The Knowledge Engineering Review, Vol. 26:2, 159–174.
doi:10.1017/S026988891100004X

Informal logic dialogue games in human–computer dialogue

TANGMING YUAN[1], DAVID MOORE[2], CHRIS REED[3], ANDREW RAVENSCROFT[4] and NICOLAS MAUDET[5]

[1]*Computer Science Department, University of York, Heslington, York YO10 5AT, UK;*
e-mail: tommy@cs.york.ac.uk;
[2]*School of Computing, Faculty of Arts, Environment and Technology, Leeds Metropolitan University, Beckett Park, Leeds LS6 3QS, UK;*
e-mail: d.moore@leedsmet.ac.uk;
[3]*School of Computing, College of Art, Science and Engineering, University of Dundee, Dundee DD1 4HN, Scotland;*
e-mail: chris@computing.dundee.ac.uk;
[4]*Learning Technology Research Institute (LTRI), Faculty of Art, Humanities, Language and Education, London Metropolitan University, London, E2 8AA, UK;*
e-mail: a.ravenscroft@londonmet.ac.uk;
[5]*LAMSADE Laboratory, University Paris 9 Dauphine, 75775 Paris Cedex 1, France;*
e-mail: maudet@lamsade.dauphine.fr

Abstract

Informal logic (IL) is an area of philosophy rich in models of communication and discourse with a heavy focus on argument and 'dialogue games'. Computational dialectics is a maturing strand of research that is focused on implementing these dialogue games. The aim of this paper is to review research on applying IL dialogue games into human–computer dialogue design. We argue that IL dialogue games tend to have a number of attractive properties for human computer dialogue and that their computational utilization in this area has been increasing recently. Despite the strength of the case for IL, a number of important barriers need to be overcome if the potential of IL is to be fulfilled. These barriers are examined and means of overcoming them discussed.

1 Introduction

Human–computer dialogue design encompasses two broad issues. The first concerns the manner in which the user will interact with the machine, whether, for example, they will be presented with a menu of options, a command line interface, or some form of question–answer interaction. The second area concerns the attempt to emulate dialogue of the sort engaged in by human conversants, in which topics of mutual concern are discussed, and in which each conversant has substantive points to make. The interest of this area is in the content and form of the dialogue, rather than the manner of its physical implementation. It is the second area with which we are chiefly interested in this paper.

There are at least two approaches to dialogue design, including the computational approach and the philosophical approach. Conjoining these two, compared with linguistic approaches, in the ways we propose is original and timely. The computational approach focuses on specification of protocols, for example, in the context of multi-agent systems (MAS) communication. FIPA specifications (2002) offer a number of examples expressed using AUML (agent unified modeling language) interaction diagrams (i.e. `www.auml.org`). For the task at hand, the computational approach falls short in several respects. The focus in the computational approach has, for obvious reasons, been placed squarely upon the design of a clear and unambiguous means of multi-agent communication, rather than upon modelling real world communication. This means that MAS models are poorly suited to being extended to handle the intelligent mediation of human–human or even human–computer interaction. Further, there are also computational limitations to implemented systems. One of the most crippling of these limitations is that the finite state machine approach, which is common throughout models of agent communication, is inflexible and limited. The philosophical approach utilizes 'Dialogue Game Theory' models developed within the field of Informal Logic (IL) to prescribe how dialogue should be regulated. It is the second approach in which we are chiefly interested. In particular, we discuss the role of IL as a vehicle for the conduct of significant aspects of dialogue as so defined.

The paper is therefore organized as follows. We start with a brief overview of the field of IL and Dialogue Game Theory in particular. We then present a case for the use of IL within human–-computer interaction (HCI), and an overview of current systems utilizing IL theories. Despite the strength of the case for IL, however, we argue that a number of important barriers need to be overcome if the potential of IL is to be fulfilled. The remainder of the paper outlines how current research, by the authors and others, is attempting to overcome these barriers.

2 Basics of informal logic

The field of IL can be seen as an attempt to develop tools that can analyse and evaluate the reasoning and arguments that occur in contexts such as education (e.g. Andrews, 1995; Jackson, 1998; Ravenscroft, 2007), political debate, and legal proceedings (e.g. Walton, 1989b; Fisher, 2000; Johnson & Blair, 2000). Johnson and Blair (2000) identify 14 recent areas of research in IL and Groarke (2002) suggests that three approaches to IL can be characterized, concerned with fallacy theory, rhetoric, and dialogue. The last of these is often referred to as 'dialectics' (e.g. Walton, 1998) and has been of much recent interest to people working in human–computer dialogue and in artificial intelligence (AI; cf. Vreeswijk *et al.*, 2003; Reed & Grasso, 2007; Rahwan & McBurney, 2007). Gordon (1996), for example, speaks of 'computational dialectics' as a new subfield of AI, and Bench-Capon and Dunne (2007) claim that 'argumentation has come to be increasingly central as a core study within Artificial Intelligence'. Further, Computer-supported collaborative argumentation (CSCA) has become an established subfield of computer-supported collaborative learning (CSCL).

A common approach within dialectics is to construct *dialogue games* (e.g. Hamblin, 1971; Walton, 1984; Mackenzie, 1990; Loui, 1998). A dialogue game can be seen as a prescriptive set of rules, regulating the participants as they make moves in the dialogues. These rules legislate as to permissible sequences of moves, and also as to the effect of moves on participants' 'commitment stores', conceived as records of statements made or accepted. Some dialogue games also include challenges and other locutions among commitments, for example, Mackenzie (1979). Such dialogue games have received much recent interest from the AI community and much of the current paper will be concerned with them. A thorough review of dialogue games can be found in Prakken (2006) who explicitly focuses on games for persuasion (our focus here is somewhat broader) and provides a very useful example dialogue to which he applies various dialogue game models.

One such game, for example, is 'DC' (Mackenzie, 1979), a system that has received much attention as a vehicle for interactive computer systems (e.g. Moore & Hobbs, 1996; Amgoud *et al.*, 2000; Maudet & Moore, 2001; Yuan *et al.*, 2007a, 2008; Reed & Wells, 2007). The system allows five move types: statement ('P', 'Q', etc., and their truth functional compounds), withdrawals (e.g. 'no commitment to P'), questions ('is it the case that P?'), challenges ('why is it held that P?'), and resolution demands ('resolve whether P'). There are four rules regulating commitment stores, which are as follows. Stores are null at dialogue commencement. Statements by either participant are added to the store of each. A statement P in response to a challenge of Q results in both P and $P \rightarrow Q$ being added to each store. A challenge of P results in P being added to the store of the hearer, and P being removed from, and why P is being added to, the store of the maker of the move.

There are six dialogue rules, specifying the protocol under which dialogue takes place, as follows. Participants may utter individual permitted locutions in turn. Mutual commitments may not be uttered. The question 'P?' must be answered by 'P', 'not P', or 'no commitment P'.

The challenge 'why P?' must be responded to by a withdrawal of 'P', a statement not under challenge by its speaker, or a resolution demand of any commitments of the hearer which immediately imply 'P'. Resolution demands may be made only if the hearer is committed to an immediately inconsistent conjunction of statements, or withdraws or challenges an immediate consequent of his commitments. A resolution demand must be followed by withdrawal of one of the offending conjuncts, or affirmation of the disputed consequent.

We argue that dialogue games developed within the field of informal logic, such as the one just outlined, tend to have a number of attractive properties for human–computer dialogue.

3 A case for the use of informal logic in human–computer dialogue

The essential argument for the adoption of a dialogue game framework is that the games purport to be models of 'what is fair and reasonable in argument and criticism' (Walton, 1985; cf. Prakken & Sartor, 1996; Loui, 1998; Bouwer, 1999). Given this, then constraining both computer and user to such a game will, if the game is valid, yield—or at least encourage—'fair and reasonable' dialogue, and this presumably is what is sought especially in human–computer dialogue and educational dialogue. And since it has been shown (Amgoud *et al.*, 2000) that the DC model sketched above, for example, can cater for Walton's six basic types of dialogue, namely persuasion, negotiation, inquiry, deliberation, information-seeking, and eristic dialogues (Walton & Krabbe, 1995; Walton, 1998, 2000), this would represent a considerable broadening of human–computer interaction, especially when considered with the work of Ravenscroft *et al.* (2008), which has extended the usability of dialogue games to realize semi-natural and informally logical dialogue interaction.

