My primary research area is on modal logics for reasoning about information flow in multi-agent systems. However, much of my work has an inter-disciplinary character, touching on fields as diverse as Game Theory, Decision theory and Social Choice theory, Linguistics, Cognitive Studies, Artificial Intelligence, Quantum Physics and Quantum Computation, Epistemology, Foundations of Mathematics. This is apparent from my list of publications, e.g. Mathematical Structures in Computer Science, Bulletin of Symbolic Logic, Bulletin of Economic Research, International Journal of Theoretical Physics, Synthese etc.

1 Logical Models for multi-agent information flow

In a number of papers, starting with my 1998 joint paper with Moss and Solecki (A. Baltag, L.S. Moss, S. Solecki, 1998, “The Logic of Public Announcements, Common Knowledge and Private Suspicious” Proceedings of TARK’98, pp. 43-56.), usually referred to as the ‘BMS paper’, and continuing with a number of other papers throughout the last 11 years (e.g. A Baltag and L. Moss, 2004, “Logics for Epistemic Programs”, Synthese 139 (2): 165-224; A. Baltag, 2002, “A Logic for Suspicious Players: Epistemic Actions and Belief Update in Games”, Bulletin of Economic Research, 54 (1): 1-46; A. Baltag, B. Coecke and M. Sadrzadeh, 2007, “Epistemic Actions as Resources”, Journal of Logic and Computation 17 (3): 555-585; etc), I have developed a general logical setting for the analysis of communication, information update and belief upgrade in multi-agent systems. The BMS paper is considered one of the seminal papers that inaugurated the recently fast-growing area known as Dynamic Epistemic Logic (DEL). Indeed, the main features of the “BMS approach” (the notion of “epistemic action model” or “event model”, the “product update” operation and an axiomatization that refers to the “appearance” of a given action to an agent) are now considered standard basic features of DEL. While related to the work of Fagin, Halpern, Moses and Vardi, this approach has the advantages of modularity and compositionality, being applicable to open systems and being able to explicitly formalize and classify types of multi-agent information-changing actions (e.g. secret message passing, insecure communications, interception of messages etc).


2 Modal Logics for interactive belief revision

In more recent years, Dynamic Epistemic Logic has evolved towards a mutually beneficial merge with the older field of Belief Revision theory. My paper with Mehrnoosh Sadrzadeh (A. Baltag and M. Sadrzadeh, 2007, “The Algebra of Multi-Agent Dynamic Belief Revision”, Electronic Notes in Theoretical Computer Science 157 (4): 37-56) was one of the first contributions in this direction. My papers with Sonja Smets on the topic of interactive belief revision (A. Baltag and S. Smets, 2006, “Conditional Doxastic Models: A Qualitative Approach to Dynamic Belief Revision”, Electronic Notes in Theoretical Computer Science, 165: 5-21; A. Baltag and S. Smets, 2008, “A Qualitative Theory of Dynamic Interactive Belief Revision”, Texts in Logic and Games 3: 11-58; etc) have been very influential in this area. In particular, the paper “A Qualitative Theory of Dynamic Interactive Belief Revision” has been viewed by some influential authors as the key stepping stone towards unifying the ‘BMS’ approach with the Belief Revision theory; by replacing the (symmetrical) Product Update operation with the (asymmetrical) Action-Priority Update operation, this paper incorporates in a natural way within a DEL setting the main intuitions underlying the standard account (the so-called AGM approach) in Belief Revision theory.


3 Logics for Quantum Computation and Quantum Information Flow

In a joint paper with S. Smets (A. Baltag and S. Smets, 2005, “Complete Axiomatizations for Quantum Actions”, International Journal of Theoretical Physics 44 (12): 2267-2282, 2005), I developed an dynamic quantum logic, provided a model for quantum programs (in terms of
quantum transition systems) and gave a complete axiomatization for single-partite quantum systems; the last was the first such completeness result (with respect to Hilbert spaces) for an axiomatic-logistic setting. In subsequent joint papers (A. Baltag and S. Smets, 2004, “The Logic of Quantum Programs”, Proceedings of QPL’04 33: 39-56; A. Baltag and S. Smets, 2006, “LQP: The Dynamic Logic of Quantum Information”, Mathematical Structures in Computer Science, 16 (3): 491-525), we developed a multi-partite version of this logic to reason about quantum information flow in entangled systems. We used this logic for the formal verification of some protocols in Quantum Computation (e.g. Teleportation, Quantum Secret Sharing etc.). As far as I know, these were the first such quantum-protocol correctness proofs (fully formalized in a finitary axiomatic system, in principle implementable as a theorem prover) in the literature. In another joint paper with S. Smets (A. Baltag and S. Smets, 2009, “Correlated Information: A Logic for Multi-Partite Quantum Systems”, ENTCS), we restated this work as an “epistemic” logic for multi-agent systems, showing its connections with (as well as the differences from) the “classical” Dynamic Epistemic Logic and giving “epistemic” characterizations of quantum entanglement, Bell states etc.

