Report from Dagstuhl Seminar 15221

Multi-disciplinary Approaches to Reasoning with Imperfect Information and Knowledge – a Synthesis and a Roadmap of Challenges

Edited by

Igor Douven[1], Gabriele Kern-Isberner[2], Markus Knauff[3], and Henri Prade[4]

1 **Paris-Sorbonne University, FR,** igor.douven@paris-sorbonne.fr
2 **TU Dortmund, DE,** gabriele.kern-isberner@cs.tu-dortmund.de
3 **Universität Giessen, DE,** markus.knauff@psychol.uni-giessen.de
4 **Paul Sabatier University – Toulouse, FR,** prade@irit.fr

Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 15221 "Multi-disciplinary Approaches to Reasoning with Imperfect Information and Knowledge – a Synthesis and a Roadmap of Challenges".

This multi-disciplinary seminar brought together researchers from computer science, philosophy and psychology dealing with topics of rational reasoning, reasoning with imperfect information and rational decision making in real world problems. The different views from computational, logical and cognitive perspectives provided new insights on overlapping goals and complemtary questions, for instance, when psychologists being interested in new formal models and computer scientists being interested whether their developed methods are materially adequate discussed logical and terminological backgrounds with philosophers. The combination of introductory talks, presentations and discussions of current work of the participants and discussion groups dealing with general questions lead to fruitful discussions where challenges for new paradigms of rational reasoning as well as visions and foci for interdisciplinary work were raised.

Seminar May 25–29, 2015 – http://www.dagstuhl.de/15221
1998 ACM Subject Classification F.3.0 Logics and Meanings of Programs (general), I.2.0 Artificial Intelligence (general), I.2.4 Knowledge Representation Formalisms and Methods
Keywords and phrases uncertain reasoning, commonsense reasoning, rational reasoning, conditionals, nonmonotonic logics, belief revision, similarity-based reasoning: case-based, interpolative, extrapolative, and analogical reasoning, reasoning on time, space, and causality, abductive reasoning, semantical frameworks for reasoning, decision making, decision support systems, intelligent agents, multiagent systems, knowledge engineering, ontologies, description logics, formal epistemology, formal social epistemology, philosophy of probability, philosophy of uncertainty modeling, cognitive aspects of rational and uncertain reasoning, cognitive theories of uncertain reasoning, empirical studies on rational and uncertain reasoning, belief revision
Digital Object Identifier 10.4230/DagRep.5.5.92
Edited in cooperation with Christian Eichhorn

Except where otherwise noted, content of this report is licensed under a Creative Commons BY 3.0 Unported license
Multi-disciplinary Approaches to Reasoning with Imperfect Information and Knowledge – a Synthesis and a Roadmap of Challenges, *Dagstuhl Reports*, Vol. 5, Issue 5, pp. 92–114
Editors: Igor Douven, Gabriele Kern-Isberner, Markus Knauff, and Henri Prade
Dagstuhl Reports
Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

1 Executive Summary

Igor Douven
Gabriele Kern-Isberner
Markus Knauff
Henri Prade

License Creative Commons BY 3.0 Unported license
© Igor Douven, Gabriele Kern-Isberner, Markus Knauff, and Henri Prade

This multi-disciplinary seminar with attendees from computer science, philosophy, and psychology addressed typical problems that smart and intelligent systems in real-world scenarios have to deal with both from formal and empirical points of view. Such systems have to face, in particular, the problem of reasoning with uncertain, imprecise, incomplete, or inconsistent (in short, imperfect) information which often renders more classical, i.e., strict or deductive methods obsolete or fallacious. Reasoning with imperfect information plays a central role in practical deliberation and rational decision making. Models of human context-dependent reasoning that synthesise logical, philosophical and psychological aspects would be helpful for designing better systems. In psychology, an increasing interest in new formal methods for rational human reasoning under uncertainty can be observed, and on the other hand, philosophers and computer scientists have shown an increased attention to the experimental methods of psychology recently. In particular for computer scientists and AI researchers, it is becoming more and more interesting to see whether the systems they have been developing are materially adequate. A synthesis of rational reasoning with imperfect information that takes into account research done in artificial intelligence, but also in psychology and philosophy is needed for providing a clearer view of where we are and what are the pending issues both from computational resp. logical and cognitive viewpoints. This will help making intelligent systems more effective, and more helpful for their human users.

This seminar brought together researchers interested in rational and uncertain reasoning from a very broad scientific scope to present and discuss problems and approaches from different disciplines, consolidate common grounds, and initiate new interdisciplinary collaborations. The seminar took profit from the fact that computer scientists, philosophers, and psychologists have started quite recently to work in a common methodological paradigm with overlapping goals, converging interests, and largely shared research tools. The attendees identified challenges for new paradigms of rational reasoning, and discussed visions and foci for more interdisciplinary work.

The first day, the seminar started with (invited) survey talks on central cross-field topics, where each topic was addressed by two researchers from different disciplines:

- *Nonmonotonic reasoning and change of knowledge and beliefs*
  Marco Ragni (CS/Psy), Hans Rott (Phil)
- *Uncertain reasoning and decision theory*
  Wolfgang Spohn (Phil), Henri Prade (CS)
- *Argumentation and reasoning under inconsistency*
  Ofer Arieli (CS), Ulrike Hahn (Psy)
- *General forms of human reasoning (e.g., analogical reasoning, interpolation, and extrapolation, case-based reasoning)*
  Vittorio Girotto (Psy), Steven Schockaert (CS)

The schedule for the next days included both sessions where attendees could present and discuss their work with the audience, and time slots for discussion groups. The topics of the

discussion groups were discussed in a plenary session, and four groups came out of that:

- *Topics of group 1:* Philosophers' and psychologists' view on human reasoning, and what computer scientists can contribute to that; axiomatic systems vs. psychological models – how do they fit?
- *Topics of group 2:* Empirical implications of formal reasoning systems and vice versa
- *Topics of group 3:* Combination/mixture of reasoning methods, qualitative vs. quantitative approaches; formal axiomatic systems are suitable for decision making(?)
- *Topics of group 4:* Promises and problems of probability theory; reliability, coherence, higher order probabilities

Groups 1 and 2 joined after the first session due to the closeness of the discussed topics. On Friday morning, the results of the working groups were presented, and a final, lively discussion in the plenary session closed the seminar.