Further, such a model has a number of desirable properties from the computational perspective. The model's rules can be used to establish the legality of user input, and to assist in formulating a response by restricting attention to the set of legal moves, thus guiding the dialogue beyond a single question/answer interaction. The rules of the model are typically quite tight (cf. Reed, 1998): they can prescribe as few as three types of responses to an incoming move type, thus easing the task of checking for legality, and reducing both the search problem for the computer's rejoinder and the strategic issue of selection between competing alternatives. Thus, as argued by Hulstijn (2000), dialogue game rules can be regarded as 'recipes for joint action' between the dialogue partners.

The games' concern with modelling *commitment* rather than *belief* (Walton, 2000; Lewin, 2000) is also attractive from a computational perspective. Commitments are incurred during the dialogue, in line with clearly stated commitment rules, and the resulting 'commitment store' is seen not as a psychological model of memory, but rather as akin to a publicly inspectable set of statements recorded on a slate (Hamblin, 1970; Mackenzie, 1979). This separation of commitment from belief has the advantage that it obviates the need for sophisticated models of belief, knowledge, and sincerity in the context of dialogue. Further, the explicit nature of the commitment function aids computational utilization, and since at any stage the number of entries in a store is at most twice the number of moves made to that stage in the dialogue, combinatorial explosions of commitments cannot occur (Mackenzie, 1990). Neither do the models require consistency of commitments—inconsistency is allowed, after which the other dialogue participants may demand retraction of one of the sources of the inconsistency (Prakken, 2000).

The characterization of dialogue moves is also advantageous from the computational point of view, for several reasons. For one, the content of a move is often restricted to one 'locution', that is, a statement together with a statement operator (e.g. assert, question, and withdraw). This has the computational advantage of avoiding complexities such as deciding on a practical length for turns (Clark & Schaefer, 1989), or formulating a turn-length control policy (Frohlich & Luff, 1990), and difficulties involving moves spanning more than one speaker turn (Reichman, 1985). Further, the restricted range of move types allowed by the games makes it possible to use a menu scheme for user input and enables relatively straightforward checks on the legitimacy of input.

Perhaps the main computational attraction, however, is the clarity and expressiveness provided by the moves. Their pre- and post-conditions relate purely to explicit moves and to participants' (inspectable) commitment stores, so that complications concomitant upon implicit moves never arise. Neither is there any requirement to attempt the difficult task of divining the intentionality of the maker of the move (cf. Reichman, 1985; Mackenzie, 1990), given the moves' clearly defined function within the game. Intentionality is, in effect, embedded within the move (Ravenscroft & Pilkington, 2000). The difficulty of interpreting pragmatic content is, therefore, largely overcome (Pilkington, 1992).

Further, support for their computational utilization is also forthcoming from researchers in the field of IL itself. Thus, for example, Walton (1998):

> One of the primary uses of the new dialectic is to show people how to avoid common errors and fallacies in arguments. But the influence that will lead more directly to the acceptance of the new dialectic as a normative model of argumentation is its adoption in the field of computer science, especially in Artificial Intelligence, in the field of human-computer interactions (developing user-friendly computers), and in the use of computers to assist group deliberations and argumentative dialogues.

4 Current uses of informal logic in human–computer dialogue

There is, then, a strong prima facie case for the use of IL within human–computer dialogue. Although Carbogim *et al.* (2000) argue that 'only a few argument systems have been deployed in real, complex domains', much evidence of increasing interest in the use of IL can be found in the literature.

One major use concerns the mediation of argument. Mediation in a legal context has been particularly important (cf. Bench-Capon, 2000; Carbogim *et al.*, 2000). Gordon (1994), for example, has developed a model of civil pleading, the 'pleadings game', where the plaintiff and defendant confront each other. Bench-Capon (1998) argues that 'the rule-governed environment of a dialogue game can provide the necessary structured context for a quasi-courtroom argument', and develops 'Toulmin Dialogue Game (TDG)', a dialogue game based on Toulmin's argument schema, for this purpose. This game can be used to mediate discussions between human participants and seeks to ensure that the argument resulting from the dialogue has an appropriate (Toulmin-based) structure (Bench-Capon, 1998). Similarly, the dialectical argumentation system 'DART' has been used to model legal reasoning and argumentation (Freeman & Farley, 1996). The model captures arguments both as supporting explanations—connecting claims with appropriate supporting data—and as dialectical process—'alternating series of moves made by opposing sides for and against a given claim' (cf. Prakken and Sartor, 1996, p. 166). The DART model incorporates a 'burden of proof' concept, enabling it to support decisions ranging from 'sceptical' to 'credulous'. Similarly, Prakken and Sartor (1996) develop a dialogue game to assess conflicting arguments in legal reasoning. Leenes *et al.* (1994) argue for using a dialogue game model of legal justification and develop the dialogue game DiaLaw (Lodder & Herczog, 1995; Lodder, 1998). They also argue that dialogue games requiring students to construct legal arguments provide a useful means of teaching legal skills. Again, Prakken (2008) presents a formal dialogue game for adjudication dialogues. The model reconciles logical aspects of burden of proof induced by the defeasible nature of arguments with dialogical aspects of burden of proof as something that can be allocated by explicit decisions on legal grounds.

Grasso *et al.* (2000) outline a system designed to change the attitudes of its users in the domain of health promotion. The system is based on informal argumentation theories (Walton, 1989b), on the grounds that the theory is able to capture 'everyday arguments and the way they are used to change opinions and values' (p. 1080). The system's dialogue manager can be armed with a differing range of dialogue games according to prevailing circumstances. Atkinson *et al.* (2005) propose a dialogue game protocol for practical reasoning, and have constructed a system

(PARMA) operationalizing the protocol to allow two human participants to argue with each other (cf. Atkinson, 2005).

Uses for IL theories have also been proposed as enhancements to intelligent help systems (Pilkington, 1992; Moore & Hobbs, 1996) and expert system explanation generators (Bench-Capon *et al.*, 1991, 1992; Moore & Hobbs, 1996). Walton (1998) describes 'Negotiator Pro', an expert system, built on dialectical principles, that offers advice on the conduct of bargaining negotiations and elsewhere (Walton, 2000) argues that 'the growing field of expert systems provides a natural application for dialogue theory … sequences of questions and replies—dialogue in short—is a vitally important aspect of the implementation of any expert system' (p. 330).

Perhaps the main use of IL to date, however, has been within technology-enhanced learning (TEL) systems. As long ago as the mid-1980s, Girle (1986) was expressing a concern that computer-assisted learning systems may be based on assumptions about interactive communication that could put the interaction into a very narrow and inflexible mode. This concern is reflected in Laurillard's concern that 'too often the multimedia products on offer to education use the narrative mode, or unguided discovery, neither of which supports the learner well nor exploits the capability of the medium' (Laurillard, 1995: 184; Retalis *et al.*, 1996; Cumming & McDougall, 2000; Yuan *et al.*, 2008). Given the history of its use to improve critical thinking skills (Walton, 2000), IL is seen as a means of widening the communications channel and thus surmounting this concern with undue didacticism.

