

Formal Models of Belief Change in Rational Agents

Dagstuhl seminar 07351, August 26-30, 2007

Executive Summary

1. Motivation

The theory of belief revision studies how a rational agent should change its beliefs when receiving or perceiving new information about the environment. This new information could include objective properties of the actual world, occurrences of events, and, in the case of multiple agents, public or private communications among agents (possibly concerning their beliefs and preferences) as well as actions taken by other agents. Not surprisingly, this area has been of interest to researchers in different communities.

The initial research in belief change came from the philosophical community, wherein belief change was studied generally from a normative point of view (that is, providing axiomatic foundations about how rational agents should behave with respect to the information flux). Subsequently, computer scientists, especially in the artificial intelligence (AI) and the database (DB) communities, have been building on these results. Belief change, as studied by computer scientists, not only pays attention to behavioral properties characterizing evolving databases or knowledge bases, but must also address computational issues such as how to represent beliefs states in a concise way and how to efficiently compute the revision of a belief state.

The most important question in Game Theory is how to rationally form a belief about other players' behavior and how to rationally revise those beliefs in light of observed actions. Traditionally Game Theory has relied mostly on probabilistic models of beliefs, although recent research has focused on qualitative aspects of belief change. A new branch of logic, called Dynamic Epistemic Logic, has emerged that investigates the epistemic foundations of game theory from the point of view of formal logic. Another, related, new field of research, called Social Software, maintains that mathematical models developed to reason about the knowledge and beliefs of a group of agents can be used to deepen our understanding of social interaction and aid in the design of successful social institutions. Social Software is the formal study of social procedures focusing on three aspects: (1) the logical and algorithmic structure of social procedures (the main contributors to this area are computer scientists), (2) knowledge and information (the main contributors to this area are logicians and philosophers), and (3) incentives (the main contributors are game

theorists and economists).

There are various newly emerging links between the research areas mentioned above. The purpose of the Workshop was to bring together researches from all these different areas; these researchers normally do not meet together. Workshops such as this one promote an exchange of ideas and cross-fertilization across different fields.

2. Goals and Content of the Seminar

As mentioned above, the area of belief change can be regarded as originating in the philosophical logic community. This work provided abstract, formal, and precise specifications of desirable properties for belief change operators, as well as the identification of distinct types of change. However, this research says nothing about specific implementable operators nor computational issues – issues of fundamental importance to computer scientists. Researchers in artificial intelligence and computer science have followed up on these issues, as well as developed other specific operators (addressing e.g. sensor fusion and belief base merging) and examined their complexity characteristics. In artificial intelligence, the relatively recent emergence of the field of cognitive robotics, which is concerned with endowing artificial agents with cognitive functions that involve reasoning, for example, about goals, actions, the states of other agents, collaboration and negotiation, etc., has given impetus to the development of computational operators for belief change and the identification of issues arising from concrete, evolving sets of knowledge. More recently, economists have been using work in belief revision, and applying it to notions of mistaken and changing beliefs among interacting and negotiating agents. Such work is also of obvious interest to researchers in artificial intelligence.

Previously, there has been limited interaction among these communities. Clearly there are deep problems of common interest, and results in one area will contribute to another. We have already mentioned that research in economics has made use of the work from the philosophical community, and that such results will be of use to researchers in AI. Furthermore, contributions may also flow back from economics to research in the foundations of belief revision. For example, recently it has been suggested that that economic principles (dealing with choice, preferences, and utility) may provide a more appropriate foundation for belief change. Computational issues raised and addressed by researchers in computer science and AI will be of use to economists addressing related problems; as well, such work can contribute to the other areas by further elucidating the abstract area of belief change, as well as providing implementations and identifying philosophically-interesting “pragmatic” or “practical” problems.

Thus we saw the Dagstuhl seminar as providing a forum where

researchers in three broad areas (philosophy and logic, artificial intelligence and computer science, and economics and game theory) could address highly related (in some cases, the same) problems, in which work in one area could benefit research in another. Hence for the Dagstuhl seminar, we felt that there would be valuable interactions and contributions that would be facilitated by bringing people together in these areas.

3. The participants

The seminar gathered 34 researchers from the following countries:

Australia (2), Austria (1), Canada (3), France (7),
Germany (4), Greece (1), Israel (1), Luxemburg (3),
Portugal (2), Sweden (2), Switzerland (1), Thailand (1),
United Kingdom (4), United States (2).

The participants come from computer science (mainly Artificial Intelligence), philosophy, mathematics (formal logic) and economics. The different backgrounds of the researchers resulted in stimulating discussions on various issues.

