time logic with imperfect recall", *Electronic Notes in Theoretical Computer Science 85*, 2, 2004, p. 82–93.

[JÅ06] W. Jamroga, T. Ågotnes, "What agents can achieve under incomplete information", *in: Proceedings of the fifth international joint conference on Autonomous agents and multiagent systems*, ACM, p. 232–234, 2006.

[Dim09] C. Dima, "Revisiting satisfiability and model-checking for CTLK with synchrony and perfect recall", *in: Computational Logic in Multi-Agent Systems*, Springer, 2009, p. 117–131.

[BJL11] F. Belardinelli, A. V. Jones, A. Lomuscio, "Model Checking Temporal-Epistemic Logic Using Alternating Tree Automata", *Fundam. Inform. 112*, 1, 2011, p. 19–37.

Automata are wonderful mathematical tools, tightly coupled to logic, in order to represent sets of models. They offer computational facilities and often reveal intuitive algorithms to handle specifications. For example, tree automata [Tho97,FGW07] denote sets of infinite trees, widely needed in verification to representation branching-time system executions. It is well known that tree automata equipped with the parity condition capture the expressive class of ω-regular tree languages, with the highly expressive propositional μ-calculus logic in the background [EJ91,AN01,GTW02].

Other approaches have been considered to combine knowledge, time and strategies. A fairly old one originates from the control theory of discrete-event systems, from the point of view of (controllers') strategic abilities only. Controllers are seen as state-transition devices, and such devices can be subject to structural constraints, such as looping e-transitions in every state to capture unobservability of event e by the device, or many variants of such constraints [Bri06b]. Structural constraints can be specified by extending temporal logics with a new atomic propositions to express, e.g. existence of looping transitions. The resulting logics, although no more bisimulation invariant, still has automata counterparts [AVW03]. Such automata can be used to synthesize controllers by *automata quotient techniques* [AVW03,PR05,Bri06b,Bri06a]. Note that these approaches cannot address epistemic features in the control objectives.

We defend the idea that an automata-theoretic approaches is a promising track. For instance, we have started to identify classes solvable multi-player games with imperfect information allowing for epistemic objectives with a focus on the theoretical properties of agents' indistinguishable binary relation along plays [61, 58]. The starting point are rational binary relations. For example, we have shown that if binary relations are restricted to *recognizable*, objectives that mix knowledge and time with classic CTL* operators can be solved. These results stem from our pioneer studies on *uniform strategies* [62], which reveal very powerful and whose study should be pursued, as shown below.

Also, in our attempt to find clean mathematical settings to combine knowledge and time, one may think of an enrichment of the class of tree automata, in such a way that those devices

[Tho97] W. Thomas, "Languages, Automata, and Logic", *in: Handbook of Formal Language Theory, III*, Springer, 1997, p. 389–455.

[FGW07] J. Flum, E. Grädel, T. Wilke, *Logic and Automata: History and Perspectives*, Amsterdam University Press, 2007.

[EJ91] E. A. Emerson, C. S. Jutla, "Tree Automata, Mu-Calculus and Determinacy", *in: Proceedings 32nd Annual IEEE Symp. on Foundations of Computer Science, FOCS'91, San Jose, Puerto Rico, 1–4 Oct 1991*, IEEE Computer Society Press, Los Alamitos, California, 1991, p. 368–377.

[AN01] A. Arnold, D. Niwiński, *Rudiments of μ-calculus*, *Studies in Logic and the Foundations of Mathematics*, *146*, North-Holland, 2001.

[GTW02] E. Grädel, W. Thomas, T. Wilke (editors), *Automata, Logics, and Infinite Games*, *LNCS*, *2500*, Springer, 2002.

[Bri06b] X. Briand, *Sur la décidabilité de certains problèmes de synthèse de contrôleurs*, PdD Thesis, Université de Bordeaux I, June 2006.

[AVW03] A. Arnold, A. Vincent, I. Walukiewicz, "Games for synthesis of controllers with partial observation", *Theoretical Computer Science 1*, 303, 2003, p. 7–34.

