1. Chance Discovery Using Dialectical Argumentation

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Summary.

We propose the use of a dialectical argumentation formalism for chance discovery in domains where knowledge is distributed across a number of distinct knowledge-bases, as in a system of autonomous software agents. Each agent may have only a partial view of a problem, and may have insufficient knowledge to prove particular hypotheses; our formalism provides a means to aggregate across these partial views in a consistent manner. We identify a novel type of dialogue, which we call a discovery dialogue, and propose a formal model for its conduct. We then present locutions and rules for the implementation of these dialogues as dialogue-games.

1.1 Introduction

In 1994-5, the British Government privatized the state-owned national railway monopoly, British Rail. They did this by creating one private company, Railtrack Ltd, to own and operate the physical network of railway track, and then created 25 separate licences, each awarded by competitive tender, to operate train services along these tracks in specific geographic regions. In addition, other companies were created to provide specific services to Railtrack and to the train operating companies, for instance, railway communications. The new private companies also outsourced functions which had previously been undertaken within British Rail, such as carriage ownership and track inspection and maintenance. By one estimate there are now more than 100 companies where previously there was just one. Thus, what was once a single and unified system, is now fragmented, with disparate responsibilities, distributed knowledge and possibly conflicting interests. No one company in the network now has all the information needed to manage it. The results of this were seen on 17 October 2000, when faulty track caused a derailment at Hatfield, killing four people and injuring 70. Although an inquiry still has to establish ultimate responsibility for the accident, knowledge of the faulty track appears to have been known to the company tasked with network inspection, a sub-contractor to Railtrack [4].

The problem of interest here is how to identify risks and opportunities (*"Chance Discovery"*) in situations where knowledge is distributed across multiple autonomous agents. We believe that systems of dialectical argumentation, which enable the coherent combination of disparate knowledge types and sources, are applicable to this problem and we present here a formalism for such a system. For simplicity, we assume that the agents involved do not perceive they have divergent economic or other interests, and so are willing to share information fully with each other. We present our formalism in Section 3, after briefly reviewing argumentation and formal dialogue games in Section 2. In earlier work, we presented a similar dialectical argumentation structure for dialogues over risk in environmental domains, which we which termed a *Risk Agora* [7]. Accordingly, we call the formalism presented in this paper a *Discovery Agora*. Section 4 concludes the paper.

1.2 Argumentation

In common English usage, an *"argument"* has two meanings: a case for (or against) a particular claim, and a debate between two or more people. Arguments in both senses have been studied by philosophers since at least the time of Aristotle, in a branch of philosophy now called argumentation theory. In this paper, we will use the word *argument* for only the first meaning, and the words *debate* or *dialogue* for the second. Considering arguments as cases for claims, argumentation theory has examined issues such as what constitutes a good or bad argument, under what circumstances is it rational to use non-deductive arguments, and what relationships may exist between distinct arguments. For dialogues and debates, philosophers have explored issues such as how may such debates be organized and structured, what rules are appropriate for different types of interaction, and what impacts arise from variations in these rules. In both areas, philosophers of argumentation have been particularly active since the mid-1950s, perhaps in response to the development of formal, deductive logic in the century before that. See [11] for a comprehensive review of argumentation theory, and [2] for a review of some applications of argumentation in Artificial Intelligence. In this paper we will use formal dialogue games to model dialogues, so we first discuss different types of dialogues.

In an influential typology, Doug Walton and Erik Krabbe [12] identified six primary types of dialogue, distinguished by their initial situations, the goals of each of their participants, and the goals of the dialogue itself (which may differ from those of its participants). The six dialogue types were: *Information-seeking dialogues*, in which participant seeks the answer to some question from another participant; *Inquiries*, in which all participants collaborate to answer some question to which none has the answer; *Persuasion dialogues*, in which one participant seeks to convince others of the truth of some proposition; *Negotiations*, in which participants attempt to divide up a scarce resource; *Deliberations*, in which participants collaborate to decide what actions to take in some situation; and *Eristic* (strife-ridden) dialogues, in which participants quarrel verbally as a substitute to physical fighting. Most human dialogues may be seen as examples of these six or combinations thereof, although Walton and Krabbe do not claim their typology is comprehensive.

