Recent Advances in Computational Models of Natural Argument

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Abstract. This paper reviews recent advances in the interdisciplinary area lying between artificial intelligence and the theory of argumentation. The paper has two distinct foci: first, examining the ways in which argumentation has inspired new models of logical and computational intelligence; and second, exploring how AI techniques have been used and extended to model and handle real world argument in a wide variety of domains including law, education, medicine and e-commerce.

1. Introduction

Our aim here is to give a brief overview of current research in the interdisciplinary area lying between artificial intelligence and the theory of argumentation. We begin with a summary of the background with pointers to earlier reviews, and then in that context, sketch the current landscape. The objective is to provide a backdrop against which the papers in this special issue might take centre stage.

There are two distinct ways in which AI has developed systems involving argumentation. The first is in using concepts and intuitions about argument to inspire and provide foundations for the development of formal systems (and often, specifically, formal nonclassical logics). This approach we might term, modelling *with* argument. A second approach is to construct models that reflect aspects of, or abstractions of, real world practices of argumentation between humans. This approach we might term, modelling *of* argument. In occasional places, the two come close, but for the most part, given research projects fit squarely into one approach or the other.

2. Modelling *with* Argument

2.1 History

Traditional symbolic AI models of reasoning are typically founded upon first order predicate calculus, or some subset thereof. Such first order reasoning systems, however, are obliged to make a number of assumptions: that a given problem is fully specified (such that the solution to a problem lies within the closure of the database of clauses); that the specification is consistent; and that any new facts which are introduced are consistent with the specification and do not lead to retraction of any propositions from it, that is, the accrual of new information is *monotonic*. Systems built upon these assumptions are inadequate for dealing with situations which are incomplete, uncertain, or dynamic.

Of course, many real-world situations are indeed dynamic, with reasoning systems building, perforce, uncertain and incomplete models of the world, due primarily to limited sensing abilities. To manipulate such representations of the world, a variety of *nonmonotonic* reasoning techniques have been proposed (for an introductory review see e.g. (Rich and Knight, 1991: 195-229)). These techniques have proved to be very successful, and have become more numerous and more refined as a result. There is, however. a relatively small number of key papers that, as antecedents, represent the main phyla of the current panoply of species of nonmonotonic reasoning. Reiter's (1980) *default logic* represents one of the first, and introduces the concept of reasoning in the face of default or presumptive information; McDermott and Doyle's (1982) *nonmonotonic* logic is the ancestor of modal interpretations of such reasoning; Reiter's (1978) reasoning with the Closed World Assumption tackles one of AI's oldest and thorniest problems, the *frame problem* (McCarthy and Hayes, 1969), its implementation as negation as failure (Clark, 1978) forms a cornerstone of logic programming in general and Prolog in particular, and a set of *circumscription* based techniques introduced in (McCarthy, 1986) and (Lifschitz, 1987) have more recently been used in components of a more general solution to the frame problem in the context of "cognitive robotics" (Shanahan, 1997). What is remarkable is that each of these apparently different techniques (and thereby their many modern descendants) have been brought together as specialisations of a formal framework described by its authors as an *argument system* (Lin and Shoham, 1989).

The theory is based upon a logic programming style predicate logic language (where expressions are either atomic or rules of the form $A_1, ..., An \quad B$) extended with the connective, from which are formed 'nonmonotonic rules' (the work does not assume truth functional semantics). From a set of 'deductive' and 'nonmonotonic' rules, it is then possible to define *arguments* as trees with just two layers; at their single root a conclusion, and at the leaves, atomic facts or arguments supporting the conclusion through the rules. Using just these concepts, which they term collectively an *argument system*, Lin and Shoham proceed to capture each of default logic, nonmonotonic logic, negation as failure, and circumscription as examples of argument systems (1989: 247-253).

Lin and Shoham make no claims about - indeed, no mention of - the relationship between their abstract notion of an argument system and real argument; the latter seems to have given brief insight at the work's inception. In their definition of an argument system, they include demands that all base facts be included, that all deductively valid inferences be executed and included, and that inconsistency is barred. Clearly, these are not generally features of real argumentation.