[PR05] S. Pinchinat, S. Riedweg, "A decidable class of problems for control under partial observation.", *Inf. Process. Lett. 95*, 4, 2005, p. 454–460.

[Bri06a] X. Briand, "Dynamic Control with Indistinguishable Events.", *Discrete Event Dynamic Systems 16*, 3, September 2006.

can check properties not only in a given node of tree but also in "related" nodes, where the relation reflects the possible words for a given agent. This amounts to allowing the automata to make jumps between different branches of the tree. Recently, we have developed a class of such devices called *jumping tree automata (JTA)* [61] which permit to consider agents whose distinguishing inabilities are *rational relations*. JTA are promising objects. Even though their language emptiness is undecidable in general, they may enjoy several good properties when. e.g. restricting to *recognizable* relations.

These results have been stabilized in journal versions [?] and have successfully applied the theory to Epistemic Protocole Synthesis [3].

Relying on the idea of considering binary path relations, we have proposed an extension of two yardstick logics, namelly the *jumping μ-calculus* and the *Monadic Second-order Logic*, known to coincide [JW96] when the latter is restricted the latter to the bisimulation invariant fragment. This extension leads to the *jumping μ-calculus* and to the *Monadic Second-order Logic with path relation* respectively.

The jumping μ-calculus happens to be the logical counterpart of the JTA, and the relationship with Monadic Second-order Logic with path relation turns out to be a complexe question depending on the kind of path relation ones considers [32, 33].

3.4 Formal approaches for the design of attack trees

Participant: Maxime Audinot, Sophie Pinchinat.

In order to make attack trees more concrete objects, we consider the famous Stuxnet attack. In June 2010, a complex computer worm was discovered, which effectively disabled Iran's nuclear program for more than a year. Later this worm was given the name Stuxnet. It is suspected that the worm initially propagated from thumb drives that were carried by personnel from one computer to another. For almost 17 months, Stuxnet targeted a specific Siemens centrifuge control component to moderate the speed at which the nuclear facilities' centrifuges rotated in order to damage, but not destroy them [Bar10].

Figure 1 shows an attack tree that describes a part of the Stuxnet attack [FMC11,MRHM10], inspired by a model proposed in [KBPC12][3].

[3] The standard is to depict trees upside down with the root at the top.

[JW96] D. Janin, I. Walukiewicz, "Results on the expressive completeness of the propositionnal mu-calculus with respect to monadic second order logic", *in: Concurrency Theory, 7th International Conference*, *lncs*, *1119*, Springer, p. 263–277, Pisa, Italy, August 1996.

[Bar10] E. Barnes, "Mystery surrounds cyber missile that crippled Iran's nuclear weapons ambitions", *Fox News 26*, 2010.

[FMC11] N. Falliere, L. Murchu, E. Chien, "W32. Stuxnet Dossier, v1. 4", *White paper, Symantec Corp., Security Responsen*, 2011.

[MRHM10] A. Matrosov, E. Rodionov, D. Harley, J. Malcho, "Stuxnet under the microscope", *ESET LLC (September 2010)*, 2010.

[KBPC12] S. Kriaa, M. Bouissou, L. Piètre-Cambacédès, "Modeling the Stuxnet attack with BDMP: Towards more formal risk assessments", *in: Risk and Security of Internet and Systems (CRiSIS), 2012 7th International Conference on*, IEEE, p. 1–8, 2012.