One approach is to have the TEL system engage its student in educational *debate* on controversial issues such as capital punishment and abortion. Vreeswijk (1995) has designed 'IACAS', an interactive argumentation system enabling disputes between a user and the computer. Yuan *et al.* (2007b) have applied the argument game (Wooldridge, 2002: 153–154) and the abstract argumentation system (Dung, 1995) and constructed a computer game 'Argumento'. Argumento enables human–agent, agent–agent, and human–agent to exchange abstract arguments, and is being extended to exchange concrete arguments as well (Yuan & Schulze, 2008). The game is expected to be used as an assistive tool for students who are studying argument games and abstract argumentation. User evaluation suggests that the game is both challenging and entertaining (Yuan *et al.*, 2007b). Another raft of projects in Digital Dialogue Games (DDG; see `www.interloc.org`) conducted by Ravenscroft *et al.*, that is mentioned later, has developed a number of tools (e.g. CoLLeGE, Academic Talk, and InterLoc) that have been adopted and evaluated in a broad range of contexts (e.g. see Ravenscroft, 2007 for a review). These have laid particular emphasis on how dialogue game features are rendered within interfaces to realize human and machine locutions within collaborative learning interactions.

Mackenzie's (1979) DC system has been used for competitive debate, and its applicability has been tested in educational discourse contexts (Moore 1993, 2000; Moore & Hobbs, 1996; Moore, 2000; Maudet & Moore, 2001). The DC system has been further evaluated through a two-agent system, and this motivated the development of a further system DE (Yuan *et al.*, 2003) which has been used as the underlying model for a human–computer debating system (Yuan, 2004; Yuan *et al.*, 2007a, 2008). In the debating system, the computer offers the student a choice of positions on a controversial issue, takes up the position diametrically opposed to that of the student, and engages the student in debate on that issue. This, it is held, may foster the student's debating skills and level of critical awareness, and make him more aware of the substantive issues involved (Moore & Hobbs, 1996; Retalis *et al.*, 1996; Quignard and Baker, 1997; Bouwer, 1998, 1999). The educational benefit of such a system seems clear, in that the importance of discussion and debate in education is frequently stressed at the primary (e.g. National Curriculum Council, 1990a), secondary (e.g. National Curriculum Council, 1990b), and tertiary (e.g. Garrison, 1991) levels. The argument is given extra force by Laurillard's mention of an 'emphasis on whole-class teaching … at the expense of opportunities for discussion and interaction', and her claim that 'reflection is too often neglected in the teaching–learning process' (Laurillard, 1995: 182). Empirical evaluation of the debating system in use suggests that it can be used to help the students practise argumentation (Yuan *et al.*, 2008).

Other work goes beyond debate, to incorporate other interaction styles. Lewin (2000) has implemented a dialogue manager, based on 'conversational game theory', for task-oriented instructional dialogue. Pilkington *et al.* (1992) have used dialogue games to implement a computer-mediated argumentation system called DIALAB, and in a similar vein, Burton *et al.* (2000) use dialogue games to implement CLARISSA, a computer-modelling laboratory for investigating collaboration. Pilkington (1998) (cf. Pilkington & Parker-Jones, 1996) demonstrates enhancements to a medical simulation-based learning system brought about partly by the adoption of dialogue games. Two types of dialogue games are identified, an inquiry dialogue with asymmetrical participant roles and a more collaborative game-generating cognitive conflict and reflection (Pilkington & Parker-Jones, 1996; Pilkington & Mallen, 1996; Pilkington, 1998).

Ravenscroft *et al.* have shown how dialogue games can support conceptual change in science (e.g. Ravenscroft & Pilkington, 2000) and also foster inclusive, engaging, and reasoned learning dialogues of a more generic nature (e.g. McAlister *et al.*, 2004; Ravenscroft & McAlister, 2006; Ravenscroft *et al.*, 2007). For example, Ravenscroft and Pilkington (2000) used a dialogue game framework to facilitate a 'structured and constrained dialectic', which in turn aided the student in enhancing explanatory domain models in ways that led to conceptual development concerning the physics of motion. Their dialogue game framework was able to simulate the tutorial tactics of an expert tutor within a 'collaborative argumentation' approach to 'learning as knowledge refinement'. Thus, the game involved asymmetrical participant roles, the computer being a 'facilitating tutor', and the student the 'explainer'. The framework has been implemented in a prototype system 'CoLLeGE' (Computer-based Lab for Language Games in Education). Empirical studies have shown the effectiveness of the dialogue game framework (Ravenscroft, 2000; Ravenscroft & Matheson, 2002). More recently, Ravenscroft and his colleagues have developed the *Academic Talk* and subsequent *Interloc* tools that mediate dialogue games that realize engaging and 'reasoned' discourse and critical thinking through 'live' peer interaction (McAlister *et al.*, 2004; Ravenscroft *et al.*, 2006; Ravenscroft, 2007). These approaches have been particularly successful in realizing attractive, usable, and engaging dialogue games that link to related digital practices, for example, with widespread and related learning and social software technologies (Ravenscroft, 2008; Ravenscroft *et al.*, 2008). A recent project (Ravenscroft *et al.*, 2009) has involved evaluations of this DDG approach with over 350 students and 10 tutors. This showed that the DDG approach and InterLoc tool was easy and intuitive to use; popular with, and valued by, tutors and students, where in all cases the tutors/institutions were keen to continue to use it; perhaps most notably, it succeeded in providing a unique way to stimulate critical and collaborative thinking among students, which was evidenced through student and tutor appraisals and analyses of the dialogues; and the generated content or Collaborative Thinking Texts (CTTs) were used in varied, and sometimes unanticipated, ways by students and tutors. In brief, as Ravenscroft *et al.* (2009) point out, 'the DDGs stimulated and supported learners to think critically on the web and linked this to learning and pedagogical practices'.

5 Major barriers

Thus far, we have shown that there is increasing evidence of the use of dialogue games within computer dialogue systems. However, there are, we argue, five potential and yet significant barriers to the use of dialogue games in this role. For the remainder of this paper, we examine these barriers in turn and, by discussing current research work, explore routes to overcoming them.

5.1 Barrier 1: lack of flexibility

Since in the main the games purport to be normative, prescriptive models of dialogue, they tend to represent idealized rather than everyday interactions (Walton, 1998) and their prescriptions may impose an unduly high cognitive load on the would-be user. There is some evidence, however, that mastery of the systems' stipulations is not unduly problematic (Moore & Hobbs, 1996), particularly in a computational environment (Ravenscroft, 2000; Yuan *et al.*, 2008). A further concern is that such dialogues as can be generated through a dialogue game may be rather stilted (e.g. Bench-Capon, 1998). For example, most dialogue game systems tend to restrict questions to the yes/no variety and to questions asking for grounds of commitments ('challenges'), and to insist that they be answered directly. This may not always represent a reasonable approach to dialogue (Walton, 1998), and work in the logic of questions could be profitably considered. It seems likely, however, that many such weaknesses can be overcome in a computational environment. For example, arranging for key points of the computer's dialogue contribution to be represented as hypermedia nodes (Moore, 2000) enables a user to clarify points from the computer's dialogue contributions and thus to bypass the restriction on yes/no questions. More generally, we argue (Maudet & Moore, 2001) that enriching the dialogue with varying forms of media may solve the problem of the potentially stilted nature of the dialogue. This point has been vindicated by recent research by Ravenscroft *et al.* through their development of the InterLoc tool (e.g. see Ravenscroft *et al.*, 2008), which supports multimedia and multimodal dialogue games that have proved to be attractive and engaging to users in addition to being configurable in ways that evolve with related requirements and ambitions in the context of students developing digital literacies.