	Tuesday **May 26th**	**Wednesday** **May 27th**	**Thursday** **May 28th**	**Friday** **May 29th**
8:45/9:00	8:45 Opening Survey Talk 1	Working groups	Presentations	Presentations Working groups
10:30–11:00		**Coffee break**		
	Survey Talk 2	Presentations	Presentations	Presentations Working Groups Wrapping up
12:15–14:00		**Lunch**		
	Survey talk 3	Working groups	Presentations	
15:30–16:00		**Coffe Break**		
	Survey talk 4 17:30 Setting up working groups	Short walk bike ride, . . .	Working Groups	
18:00	**Dinner**	**Barbecue**	**Dinner**	

2 Table of Contents

Working Groups

3 Overview of Talks

3.1 Desirable Properties of Paraconsistent Logics

Ofer Arieli (Academic College of Tel Aviv, IL)

License 🅭 Creative Commons BY 3.0 Unported license
© Ofer Arieli
Joint work of Arieli, Ofer; Avron, Arnon; Zamansky, Anna

Paraconsistent logics are logics that tolerate inconsistent information in a non-trivial way. However, it is not always clear what should be the exact nature of such logics, and how to choose one for a specific application.

In this talk, we formulate a list of desirable properties that a 'decent' paraconsistent logic should have, and investigate the relations between them. This is exemplified in the context of 3-valued semantics, which is the simplest and the most popular framework for reasoning with contradictory data.

3.2 Towards a dual process cognitive model for argument evaluation

Florence Bannay-Dupin de St-Cyr (Paul Sabatier University – Toulouse, FR)

License 🅭 Creative Commons BY 3.0 Unported license
© Florence Bannay-Dupin de St-Cyr
Joint work of Bisquert, Pierre; Croitoru, Madalina; Bannay-Dupin de St-Cyr, Florence

In this study we are interested in the computational and formal analysis of the persuasive impact that an argument can produce on a human agent.

We propose a dual process cognitive computational model based on the highly influential work of Kahnemann and investigate its reasoning mechanisms in the context of argument evaluation. This formal model is a first attempt to take a greater account of human reasoning and is a first step to a better understanding of persuasion processes as well as human argumentative strategies, which is crucial in collective decision making domain.

3.3 Non-Classical and Cross-Domain Reasoning

Tarek R. Besold (Universität Osnabrück, DE)

License 🅭 Creative Commons BY 3.0 Unported license
© Tarek R. Besold

Analogy and analogical reasoning is one of the most studied representatives of a family of non-classical forms of reasoning working across different domains.

In the first part of the talk, I will shortly introduce general principles of computational analogy models (relying on a generalization-based approach to analogy) and will have a closer look at Heuristic-Driven Theory Projection (HDTP) as an example for a theoretical framework and implemented system. HDTP has been applied to model a diverse range of phenomena including "classical" analogical reasoning, but also inductive generalization and concept formation in mathematics, transfer learning, or essential part of concept blending processes.

The second part will deal with some short reflections on the application of complexity theory and tractability considerations to (theoretical and/or computational) cognitive models, using HDTP as a worked out example. I will advocate the need for cognitive models and systems to be plausible also with respect to the required computational resources, suggesting parameterized complexity theory and approximation theory as sources of inspiration for analysis.

3.4 Coherent uncertain reasoning

Nicole Cruz de Echeverria Loebell (University of London, GB)

License Creative Commons BY 3.0 Unported license
© Nicole Cruz de Echeverria Loebell
Joint work of Cruz, Nicole; Baratgin, Jean; Oaksford, Mike; Over, David

The psychology of reasoning has traditionally used binary logic to assess whether people's beliefs are consistent and their inferences valid. But most of our beliefs, premises, and conclusions in both everyday life and science are uncertain, and this uncertainty cannot be expressed in binary logic. The probabilistic approach to deductive reasoning proposes a generalisation of consistency for categorical beliefs to coherence for degrees of belief. We examined the coherence of people's probability judgments for a range of one-premise inferences with conditionals, conjunctions and disjunctions.

People's responses were coherent at above chance levels for all inferences investigated, with two qualifications. First, people committed the conjunction fallacy, violating coherence, when the and-elimination inference ($p \wedge q$, therefore p) was presented using the materials typically leading to the fallacy.

Second, people's responses were coherent above chance levels assuming that the conditional was interpreted as satisfying the Equation $P(\text{if } p \text{ then } q) = P(q|p)$; but responses were incoherent above chance levels assuming that the conditional was interpreted as the material conditional of binary logic, with $P(\text{if } p \text{ then } q) = P(not - porq)$.

3.5 Abstract Girotto Talk

Vittorio Girotto (University of Venezia, IT)

License Creative Commons BY 3.0 Unported license
© Vittorio Girotto
Main reference L. Fontanari, M. Gonzalez, G. Vallortigara, V. Girotto, "Probabilistic cognition in two indigenous Mayan groups," in Proc. of the National Academy of Sciences, 111(48):17075–17080, 2014.
URL https://dx.doi.org/10.1073/pnas.1410583111

Correct probabilistic evaluations are one of the hallmarks of rationality. A classical view is that the ability to make them depend on formal education.

Following this view, individuals living in traditional cultures are unable to reason about probabilities, and premodern individuals lacked even the basic notions of probability. Another view, which one can trace back to John Locke, is that a sense of chance emerges regardless of instruction and culture. This talk reviews recent studies showing that young children and adults with no formal education are able to solve a variety of probabilistic problems. The talk discusses the implications of this finding for the question of the relation between normative and common reasoning.