2.2 Development

Two later landmarks aimed to bring formal models of argumentation closer to real world practice. The first is Krause *et al*.'s (1995) *logic of argumentation*, LA, that uses a labelled deductive system to support the construction of an *argumentation theorem prover*, ATP. One feature of argumentation focused upon in LA is the variety of means by which arguments can be aggregated: with various arguments lending support to or detracting from a proposition, there is a problem of how to combine the information into an evaluation with respect to that proposition. Krause *et al*. define means of aggregation that work over arbitrary dictionaries of argument strength, including binary, multi-valued and probabilistic approaches. They extend their account to develop *acceptability classes* of arguments, from arbitrary well formed arguments, through consistent arguments, then arguments with no rebutters, then arguments with no defeaters of any sort, and finally, logical tautologies. They then associate linguistic terms (supported, plausible, probable, confirmed, certain) with these classes, in a drive to bring together cognitive science analyses and formal rigour.

Dung's (1995) work, can be seen as an extension to that of Lin and Shoham. Dung's notion of an *argumentation framework* is similar in scope to that of a Lin and Shoham argument system, but it does not specify the internal structure of an argument (rather, an argument is seen as synonymous with the conclusion it tries to establish), and it also introduces *attacks* - ordered pairs of arguments in which the first "represents an attack against" the second. Upon this foundation, Dung proceeds to define two key concepts: first, the *acceptability* of an argument *A* with respect to a set of arguments *S* - that for all counterarguments against *A* there are counter-counterarguments in *S*; and secondly, the *admissibility* of a set of arguments *S* - just in case each argument in *S* is acceptable.

The theory that Dung develops is then shown to be a powerful tool in addressing an important class of problems in game theory. Finally, Dung claims that a range of nonmonotonic reasoning systems are in fact forms of argumentation, and goes in to some detail in the case of default logic, negation as failure, and Pollock's (1987; 1991; 1994) theory of defeasible reasoning. Like Pollock, Dung is motivated by every-day human argument, claiming in his introduction that the "theory captures naturally the way humans argue to justify their solutions to many social problems" (p324), and then that the work constitutes "a formal account of the principle of argumentation".

2.3 Recent Advances

There is a wide range of formal techniques founded upon these two approaches: (Vreeswijk, 1997), (Kowlaski and Toni, 1996), and (Bondarenko *et al.*, 1997) have been particularly influential, and two excellent reviews of recent work can be found in (Chesñevar and Maguitman, 2000) and (Prakken and Vreeswijk, 2002a). Three areas justify further brief mention here.

The first is the structuring of communication protocols for interaction between software agents. One of the earliest examples, (Parsons and Jennings, 1996) grew from the work on LA (Krause *et al*. 1995) introducing a distributed component, demonstrating how arguments (in the LA sense) could be exchanged between agents that maintained discrete belief databases. The acceptability criteria could then be operationalised by agents in order to judge (at least in part) whether incoming arguments should successfully change the agent's beliefs or not. Similarly, work has also extended the Dung approach, with Amgoud and Cayrol's (2002) model of argument exchange building directly upon Dung's notion of acceptability, and Kakas *et al*. (2005) using the Dung model as a foundation for protocol specification. Various rhetorical notions (such as the appeals *ad*) have also inspired multi-agent implementations, from Sycara's early work (1990) founded on simple intuitions about rhetotorical appeals, through to detailed accounts of persuasion such as (Ramchurn *et al*., 2003; Bentahar *et al*., 2005a).

The general approach has been developed and extended to cover negotiation in (Parsons *et al*. 1998). Argument-based negotiation, as distinguished from game-theoretic approaches characterised by weightier assumptions and more specific, less flexible communication, has become a key area of development (Jennings *et al*., 1998; Maudet, 2003; McBurney *et al*., 2003; Rahwan, 2005; Karuntillake and Jennings, 2005). But as recognition of Walton and Krabbe's (1995) dialogue typology, and then Walton's (1998) explication of it, has started to filter through to multi-agent systems research, the latter started to introduce machinery for handling additional dialogue types, and then for exploiting the very fact that different types of dialogue may be available. Thus Dignum *et al*. (2001) explore a number of different types of dialogue, including information-seeking and persuasion (including Walton and Krabbe's specialisation, 'rigorous persuasion'), Atkinson *et al*. (2005) focus on persuasion, McBurney *et al*. (this volume) explore deliberation, and Reed (1998) explores mechanisms by which dialogues of different types can be bid and accepted, and how one dialogue can be functionally embedded in another. Indeed, the proliferation of research in the area led to a specification of desiderata for agent argumentation (McBurney *et al*., 2002), and comparative work has been carried out in (Norman *et al*., 2003) and (McBurney and Parsons, 2002).

