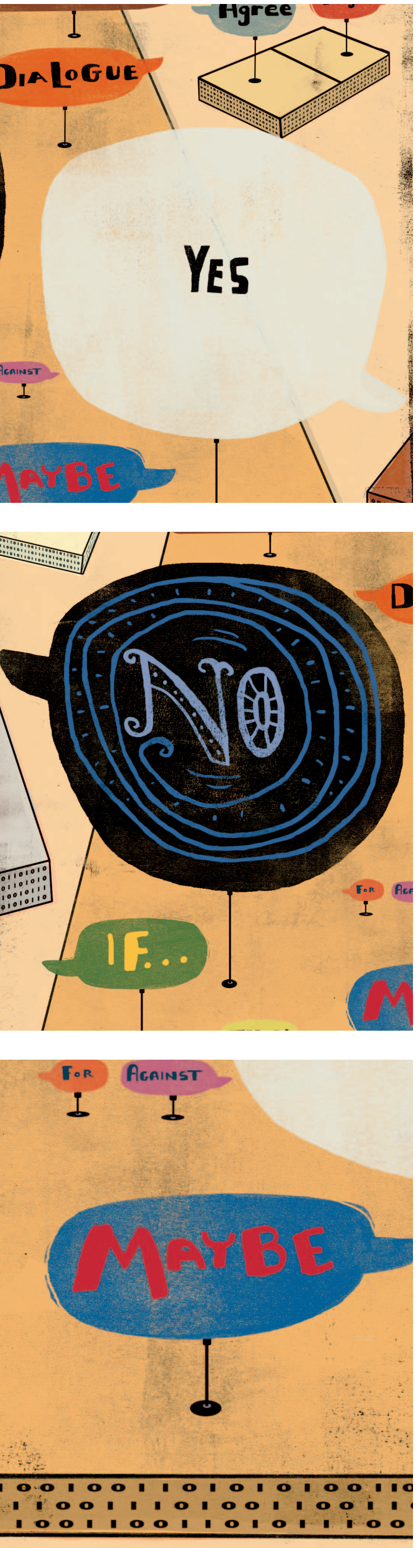

Argumentation Technology

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With the Internet's rise to prominence, we're moving to a new understanding of the nature of computation.[1] From the times of Leibniz and Babbage until the late 1950s, computation was understood as calculation, or the manipulation of numbers. Throughout the next decade (and still perhaps for many people), computation came to be understood as information processing, or the manipulation of data. With the rise of AI, logic programming, and expert systems, the idea arose of computation as cognition, or the manipulation of concepts. With the growth of the Internet and the World Wide Web, a new metaphor is appropriate: computation as interaction, or the joint manipulation of concepts and actions by discrete entities, both human and software agents.

To the extent that such agents are autonomous, no one agent can impose its will on another. To the extent that agents are intelligent, they will need to persuade one another to adopt particular beliefs or courses of action, or negotiate with one another to divide scarce resources between them. Such activities are examples of argument, which we might define as rational, or reason-based, interaction between autonomous and intelligent agents to achieve particular goals. Argumentation, the study of argument, goes back a long time. Aristotle, for example, wrote on the topic around 350 BCE,[2] starting a scholarly discourse that continued, with the help of Islamic and Roman Catholic philosophers, through the Middle Ages down to modern times. The study of argument by Indian philosophers has a similarly long history.

Applications of computer argumentation

Applications of argumentation technologies have developed over the last two decades. The first applications were primarily to expert systems and tutorial systems, explaining their recommendations or decisions.[3] Because of medical applications' prominence in early expert systems, it was perhaps natural that the main center for the initial development of argumentation technologies was the Advanced Computation Laboratory at the Imperial Cancer Research Fund (now called Cancer Research UK). The lab, founded and led by John Fox, was part of the the largest cancer research organization in Europe. Applications developed there included systems to advise doctors on patient-specific medications, including the arguments for and against each proposed medication, and systems to advise doctors and patients on the diagnostic testing and treatment of breast cancers. In this special issue, "Argumentation-Based Inference and Decision Making—A Medical Perspective," by John Fox, David Glasspool, Dan Grecu, Sanjay Modgil, Matthew South, and Vivek Patkar, reviews these and other medical applications.