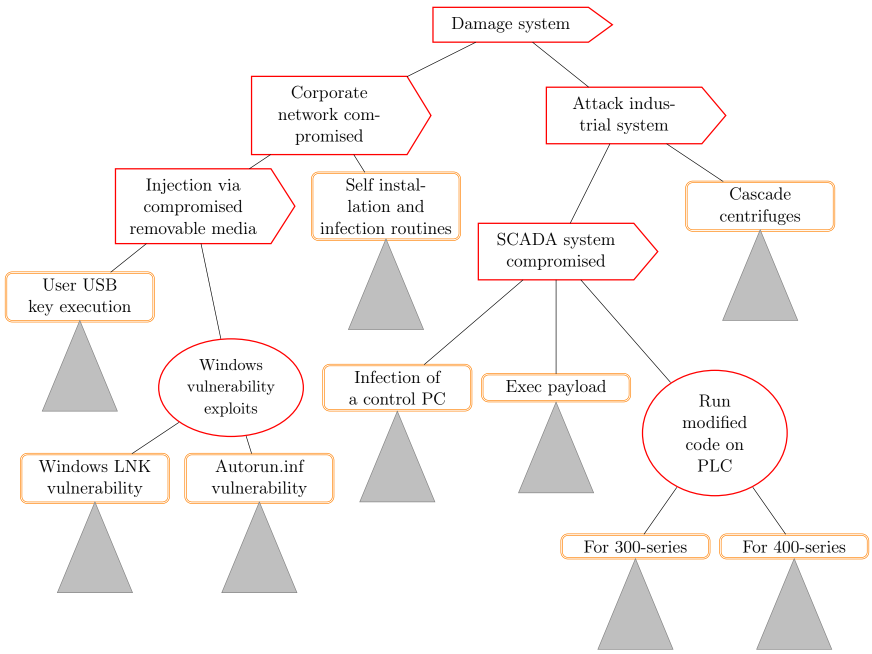

Figure 1: An attack tree describing the Stuxnet attack.

Each internal node of the tree denotes a higher-level goals, and is typed according to how its children relate to each other. Originally, types were of two kinds: so-called "*or*" nodes and "*and*" nodes, with the intuitive meanings that the children are alternatives to refine the current goal, and that all children need being achieved to refine the current goal, respectively. More recently, the type "*sequential*" has attracted the attention of designers as a legitimate way of combining sub-goals in a fixed order, as opposed to the type "*and*", which features a combination of sub-goals in a parallel manner [JKM+15,PAV14,AGKS15]. "Terminal" nodes, the leaves, can be understood as primitive goals that can be called *actions*, which will be analyzed later on in terms of their feasibility.

The upper part of the tree depicted in Figure 1 results from a manual design. Internal nodes typed "or" and "sequential" are shaped as red circles and red rightward-pointing rectangles, respectively. No "and" nodes are used in this example; they would be shaped as red rectangles. "Terminal" nodes are shaped as orange doubled-rounded-corner rectangles. With an ideal assistant, the expert can further launch an automated generation tool to complete the trees below terminal nodes (grey triangles below terminal nodes in the picture).

[JKM+15] R. Jhawar, B. Kordy, S. Mauw, S. Radomirovic, R. Trujillo-Rasua, "Attack Trees with Sequential Conjunction", *in: IFIP SEC 2015, IFIP AICT, 455*, Springer, p. 339–353, 2015.

[PAV14] S. Pinchinat, M. Acher, D. Vojtisek, "Towards Synthesis of Attack Trees for Supporting Computer-Aided Risk Analysis", *in: Workshop on Formal Methods in the Development of Software (co-located with SEFM)*, Grenoble, France, sep 2014, `http://hal.inria.fr/hal-01064645`.

[AGKS15] F. Arnold, D. Guck, R. Kumar, M. Stoelinga, "Sequential and Parallel Attack Tree Modelling", *in: Proc. of SAFECOMP and Workshops*, p. 291–299, 2015.

An attack tree, whether obtained manually or automatically, can be understood as a structured summary of possible courses of actions that achieve the attack objective: each course of actions results from pruning the tree by selecting a single child of each "or" node, and by visiting the leaves of this pruned tree from left to right. In Figure 1, the visible part of the attack tree denotes four attack scenarios, among which the sequence of actions: *"User USB key execution"."Autorun.inf vulnerability"."Self-installation and infection routines"."Infection of a control PC"."Exec payload"."For 300-series"."Cascade centrifuges"*.

Traditionally, analysts and technicians construct attack trees manually, based on their knowledge and experience. This (manual) construction mostly relies on the ability of experts to imagine attack scenarios in the top-down manner, starting from very abstract goals iteratively refined as combinations of sub-goals.