3.6 Argumentation and reasoning under inconsistency (in psychology)

Ulrike Hahn (University of London, GB)

License Creative Commons BY 3.0 Unported license
© Ulrike Hahn

On the one hand, there is a widespread sense that the human cognitive system is riddled with inconsistent and conflicting beliefs. At the same time, however, human cognitive flexibility in light of a noisy, changing environment far surpasses and machine system to date. The talk surveys work in a variety of fields within psychology on how human beings respond to conflicting and/or inconsistent information.

3.7 Bayesian Argumentation

Stephan Hartmann (LMU München, DE)

License Creative Commons BY 3.0 Unported license
© Stephan Hartmann

I will motivate and sketch a Bayesian theory of argumentation. According to this theory, an agent has prior beliefs about some propositions A, B,.... These beliefs are represented by a probability distribution P. The agent then learn the premisses of an argument from some information source. She may, for example, learn that A is the case and that A implies B. This amounts to the following constraints on the agent's new probability distribution $P' : P'(A) = 1$ and $P'(B|A) = 1$. The full new probability distribution is then determined by minimization of the Kullback-Leibler divergence between P' and P. One then obtains $P'(B) = 1$ as one would expect from modus ponens. In a similar way, one can examine the inference patterns modus tollens, affirming the consequent, and denying the antecedent. This approach can be generalized in many respects. The agent may, for example, not fully trust the source that A is true and only assign a very high new probability to A (in the case of modus ponens). Or she may have beliefs about a disabling condition D that inhibits B. In this case the agent learns (or so I argue) that $P'(B|A, \neg D) = 1$ where the variable D has to be properly integrated into a causal Bayes net that represents that conditional independences that hold between the various variables. Finally one may want to study alternatives to the Kullback-Leibler divergence and explore what follows from these measures. All this will, or so I hope, nicely connect to empirical studies.

3.8 An epistemic extension of equilibrium logic and its relation to Gelfond's epistemic specifications

Andreas Herzig (Paul Sabatier University – Toulouse, FR)

License Creative Commons BY 3.0 Unported license
© Andreas Herzig
Joint work of Fariñas del Cerro, Luis; Herzig, Andreas; Iraz Su, Ezgi
Main reference L. Fariñas del Cerro, A. Herzig, E. Iraz Su, "Epistemic Equilibrium Logic," in Proc. of the 24th Int'l Joint Conf. on Artificial Intelligence (IJCAI'15), pp. 2964–2970, 2015; pre-print available from author's webpage.
URL http://ijcai.org/papers15/Abstracts/IJCAI15-419.html
URL http://www.irit.fr/~Andreas.Herzig/P/Ijcai15.html

We add epistemic modal operators to the language of here-and-there logic and define epistemic here-and-there models. We then successively define epistemic equilibrium models and autoepistemic equilibrium models. The former are obtained from here-and-there models by the standard minimisation of truth of Pearce's equilibrium logic; they provide an epistemic extension of that logic. The latter are obtained from the former by maximising the set of epistemic possibilities; they provide a new semantics for Gelfond's epistemic specifications. For both definitions we characterise strong equivalence by means of logical equivalence in epistemic here-and-there logic.

3.9 Open conditionals in the light of dynamic epistemic logics

Andreas Herzig (Paul Sabatier University – Toulouse, FR)

License Creative Commons BY 3.0 Unported license
© Andreas Herzig

We argue that Public Announcement Logic accounts an open epistemic conditional and show that it validates the principle of Stalnaker's basic conditional logic, while it invalidates all the further principles of Lewis's sphere-system-based logic of conditionals but the principle $A > \mathit{false} \rightarrow (A \wedge A') > \mathit{false}$.

3.10 Short Introduction to Computational Models of Argument

Anthony Hunter (University College London, GB)

License Creative Commons BY 3.0 Unported license
© Anthony Hunter

Argumentation is an important cognitive process for dealing with incomplete, inconsistent, and uncertain information, and for dealing with conflicting view between agents. Computational models of argument aim to formalize aspects of argumentation for use in software. In this talk, we will consider models based on abstract argumentation, logical argumentation and dialogical argumentation.

3.11 The dual-strategy model of deductive inferences

Henry Markovits (University of Montreal, CA)

License Creative Commons BY 3.0 Unported license
© Henry Markovits
Joint work of Markovits, Henry; Janie Brisson, de Chantal, Pier-Luc

The ability to make deductive inferences, that is, to understand that a single conclusion is a logical consequence of whatever preconditions are assumed is possibly the highest form of human cognition. A great deal of evidence has found that the inferences made even by educated adults are highly variable, but that this variability is not random. Instead people show clear patterns that reflect the specific content of the premises used in deductive problems. This variability underlies the development of probabilistic theories of inferential reasoning (Evans, Over & Handly, 2005; Oaksford & Chater, 2007). Although specific details differ, these theories suggest that people construct a statistical estimation of the probability that a putative conclusion is true, given what they know about the real world and the given premises, and that this statistical estimation is then used to produce a deductive conclusion. The other principle theory of deductive reasoning is mental model theory (Johnson-Laird, 2001; Johnson-Laird & Byrne, 2002), which proposes in contrast that people use a relatively conscious, working-memory intensive process to make inferences. This theory suggests that people construct representations of problem premises that consist of a series of models corresponding to combinations of antecedent and consequent terms that are semantically possibly true. The key aspect of this approach is the idea that if a reasoner can generate an explicit representation that includes a counterexample to a putative conclusion, this conclusion will be rejected. Recently, the Leuven group (Verschueren, Schaeken, & d'Ydewalle, 2005a; 2005) proposed a dual process theory of deductive reasoning which claims that people can use a combination of probabilistic and mental model forms of reasoning. We have been trying to confirm and extend this basic theory. We have been able to develop a method for evaluating the strategy used by reasoners (Markovits, Lortie Forgues, & Brunet, 2012). We have demonstrated that when people have a limited time to make inferences, they will preferentially use a probabilistic strategy, but will change to a mental model strategy when allowed more time (Markovits, Brunet, Thompson & Brisson, 2013). We have also shown that responses to deductive updating problems vary according to strategy use (Markovits, Brisson, de Chantal, in press). These results provide strong support for the dual strategy model.