4. The program

We organized the program so as to have rather homogeneous sessions, each session being focused on related issues.

The speakers for the first day (**Monday, August 27**) were:

Keynote talk: **Dov Gabbay** (King's College, London, UK)

Daniel Eckert (University of Graz, Austria),
Judgment aggregation and multi-agent belief revision

Patricia Everaere (Université d'Artois-Lens, France)
Set inclusion based merging

Richard Booth (Mahasarakham University, Thailand)
Equilibrium in social contraction

Sébastien Konieczny (Université d'Artois-Lens, France)
Inconsistency measures and applications to belief change

Dongmo Zhang (University of Western Sidney, Australia)
The logic of bargaining: a survey of belief-revision-
based bargaining theory

Alexander Bochman (Holon Institute of Technology, Israel)
Enhanced contraction functions and (in)dependence of
propositions

The speakers for the second day (**Tuesday, August 28**) were:

- Keynote talk: **David Makinson** (London School of Economics, UK)
Relevance and belief change
- Mauricio Reis** (University of Madeira Funchal, Portugal)
A survey of multiple contraction
- John Cantwell** (Stockholm University, Sweden),
Defeasible acceptance, assumptions and conditionals
- Gabriele Kern-Isberner** (University of Dortmund, Germany)
A conceptual framework for revision, update and non-monotonic reasoning
- Isaac Levi** (Columbia University, USA)
Why indeterminacy in probability judgment?
- Alexander Nittka** (University of Leipzig, Germany)
A method for reasoning about other agents' beliefs from observations
- Alexandru Baltag** (University of Oxford, UK)
Iterated dynamic revision of multi-agent higher-level beliefs: a semantic approach
- Giacomo Bonanno** (University of California at Davis, USA)
Semantic structures for (iterated) belief revision
- Guillaume Aucher** (IRIT – Toulouse, France)
Subjective belief states

The speakers for the third day (**Wednesday, August 29**) were:

- Keynote talk: **Kristen Segerberg** (Uppsala University, Sweden)
Modal logics for three kinds of change
- Odinaldo Rodrigues** (King's College, London, UK)
Common foundations for belief revision, belief merging and voting
- Andreas Herzig** (IRIT - Toulouse, France),
Optimal regression for reasoning about knowledge and actions
- Laurent Perrussel** (IRIT - Toulouse, France)
Minimal change

The speakers for the fourth day (**Thursday, August 30**) were:

- Wolfgang Spohn** (University of Konstanz, Germany)
Measuring ranks via the complete laws of iterated contraction
- Emil Weydert** (Luxemburg University, Luxemburg)
Ranking revision reloaded
- Pavlos Peppas** (University of Patras, Greece)
Semantics for relevance-sensitive belief revision
- Jim Delgrande** (Simon Fraser University, Canada)
Belief change and cryptographic protocol verification
- Randy Goebel** (University of Alberta, Canada)
Isn't it time to apply belief revision?
- Steven Shapiro** (University of Leipzig)
Dynamic interactions between goals and beliefs
- Gabriella Pigozzi and Leon van der Torre** (Luxemburg University)
Judgment aggregation
- Jérôme Lang** (IRIT – Toulouse)
From belief change to preference change
- Abhaya Nayak** (Macquarie University, Sidney, Australia)
Update and forget – an exploration
- Hans Rott** (Regensburg University, Germany)
Two-dimensional belief change.

Besides the formal talks, which were attended by all the participants, there were several discussions and active interactions among small groups of participants throughout the duration of the Workshop.

5. Conclusion

We found the Workshop successful, especially on the following two achievements: first, the seminar made participants aware of a commonality of interests across different disciplines; second, it suggested new directions for research that will probably be taken up by researchers in the next couple of years.

Where is the field going? We can mention at least two emerging issues:

- the field is broadening with respect to theoretical underpinnings and is beginning to incorporate notions from game theory and social choice theory. It is also broadening with respect to application areas, moving beyond traditional areas in AI and database systems, to include areas in description logics, the semantic web and economics.
- there is an emerging focus on epistemic notions having to do with communicating, negotiating, competing, and collaborating agents. Dynamic epistemic logic seems to have an important role to play here.

Moreover, it looks like belief merging and iterated belief revision are still hot topics and will remain so for the next few years.

For the future, we plan further workshops to encourage continued interdisciplinary interactions.

The organizers:

Giacomo Bonanno
James Delgrande
Jérôme Lang
Hans Rott