A large number of tools for editing attack trees and analyzing them for quantitative aspects (such as the fastest attack, the one with higher probability, etc.) exist [Iso,Ame12,Mel10,KKMS13]. Regrettably, manual design of attack trees turns out to be time-consuming and error-prone, especially if the size of the attack tree becomes substantial. Indeed, attack trees drawn for a reasonably large system commonly have thousands of nodes. Furthermore, it is known that manual tree design is often incomplete and/or unsound w.r.t. the security issues of the system under consideration, and, to our knowledge, there is very little known scientific foundations that target these concerns.

As a consequence, automated generation of attack trees currently attracts the attention of both researchers and industry practitioners [VNN14,Pau14,HKT13,TRE16], [66, 67, 7]. Indeed, supported by automation, practitioners can avoid the tedious manual design of large parts, if not all, of attack trees. Moreover an automated process can be relaunched if, e.g. the system evolves, with a minimal cost of effort.

[Iso] Isograph, "AttackTree+", `http://www.isograph-software.com/2011/software/attacktree/`.

[Ame12] Amenaza, "SecurITree", `http://www.amenaza.com/`, 2001–2012.

[Mel10] P. H. Meland, "SeaMonster", `https://sourceforge.net/projects/seamonster/`, 2010.

[KKMS13] B. Kordy, P. Kordy, S. Mauw, P. Schweitzer, "ADTool: Security Analysis with Attack–Defense Trees", *in: QEST*, K. R. Joshi, M. Siegle, M. Stoelinga, P. R. D'Argenio (editors), *LNCS*, *8054*, Springer, p. 173–176, 2013.

[VNN14] R. Vigo, F. Nielson, H. R. Nielson., "Automated Generation of Attack Trees", *in: CSF'14*, IEEE, 2014.

[Pau14] S. Paul, "Towards Automating the Construction & Maintenance of Attack Trees: a Feasibility Study", *in: GraMSec*, B. Kordy, S. Mauw, W. Pieters (editors), *EPTCS*, *148*, p. 31–46, 2014.

[HKT13] J. B. Hong, D. S. Kim, T. Takaoka, "Scalable Attack Representation Model Using Logic Reduction Techniques", *12th IEEE International Conference on Trust, Security and Privacy in Computing and Communications*, 2013, p. 404–411.

[TRE16] TREsPASS, "Technology-supported Risk Estimation by Predictive Assessment of Socio-technical Security, FP7 project, grant agreement 318003", 2012–2016, `http://www.trespass-project.eu/`.

4 Application Domains

4.1 Prototyping for physical security

Participants: Maxime Audinot, Sophie Pinchinat.

Risk Analysis is a discipline consisting in identifying and evaluating risks that threaten a given system in order to reduce or annihilate them by defining actions to engage (risk management). Such analysis is central when the aim is to ensure the security of an information system means guaranteeing data availability, integrity and confidentiality.

Current methods follow mostly a common methodology: one decomposes the system to analyze into subsystems and produces a model, then one draws up a list of feared events, and finally determines the potential reasons of their emergence.

For the particular case of risk analysis in physical security, these steps are mostly processed by hand, based on knowledge and experiences of analysts and technicians. In order to match the standards of experts in risk analysis, the whole process is conducted in two steps:

Step 1 One produces an *attack/defense tree*, that is a tree-like structure where one easily reads the attacker's abilities to achieve her attack and the weaknesses of the defender's capabilities to counter them. The attack/defense tree levels describe successful attacks at different level of abstraction. The attack/defense tree is meant to describe all successful attacks, independently of their realism due to intrinsic cost of their application.

Step 2 The attack/defense tree obtained in Step 1 is reworked to incorporate cost features on actions and then exploited to reveal the more realistic scenarios.

We develop an entire tool-supported methodology to help security experts in prototyping secure sites on the basis of attack/defense trees.

4.2 Cour de Cassation project

Participants: François Schwarzentruber.

This project was a collaboration with Cour de Cassation, with a very modest objective which at a first glance does not fall into the main scientific objectives of the LogicA project. However, our will to promote logical approaches for societal concerns is strong.