How may specific types of dialogues be modeled? To do this, we draw on the formal dialogue games proposed by philosophers to better understand fallacious modes of reasoning [3]. These are games between two or more players, where the "moves" made by the players are locutions, i.e. spoken utterances. Recently, such games have been applied in Artificial Intelligence [1], particularly for automated dialogues between autonomous agents, and we have been led to propose a formal model for dialogue-games [8]. In our model, it is assumed that the topics of discussion between the participants are represented in some logical language, whose well-formed formulae are denoted by the lower-case Roman letters, p, q, r, etc. The rules of the dialogue-game can be divided into several distinct types:

Commencement Rules: Rules which define the circumstances under which the dialogue commences.

Locutions: Rules which indicate what utterances are permitted. Typically, legal locutions permit participants to assert propositions, permit others to question or contest prior assertions, and permit those asserting propositions which are subsequently questioned or contested to justify their assertions.

Combination Rules: Rules which define the dialogical contexts under which particular locutions are permitted or not, or obligatory or not. For instance, it may not be permitted for a participant to assert a proposition p and subsequently the proposition $\neg p$ in the same dialogue, without in the interim having retracted the former assertion.

Commitments: Rules which define the circumstances under which participants express dialogic commitment to a proposition. Typically, assertion of a claim p in the debate is defined as indicating to the other participants some level of commitment to, or support for, the claim. Since Hamblin [3], it is common to track commitments in publicly-accessible stores called Commitment Stores.

Termination Rules: Rules which define the circumstances under which the dialogue ends. These rules may be expressible in terms of the contents of the Commitment Stores of one or more participants.

Instantiating these rules for different types of dialogue has been a recent research focus. For example, Walton and Krabbe [12] presented formal models for persuasion dialogues, and, in joint work with David Hitchcock [6], we have proposed the first formal model for deliberation dialogues.

1.3 The Discovery Agora: Formal Structure

With these considerations in mind, we now present our formal structure for the argumentation system for chance discovery, which we have called a *Discovery Agora*. We assume, as above, that the topics of discussion between the participants are represented in some logical language, $\mathcal{L}$, closed under the usual connectives, whose well-formed formulae are denoted by the lower-case Roman letters, p, q, r, etc. Although the participants may believe different sets of axioms (premises) to be true, we assume they have agreed a set of deductive inference rules. We refer to this logical language and the agreed inference rules as the common logic of the Agora. We further assume a denumerable set of autonomous software agents who participate in the dialogue, each of whom is denoted by $\mathcal{P}_i$, indexed by $i \in \mathcal{I}$. We assume in this paper that each agent uses the same logical language and rules of inference, and that they differ only in the information they know to be true (i.e. in their premises). Thus, each participant may know part of the story but not the whole story. We further assume that the agents have no inhibitions about sharing information with each other in the Agora.

In this section we present the formal model for the Discovery Agora. We do this, firstly, in Section 3.1, with an informal discussion of discovery dialogues to motivate our formalism, then, in Section 3.2, a formal model of a Discovery Dialogue in the Agora. Section 3.3 presents the rules for a dialogue game in conformance with the formal model.

1.3.1 Discovery dialogues

We assume the agents in the Discovery Agora are engaged in dialogue. Which of the Walton and Krabbe [12] dialogue types mentioned above is appropriate to this domain? The closest type would appear to be an Inquiry dialogue, where participants collaborate to ascertain the truth of some question. However, for the domain of Chance Discovery we want to *discover* something not previously known; the question whose truth is to be ascertained may only emerge in the course of the dialogue. This feature is similar to Deliberation dialogues, where the course of action adopted by the participants may also only emerge in the course of the dialogue itself. The other five types of dialogue all begin with some question or issue for discussion. We therefore believe that the dialogue type appropriate to the Chance Discovery domain is not one of the types of Walton and Krabbe. We will call it a *Discovery Dialogue*.

These dialogues differ from Inquiries in another way. In a pure inquiry, the participants would wish to seek the truth, unadulterated by their preferences or emotional responses. This is unlike a Deliberation, where the preferences or emotions of the participants could play an important part in the selection of an optimal course of action. While the participants in a Discovery dialogue are also seeking truth, there may be many possible truths. It would be sensible for the participants to filter the truths they discover by what is interesting, novel or important. Discovering risks, for instance, means identifying potential outcomes with significant and deleterious consequences.