4 Epistemology, Philosophy of Information and Philosophy of Science

In joint papers (A. Baltag and S. Smets, 2005, “What Can Logic Learn from Quantum Mechanics?”, Proceedings of ECAP 5; A. Baltag and S. Smets, 2008, “A dynamic-logical perspective on quantum behavior”, Studia Logica 89: 185-209; A. Baltag and S. Smets, 2009, “Quantum Logic as a Dynamic Logic”, to appear in Synthese), I used the above-mentioned quantum version of Dynamic Epistemic Logic to address an important debate in Philosophy of Physics, centered around two main questions: (1) what is the nature and the source of quantum “non-classicality”, and (2) does Quantum Mechanics force us to give up the classical laws of Propositional Logic? Our answers, based on our logical investigation, are that the main source of “non-classicality” of a quantum system is its non-classical logical dynamics, its non-classical dynamic behavior when it is subjected to observations; and that, as a consequence, the classical propositional laws governing “static” information are not in any way threatened, but they must be complemented by non-classical laws governing informational dynamics.

In a joint paper (A. Baltag and S. Smets, 2008, “A Qualitative Theory of Dynamic Interactive Belief Revision”, Texts in Logic and Games 3: 11-58), I provided a common setting (building on the work of Stalnaker) for formalizing both Keith Lehrer’s notion of “defeasible knowledge” and the standard Aumann-Hintikka notion of knowledge (which we call “irrevocable knowledge”). I investigated the logical properties of these two types of knowledge, characterizing them in terms of their different dynamics under belief revision. I gave a full axiomatization for the logic of these two “knowledges”, and showed that together (and only together) they can define the usual concepts of “belief” and “conditional belief”, as well as other doxastic attitudes such as “strong belief”. The epistemological lesson I extract from this seems close to (and yet is very far from) Williamson’s motto: Not “knowledge comes first”, but “knowledges come first”; and, at a deeper level, “knowledge dynamics comes first” (since the dynamics is what defines and distinguishes each type of knowledge).

These contributions are presented more extensively in my joint work with L. S. Moss and H. van Ditmarsch (A. Baltag, H. P. van Ditmarsch and L.S. Moss, 2008, “Epistemic logic and information update”, in Philosophy of Information, part of Handbook of Philosophy of
Science 8: 361-455), where the relevance of this work (as well as of other work in DEL) to epistemology and to a better understanding of the notion of information is made more explicit.

In my interview on epistemology with V. Hendriks and D. Pritchard (A. Baltag, “An Interview on epistemology”, Epistemology: 5 Questions: 21-38), as well as in my on-going work (A. Baltag, J. van Bethem and S. Smets, “A Dynamic-Logical Approach to Epistemology”, work in progress) with Johan van Benthem and Sonja Smets, I argue that Dynamic Epistemic Logic is of great potential value to epistemology: first, it shows the importance of dynamic epistemics; only by taking seriously (as DEL does) “epistemic events” as primitive logical notions (and as the original “sources” of our beliefs and the main “triggers” of belief revision) we can correctly understand and classify the various types and levels of “knowledge”. This leads to my proposal for an “Erlangen program for epistemology”: in the spirit of Felix Klein’s 1862 Erlangen program for mathematics, I argue that “static” epistemic notions and properties are best characterized in terms of their transformations, their potential dynamics. In the above-mentioned joint on-going work, we develop this program, by looking at various concepts of knowledge proposed by epistemologists, and investigating their specific informational dynamics. The other lesson that DEL can offer to epistemology is the primacy of “social” epistemics: the fundamentally social character of epistemic events. In contrast to the stress put by traditional epistemology on the knowledge possessed, acquired (or never reached) by an individual epistemic agent considered in isolation, DEL stresses the social aspect of learning by taking the epistemic interactions as the basis of epistemological inquiry. Moreover, in the mentioned joint work we argue that the dynamic and the social aspects are two sides of the same coin, by showing that a single agent’s belief revision after some new observation can be thought of as a form of “virtual interaction”, a type of virtual belief merge (between the old beliefs before the observation and the current beliefs about the observation).