The Cour de Cassation is aware of the following problem: judges have to handle legal cases that are not frequent. Such a legal case may be the following one: contest the union's representational capacity. It is really difficult for a judge to acquire all the experience in solving such legal cases. Up to now, writing judgments for such legal cases is done manually with the help of documents explaining how to write them. In this subsection, we refer to these documents as the how-to documents.

The Cour de Cassation expressed the need to develop a computer-aided judgment writer. This software should analyze the reasoning process made by the judge, assist him/her in his/her decisions. Meanwhile, the software generates the text of the judgment.

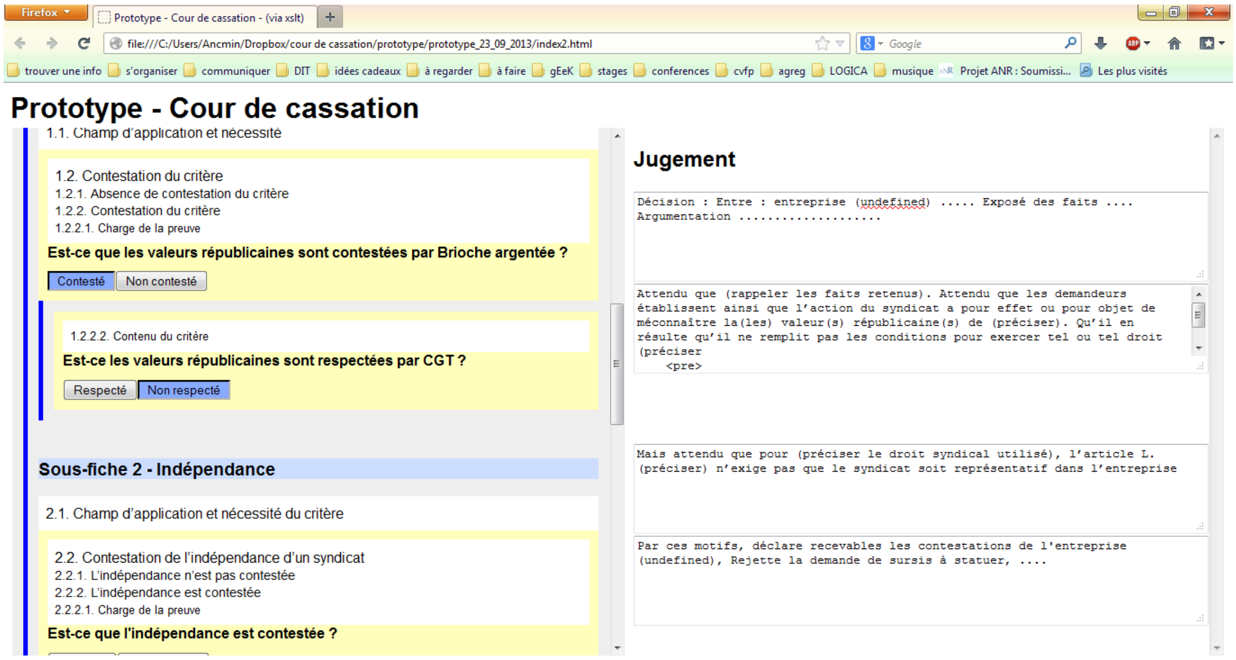

Figure 2: The Cour de Cassation software

We implemented a software that takes as an input a how-to document and proposes a graphical interface for producing judgments. The internal representation is based on binary decision diagrams.

5 New Results

5.1 On the Impact of Modal Depth in Epistemic Planning

Participants: Tristan Charrier, François Schwarzentruber.

Epistemic planning is a variant of automated planning in the framework of dynamic epistemic logic. In recent works, the epistemic planning problem has been proved to be undecidable when preconditions of events can be epistemic formulas of arbitrary modal depth. It is known however that when preconditions are propositional (and there are no postconditions), the problem is between PSPACE and EXPSPACE. In this work we bring two new pieces to the picture. First, we prove that the epistemic planning problem with propositional preconditions and without postconditions is in PSPACE, and is thus PSPACE-complete. Second, we prove that very simple epistemic preconditions are enough to make the epistemic planning problem undecidable: preconditions of modal depth at most two suffice.

This work has been published in [24].