One criticism of this approach is founded upon a problem of verification described in (Wooldridge, 1998). One of the fundamental tenets of agent theory is the autonomy of agent activity: it is an anathema to many researchers to require direct access to agents' internal states – such access should instead, it is argued, be mediated through the agent communication language. Unfortunately, if it is exactly that communication language that is under investigation – particularly if the aim is to assess an agent's compliance with the specification of such a language – then using the language itself to carry out the investigation leads to a regress. (So, for example, if a part of the specification of an communication language's *inform* primitive is that an agent is sincere, then inquiring of an agent if it is, in fact, sincere might elicit an *inform* in response – and there is no way of knowing if that inform is sincere). This conundrum has led to a proposal for the definition of agent communication languages built not on mental states, but (at least partly) in terms of externally visible and verifiable commitments. Such a commitment-based approach has examined extant commitment-based dialogue models (Hamblin, 1970; Krabbe, 1985; Mackenzie, 1990; etc.) for means of constructing conversation protocols. The leading proponent of the approach is Singh: in (Singh, 2000) he introduces a tripartite commitment structure, that in (Yolum and Singh, 2002), *inter alia*, is developed and implemented. One of the aims of the work – to handle the problem of verification – is then explored in more detail in (Venkatraman and Singh, 1999). The flow of commitment change in agent communication has been explored using CTL* in (Bentahar *et al*., 2005b). A review of some of this work can be found in (Maudet and Chaib-draa, 2002). Propositional commitment in this sense is increasingly a cornerstone of agent-based argumentation, with traditional theories of dialectic systems being implemented more or less directly. With McBurney's desiderata for agent argumentation comes, therefore, the need for evaluative and comparative metrics for dialectic systems, which are just starting to be explored (Parsons *et al.*, 2003; Wells and Reed, 2005).

The second, and emerging area of recent work is in using argument-based techniques for belief revision. So for example, dynamic environments that can be sensed require complex reasoning to maintain an accurate belief database, and Capobianco *et al*. (2005) use argument structures in a defeasible reasoner to achieve this. Argument-based protocols can be harnessed for structuring belief revision (Malheiro and Oliveira, 2001), and argumentation internalised for solo-agent belief revision (Paglieri and Castelfranchi, 2005).

Finally, a specific class of AI models of reasoning – those based on Bayesian probability – are also being extended through argumentation structures. One of the most sophisticated is Vreeswijk's (2005) Bayesian belief network into which has been introduced Dungian style notions of argument, attack and defeat. Das (2002) takes a similar tack, but founded upon LA. Gratton (2002) offers a probabilistic account specifically of counterargumentation, and Saha and Sen (2005) use Bayesian belief models to execute decision making during the course of argumentation.

3. Modelling *of* Argument

One key area of application of these nonmonotonic logics is in representing legal reasoning, where defaults and defeasibility of rules have close analogies in the law, and where there are established procedures for the relative prioritisation of conflicting rules. An early model of this kind is offered by Loui (1987), in which a concept of defeat between arguments is developed which closely matches legal practice, involving directness, specificity and preferences between inferences. It is here too that formal models of burden of proof (e.g. (Farley and Freeman, 1995)), prima facie reasoning (Verheij, 2003a) and case-based reasoning (Skalak and Rissland, 1991) occur, complementing more pragmatic avenues followed in argumentation theory typified by (Walton, 2002). A comprehensive review of legal systems using models of argumentation is provided in (Bench-Capon *et al*., 2003).