5 Coalgebraic Logic, Non-wellfounded Set Theory, Logics for Simulation and Circularity

My PhD thesis (A. Baltag, STS: A Structural Theory of Sets, Ph. D. Thesis. Indiana University. Bloomington, Indiana USA, 1998) was concerned with developing a consistent Universal Set Theory (that extends Peter Aczel’s universe of non-wellfounded sets) using as its basis infinitary modal logic. In this view, “sets” are abstractions of observational processes, with “membership” being an abstraction of the one-step act of “observing further” an unknown structure, “unfolding it further” or “decomposing” it into its components. As “sets”, these structures exist (are defined) only up to observational equivalence, and thus can be best described in a language that is invariant under observational equivalence. Infinitary modal logic (where the modality is interpreted as talking about the components of the current structure) is arguably the most natural such language. I showed that the full Comprehension Axiom is consistent when applied only to predicates definable in infinitary modal logic. I also showed that, when applied to infinitary modal logic, a standard construction in Modal Logic (the so-called “canonical model”) gives us a model for this full Modal Comprehension axiom, and moreover this model provides an extremely rich universe of sets, one that refines the universal of “topological Set Theory” of Forti and Honsell. I used this model to give non-classical solutions to classical paradoxes, to prove fixed-point theorems that relate recursion
and corecursion, to formalize "super-large", reflexive categories and "super-large" circular models, and to provide "natural" solutions for domain equations.

One of my papers on this topic (A. Baltag, 1999, “STS: A Structural Theory of Sets”, Logic Journal of the IGPL 7 (4):481-515) was awarded the “Best Paper Award” at a major conference in modal logic (Advances in Modal Logic 1998).

My older results on non-wellfounded sets were extensively presented in the main textbook on the subject to date: J. Barwise and L. S. Moss, Vicious Circles, CSLI Publications, Stanford 1996 (in particular, in the chapter “Baltag’s Theorems”).

My work on coalgebraic simulation and on coalgebraic modal logic (A. Baltag, 2000, “A Logic for Coalgebraic Simulation”, ENTCS 33: 41-60, 2000; A. Baltag, 2003, “A Coalgebraic Semantics for Epistemic Programs” ENTCS: 82 (1): 315-335) proved to be fertile, inspiring a number of papers by leading researchers in the area (Bart Jacobs, Yde Venema).

6 Logics for Games

In one of my papers (A. Baltag, 2002, “A Logic for Suspicious Players: Epistemic Actions and Belief Update in Games”, Bulletin of Economic Research, 54 (1): 1-46), I formalized the notion of Nash equilibrium for games of imperfect information using a dynamic epistemic logic. As far as I know, this was the first time this key game-theoretical notion was captured in full generality in a completely formal modal-logic setting.

More recently, in joint work with S. Smets and J. Zvesper (A. Baltag, S. Smets and J. Zvesper, 2009, “Keep hoping for rationality: a solution to the backward induction paradox”, Synthese, 169 (2), pp. 301-333), I apply Dynamic Epistemic Logic to the problem of understanding rationality in Game Theory and finding natural epistemic conditions ensuring that a standard game-theoretic solution concept (the ‘backward induction solution”) is actually played. We analyze the so-called “backward induction paradox”, concluding that a fair treatment requires both a new concept of rationality (which we call “dynamic rationality”) and a new epistemic condition (“common stable true belief in dynamic rationality”), weaker than Aumann’s “common knowledge of rationality”. Investigating the dynamic fixed-point logics that arise naturally in this game-theoretic context is a work in progress (ongoing joint project with J. Zvesper).

7 Games for Logics

In addition to the above-mentioned work on coalgebraic game semantics for (coalgebraic) modal logic (A. Baltag, 2000, “A Logic for Coalgebraic Simulation”, ENTCS 33: 41-60, 2000), I can also mention my older work (A. Baltag, 1999, “Interpolation and Preservation for Pebble Logics” Journal of Symbolic Logic, 64 (2):846-858) on using games to show that a large of class of infinitary “pebble logics” with generalized quantifiers has a “generalized interpolation property” (in a sense that was first introduced by Barwise and van Benthem).