5.2 Big Brother Logic: visual-epistemic reasoning in stationary multi-agent systems

Participants: Tristan Charrier, François Schwarzentruber.

We consider multi-agent scenarios where each agent controls a surveillance camera in the plane, with fixed position and angle of vision, but rotating freely. The agents can thus observe the surroundings and each other. They can also reason about each other's observation abilities and knowledge derived from these observations. We introduce suitable logical languages for reasoning about such scenarios which involve atomic formulae stating what agents can see, multi-agent epistemic operators for individual, distributed and common knowledge, as well as dynamic operators reflecting the ability of cameras to turn around in order to reach positions satisfying formulae in the language. We also consider effects of public announcements. We introduce several different but equivalent versions of the semantics for these languages, discuss their expressiveness and provide translations in PDL style. Using these translations we develop algorithms and obtain complexity results for model checking and satisfiability testing for the basic logic BBL that we introduce here and for some of its extensions. Notably, we show that even for the extension with common knowledge, model checking and satisfiability testing remain in PSPACE. We also discuss the sensitivity of the set of validities to the admissible angles of vision of the agents' cameras. Finally, we discuss some further extensions: adding obstacles, positioning the cameras in 3D or enabling them to change positions. Our work has potential applications to automated reasoning, formal specification and verification of observational abilities and knowledge of multi-robot systems.

This work has been published in [36].

5.3 Epistemic Boolean Games Based on a Logic of Visibility and Control

Participants: François Schwarzentruber.

We analyse epistemic boolean games in a computationally grounded dynamic epistemic logic. The agents' knowledge is determined by what they see, including higher-order visibility: agents may observe whether another agent observes an atom or not. The agents' actions consist in modifying the truth values of atoms. We provide an axiomatisation of the logic, establish that the model checking problem is in PSpace, and show how one can reason about equilibria in epistemic boolean games.

This work has been published in [44].

5.4 A Tool for Generating Interactive Euler Diagrams (demo)

Participants: François Schwarzentruber.

We describe a tool for generating Euler diagrams from a set of region connection calculus formulas. The generation is based on a variant of local search capturing default reasoning for improving aesthetic appearance of Euler diagrams. We also describe an optimization for diagrams to be interactive: the user can modify the diagram with the mouse while formulas are still satisfied. We also discuss how such a tool may propose new relevant formulas to add to the specification using an approximation algorithm based on the satisfiability of Horn clauses.

This work has been published in [78].

5.5 Announcements to Attentive Agents

Participants: François Schwarzentruber.

In public announcement logic it is assumed that all agents pay attention to the announcement. Weaker observational conditions can be modelled in action model logic. In this work, we propose a version of public announcement logic wherein it is encoded in the states of the epistemic model which agents pay attention to the announcement. This logic is called attention-based announcement logic. We give an axiomatization of the logic and prove that complexity of satisfiability is the same as that of public announcement logic, and therefore lower than that of action model logic. An attention-based announcement can also be described as an action model. We extend our logic by integrating attention change. Finally, we add the notion of common belief to the language, we exploit this to formalize the concept of joint attention, that has been widely discussed in the philosophical and cognitive science literature, and we provide a corresponding axiomatization. This axiomatization also employs the auxiliary notion of attention-based relativized common belief.

This work has been published in [12].

5.6 Building Epistemic Logic from Observations and Public Announcements

Participants: Tristan Charrier, François Schwarzentruber.

We study an epistemic logic where knowledge is built from what the agents observe (including higher-order visibility) and what the agents learn from public announcements. This fixes two main drawbacks of previous observability-based approaches where who sees what is common knowledge and where the epistemic operators distribute over disjunction. The latter forbids the modeling of most of the classical epistemic problems, starting with the muddy children puzzle. We integrate a dynamic dimension where both facts of the world and the agents' observability can be modified by assignment programs. We establish that the model checking problem is PSpace-complete.

This work has been published in [23].

5.7 Relating Paths in Transition Systems: the Fall of the Modal mu-Calculus

Participants: Sophie Pinchinat.