At the less formal end of the spectrum, there are a variety of models and systems that employ argumentation to structure and support interaction with a variety of stored data. Such 'knowledge engineering' has enjoyed significant success. One good review is offered in (Carbogim *et al*., 2000); here the focus is maintained upon the major landmarks. One of the earliest analyses is in Birnbaum's (1982) analysis of *argument molecules*, which touched briefly upon many of the central issues in argumentation theory, including the structure of argumentation schemes, of diagramming, and of argument contexts. The similarly rich model of representation put forward in (Alvarado *et al*., 1990) includes a variety of structures based upon a mentalistic account of the writers and readers of Comment pages in newspapers. Sillince and Minors (1992) provide yet another argument representation language, focusing upon handling field-dependent argument strength, providing what Krause *et al*. (1995) would regard as a data dictionary for evaluation. In some cases, argument based knowledge engineering has been driven by specific applications, with good examples in safety critical computing, where Bayesian models have enjoyed particular success (Fox and Das, 2000; Gurr, 2002).

One problem with many of these approaches throughout AI is that they focus exclusively upon the structure of argument, with a functional analysis of an argument's components, and a means of evaluating or classifying argument parts and wholes. From an argumentation-theoretic point of view, they focus upon the sort of argument that one offers, or puts forward – not the sort of argument in which people engage. That is, in the terminology of O'Keefe (1977), these models focus upon $argument_1$, the argument 'product', ignoring the fact that arguments are also identified, in common parlance, with a type of interaction – the process of $argument_2$. Formal models of the process of argument are common in argumentation theory as an upshot of research into the rules governing fallaciousness, with early work by Hamblin (1970) Mackenzie (1981), and Woods and Walton (1978), and formal properties explored by Krabbe (1985).

In AI, process oriented models of argument are much rarer. One notable exception is (Brewka, 2001) which employs the situation calculus (McCarthy and Hayes, 1969) to characterise contributions from interlocutors. Within AI and law, the nature of the domain suggests a greater emphasis on dialogic models. Thus, Gordon (1995), in his Pleading's Game, includes turn taking between Plaintiff and Defendant as a fundamental component in a model that also integrates abductive reasoning and a defeasible interpretation of Toulminian warrants (1958). Prakken (2001) models the disputational status of claims as the dialogue proceeds, labelling moves as 'in' or 'out' according to dialogical rules (in effect, he is implementing a substantial part of what Walton and Krabbe (1995) describe as *stability adjustments*). AI models of the dynamic processes in argumentative exchange have been termed *computational dialectics*, with early workshops on the topic at AAAI94 and FAPR96 exploring many of the themes that now characterise the full range of computational models of, and with, argument.

Similar techniques have also been used for supporting argumentation in a variety of other domains. Gordon's own subsequent work on the Zeno system (Gordon and Karacapilidis, 1997) offers a good example, but systems that offer generic support for various forms of argument are quite widespread. One of the earliest is Matwin *et al.*'s (1989) Negoplan, that provided expert system support for negotiation in particular, and many more recent systems have focused on argumentation as a mechanism for supporting and interacting with predominantly human negotiation and decision making (Girle *et al.*, 2003; Prakken and Vreeswijk, 2002b). More recent research been focused specifically upon the online community, with applications developed for e-democracy (Gordon and Richter, 2002); (Atkinson *et al.*, 2004) and online dispute resolution (Lodder, 2001) with popular implemented and deployed solutions such as SmartSettle (see www.smartsettle.com). The gIBIS system (Conklin and Bergman, 1988) was developed in an attempt to structure policy discussion (or what Walton (1998) would probably term 'deliberation'), using Rittel and Webber's (1973) IBIS information structures.

One novel emphasis in the gIBIS work is upon diagrammatic presentation of the information to facilitate navigation, summary and interaction with arguments in a complex domain. Diagrammed arguments have been demonstrated to be useful tools for summarising a range of topics (Horn, 1998), and have an important role to play in education (Brna *et al*. 2001), so it is not surprising, therefore, that one very active area of recent research has explored computer-based models of argument diagram generation. The overview presented by (Kirschner *et al*., 2003) covers many recent developments. Examples include Reason!Able (van Gelder, 2001) aimed at teaching, Araucaria (Reed and Rowe, 2004) aimed at research and corpus mark-up, ArguMed (Verheij, 2003b) aimed at legal argument, and ClaiMaker (Li *et al*., 2002; Buckingham Shum *et al.*, this volume) aimed at organising academic documents in a semantically rich network. As with all diagramming, one of the most important challenges is to determine the level of detail that is included in a diagram, and in the way that diagramming is carried out. There is a fundamental trade-off between, on the one hand, the complexity of the diagram (and consequently of the interface required to produce it), and on the other, the clarity of that diagram (and simplicity of the interface). Of course, greater complexity allows greater flexibility, expressiveness and generality. For the most part the designers of these systems have selected a particular point of trade-off between expressiveness and simplicity, determined in large part by the intended use and users.