In any event, such problems represent weaknesses with the dialogue models *per se* combined with the complexities of language use, rather than with their computational utilization. As such, they can be overcome by suitable amendments to the models. For example, Yuan *et al.* (2003) use a two-agent dialogue simulation system to facilitate evaluation of Mackenzie's (1979) DC system in preventing fallacious arguments, in the light of which they develop a further system DE as the underlying model for their debating system. Similarly, Loui details four game systems 'exhibiting a range of considerations that have been raised in the design of defeasible reasoning systems' (Loui, 1998: 22), the InterLoc dialogue games adapt and extend some of DC's moves to facilitate a 'richer and more flexible dialogue game' (Ravenscroft *et al.*, 2006), and Prakken (2001, 2005) adopts some of the DC and permissive persuasion dialogue (PPD) (Walton & Krabbe, 1995) moves and defines various systems enabling more than one move in a turn, postponing of replies, and backtracking. Ravenscroft and Pilkington (2000) also talk of '… providing future designers with a toolkit for investigating dialogue games to suit their own applications' (p. 294) and have operationalized this in recent DDG projects (see `www.interloc.org`) that now provide a dialogue game authoring tool along with means for their practical application to realize learning interactions among small groups (InterLoc5) within ecosystems for cyber-argumentation (Ravenscroft & McAlister, 2008). The two-agent dialogue simulation system developed in (Yuan *et al.*, 2003) can be enhanced to provide IL researchers with a tool to evaluate their dialogue models and strategies. Indeed, computational use of the models can be expected to help clarify the models themselves (Krabbe, 2000), so that research in dialectics and in human–computer dialogue works to each other's mutual advantage (Hitchcock, 2000; Maudet & Moore, 2001).

A further approach, complementary to that of extending the dialogue games, is to provide for the synthesis of multiple dialogue game types into a single dialogue. Walton suggests that 'the problem of how to formally represent … functional embeddings of dialogues has not yet been solved. It is by no means a purely philosophical problem, and also represents a real problem for the development of computer dialogue systems' (Walton, 2000: 338). However, approaches have been investigated that allow diverse dialogue types to be modelled as games within a larger structure reflecting the global coherence of dialogue (Reed, 1998; Maudet & Evrard, 1998; Maudet & Moore, 2001; cf. Hulstijn, 2000; McBurney & Parsons, 2002). On this model, extended dialogues are seen as potentially consisting of sequences, embeddings, and other combinations of dialogue games, which can be distinguished from each other through topic (different games of the same type), aim (different game types, same topic), or both (different game types and different topics).

5.2 Barrier 2: computer strategy

Dialogue games tend to be very sparse if seen as functional specifications (Moore & Hobbs, 1996). Although this is advantageous in some respects from the computational point of view, the cost of the models' simplicity is a reliance on the strategic wisdom of the participants, for example, to maintain relevance. In strategic knowledge lies the potential for a link between the logic of argumentation, as modelled by dialogue games, and the semantics of discourse. Without this link, it might be suggested, dialogue games will add nothing to currently available computer dialogue systems. For it is possible for locutions to be syntactically correct and semantically meaningful, yet inappropriate at the pragmatic level (cf. Poesio & Traum, 1998; Dessalles, 1998; Pasquier & Chaib-draa, 2005). Further, one possible weakness of dialogue game models is that they tend to be largely neutral vis-à-vis focus and relevance considerations, and this places a further burden upon participants' strategic reasoning. Indeed, the ability to capture this wisdom could be seen as the crucial aspect of computational use of dialogue games.

For the practical use of IL in HCI, therefore, there must be a suitable link to semantics. It should be noted that any link to the discourse semantics forged via such strategic decisions is largely an extra-game consideration: all that the IL model does is to legitimize a set of move types given the prevailing circumstances and occasionally give some indication of the semantic possibilities. One might think that the model would indicate what is legally available, a strategic choice would be made from this range, and the choice would then be 'filled up' with semantic content. Such a view would be too simple, however, for the strategic decision is likely to rely heavily on the available content, and a strategic decision may be needed between alternative contenders for the content (different supporting evidence, for example). In any computerized system, some interplay between strategic and semantic components is therefore needed.

Considerable research effort has therefore been devoted to the development of suitable computational strategies. For a dialogue involving competitive debate, for example, we argue that there are three levels of decisions to consider (Pilkington *et al.*, 1992; Moore & Hobbs, 1996; Maudet & Moore, 2001; Yuan, 2007a). At *level* 1, the issue is whether to retain or change the current focus. At *level* 2, the decision for the computer is whether to try to 'demolish' the user's position, or to seek to 'build' its own position. In a similar manner, Freeman and Farley (1996) picture side-1 building support for its claim, and side-2 seeking to refute side-1's arguments via 'undercutting' or 'rebutting'. At *level* 3, the decision involves which *method* to adopt in fulfilment of the objectives set at levels 1 and 2.

For dialogue types other than debate, other strategies may be appropriate. Grasso *et al.* (2000), for example, adopt, for their nutritional advice-giving system, schemas derived from Perelman and Olbrechts-Tyteca's (1969) 'New Rhetoric', and Ravenscroft and Pilkington (2000) have 'a repertoire of legitimate tactics available for addressing common conceptual difficulties' (p. 283) that can be selected based on a strategic pedagogy developed through modelling effective tutor behaviour (Ravenscroft, 2000). Amgoud and Maudet (2002) suggest 'meta-preferences', such as 'choose the smallest argument', to drive the choice of move, and Freeman and Farley (1996) delineate ordering heuristics as guidelines for selecting argument moves. Prakken (2001, 2005) suggests, in line with his dialogue framework, that the dialogue focus and dialectical relevance can be maintained by restricting dialogue participants to replying and backtracking to the previous move. Yuan *et al.* (2007b) implement a probability–utility-based strategy, which enables a software agent to compute all the possible dialogue sequences and then select a legal move with the highest probability of winning an abstract argumentation game.

5.3 Barrier 3: group dialogues

Although the trend is starting to shift, dialogue game research to date has focused predominantly on two-party games. An important development is to relax this assumption and enable multiple participants. This is an important issue in current interactive systems, given the importance of group work in education (e.g. Cumming & McDougall, 2000) and the growing interest in CSCL in general (Steeples *et al.*, 1996; Hoadley, 1999; Stahl, 2006) and CSCA in particular (e.g. Veerman *et al.*, 2002; Ravenscroft, 2007; Ravenscroft *et al.*, 2007). Further, the burgeoning of social software practices including widespread collaborative argumentation provides a fertile landscape for the application of the next generation of dialogue game technologies (Ravenscroft & McAlister, 2008). Thus, building on these contemporary practices, Ravenscroft *et al.* have produced tools for group dialogue games and performed significant evaluations of their acceptability and effectiveness (see Ravenscroft, 2007; Ravenscroft *et al.*, 2009).

An IL model designed explicitly for supporting group discussion offers suggests, in our view, two major advantages in this context. One major benefit of an IL model is its ability to provide a regulatory framework for interactions within collaborative discussions. Means of suitably controlling the evolving discussion are required (cf. Okamoto & Inaba, 1997). And given that, as suggested earlier, IL models purport to be models of 'fair and reasonable' dialogue, the case for their adoption as the regulatory framework seems clear. In a similar manner, Finkelstein and Fuks (1990) use a dialogue games model as the basis for a system for providing automated support for groups collaborating on the development of software specifications (cf. Finkelstein, 1992; Burton *et al.*, 1997; Bouwer, 1998). Similarly, the Zeno Argumentation Framework (Gordon & Karacapilidis, 1997; Gordon *et al.*, 2001) is an Internet-based environment for supporting argumentation, negotiation, and group decision-making, based on IL principles. The system is conceived as an 'intelligent support system for human mediators', which 'transforms Issue-Based Information System (IBIS) from a lifeless method to organize and index information into a playing field for stimulating debate'.