3.12 A prioritized assertional-based revision for DL-Lite knowledge bases

Odile Papini (University of Marseille, FR)

License Creative Commons BY 3.0 Unported license
© Odile Papini

We investigate Prioritized Removed Sets Revision (PRSR) for revising DL-Lite knowledge bases when a new sure piece of information, calles the input, is added. The strategie of revision is based on inconsistency minimization and consists in determining smallest subsets of assertions (removed sets) that should be dropped from the current knowledge base in order to restore consistency and accept the input. We consider a DL-Lite knowledge base where the ABox is stratified, and we consider different form of input: membership assertion, positive or negative axiom. To characterize an revision approach, we rephrase the Hansson's postulates for belief basis revision within DL-Lite settings and we give the logical properties of PRSR operators

3.13 Coherence under uncertainty: Philosophical and psychological applications

Niki Pfeifer (LMU München, DE)

License Creative Commons BY 3.0 Unported license
© Niki Pfeifer
Joint work of Pfeifer, Niki; Sanfilippo, Giuseppe; Gilio, Angelo
Main reference A. Gilio, N. Pfeifer, G. Sanfilippo, "Transitive Reasoning with Imprecise Probabilities," in Proc. of the 13th Europ. Conf. on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU'15), LNCS, Vol. 9161, pp. 95–105, Springer, 2015.
URL https://dx.doi.org/10.1007/978-3-319-20807-7_9

After sketching selected philosophically and psychologically interesting key features of coherence-based probability logic, we illustrate our approach by inferences about conditionals and quantified statements. Specifically, we discuss Modus ponens, Modus tollens, Cut, Contraposition, and selected paradoxes of the material conditional. Moreover, we present first steps towards a coherence-based probability semantics of categorical syllogisms. Finally, we discuss the importance of managing zero antecedent probabilities for reasoning under uncertainty (uncertain conditionals, probabilistic existential import assumptions, etc.).

3.14 Why not just (Bayesian) probabilities?

Henri Prade (Paul Sabatier University – Toulouse, FR)

License Creative Commons BY 3.0 Unported license
© Henri Prade
Joint work of Prade, Henri; Dubois, Didier

This attempt at providing a brief overview of uncertainty modeling in artificial intelligence starts by recalling some limitations of precise probabilities with respect to the representation of epistemic uncertainty. The settings of possibility, belief function, and imprecise probability theories that rely on the use of two dual set functions, are shown to be appropriate for modeling (partial) ignorance. Then the importance of a proper view of conditioning, via conditional objects, is stressed, together with its relation to nonmonotonic reasoning, and its application to perceived causality. The distinction between qualitative possibility vs. quantitative possibility theory that relies on different definitions of conditioning is then recalled. Motivations for decision criteria beyond expected utility are also briefly indicated in presence of epistemic uncertainty for one-shot decisions. Lastly, two recent research trends are briefly mentioned:

1. The structure of the cube of opposition that applies to possibility and belief function theories (as well as to many other knowledge representation frameworks) emphasizes the existence of two other set functions of interest in these two settings
2. The existence of a qualitative counterpart to belief function theory based on imprecise possibilities.

3.15 Nonmonotonic reasoning

Marco Ragni (Universität Freiburg, DE)

License Creative Commons BY 3.0 Unported license
© Marco Ragni

In the last decades psychological findings show that human reasoning strongly deviates from classical logical approaches. Nonmonotonic logics provide a better predictability of logical inferences. In this talk I will first introduce a variety of formal nonmonotonic reasoning approaches, from Reiter's Default Logic, System P, System C and focus especially on promising semantic and syntactic approaches. Accompanying questions about psychological demands for an adequate cognitive nonmonotonic theory are discussed.

3.16 Four floors for the theory of belief change (and in particular, the case of imperfect discrimination)

Hans Rott (Universität Regensburg, DE)

License Creative Commons BY 3.0 Unported license
© Hans Rott
Main reference H. Rott, "Four Floors for the Theory of Theory Change: The Case of Imperfect Discrimination", in Proc. of the 13th Europ. Conf. on Logics in Artificial Intelligence (JELIA'14), LNCS, Vol. 8761, pp. 368–382, Springer, 2014.
URL http://dx.doi.org/10.1007/978-3-319-11558-0_26

The classical qualitative theory of belief change due to Alchourrón, Gärdenfors and Makinson has been widely known as being characterized by two packages of postulates. While the basic package consists of six postulates and is very weak, the full package that adds two further postulates is very strong. I revisit two well-known constructions of belief contraction, viz., contraction based on possible worlds and entrenchment-based contraction, and argue that four intermediate levels can be distinguished that play – or ought to play – important roles within qualitative belief revision theory. Levels 3 and 4 encode two ways of interpreting the idea of imperfect discrimination of the plausibilities of possible worlds or propositions.

3.17 Human plausible reasoning as a model for robust inference from imperfect knowledge

Steven Schockaert (Cardiff University, GB)

License Creative Commons BY 3.0 Unported license
© Steven Schockaert

An increasing amount of structured knowledge is becoming available on the web (e.g. extracted from natural language). Unfortunately, classical logic is ill-suited for dealing with the uncertainty, vagueness, subjectivity and context-dependence that is prevalent in knowledge bases which have been derived from the web. In general, problems tend to arise whenever we need to reason about knowledge that has been encoded by humans (e.g. regulations, expert systems, ontologies). The challenge in reasoning about human knowledge is two-fold. First, such knowledge tends to capture statistical regularities (i.e. observations about the world) rather than tautologies. This is addressed, for example, in probabilistic extensions to classical logic (e.g. Markov logic), as well as in frameworks for non-monotonic reasoning. Second, many of the concepts and properties about which we need to reason cannot be adequately defined using necessary and sufficient conditions. This has led to the use of geometric models of reasoning, inspired by cognitive theories of meaning (e.g. prototype theory), in particular various forms of similarity and analogy based reasoning.