One potential extension to these systems of diagramming which is particularly liable to reduce clarity is the ability to handle dialogue. At the time of writing, there is no good method for diagramming complex dialogic argument, though work is underway in a number of areas to abstract from the detail of dialogue to provide useful starting points for computational interpretation – a good example is Mann's (2002) work on Dialogue Macrogame Theory, Krabbe's (1999) work on Profiles of Dialogue, and the directions indicated by work based in monological models such as (Kirschner *et al*., 2003) and (Reed and Rowe, 2004). Further work at the boundaries between diagramming, AI, argumentation theory and discourse analysis is required to tackle the problems presented by dialogue.

Teaching (or rather, learning) of both argumentation and domain-specific skills can also be supported through dialogic models of argument. Thus (Pilkington *et al*., 1992) offers an early example of the use of a dialogue model in teaching in the medical domain and (Suthers and Jones, 1997) in other science domains. Mackenzie's (1979) DC system was adopted as the framework, around which a combination of strategies were implemented in an attempt to (partially) automate pedagogic interaction. This work was then subsequently extended to other domains in (Hobbs and Moore, 1996). DC's shortcomings with respect to educational dialogue have been tackled in a series of papers arising from that work that develop a model of a derived system called DE (Yuan *et al.*, this volume). Finally, even duplicitous argumentation can be used in support of educational goals (Carofiglio and de Rosis, 2001; Sklar *et al*., 2005) – though the ethical implications of computer systems that argue untruthfully are complex (Crosswhite *et al*., 2003).

In yet other domains, more ad hoc models of argument are used as motivation and scaffold for computer assisted learning systems: the CATO system in law (Aleven and Ashley, 1994); Cavilla-Sforza *et al*.'s (1993) tools for teaching science (and in particular, the dialectical nature of scientific development – they use paleontology as a case study), the DREW system (Baker *et al*., 2002) again for scientific discussion, and the mathematical proof explanation and hinting system *P. Rex* (Fiedler and Horacek, this volume) Finally, argumentation is also employed pedagogically in areas in which the textual form of presentation is crucial. Health education is a canonical example. Grasso's (Grasso, 1998; Grasso *et al.,* 2000) DAPHNE system, for example, exploits argument schemas offered in (Perelman and Olbrechts-Tyteca, 1969) to persuade users to adopt healthier nutritional lifestyles; Reiter's (2000) STOP project follows a similar path, but is situated in a realistic domain, replete with length limitations and non-textual data, used to produce letters that are tailored to particular audiences to encourage them to stop smoking.

The emphasis on presentation of information is typical of systems that include a natural language generation component, and it is not surprising that ideas and theories of argumentation have been brought to bear throughout the area. Natural language processing offers a prime example of early research in AI that explores argumentation. In a technical report, Kamp (1969) focuses upon the problem of a logical interpretation of enthymemes – one that has taxed philosophers of argument for some time (see, e.g. (Hitchcock, 1985)). Since then, computational systems for building arguments of one sort or another have been relatively common. Reichman's (1987) model focused on a stack model of the shifts in topic during an argument, rather like the dynamics prescribed by logics of dialogue (Krabbe, 1985). A more product-oriented view is put forward in (Cohen, 1987), in which the structure of large arguments is used as a basis for determining the linguistic coherence of the textual expression of those arguments. Maybury (1993) develops a plan-based account with individual plan operators such as 'convince' built on definitions of the mental states of the speaker and hearer. A hybrid of these approaches was put forward in (Reed, 1999) that built Cohen-like structures from Maybury-like plan operators. Elhadad (1995) takes a somewhat different approach, based upon Anscombre and Ducrot's (1983) theory of argument according to which the argument generation process is seen as one of managing topoi-based and lexical-based constraints. Gilbert *et al*. (2003) construct a broad architecture for argument based HCI integrating both natural language understanding and generation part employing both operator composition and constraint management. Finally, Zukerman *et al.* (1999) demonstrate a model for producing “nice” arguments based on a Bayesian underpinning, and Carenini (2001) follows a similar path based his GEA system upon decision trees. Green's model (this volume) also uses a Bayesian characterisation as a part of argument generation in the domain of genetic counselling. Finally, Carofiglio and de Rosis (Carofiglio and de Rosis 2001; Carofiglio, 2004) combine a Bayesian underpinning with Toulmin (1958) structures to tackle representation of uncertain information. All these various systems are founded upon the assumption that argumentation offers a relatively simple and intuitive means of presenting complex information at the human-computer interface.