We revisit Janin and Walukiewicz's classic result on the expressive completeness of the modal mu-calculus w.r.t. MSOL, when transition systems are equipped with a binary relation over paths. We obtain two natural extensions of MSOL and the mu-calculus: *MSOL with path relation* and the *jumping mu-calculus*. While "bounded-memory" binary relations bring about no extra expressivity to either of the two logics, “unbounded-memory” binary relations make the bisimulation-invariant fragment of MSOL with path relation more expressive than the jumping mu-calculus: the existence of winning strategies in games with imperfect-information. This work has been published in [33].

5.8 On the Soundness of Attack Trees

Participants: Sophie Pinchinat, Maxime Audinot.

We formally define three notions of soundness of an attack tree w.r.t. the system it refers to: *admissibility*, *consistency*, and *completeness*. The system is modeled as a labeled transition system and the attack is provided with semantics in terms of paths of the transition system. We show complexity results on the three notions of soundness, and the influence of the operators that are in the attack tree.

This work has been published in [7].

6 Contracts and Grants with Industry

6.1 French Ministry of Defense on Physical Security

Participants: Maxime Audinot, Sophie Pinchinat.

The project is a collaboration with the French Defense Ministry for physical security. The goal of this project (2015-2018) is to develop assistant tools for the design of attack/defense tree, given a specification of a building and some critical resource to protect from attacks (e.g., a safe containing a classified document). This collaboration has been made formal in 1rst December 2015 as a financial support for the preparation of Maxime Audinot's PhD thesis. In this context, the LogicAteam has joint the Pole d'Excellence Cyber `https://www.univ-rennes1.fr/actualites/pole-dexcellence-cyber-des-industriels-lirisa`.

6.2 Cour de Cassation

Participants: François Schwarzentruber.

The contract was signed on the 22^{nd} of April 2013 and started soon afterwards. The project stopped in April 2016. We have developped a software prototype. We have also elicited the different requirements that the language for lawyers should fulfill. We submitted a paper to ICAIL 2017.

7 Other Grants and Activities

7.1 International Collaborations

- Sophie Pinchinat collaborates with Tim French [University of Western Australia] on logical foundations of multi-agent systems, and with Laura Bozzelli [Universidad Politécnica de Madrid] on complexity issues in verification. She also has started an active collaboration with research group of Aniello Murano at the Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione of the Università degli Studi di Napoli Federico II. This latter collaboration serves the research line on the development of logical formalism for strategic reasoning in multi-agent systems.

Finally, she collaborates with the Professor Sjouke Mauw, the head of the group "Security and Trust of Software Systems" at the University of Luxembourg in the Computer Science and Communications Research Unit, on the topic of attack trees.

- François Schwarzentruber collaborated with Thomas Bolander [DTU, Copenhagen] and Valentin Goranko [University of Denmark] for logics in Artificial Intelligence.

7.2 National Collaborations

- Sophie Pinchinat is collaborating with the DGA (French Defense Ministry) on Physical Security, supervising the PhD student Maxime Audinot. In this context, she collaborates with Yann Thierry-Mieg from the LIP6 laboratory in Paris as a partner in the development of the ATSyRA plate-form that aims at assisting security experts in the design of attack trees for physical security.

- François Schwarzentruber is collaborating with researchers of IRIT (Toulouse) and with Hans van Ditmarsch (LORIA, CNRS, Nancy).

- Sophie Pinchinat and François Schwarzentruber are involved in an associated team of INRIA (DISTOL project, for "DIStributed and STOchastic systems, Logic") `http://www.irisa.fr/sumo/DISTOL/` with the Institute of Mathematical Sciences, Chennai and the Chennai Mathematical Institute (2013-2017).

7.3 Project submissions

- Sophie Pinchinat has submitted a 48-month project to the ANR 2016 Projet de Recherche Collaborative – Internationale" call under the name **AGAT** for "**A**ssisted **G**eneration of **A**ttack **T**ress. The partners are the group "Security and Trust of Software Systems" at the University of Luxembourg in the Computer Science and Communications Research Unit. University of Luxembourg, head by Professor Sjouke Mauw, and the Associate Professor Yann Thirry-Mieg from the group MoVe of LIP6 laboratory in Paris.