Existing approaches for reasoning about human knowledge can broadly be categorised based on how they handle uncertainty (i.e. the first challenge) and concept representation (i.e. the second challenge), and based on whether they deal with these challenges in a qualitative or in a numerical way. Qualitative approaches have the advantage that their reasoning processes are more transparent, and accordingly, that intuitive explanations for inference results can easily be provided. Qualitative knowledge bases are also easier to learn, as there is no need for context-specific weights to be chosen. However, qualitative approaches are often too cautious in practice, which means that most existing applications rely on numerical, often heuristic approaches to reasoning. Numerical approaches, on the other hand, have to rely on weights, which may be difficult to learn in a principled way. This becomes especially problematic in approaches that handle both uncertainty and concept representation in a numeric way. While such approaches have already proven useful in applications, their knowledge bases rely on weights which are highly context-specific, and are difficult to maintain as a result.

The limited transferability of weighted knowledge, along with the difficulty to generate faithful and intuitive explanations for inference results from such knowledge, is likely to become increasingly problematic, as artificial intelligence methods are becoming increasingly central to human decision support. For example, doctors are unlikely to put much faith in computer-generated diagnoses, when they are based on imperfect methods, unless they can verify the reasoning process behind them. Similarly, regulators may insist on some degree of transparency when automated methods are used e.g. for approving mortgages, deciding insurance premiums, or assessing job candidates. An important challenge thus consists in developing methods that combine the effectiveness of numerical methods with the explainability and transferability of qualitative knowledge. While some progress in this area has already been made (e.g. transfer learning), hybrid forms of reasoning, combining qualitative and numerical forms of inference (e.g. inspired by dual process accounts of human reasoning) remain largely unexplored.

3.18 Uncertain Reasoning and Decision Theory

Wolfgang Spohn (Universität Konstanz, DE)

License Creative Commons BY 3.0 Unported license
© Wolfgang Spohn

The talk modestly gives a survey of the various attempts of uncertainty measures and their extension to a decision theory. It will discuss the various theoretical achievements such an attempt has to provide, and it will emphasize the requirements such an attempt has to meet in order to be able to serve as a normative and/or as an empirical theory.

3.19 Knowledge, Uncertainty, and Ignorance

Sara L. Uckelman (Durham University, GB)

License Ⓒ Creative Commons BY 3.0 Unported license
© Sara L. Uckelman

What is the relationship between knowledge, uncertainty, and ignorance? If knowledge is lack of uncertainty, and lack of knowledge is ignorance, then are ignorance and uncertainty the same thing? Drawing on arguments made by Paul of Venice (c1399) in his Logica Magna, we argue that they are ignorance and uncertainty are not the same thing; make a distinction between *mere* uncertainty and *fixed* uncertainty; and show how maybe knowledge shouldn't be defined as lack of uncertainty in the first place.

3.20 Possible Worlds Semantics for Conditionals: The Case of Chellas-Segerberg Semantics

Matthias Unterhuber (LMU München, DE)

License Ⓒ Creative Commons BY 3.0 Unported license
© Matthias Unterhuber

This talk focuses on Chellas-Segerberg semantics, a base possible worlds semantics for conditionals. It is sketched in which way this semantics allows for structural frame conditions and can be expanded to a lattice of frames which allows one to describe a corresponding lattice of conditional logic system as described by thirty pairs of conditional logic principles and frame conditions.

In particular, it is explained which type of correspondence properties these pairs enjoy and which type of structure is required in order to arrive at a general non-trivial completeness result.

3.21 Knowledge and gossip

Hans Van Ditmarsch (LORIA – Nancy, FR)

License Ⓒ Creative Commons BY 3.0 Unported license
© Hans Van Ditmarsch
Main reference M. Attamah, H. van Ditmarsch, D. Grossi, W. van der Hoek, "The Pleasure of Gossip," in C. Başkent, L. Moss, R. Ramanujam (Eds.), "Rohit Parikh on Logic, Language and Society," Springer, to appear; pre-print available at author's webpage.
URL http://personal.us.es/hvd/FrohitFest.pdf

Gossip protocols are to disseminate secrets by peer-to-peer communication in networks. In epistemic protocols the agents themselves choose whom to call. We present an example, and a version also involving exchange of telephone numbers.

3.22 Back to the Future – On the State of the Art in Default Reasoning

Emil Weydert (University of Luxembourg, LU)

License Creative Commons BY 3.0 Unported license
© Emil Weydert
URL http://materials.dagstuhl.de/files/15/15221/15221.EmilWeydert.Slides.pdf

Default inference based on ranking measures (quasi-probabilistic plausibility valuations generalizing Spohn's ranking functions, rational/real-valued) constitutes a powerful semantic approach to default reasoning. The idea is to let defaults induce constraints over ranking measures, to specify among the resulting ranking models preferred ones, and to use these to determine the defeasible conclusions conditional on a fact base. If we focus on those ranking models constructible by iterated revision with material implications reflecting the default base, which amounts to add a ranking weight for each default a world violates, we obtain well-behaved default consequence notions with nice inheritance features:

- System J (all the constructible models are preferred) – simple but rather weak.
- System ME (canonical preferred ranking model based on maximum entropy for non-standard probability) – probabilistic justification but representation-dependent, i.e. not invariant under boolean automorphisms, and not easy to compute.
- System JZ (canonical ranking construction implementing plausibility maximization, construction minimization, and justifiable constructibility).
- Z-style algorithm, verifies most desiderata, representation-independent.

Note however that for inheritance-friendly default formalisms, default bases are not characterized by their ranking-semantic content.