One remarkable feature in this work has been a focus upon structural components of argumentation in a highly logical style. Relatively little work has focused upon the rich body of research in rhetoric and the heuristic structures and audience-centered approach developed there, including, as a prime example (Perelman and Ohlbrects-Tyteca, 1969). This, despite the fact that a very wide potential role has been described for 'technologies of persuasion' in AI and computer applications in general (King and Tester, 1999). Notable exceptions to the trend include Grasso (1998; 2002) who has worked at bringing rhetorical concepts and analyses to bear on operational problems in language generation; Bench-Capon (2002; 2003) who introduces values into formal models of argument to account for persuasive structure; (Reed, 1999) in which a wide range of specifically rhetorical moves are characterised as planning operators; and (Crosswhite *et al.*, 2003) in which formal systems of context are harnessed to represent and reason about structures of rhetoric. Tapping in to the emotional component or “mode” of argument (Gilbert, 1997) is similarly sparsely explored, with some tentative explorations in (de Rosis and Grasso, 2000; Gilbert and Reed, 2002; Guerini *et al.*, 2003; Carofiglio and de Rosis, 2004). A similarly surprising omission is the growing tradition of pragma-dialectics (Eemeren and Grootendorst, 1992), which, as it is founded in speech act theory, might be expected to offer a good fit for speech act based computational models of natural language processing.

There are, finally, three particularly striking outstanding issues that cut right across models of argument oriented towards knowledge engineering, towards natural language processing and towards agent communication. The first issue is the rather narrow view taken of argument structure: Snoeck Henkemans (2000) points out, in a tradition following (Freeman, 1991; Yanal, 1991) and many others, that the identification of 'an argument', and the means by which basic components can be composed into linked and convergent structures, are far from satisfactory. Many areas within AI might be well placed to contribute to this discussion. The second issue is the mechanism by which argumentation is driven. The goal machinery that leads to arguments being automatically generated has been only briefly touched upon (Gilbert, 2001; Norman *et al.*, 2003; Amgoud and Kaci, 2005), and yet is clearly fundamental to the endeavour. The challenge entails specific problems in architecture design, natural language production, knowledge representation, practical reasoning and so on. The third issue is the potential for use of argumentation schemes (Walton, 1996; Eemeren *et al.* 1992). In almost all of the areas of AI in which argumentation has acted as a catalysis for development of new techniques and approaches, there have been nascent concepts of stereotypical patterns of argument, developed on an ad hoc and intuition-driven basis (Bex *et al*., 2003; Reed and Walton, 2005; Verheij, 2003c). As research effort within argumentation theory turns to such scheme-based reasoning, the potential for collaboration and cross-disciplinary utilisation becomes much greater, with the potential to develop in tandem both theoretical and implemented models of argumentation schemes.

Concluding Remarks

This review offers a brief insight into the breadth of computational models of argument, both in AI's modelling *with* argument in formal systems, and its modelling *of* argument in a more or less naturalistic style. The breadth of work covered here represents reasonably accurately the breadth of the workshop series in *Computational Models of Natural Argument*, which was hosted with ICCS in its first year, and alternately at IJCAI and ECAI thereafter. The papers in this special issue represent resubmitted and revised versions of a subset of the papers at the first three of those workshops from 2001, 2002 and 2003, and naturally provide depth in a few of those areas.

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