A second major benefit of IL models to computer-supported collaboration is that, by providing a computationally tractable model of dialogue, the model makes it possible in principle for a computational agent to participate in the dialogue. This is advantageous in a number of ways. CSCL work is often of a discursive nature (Simon, 1997) and the ability of the computational agent to play the role of 'devil's advocate' is potentially of educational value (cf. Retalis *et al.*, 1996). This is especially the case, perhaps, in contexts in which the human participants all agree but it is felt educationally advantageous for them to critically explore their shared view. Further, it may be the case in asynchronous computer conferences that propositions posed by one participant evoke no response (Hewitt & Teplovs, 1999; Cunningham-Atkins *et al.*, 2004) and that discussion is therefore stymied. A computational agent could potentially provoke discussion in such circumstances, and play the role of symmetrical participant or asymmetrical facilitator or expert. A further advantage of computational participation is that it affords participants the possibility of their own 'private' discussion with the agent. This might be used for rehearsal and practice prior to entering the group discussion (perhaps to resolve any 'intra-agent conflict' (Amgoud & Maudet, 2000)), and/or reflection and analysis after a group discussion. The facility may be particularly useful for people reluctant to enter the group discussion or for people with a social disability, such as autism, which restricts their participation (cf. Moore *et al.*, 2000). A final advantage of computational participation is that it would enable a number of computers to hold discussions with each other, in a multi-agent system (Amgoud *et al.*, 2000) and, given claims concerning the educational benefits of vicarious learning from the dialogue of others (Cox *et al.*, 1999; Stenning *et al.*, 1999; Lee, 2006), the resulting transcripts might make educationally valuable study material.

Challenging research issues arise, however, when seeking to apply dialogue games to group discussions. In the event that the group discussion involves two teams being formed, the issue of how team commitment stores (CS) should be updated is complex. The usual arrangement is '*de facto* commitment'—a participant has to explicitly withdraw from his commitment store those statements of his interlocutor to which he is not prepared to commit (Mackenzie, 1979). The position is more complex in a team situation: for different theses can be expressed within a team and this raises the issue of how the other team's CS should be updated. A more radical position on the role of commitment within group discussion has been adopted by Ravenscroft and his colleagues (e.g. see Ravenscroft, 2007, for a review). The dialogue games performed through their InterLoc tool do not have any explicit shared CS that are displayed separately from the dialogue itself. Their emphasis is on mediating and scaffolding legitimate 'thinking conversations', where the IL of the dialogue is contained through the rules about legitimate move patterns rather than through implied and explicitly displayed commitment. In other words, the underlying logic subserves the play of dialogue instead of driving it.

A further issue with the team arrangement concerns turn taking. Many dialogue games reduce the turn-taking problem to the following equation: *one move = one turn*. Grasso *et al.* (2000) express some concern about such an arrangement, and in the context of a set of participants, in particular, the definition may need to be refined: for it may not be realistic to allow only one move for the whole team, or to oblige one move for each player of the team. Some dialogue games support more complex move/turn structures (Walton & Krabbe, 1995), although this approach often leaves open the problem of determining what, in a given case, constitutes a turn. A possible solution could be to introduce an explicit turn-taking move, in line with Bunt's 'dialogue-control-acts' (Bunt, 1994; cf. Poesio & Traum, 1998). Ravenscroft *et al.* (2008) have introduced a straightforward turn-taking model that is not just acceptable to users but also stimulates them to 'listen' and reflect.

In the event of genuine 'polylogues', dialogues in which each player wants to achieve a different goal and teams do not therefore form, it is not currently clear what alterations will be needed to the model (cf. Traum, 2004). This, in fact, is an example of what we believe to be a fundamentally important research issue, namely the ramifications of computer dialogue research for the field of IL itself. The crucial point, we argue, is that the computer environment can act as a test-bed in which the dialectical theories can be evaluated and refined. Walton (1998: 29) argues: 'the formal systems of dialogue that have proliferated in recent times appear potentially useful, but … they are too diffuse, too multiple and too abstract'. Further, a computational test-bed is likely to provide a useful facility for rationalizing the proposed models and making them less abstract. One useful approach might be to allow two or more computer systems to run with a proposed system in dialogue with each other, and to study the results. As Amgoud and Maudet (2000) point out: 'conversation simulation between computational agents is more and more considered as an important means to get empirical results about dialogue structures and behaviours' (cf. Hitchcock, 2000; Krabbe, 2000; Dignum & Vreeswijk, 2004).

5.4 Barrier 4: natural language

Argument and debate are home to some of the most complex and sophisticated examples of language use: they go far beyond what current natural language processing might hope to tackle. This barrier, though, also represents a key opportunity for IL. Where NLP is an unrealistic goal, IL offers a route to some structured headway—without precluding subsequent NLP contributions. The debating system (Yuan *et al.*, 2007a), for example, operates on the basis of a predetermined (albeit expandable) set of propositions. The Hartley and Hintze mediating system (Hartley & Hintze, 1990) operates on strings, Yuan *et al.*'s (2007b) abstract argument game operates on a graph with a set of visual arguments, Ravenscroft and Pilkington's (2000) CoLLeGE system adopts a 'menu and template scheme', and in the Grasso *et al.* system, input and output 'consists at the moment of sentences in a first-order language' (Grasso *et al.*, 2000: 1097).

One can speculate that much of the difficulty in unregulated discussions concerns semantic shifts, and that this would be largely ruled out by the propositional logic of the dialogue games. Further, the models provide a valuable service at the propositional logic level, for example, by keeping track of commitments and pointing up inconsistencies and consequences of extant positions. In addition, it may be that attempting to work within the confines of propositional logic will turn out to be revealing about what Walton (1989a) sees as the contested ground between semantics and pragmatics.

5.5 Barrier 5: representation

The systems we have outlined face two distinct representational problems. The first is in representing the argument content that is contributed by users or offered by a system. The second is in representing the structure of the protocol that governs the dialogue game as it unfolds. We may, for example, build a system that is to use the protocol of DE to argue about capital punishment, but how are we to store the arguments about capital punishment, and how are we to store the rules of DE? To date, computational dialectic systems have approached the first problem with a wide range of idiosyncratic solutions, and have avoided the second problem entirely by building the logic of a game into the program structure itself. Idiosyncrasy in representation is problematic because resources cannot be shared or reused between the many systems that exist. Building game logic into a program means that a system is unable to play more than one game, and cannot even easily be rewritten to play a different game.

The Argument Interchange Format (AIF), is a nascent agreement in the argumentation community for an approach to simultaneously solving both problems (Chesnevar *et al*., 2006). Applications of the AIF to date have focused on monologic argument representation—that is, on the first of our two representational problems. The results from these early investigations have demonstrated the power and flexibility of the AIF, particularly in semantically rich environments (such as Semantic Web services (Rahwan *et al*., 2007)). AIF systems such as ArgDF (`www.argdf.org`) might reasonably be expected to provide input to systems of computational dialectics. The challenge lies in building interchangeable representations of dialogue systems and (most difficult of all) tying those representations into the representations of monologic argument. Thus, for example, DE's rule R_{CHALL} involves the troublesome *imc* from Mackenzie's original presentation of DC—one of the ways of responding to a challenge, 'Why P?', is with a resolution demand of any of the challenger's commitments that immediately imply P. Representing this rule is not currently possible in the AIF because 'immediate implication' is something that could be computed only by a procedure over the monologic part (i.e. the arguments and CS of the interlocutors). More troublesome yet, it is difficult to see how the AIF, as it stands, could tie together in a principled way the result of a resolution demand specified by R_{CHALL} and the update to the monologic structure. Implemented tools such as those described above may provide a concrete basis from which to develop the next iteration of the AIF.

6 Summary

This paper has outlined recent work in applying dialectical theories developed within the field of IL to dialogue involving people and computers, that is, 'computational dialectics' (Gordon, 1996). We have highlighted five barriers to be addressed if IL theories are to be successfully applied to human–computer dialogue, and reviewed current and potential approaches being taken by the authors and others to overcoming these barriers. Specifically, barrier 1, a lack of flexibility, is being addressed by: enriching the dialogue with varying forms of media; experimenting with amendments to the IL models; providing for the incorporation of multiple dialogue game types into a single dialogue; and the development of usable and configurable interfaces. Substantive strategies are being developed, for both players of individual dialogue games and for facilitating dialogues involving multiple games, to address barrier 2, the issue of strategies being needed to operationalize IL models. Barrier 3 concerns the facilitation of group dialogue. For team-based dialogue, this is being addressed by amending the IL models to allow for '*de facto* commitment' and explicit turn-taking moves or deemphasizing the requirement for shared CS as the drivers of reasoned conversational practice. Means of catering for polylogues remains an open question. The issue of natural language processing (barrier 4) falls outside the remit of IL as such, being rather a matter of computational linguistics, but a variety of practical 'ways round' the problem are being adopted in the meantime. Turning to the final barrier—how to reuse system argument contents and dialogue game models, the AIF appears to be providing a promising approach to simultaneously solving both problems; challenging issues however still remain in the representation of dialogue games.