3.23 Dilation and Delayed Decisions

Gregory Wheeler (LMU München, DE)

License Creative Commons BY 3.0 Unported license
© Gregory Wheeler
Joint work of Pedersen, Arthur Paul; Wheeler, Gregory
Main reference A. P. Pedersen, G. Wheeler, "Dilation, Disintegrations, and Delayed Decisions," in Proc. of the 9th Int'l Symp. on Imprecise Probability: Theories and Applications (ISIPTA'15), pp. 227–236, 2015.
URL http://www.sipta.org/isipta15/data/paper/23.pdf

Dilation has been alleged to conflict with a fundamental principle of Bayesian methodology that we call Good's Principle: one should always delay making a terminal decision between alternative courses of action if given the opportunity to first learn, at zero cost, the outcome of an experiment relevant to the decision. In particular, dilation has been alleged to permit or even mandate choosing to make a terminal decision in deliberate ignorance of relevant, cost-free information. This article presents dilation and a decision problem in which Good's principle is violated. Our analysis shows that dilation, alone, is not enough to generate a violation of Good's principle, but that the principle is only violated with respect to some decision rules, such as Gamma- Maximin, but not in terms of others, such as E-admissibility.

The slides also include a characterization result of dilation (which was not discussed in the talk) in terms of deviations from stochastic independence, which is a new result. The result tells us that dilation occurs when there are probability distributions in your "credal set" which render the two variables positively correlated and negatively correlated, which means that uncertainty about how the two variables are related to one another is a key feature to dilation. We argue that in some circumstances discovering the possible consequences of your uncertainty concerning how the two variables are related to one another can be useful information to the decision-maker, meaning that dilation itself should not be viewed as a pathological feature of imprecise probability.

3.24 Representation and Bayesian Rational Predication

Momme von Sydow (Universität Heidelberg, DE)

License Creative Commons BY 3.0 Unported license
© Momme von Sydow
Main reference M. von Sydow, "The Bayesian Logic of Frequency-Based Conjunction Fallacies," Journal of Mathematical Psychology, 55(2):119–139, 2010.
URL http://dx.doi.org/10.1016/j.jmp.2010.12.001

In some contexts humans are able to deal with standard probabilities or even probability bounds. However, there are conceptual and empirical problems, if standard probability is used as a criterion of adequate predication. Whereas standard probabilities can directly be used for specifying the proportion of elements falling into a logically defined set, it is argued that for the goal of describing a situation in terms of logically connected predicates, standard probabilities do not (directly) provide a reasonable adequacy criterion: The Lockean thesis always allows to predicate more general but less informative logical hypotheses as well. Bayesian (pattern) logic (BL) addresses this problem by specifying the probability of alternative generative hypotheses (probability tables corresponding to standard truth tables) that provide a noisy-logical explanation or characterization of a situation. Here BL is not investigated in the context of dyadic logic, but in the context of monadic logic. We here extend this discussion to polytomous classes. BL predicts that the number of subclasses within an affirmation or within its negation should matter. The reported experiment provides evidence for this and shows strong deviations from standard probability (and also, for instance, from support theory). Although BL builds on standard extensional probabilities, it provides an intensional approach sensitive for the number of involved subclasses. Thus BL extends the scope of a probabilistic approach by advocating a goal-dependent pluralism within this approach.

4 Working Groups

4.1 Working Group "Combining and comparing qualitative and quantitative approaches to decision theory"

Ofer Arieli, Christoph Beierle, Tarik Besold, Florence Bannay-Dupin de Saint-Cyr, Steven Schockaert, Wolfgang Spohn, Sara L. Uckelman, and Emil Weydert

License Creative Commons BY 3.0 Unported license
© Ofer Arieli, Christoph Beierle, Tarik Besold, Florence Bannay-Dupin de Saint-Cyr, Steven Schockaert, Wolfgang Spohn, Sara L. Uckelman, and Emil Weydert
URL http://materials.dagstuhl.de/files/15/15221/15221.FlorenceBannay-Dupin%20de%20St-Cyr1.Slides2.pdf

The result of the discussions have allowed us to propose a roadmap and define the challenges for the future.

4.1.1 Landscape

	Beliefs	Utility	Expected Utility
binary	B_1 B'_1	U_1 U'_1	E_1 E'_1
ordinary	B_2 B'_2	U_2 U'_2	E_2 E'_2
cardinal	B_3 B'_3	U_3 U'_3	E_3 E'_3

With $X \in \{B, U, E\}$, index 1=binary, 2=ordinary, 3=cardinal, X_i=complete knowlegde, X'_i=vagueness/incompleteness

- comparison, partial or total completion (X'_i to X_i)
- comparison, combination X_i and X_j
- combination of B_i and U_j into E_k (and with $'$).

4.1.1.1 Examples

- B_3: probability theory, U_3: utility theory
  Combination = Standard expected utility theory
- B_2 or B_3: possibility theory U_3: (standard) utility theory
  Combination = Choquet (quantif) or Sugeno integral assumption “commensurability of possibility and utilities degrees”, axioms defined, the combination with Sugeno integral is the only one satisfying the axioms
  NB: Choquet and Sugeno can use any uncertainty measure
- B_3: General “Ranking theories” (e.g. Spohn) U_3: (coarse-grained) ranking utility
  Combination= ranking expected utility without coarse-grained perspective, no commensurability, may entail problems. . .
- B_3 or U_3: 3 valuation classes: prob, rk, hybrid;
  Combination across classes tricky, maybe hybrid B'_3: convex sets of probabilities
- B_1 Epistemic and doxastic logic, U_1: Conditional Deontic logic, logics of desires, goals (typically weak)
  Combination C_1: Some combined logics
- B_2: total/partial plausibility orders, qualitative probability, U_2: qualitative desire orders, theory of revealed preferences
  (combinations of those? not much), C_2 Work in qualitative decision theory
- B_1’=. . . ?, $U'_1 = (+, -, ?)$, $E'_1 = (+, -, ?)$

4.1.2 Dynamics

{Beliefs, Utilities, Expected utilities} can change

- revision
- update

4.1.3 Challenges

4.1.3.1 Theoretical Challenges

- What are the possible/sensible/applicable combinations?