It was a short step from these applications to systems undertaking automated argument generation concerning, for example, the toxicity properties of new chemicals or the possible health and safety risks of some new venture. In the absence of complete or accurate information, argumentation is a means to identify and organize what can be justifiably concluded, and to present it, systematically, to human users or to merge it with the justified conclusions of other machines. The DARPA-funded Genoa project was a similar attempt to handle incomplete and inconsistent information from multiple sources using argumentation to analyze all the information relevant to decision making during a foreign geopolitical crisis.[4]

These first-generation applications typically relied on relatively simple argumentation theories, which isn't surprising given that the formal theory of argumentation is still in its infancy. For the current state of argumentation theory, see the recent reviews by Carlos Chesñevar, Ana Maguitman, and Ronald Loui;[5] Henry Prakken and Gerard Vreeswijk;[6] and Trevor Bench-Capon and Paul Dunne[7] (the third review introduces a special issue of *Artificial Intelligence* on

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computational argumentation). The application of argumentation theories to real-world application domains involves a range of technologies. Such technologies include those for supporting the representation, elicitation, storage, manipulation, and presentation of arguments. In addition, we need technologies and frameworks for generating and considering arguments, engaging in argumentative interactions (with other machines or with humans), mediating between arguments, and resolving them.

In this issue

This special issue of *IEEE Intelligent Systems* contains articles covering many aspects of these technologies, often focusing on particular application domains.

Intrinsically, the argumentation process takes into account conflicting information. When multiple arguments for and against a particular claim are presented, it's important to reconcile these conflicts and calculate whether a given claim is acceptable. In "Computing Arguments and Attacks in Assumption-Based Argumentation," Dorian Gaertner and Francesca Toni present an algorithm for doing exactly this.

Two articles describe argumentation that supports medical tasks. The first is the article by John Fox and his colleagues that we mentioned earlier. They view argumentation as a means for inspecting and manipulating evidence and for supporting decision making. In "Portia: A User-Adapted Persuasion System in the Healthy-Eating Domain," Irene Mazzotta, Fiorella de Rosis, and Valeria Carofiglio present a system that uses emotional strategies to persuade users to adopt healthy eating habits. They elicited these strategies by analyzing a corpus of natural language messages, which highlighted that human persuaders employ emotional strategies far more frequently than purely rational ones. Emotional argumentation has received little attention in the literature, but an understanding of emotions in argument will be crucial for building systems that argue with humans.

Knowledge-based systems today often require a collaborative effort to engineer formal ontologies describing a domain. A central problem in collaborative ontology engineering is that views on how to best describe a domain often conflict. In "Argumentation-Based Ontology Engineering," Christoph Tempich, Elena Simperl, Markus Luczak, Rudi Studer, and H. Sofia Pinto present a framework and tools for supporting agreement in ontology-engineering discussions. They also report on case studies using these tools.

Research has been increasing on the semantic annotation of natural language arguments (for example, the Araucaria[8] and ArgDF[9] systems). This raises the question of how to structure user interaction with this kind of content, especially where different authors represent multiple annotated arguments. In "Dialogical Argument as an Interface to Complex Debates," Chris Reed and Simon Wells offer an approach in which the user mediates a virtual discussion between software agents representing different viewpoints. The discussion takes place through a dialogue game protocol, which also lets the user express his or her opinion while interacting with the system, thus facilitating further knowledge elicitation.

Argumentation also provides a rich, intuitive metaphor for interaction among distributed autonomous or semiautonomous entities, such as software agents and Web services. In "Argumentation in the Semantic Web," Paolo Torroni, Marco Gavanelli, and Federico Chesani present the ArgSCIFF architecture, which provides a framework for exploiting argumentation as a means for flexible interaction between Web services. The framework relies on an argumentation machinery based on the SCIFF (*iff* with *c*onstraints for agent *s*ocieties) Abductive-Logic-Programming framework. In "An Argumentation Framework for Communities of Web Services," Jamal Bentahar, Zakaria Maamar, Djamal Benslimane, and Philippe Thiran present a framework, based on Horn theory, for argumentation in Web services composition. They aim to enable Web services to persuade one another to join a community of Web services. The services negotiate the terms of service composition in peer-to-peer fashion.

In "Argumentation-Based Agent Interaction in an Ambient-Intelligence Context," Pavlos Moraitis and Nikolaos Spanoudakis further highlight argumentation's significant potential as a means for interaction among services. Their framework addresses conflicting views related to dealing with a user's physical impairments, in an ambient-intelligence context. When a user suffers from a combination of impairments, various assistant agents engage in argument-based interaction to agree on the user's needs.