Much remains to be done, then, but the potential pay-off in terms of expanding human–computer communication is enormous. Further, there is great scope for an interesting and fruitful interplay between research within IL on the dialogue models *per se* and research on their computational utilization. The hope is that this paper will consolidate the work in computational dialectics and also move this interplay forward.

References

Amgoud, L. & Maudet, N. 2000. On the cooperative behaviour of an argumentation based dialogue system. In *Proceedings of the Workshop Cooperative Models Based on Argumentation in Problem Solving*, Nice, France, 1–6.

Amgoud, L. & Maudet, N. 2002. Strategical considerations for argumentative agents. In *Proceedings of the Ninth International Workshop on Non-monotonic Reasoning (NMR'2002), Special Session on Argument, Dialogue, and Decision*, Toulouse.

Amgoud, L., Parsons, S. & Maudet, N. 2000. Argumentation, dialogue, and negotiation. In *Proceedings of the Fourteenth European Conference on Artificial Intelligence*, Berlin, Germany, 338–342.

Andrews, R 1995. *Teaching and Learning Argument*. Cassel.

Atkinson, K. 2005. *What Should We Do?: Computational Representation of Persuasive Argument in Practical Reasoning*. PhD thesis, University of Liverpool, UK.

Atkinson, K., Bench-Capon, T. & McBurney, P. 2005. A dialogue game protocol for multi-agent argument over proposals for action. *Autonomous Agents and Multi-agent Systems. Special Issue on Argumentation in Multi-agent Systems* **11**(2), 153–171.

Bench-Capon, T. J. M. 1998. Specification and Implementation of Toulmin dialogue game. In *Proceedings of the 11th International Conference on Legal Knowledge Based Systems (JURIX)*, Nijmegen: Gerard Noodt Institute (GNI), 5–20.

Bench-Capon, T. J. M. 2000. Issues in argument and legal reasoning. In *Symposium on Argument and Computation*, Bonskeid House, Perthshire, Scotland. http://www.csd.abdn.ac.uk/ ~ tnorman/sac/

Bench-Capon, T. J. M. & Dunne, P. E. 2007. Argumentation in artificial intelligence. *Artificial Intelligence* **171**, 619–641.

Bench-Capon, T. J. M., Dunne, P. E. S. & Leng, P. H 1991. Interacting with knowledge based systems through dialogue games. In *Proceedings of the Eleventh International Conference, Expert Systems and Their Applications*, Avignon, 123–130.

Bench-Capon, T. J. M., Dunne, P. E. S. & Leng, P. H. 1992. A dialogue game for dialectical interaction with expert systems, In *Proceedings of the 12th International Conference, Expert Systems and Their Applications*, Avignon, France, 105–113.

Bouwer, A. 1998. ArgueTrack: the design of an argumentative dialogue interface. In *Proceedings of the 2nd International Workshop on Human-Computer Conversation*, Bellagio, Italy.

Bouwer, A. 1999. ArgueTrack: computer support for educational argumentation. Poster presentation at *AI-ED'99*. In *The 9th International Conference on Artificial Intelligence in Education*, Le Mans.

Bunt, H. C. 1994. Context and dialogue control. *Think Quarterly* **3**(1), 19–31.

Burton, M., Brna, P. & Pilkington, R. 2000. Clarissa: a laboratory for the modelling of collaboration. *International Journal of Artificial Intelligence in Education* **11**, 79–105.

Burton, M., Brna, P. & Treasure-Jones, T. 1997. Splitting the collaborative atom: how to support learning about collaboration. In *Artificial Intelligence in Education: Knowledge and Media in Learning Systems*, du Boulay, B. & Mizoguchi, R. (eds). IOS, 135–142.

Carbogim, D. V., Robertson, D. & Lee, J. 2000. Argument-based applications to knowledge engineering. *The Knowledge Engineering Review* **15**(2), 119–149.

Chesnevar, C., McGinnis, J., Modgil, S., Rahwan, I., Reed, C., Simari, G., South, M., Vreeswijk, G. & Willmott, S. 2006. Towards an argument interchange format. *Knowledge Engineering Review* **21**(4), 293–316.

Clark, H. H. & Schaefer, E. F. 1989. Contributing to discourse. *Cognitive Science* **13**, 259–294.

Cox, R., McKendree, J., Tobin, R., Lee, J. & Mayes, T. 1999. Vicarious learning from dialogue and discourse: a controlled comparison. *Instructional Science* **27**(6), 431–457.

Cumming, G. & McDougall, A. 2000. Mainstreaming AIED into education? *International Journal of Artificial Intelligence in Education* **11**, 197–207.

Cunningham-Atkins, H., Powell, N. J., Moore, D., Hobbs, D. & Sharpe, S. 2004. The role of cognitive style in educational computer conferencing. *The British Journal of Educational Technology* **35**(1), 69–80.

Dessalles, J. L. 1998. The Interplay of Desire and Necessity in Dialogue. In *Formal Semantics and Pragmatics of Dialogue*, Hulstijn, J. & Nijholt, A. (eds). University of Twente, 89–97.

Digital Dialogue Games for Learning website, 2007. *Interloc Dialogue Games*. http://www.interloc.org/, accessed 17 August 2007.

Dignum, F. & Vreeswijk, G. 2004. Towards a testbed for multi-party dialogues. In *Advances in Agent Communication*, Dignum, F. (ed.). Lecture Notes in Computer Science **2922**, 212–230. Springer-Verlag.

Dung, P. 1995. On the acceptability of arguments and its fundamental role in non-monotonic reasoning, logic programming and N-Person games. *Artificial Intelligence* **77**(2), 321–357.

Finkelstein, A. 1992. Reviewing and correcting specifications. *Instructional Science* **21**, 183–198.

Finkelstein, A. & Fuks, H. 1990. Conversation analysis and specification. In *Computers and Conversation*, Luff, N. (ed.). Academic Press.

Fisher, A. 2000. Informal logic and its implications for philosophy. *Informal Logic* **20**(2), 109–115.

Freeman, K. & Farley, A. M. 1996. A model of argumentation and its application to legal reasoning. *Artificial Intelligence and Law* **4**, 163–197.

Frohlich, D. M. & Luff, P. 1990. Applying the technology of conversation to the technology for conversation. In *Computers and Conversation,* Luff, P., Gilbert, G. N. & Frohlich, D. M. (eds). Academic Press, London and New York, 189–222.

Garrison, D. R. 1991. Critical thinking and adult education: a conceptual model for developing critical thinking in adult learners. *International Journal of Lifelong Education* **10**(4), 287–304.

Girle, R. A. 1986. Dialogue and discourse. In *Proceedings of the Fourth Annual Computer Assisted Learning in Tertiary Education Conference*, Bishop, G. & Van Lint, W. (eds). *Adelaide*, distributed by Office of Continuing Education, University of Adelaide.

Gordon, T. 1994. The pleadings game: an exercise in computational dialectics. *Artificial Intelligence and Law* **2**(4), 239–292.

Gordon, T. 1996. Computational dialectics. In *Computers as Assistants, A New Generation of Support Systems*, Hoschka, P. (ed.). Lawrence Erlbaum Associates.

Gordon, T. & Karacapilidis, N. 1997. The Zeno argumentation framework. In *Proceedings of the Sixth International Conference on Artificial intelligence and Law*, Melbourne, Australia.

Gordon, T., Angi, V., Gernot, R. & Oliver, M. 2001. Zeno: groupware for discourses on the Internet. *Künstliche Intelligenz* **2**(1), 43–45.