- François Schwarzentruber has submitted a project to the ANR 2016 call "JCJC" under the name **DELOREL** standing for 'Dynamic epistemic logic in real-life' but it was refused. He submitted a project called *Agents artificiels avec connaissance d'ordre supérieur* to *Action initiative - Projets scientifiques émergents 2016* but it was refused. He submitted a project called DELOREL on the same topic to CNRS PEPS INS2I 2016 but it was refused. He submitted a project called DELOREL on the same topic to CNRS Défi interdisciplaire InFInity, which has been accepted.

7.4 PhD students training

The two PhD students of LogicA have attended the 8th European Summer School in Logic, Language and Information (ESSLLI 2016), that was held at the Free University of Bozen-Bolzano, Italy, on August 15-26, 2016. It was organized by the Research Centre on Knowledge and Data (KRDB) at the Faculty of Computer Science, with the support of the University of Trento.

8 Dissemination

8.1 Scientific Responsabilities

- Sophie Pinchinat serves the editorial board of *Discrete-event Dynamic Systems*.
- Sophie Pinchinat was a member of the Program Committees of 4 international workshops (SR 2016, GraMSec2016, Cassting2016, WODES2016) and of 2 international conferences (CSL2016 and FSTTCS2016).
- Sophie Pinchinat has been reviewer for STACS2017, ECAI2016 but also for the journals *Fundamentae Informatica* and *Studia Logica*.
- Sophie Pinchinat joint the selection committee of the Université de Lorraine for the lecturer position number 27MCF0194.
- Sophie Pinchinat is the scientific adviser at the International Affairs of the IRISA laboratory and a member of the Computer Science and Electrical Engineering Department (ISTIC) Board.
- François Schwarzentruber was in the Program Committee of PRIMA2016, IJCAI2016, RJCIA2016 and of the workshops DARE-16.
- François Schwarzentruber has been reviewer for CSL 2016, ECAI 2016, STACS 2016, for the journal *TCS*.
- François Schwarzentruber is member of the scientific council of ENS Rennes.

8.2 Involvement in the Scientific Community

- Sophie Pinchinat has been the member of 3 PhD committees (the referee for 2 of them, among which one in the Netherlands) and the president of an HDR committee.
- Sophie Pinchinat was invited at the Institute of Mathematical Sciences, Chennai, India, for a research stay in December 2016.
- François Schwarzentruber was invited to “A decade of ICR, Luxembourg”, 17-18 march 2016.
- François Schwarzentruber was in the PhD committee of Thomas Caridroit’s defense (University of Lens).

- François Schwarzentruber was invited one week by Valentin Goranko in the University of Stockholm (28 may - 6 june 2016).
- Sophie Pinchinat and François Schwarzentruber are both the editors of the Special Issue in *IfCoLog Journal of Logics and their Applications* (Volume 4, Number 1) of *Tools for teaching logic* 2015 that appeared in January 2017.

8.3 Teaching

- Sophie Pinchinat teaches at Université de Rennes 1 and ENS Rennes: Advanced Techniques of Verification (Master 2 Research), Software Formal Analysis and Design (Master 1), Advanced Algorithmics (Master 1), Automata-theoretic approaches for Formal Verification (Master 1), An introduction to Writing and Research (Master 1), Algorithmics (Bachelor), Introductory course in Logic (Bachelor).

  She also teaches Game Theory at Supélec.

  She is an associate Professor at ENS Rennes. She participates to numerous jurys for training students of ENS Rennes at "Agrégation de Mathématiques".

  She is in co-charge of the stream "Parcours Recherche et Innovation" of the Master Informatique of the Computer Science and Electrical Engineering Department of the University of Rennes 1.
- François Schwarzentruber teaches at ENS Rennes: Design and verification (M1), Computability and complexity theory ("Agrégation de Mathématiques"), Algorithms ("Agrégation de Mathématiques"), Logic ("Agrégation de Mathématiques"), (Programming in C++ and UML ("Agrégation de mécatronique"), organization of seminars for students (L3, M1), algorithms (L3), formal languages (L3).

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