- Axioms for each Box, and each combination (justified in a normative way and by experimentations) in order to ensure/evaluate the quality of the decision
  ex: Axiom on existence of independence notion
  ex: Axiom incompleteness of ordinals on convex or not convex sets
  ex: Axiom of comparability
- Imperfect rationality
  - inconsistency (beliefs, utilities, expected utilities)
  - bounded rationality about (impossible beliefs, utilities) or because bounded combination operator
    ex: Unawareness on utility values: "transformative experiences" ([a] la L.A. Paul) e.g. I am deciding whether to have children or not.
- How to build the beliefs? clarify the notion of beliefs.
- How to build the utilities (norms, desires...)
- If Input= Expected utility and Beliefs, how to reason?
- Strategical planning (theory of dynamic choice)= incomplete information planning with epistemic and ontic actions.
  ex: goal = to increase beliefs in order to become more expert for taking a better decision

4.1.3.2 Challenges from an Application Scenario

(a) Express different kinds of uncertain, vague, incomplete knowledge coming from different sources, e.g.:
  - Probabilistic rules put forward by experts, taken from textbooks, like: "If symptoms A, B, and C are present, then D is the case with probability 0.8".
  - Qualitative rules like: "If A and B, then D is more likely than D'".
  - Preferences like: "For adults with biological age up to 50, prefer therapy type T to T'"

(b) Make inferences and suggest decisions:
  - Given some evidence, what is the most probable/likely diagnosis?
  - Which additional tests could be taken to increase diagnosis quality?
  - What are the options for a therapy plan?
  - What is the most sensible therapy given the current evidence? What is the risk for complications?

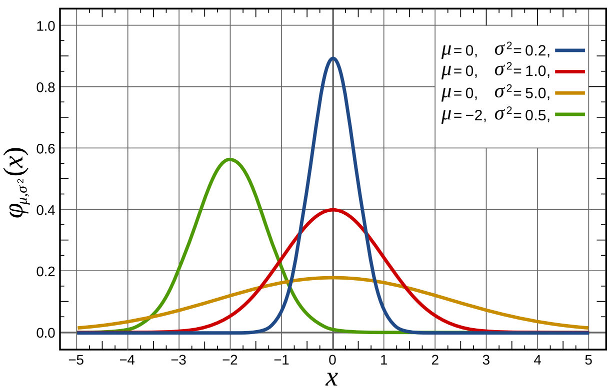
(c) Challenges
  - Provide an adequate framework where all this can be expressed.
  - Ensure and show that inferences and (suggested) decisions are rational and justified.

4.2 Working Group "Probability & Inconsistency"

Nicole Cruz, Ulrike Hahn, Stephan Hartmann, Karolina Krzyżanowska, Momme von Sydow, Matthias Unterhuber, and Greg Wheeler

License Creative Commons BY 3.0 Unported license
© Nicole Cruz, Ulrike Hahn, Stephan Hartmann, Karolina Krzyżanowska, Momme von Sydow, Matthias Unterhuber, and Greg Wheeler
URL http://materials.dagstuhl.de/files/15/15221/15221.FlorenceBannay-Dupin%20de%20St-Cyr1.Slides2.pdf

The result of the discussions have allowed us to propose a roadmap and define the challenges for the future.



tp

Figure 1 Normalized Gaussian curves with expected value μ and variance σ^2 (from: Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Gaussian_function&oldid=670515617)

4.2.1 Is the explosion problem a problem for the probabilist?

$A, \overline{A} \rightarrow \Phi \qquad \rightarrow P(\Phi|A \wedge \overline{A}) = 1$ But: $P(A \wedge \overline{A}) = 0$, so $P(\Phi|A \wedge \overline{A})$ undefined

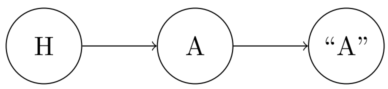
Explosion and its consequences cannot be expressed at the level of belief, so actually do not arise! (. . . even if consequences proliferate at level of logic). Nor is this possible in alternatives to Kolgomorov axioms such as Popper-Renyi functions etc. So answer ist “no”.

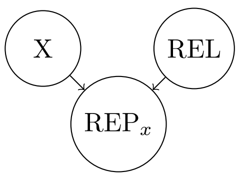
4.2.2 But what about data-bases etc.?

- Bayesian approach: consider A and $\overline{A}$ to be tokens, outputs of a random variable
- *No inconsistency*: can reason effectively with this conflicting evidence, which is weighed and aggregated just like other evidence.

Though you do need a *model* . . .

- $P(\text{“}A\text{”}|H) \ldots P(\text{“}\overline{A}\text{”}|H) \ldots$ etc
- Or exogenous model:





Many standard models exist . . .

- E.g. Figure 1
- Beyond Bayesianism (but within probabilities), non-parametric statistics . . .

4.2.3 What about probalistic incoherence?

- Location of intuition that people hold inconsistent beliefs across different areas of their belief system: e.g., views on the economy that are incompatible with their views on politics (if they bothered to think it all through . . .)

Incoherent systems of beliefs

- Incoherent beliefs seem bad, but at the same time, people seem to function well (and better than extant machine systems) in a noisy, changing world.

Pearl (1988)

- Fundamental claim that Bayesian computations are tractable in many contexts because what matters are comparatively local sets of conditional independence relations.
- Bayesian Networks encode and exploit these, and eliminate need to consider majority of joint probability distribution across variables.

Probabilistic incoherence across networks

- Are people's networks local in the sense of not being inter-linked?
- Or are they effectively local due to limited, weak links?
- Does it matter?

- Incoherence likely due to resource limitations in updating etc ...
- Enforcing coherence requires major collective effort: see e.g., law, physics, and relating variables across levels of description
- Is it worth it for bounded resource cognitive agents? Probably not, most of the time.
- Locality as a recipe for success?