Challenges

Bench-Capon and Dunne's review paper[7] provides an excellent outline of the key challenges facing argumentation theory in computer science and AI. In addition to the theoretical challenges they list, significant practical challenges to greater adoption of argumentation methods and systems also exist, some of which will require prior or simultaneous theoretical development.

We see six key practical challenges. First, frameworks and tools for diagrammatic representation of arguments and for automated reasoning over such representations are still in their infancy. Although published research on argument diagramming dates from Richard Whately's representation of 1836, John Henry Wigmore's legal charts of 1917, and Stephen Toulmin's influential model of argument of 1958, only recently have computer scientists explored this issue. As demonstrated in pure mathematics by Euclidean geometry and by category theory, human graphical reasoning over diagrams can involve sophisticated formal inference. Such reasoning over argumentation diagrams will need to be automated for the successful deployment of large-scale argumentation systems. Chris Reed, Douglas Walton, and Fabrizio Macagno provide a recent review of work in this area.[10]

Second, proven software engineering frameworks, methods, and tools specifically for designing and creating argumentation applications don't yet exist. While some combination of standard agent-oriented software engineering (AOSE) methods and knowledge-elicitation and knowledge-engineering methods might prove appropriate for the engineering of argumentation systems, this is by no means obvious a priori. To our knowledge, this area has seen no research. As with the development of AOSE methods and tools (which are themselves still in early development), this would require a mix of theoretical and practical work, with each aspect informing the other.

The development of the *Argument Interchange Format* (AIF),[11] an initial standard for the exchange of arguments between machines, is a major step toward automated exchange of arguments between intelligent software agents. Following from this work, a third challenge is to develop a sophisticated understanding of the properties of different agent interaction protocols and communication languages under different circumstances, and a good sense of when to use which protocol or language. This challenge will require considerable work—both theoretical and applied—to answer questions such as, what protocol should two agents use to undertake a negotiation, for example, and why? Should a negotiation always require the same protocol, or should the protocol depend on the type of negotiation, the number of participants, the nature of the resource or task being allocated, the time allowed, and so on? Associated with the properties of protocols and languages is the need to understand the strategies and tactics appropriate for participants under such protocols. Part of this understanding will arise from a better semantic understanding of the nature of argumentative interactions between multiple autonomous agents.

Fourth, as with knowledge engineering in general, most real-world application domains involve a surfeit of arguments and hence an argumentation-engineering bottleneck in the computational representation of arguments. Solutions to this bottleneck are required for argumentation systems' wide deployment and adoption. Perhaps the use of user-generated content and content annotation—such as folksonomies in semantic classifications—will help solve this challenge. The development of theoretical and software components that might enable this has commenced,[9] building on the AIF and exploiting Semantic Web technologies. The development of domain-specific frameworks, argument inference, and tools[12] will likely assist with this challenge.

Several of these challenges are part of a larger scalability challenge, which is fifth in our list. For argumentation systems to support, for example, millions of people engaged in deliberation about some matter of public policy, considerable work is needed to ensure that applications can scale. Prediction markets provide a means to organize the quantitative views of large numbers of people on some issue, such as the likelihood of increased interest rates or of an influenza epidemic. We desire similar systems that organize people's qualitative arguments and the justifications they hold for their views.

The sixth challenge is that the links between argumentation and other disciplines need attention for argumentation systems to find a permanent place in the ecosystem of intelligent computer systems. Examples include the relationships between argumentation and

- quantitative formalisms for representing uncertainty, such as probability theory and Dempster-Shafer theory;
- game theory, in systems with multiple, competing participants;
- political theory—for example, in systems supporting deliberative democracy; and
- organization theory—for example, in systems supporting collaborative work.

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In addition to much else, Aristotle was the founder of logic, which is the study of representations of certain kinds of arguments. If he and his colleagues had had to apply for research grant funding, they wouldn't have been able to point to early commercial spinoffs from their research. But spin-offs have eventually arrived. The development of the modern computer has been greatly influenced by developments in formal logic, and vice versa.[13] But if logic is the means by which computers think, then argumentation is the means by which intelligent computers interact, both with one another and with humans. We foresee a bright future for argumentation and argumentation technologies.

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