Grasso, F., Cawsey, A. & Jones, R. 2000. Dialectical argumentation to solve conflicts in advice giving: a case study in the promotion of healthy nutrition. *International Journal of Human-Computer Studies* **53**, 1077–1115.

Groarke, L. 2002. *Informal Logic. The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/archives/fall2002/entries/logic-informal/

Hamblin, C. 1970. *Fallacies*. Methuen, London.

Hamblin, C. 1971. Mathematical models of dialogue. *Theora* **37**, 130–155.

Hartley, J. R. & Hintze, D. 1990. Dialogue and learner modelling. In *Student Model Acquisition in a Natural Laboratory (NATLAB)*, Cheri, S. A. (ed.). GEC DELTA Project D-1016 Final Report.

Hewitt, J. & Teplovs, C. 1999. An analysis of growth patterns in computer conferencing threads. In *Proceedings of the Computer Supported Collaborative Learning Conference*, Palo Alto, California, 232–241.

Hitchcock, D. 2000. Statement on practical reasoning. In *Symposium on Argument and Computation*, Bonskeid House, Perthshire, Scotland. http://www.csd.abdn.ac.uk/~tnorman/sac/

Hoadley, C. (ed.) 1999. *Computer Support for Collaborative Learning*. Stanford University.

Hulstijn, J. 2000. Dialogue games are recipes for joint action. In *Proceedings of the fourth Workshop on Formal Semantics and Pragmatics of Dialogue (Götalog)*, Göteborg, Sweden.

Jackson, F. 1998. Postscript on Qualia. In His Mind, Method, and Conditionals: Selected Essays, London, 76–79.

Johnson, R. H. & Blair, J. A. 2000. Informal logic: an overview. *Informal Logic* **20**(2), 93–107.

Krabbe, E. 2000. Symposium on argument and computation group: argument and computational societies-position paper. In *Symposium on Argument and Computation*, Bonskeid House, Perthshire, Scotland. http://www.csd.abdn.ac.uk/~tnorman/sac/

Laurillard, D. 1995. Multimedia and the changing experience of the learner. *British Journal of Educational Technology* **26**(3), 179–189.

Lee, J. 2006. Vicarious learning and multimodal dialogue. In *Proceedings of the Sixth IEEE International Conference on Advanced Learning Technologies*, Kerkrade, Netherlands, 1202–1203.

Leenes, R. E., Lodder, A. R. & Hage, J. C. 1994. A dialogue game for legal arguments, law. *Computers and Artificial Intelligence* **3**(2–3), 211–226.

Lewin, I. 2000. A formal model of conversational game theory. In *Proceedings of the Fourth Workshop on the Semantics and Pragmatics of Dialogue*, Goteborg.

Lodder, A. R. 1998. *Dialaw: on Legal Justification and Dialogue Games*. PhD thesis, University of Maastricht.

Lodder, A. R. & Herczog, A. 1995. DiaLaw: A dialogical framework for modelling legal reasoning. In *Proceedings of the 5th International Conference on Artificial Intelligence And Law*, New York, 146–155.

Loui, R. P. 1998. Process and policy: resource-bounded nondemonstrative reasoning. *Computational Intelligence* **14**(1), 1–38.

Mackenzie, J. D. 1979. Question–begging in non–cumulative systems. *Journal of Philosophical Logic* **8**, 117–133.

Mackenzie, J. D. 1990. Four dialogue systems. *Studia Logica* **XLIX 4**, 567–583.

Maudet, N. & Evrard, F. 1998. A generic framework for dialogue game implementation. In *Proceedings of the Second Workshop on Formal Semantics and Pragmatics of Dialogue* (TWLT13), Hulstijn, J. & Nijholt A. (eds). University of Twente, Enschede.

Maudet, N. & Moore, D. 2001. Dialogue games as dialogue models for interacting with, and via, computers. *Informal Logic* **21**(3), 219–243.

McAlister, S., Ravenscroft, A. & Scanlon, E. 2004. Combining interaction and context design to support collaborative argumentation using a tool for synchronous CMC. *Journal of Computer Assisted Learning: Special Issue: Developing Dialogue for Learning* **20**(3), 194–204.

McBurney, P. & Parsons, S. 2002. Games that agents play: a formal framework for dialogues between autonomous agents. *Journal of Logic, Language and Information* **11**(3), 315–334.

Moore, D. 1993. *Dialogue Game Theory for Intelligent Tutoring Systems*. Unpublished PhD Dissertation, Leeds Metropolitan University, UK.

Moore, D. 2000. A framework for using multimedia within argumentation systems. *Journal of Educational Multimedia and Hypermedia* **9**(2), 83–98.

Moore, D. & Hobbs, D. J. 1996. Computational use of philosophical dialogue theories. *Informal Logic* **18**(2), 131–163.

Moore, D., McGrath, P. & Thorpe, J. 2000. Computer aided learning for people with autism – a framework for research and development. *Innovations in Education and Training International* **37**(3), 218–228.

National Curriculum Council 1990a. *Curriculum Guidance 7 – Environmental Education*. York: NCC.

National Curriculum Council 1990b. *Curriculum Guidance 8 – Education for Citizenship*. York: NCC.

Okamoto, T. & Inaba, A. 1997. The intelligent discussion co-ordinating system for CSCL environment. In *Proceedings of World Conference on Educational Multimedia/Hypermedia and Telecommunications*, Muldner, T. & Reeves, T.C. (eds). Calgary, **II**, AACE (Association for the Advancement of Computing in Education), 794–799.

Pasquier, P. & Chaib-draa, B. 2005. Agent communication pragmatics: the cognitive coherence approach. In *Cognitive Systems Research*, Ron Sun (ed.). Elsevier, 364–395.

Perelman, C. & Olbrechts-Tyteca, L. 1969. *The New Rhetoric: A Treatise on Argumentation*. Notre Dame Press.

Pilkington, R. M. 1992. *Intelligent Help, Communicating with Knowledge Based Systems*. Paul Chapman Publishing Ltd.

Pilkington, R. M. 1998. Dialogue games in support of qualitative reasoning. *Journal of Computer Assisted Learning* **14**, 308–320.

Pilkington, R. M., Hartley, J. R., Hintze, D. & Moore, D. J. 1992. Learning to argue and arguing to learn: an interface for computer-based dialogue games. *Journal of Artificial Intelligence in Education* **3**(3), 275–295.

Pilkington, R. M. & Mallen, C. 1996. Dialogue games to support reasoning and reflection in diagnostic tasks. In *Proceedings of the European Conference on Artificial Intelligence in Education*, Brna, P., Paiva, A. & Self, J. (eds). Fundacao Calouste Gulbenkian.

Pilkington, R. & Parker-Jones, C. 1996. Interacting with computer-based simulation: the role of dialogue. *Computers and Education* **27**(1), 1–14.

Poesio, M. & Traum, D. 1998. Towards an axiomatization of dialogue acts. In *Proceedings of the Twente Workshop on the Formal Semantics and Pragmatics of Dialogues (13th Twente Workshop on Language Technology)*, Hulstijn, J. & Nijholt, A. (eds). Enschede, 207–222.

Prakken, H. 2000. On dialogue systems with speech acts, arguments and counterarguments. In *Proceedings of the 7th European Workshop on Logic for Artificial Intelligence*. Springer. Lecture Notes in Artificial Intelligence, **1919**, 224–238. Springer-Verlag.

Prakken, H. 2001. Relating protocols for dynamic dispute with logics for defeasible argumentation. *Synthese, Special Issue on New Perspectives in Dialogical Logic* **127**, 187–219.

Prakken, H. 2005. Coherence and flexibility in dialogue games for argumentation. *Journal of Logic and Computation* **15**, 1009–1040.

Prakken, H. 2006. Formal systems for persuasion dialogue. *The Knowledge Engineering Review* **21**, 163–188.

Prakken, H. 2008. A formal model of adjudication. In *Argumentation, Logic and Law*, Rahman, S. (ed.). Springer-Verlag.