"Probabilistic fault tolerance"

- How bad (empirically) is probabilistic incoherence?
- Do graphical models show graceful degradation with increasing incoherence?
- ... address through simulation (deliverable?!)
- Coarse graining: e.g., finite precision/rounding

Some limitations

- Poor fit graphical models?
  - Numerical values assigned to variables which are incoherent, i.e., there is no probability distribution which satisfies those values and the *d*-separation properties of a graph
- What to do outside the realm of Gaussian noise?
  - From Bayesian nets (single probabilities) to credal nets (sets of probabilities).

4.2.4 Abandoning models due to evidential conflict

- Hierarchical Bayesian approach (Bayesian inference about model selection e.g., Tenenbaum and colleagues..)
- Does this work in practice? Other approaches (probabilistic and non-probabilistic)

4.3 Working Group "Empirical Implications of formal systems for reasoning and vice versa"

Igor Douven, Christian Eichhorn, Thomas Eiter, Castaneda Gazzo, Estefania Lupita, Vittorio Girotto, Andreas Herzig, Anthony Hunter, Gabriele Kern-Isberner, Markus Knauff, Henry Markovits, Odile Papini, Niki Pfeifer, Henri Prade, Marco Ragni, Hans Rott, Henrik Singmann, and Hans Van Ditmarsch

License Ⓒ Creative Commons BY 3.0 Unported license
© Igor Douven, Christian Eichhorn, Thomas Eiter, Castaneda Gazzo, Estefania Lupita, Vittorio Girotto, Andreas Herzig, Anthony Hunter, Gabriele Kern-Isberner, Markus Knauff, Henry Markovits, Odile Papini, Niki Pfeifer, Henri Prade, Marco Ragni, Hans Rott, Henrik Singmann, and Hans Van Ditmarsch

What is normative?

- Philosophy: Normative theories are theories about what one should/ought do or how one should/ought reason.
- Psychology: A standard of reference (potentially rational) against which performance is evaluated. (needed for defining errors)
- CS: Human behavior can be a norm for AI.
- We basically all agree to the first two definitions.
- Bounded Rationality: Empirical norms should take cognitive/social constraints into account.

Role of Normative Ideas

- Psychology:
  1. Buliding blocks of descriptive theories of reasoning.
  2. Provide new empirical hypotheses (framework dominates task selection).
  3. No role for normative ideas: we should simply describe behavior.
- Phil: Try to identify and justify norms of reasonign and action.
- CS: Normative Ideas help to develop theories/models and help to establish prove properties of this models.

Non-monotonic logics

- Situated between two extremes: probability theory and classical logic.
- Try to remain connected to classical logic while including the idea of conditioning on the current state of knowledge.
- How can we empirically decide between whether or not individuals reason based on probability or using NM-logic. How can this influence psychological theories? How can this influence AI models?

Example: Rational Monotony. Rational monotony holds if for all A, B, C:

$$\frac{A \mid\!\sim B \qquad A \mid\!\not\sim \neg C}{A \wedge C \mid\!\sim B}$$

with

$\mid\!\sim$: it normally follows, $\mid\!\not\sim$: it normally does not follow

Example: Rational Monotony Violation. The following gives an example in which we expect rational monotony to not hold (i.e., we expect participants to disagree with the conclusion):

students $\mid\!\sim$ love reading books
students $\mid\!\not\sim$ do not love sports
---
students who love sports $\mid\!\sim$ love reading books

5 Open Problems

From the discussions some central open questions could be indentified.

First, clear definitions of concepts and ideas that all involved disciplines can agree upon are needed. As usual with multidisciplinary work, sometimes identical terms mean totally different concepts as well as identical concepts are described by different terms in the disciplines. Here, a common language is needed to smooth interdisciplinary work.

Apart from this very general open problem we also encountered several specific topics which should be worked on:

- Given the landscape in Section 4.1.1, we see the need to clarify the different functions for belief, utility and expected utility in a way that is useful for multi-disciplinary work.
- Based on this formal clarification it can be examined which combination of belief, utility and expected utility functions is the "best" combination in a given context.

Also we saw that there are different kinds of "vagueness" (e.g. probabilistic, qualitative, preferential, ...), which lead to the following questions:

- How can we express the different kinds of vagueness without mixing things up?
- How can we decide, infer and diagnose about combinations of these?
- Can we set up a framework that covers all of the different kinds of vagueness?

Participants

- Ofer Arieli
Academic College of Tel Aviv, IL
- Florence Bannay-Dupin de St-Cyr
Paul Sabatier University – Toulouse, FR
- Christoph Beierle
FernUniversität in Hagen, DE
- Tarek R. Besold
Universität Osnabrück, DE
- Nicole Cruz de Echeverria Loebell
University of London, GB
- Igor Douven
Paris-Sorbonne University, FR
- Christian Eichhorn
TU Dortmund, DE
- Thomas Eiter
TU Wien, AT
- Lupita Estefania Gazzo Castaneda
Universität Gießen, DE
- Vittorio Girotto
University of Venezia, IT
- Ulrike Hahn
University of London, GB
- Stephan Hartmann
LMU München, DE
- Andreas Herzig
Paul Sabatier University – Toulouse, FR
- Anthony Hunter
University College London, GB
- Gabriele Kern-Isberner
TU Dortmund, DE
- Markus Knauff
Universität Gießen, DE
- Karolina Krzyzanowska
LMU München, DE
- Henry Markovits
University of Montreal, CA
- Odile Papini
University of Marseille, FR
- Niki Pfeifer
LMU München, DE
- Henri Prade
Paul Sabatier University – Toulouse, FR
- Marco Ragni
Universität Freiburg, DE
- Hans Rott
Universität Regensburg, DE
- Steven Schockaert
Cardiff University, GB
- Henrik Singmann
Universität Zürich, CH
- Wolfgang Spohn
Universität Konstanz, DE
- Sara L. Uckelman
Durham University, GB
- Matthias Unterhuber
LMU München, DE
- Hans Van Ditmarsch
LORIA – Nancy, FR
- Momme von Sydow
Universität Heidelberg, DE
- Emil Weydert
University of Luxembourg, LU
- Gregory Wheeler
LMU München, DE