Prakken, H. & Sartor, G. 1996. A dialectical model of assessing conflicting arguments in legal reasoning. *Artificial Intelligence and Law* **4**, 331–368.

Quignard, M. & Baker, M. 1997. Modelling argumentation and belief revision in agent interactions. In *Proceedings of the European Conference on Cognitive Science (ECCS97)*, Manchester, UK.

Rahwan, I., Zablith, F. & Reed, C. 2007. Towards large scale argumentation support on the semantic web. In *Proceedings of AAAI-07* (*Association for the Advancement of Artificial Intelligence*), Vancouver.

Rahwan, I. & McBurney, P. 2007. Argumentation technology: introduction to the special issue. *IEEE Intelligent Systems* **22**(6), 21–23.

Ravenscroft, A. 2008. Social Software, Web 2.0 and learning: status and implications of an evolving paradigm. *Guest Editorial for Special Issue of Journal of Computer Assisted Learning (JCAL)*, **21**(1), 1–5.

Ravenscroft, A. 2000. Designing argumentation for conceptual development. *Computers & Education* **34**, 241–255.

Ravenscroft, A. 2007. Promoting thinking and conceptual change with digital dialogue games. *Journal of Computer Assisted Learning (JCAL)*, **23**(6), 453–465.

Ravenscroft, A. & Matheson, P. 2002. Developing and evaluating dialogue games for collaborative E-learning. *Journal of Computer Assisted Learning* **18**, 93–101.

Ravenscroft, A. & McAlister, S. 2006. Designing interaction as a dialogue game: linking social and conceptual dimensions of the learning process. In *Interactions in Online Education: Implications for Theory and Practice*, Juwah, C. (ed.), Routledge, 73–90.

Ravenscroft, A., McAlister, S. & Baur, E. 2006. *Development, Piloting and Evaluation of Interloc: An Open Source Tool Supporting Dialogue Games in Education*. Final Project Report, Learning Technology Research Institute, London Metropolitan University, UK and JISC (Joint Information Systems Committee), Bristol, UK.

Ravenscroft, A. & McAlister, S. 2008. Investigating and promoting educational argumentation: towards new digital practices. *International Journal of Research and Method in Education (IJRME)*, Special Issue on Researching Argumentation in Educational contexts: new methods, new directions. Coffin C. and O'Halloran K. (eds). **31**(3), 317–335.

Ravenscroft, A. & Pilkington, R. M. 2000. Investigation by design: developing dialogue models to support reasoning and conceptual change. *International Journal of Artificial Intelligence in Education* **11**, 273–298.

Ravenscroft, A., Wegerif, R. B. & Hartley, J. R. 2007. Reclaiming thinking: dialectic, dialogic and learning in the digital age. *Special Issue of British Journal of Educational Psychology: Psychological Insights into the Use of New Technologies in Education* **11**(5), 39–57.

Ravenscroft, A., Sagar, M., Baur, E. & Oriogun, P. 2008. Ambient pedagogies, meaningful learning and social software. In *Social Software & Developing Community Ontologies*, Hatzipanagos, S. & Warburton, S. (eds). IGI Global Publishing, 432–450.

Ravenscroft, A., McAlister, S. & Sagar, M. 2009. *Digital Dialogue Games (DDGs): Cross-institutional Implementation and Evaluation of Digital Dialogue Games for Inclusive and Personalised Learning*. Final Report for UK Joint Information Systems Committee (JISC), Bristol, UK.

Reed, C. 1998. Dialogue frames in agent communication. In *Proceedings of the Third International Conference on Multi-Agent Systems*, Paris, 246–253.

Reed, C. & Grasso, F. 2007. Recent advances in computational models of argument. *International Journal of Intelligent Systems* **22**(1), 1–15.

Reed, C. & Wells, S. 2007. Dialogical argument as an interface to complex debates. *IEEE Intelligent Systems* **22**(6), 60–65.

Reichman, R. 1985. *Getting Computers to Talk Like You and Me*. The MIT Press.

Retalis, S., Pain, H. & Haggith, M. 1996. Arguing with the devil: teaching in controversial domains. In *Intelligent Tutoring Systems, Third International Conference, ITS'96*, Montreal, Canada.

Simon, J. A. 1997. Object orientation in discourse structuring. In *Proceedings of World Conference on Educational Multimedia/Hypermedia and Telecommunications*, Muldner, T. & Reeves T. C. (eds), Calgary, **II**, AACE (Association for the Advancement of Computing in Education), 984–989.

Stahl, G. 2006. *Group Cognition: Computer Support for Collaborative Knowledge Building*, MIT Press.

Steeples, C., Unsworth, C., Bryson, M., Goodyear, P., Riding, P., Fowell, S., Levy, P. & Duffy, C. 1996. Technological support for teaching and learning: computer-mediated communications in higher education. *Computers and Education* **26**(1), 71–80.

Stenning, K., McKendree, J., Lee, J. & Cox, R. 1999. Vicarious learning from educational dialogue. In *Proceedings of the Computer Support for Collaborative Learning Conference (CSCL-99)*, Stanford, 341–347.

Traum, D. 2004. Issues in multi-party dialogues. In *Advances in Agent Communication*, Dignum, F. (ed.). Lecture Notes in Artificial Intelligence **2922**, 201–211. Springer-Verlag.

Veerman, A., Andriessen, J. & Kanselaar, G. 2002. Collaborative argumentation in academic education. *Instructional Science* **30**, 155–186.

Vreeswijk, G. A. W. 1995. IACAS: an implementation of Chisholm's principles of knowledge. In *Proceedings of the 2nd Dutch/German Workshop on Non-monotonic Reasoning*, Utrecht, 225–234.

Vreeswijk, G. A. W., Brewka, G. & Prakken, H. 2003. Special issue on computational dialectics: an introduction. *Journal of Logic and Computation* **13**(3), 317–318.

Walton, D. N. 1984. *Logical Dialogue Games and Fallacies*. University Press of America.

Walton, D. N. 1985. New directions in the logic of dialogue. *Synthese* **63**, 259–274.

Walton, D. 1989a. *Question-Reply Argumentation*. Greenwood Press.

Walton, D. 1989b. *Informal Logic:A Handbook for Critical Argumentation*. Cambridge University Press.

Walton, D. 1998. *The New Dialectic: Conversational Contexts of Argument*. University of Toronto Press.

Walton, D. 2000. The place of dialogue theory in logic, computer science and communication studies. *Synthese* **123**, 327–346.

Walton, D. & Krabbe, E. 1995. *Commitment in Dialogue. Basic Concepts of Interpersonal Reasoning*. State University of New York Press.

Wooldridge, M. 2002. *An Introduction to Multi-agent Systems*. John Wiley and Sons.

Yuan, T. 2004. *Human Computer Debate*, *A Computational Dialectics Approach*. PhD thesis, Leeds Metropolitan University.

Yuan, T., Moore, D. & Grierson, A. 2003. Computational agents as a test-bed to study philosophical model "DE", a development of Mackenzie's "DC". *Journal of Informal Logic* **23**(3), 263–284.

Yuan, T., Moore, D. & Grierson, A. 2007a. A human computer debating system and its dialogue strategies. *International Journal of Intelligent Systems, Special Issue on Computational Models of Natural Argument* **22**(1), 133–156.

Yuan, T., Moore, D. & Grierson, A. 2008. A human-computer dialogue system for educational debate, a computational dialectics approach. *International Journal of Artificial Intelligence in Education* **18**, 3–26.

Yuan, T. & Schulze, J 2008. ARG!Draw: an argument graphs drawing tool. In *The Second International Conference on Computational Models of Argument*, Toulouse.

Yuan, T., Svansson, V., Moore, D. & Grierson, A. 2007b. A computer game for abstract argumentation. In *Proceedings of IJCAI'2007 Workshop on Computational Models of Natural Argument*, Hyderabad, India, 62–68.