How might a dialogue concerning chance discovery proceed? We could imagine a number of elements to such a dialogue. Firstly, there would be agreement (perhaps implicit) about the purpose of the dialogue; this could be, for instance, to assess the risks inherent in some situation or technology. Next there may be the sharing of relevant information known by each of the participants and the pooling of this knowledge to generate new knowledge. For dialogues seeking to discover consequences or risks, there may also be discussion concerning the possible mechanisms by which such risks or consequences could occur. These mechanisms may be chains of possible scientific causality (as in cellular-level biomedical mechanisms) or metaphorical or analogical modes of reasoning. Legal reasoning concerning the potential motives, opportunity and means of a suspect to commit a crime is another example of such mechanisms. Then, once potential discoveries have been articulated in the dialogue, there may be discussion over their attributes. For instance: Are they equally important? What are their relative consequential losses or benefits? etc. This discussion over attributes may in turn lead to consideration of experiments or data collection activities to verify which of competing hypotheses is more likely correct in explaining causal effects. In human dialogues, of course, such discussions do not occur in a linear fashion, but move back and forth between these various elements as the discussion evolves. Our formal model, to be presented next, will include each of these elements and allow for non-linear dialogues.

1.3.2 Model of a discovery dialogue

In this section we formalize the discussion just presented. We begin by defining the elements of the discovery dialogue, drawing on the model of an argument proposed by Stephen Toulmin [10].

Purpose: The Purpose of a dialogue is the overall issue or issues which motivated the participants to convene and which governs their dialogue. Examples include the risks or the opportunities of some situation. We assume that a discovery dialogue is initiated by one of the participants with a proposed purpose. However, the other participants may not share the same understanding of the dialogue's purpose, and so this needs to be discussed at the outset.

Data Item: A Data Item is a proposition for which at least one dialogue participant has a proof, using premises in that participant's knowledge base and using the rules of inference of the common logic. Participants who articulate data items will be required to present the arguments for them, if requested in the Agora.

Inference Mechanism: An inference mechanism is a warrant which justifies the drawing of a conclusion from one or more data items. Examples of mechanisms include: the rules of deductive inference of the common logic of the participants; default rules; causal mechanisms; metaphors and analogies; legal precedents, etc.

Consequence: A consequence is a claim arising from the application of an inference mechanism to one or more data items.

Criterion: A criterion is an attribute of a data item or a consequence, which may be used to compare one data item or consequence with another. Examples of criteria include: novelty; importance; costs; benefits; feasibility; etc.

Test: A test is a procedure, generally undertaken outside the Discovery dialogue, to ascertain the truth-value of some unknown variable. Examples include: scientific experiments; data collection exercises; information-seeking dialogues.

Conclusion: A conclusion is a full or partial response to the purpose of the dialogue. For example, conclusion could include significant risks identified in the course of the dialogue or interesting opportunities.

With these elements defined, we now present a formal model of the dialogue itself, which moves through ten stages. Our model is similar in approach to the formal model for deliberation dialogues we developed with David Hitchcock in [6].

Open Dialogue: Opening of the discovery dialogue.

Discuss Purpose: Discussion of the purpose of the dialogue.
Share Knowledge: Presentation of data items relevant to the purpose, drawing only on each participant's individual knowledge base.
Discuss Mechanisms: Discussion of potential rules of inference, causal mechanisms, metaphorical modes of reasoning, legal theories, etc.
Infer Consequences: Identification of the consequences arising from the application of inference mechanisms to the data items presented by the participants.
Discuss Criteria: Discussion of possible criteria for assessment of the consequences presented.
Assess Consequences: Discussion of the data items and consequences against the criteria previously suggested.
Discuss Tests: Discussion of need for undertaking tests of proposed consequences. If such tests are conducted outside the dialogue, the results may be reported back to the dialogue in a **Share Knowledge** stage.
Propose Conclusions: Proposing one or more conclusions for possible acceptance by the participants.
Close Dialogue: Closing of the discovery dialogue.

Agreement is not necessary in these dialogues unless the participants so desire it. If so, the **Propose Conclusions** stage allows a participant to propose a conclusion for possible acceptance, and then allows participants to indicate to the Agora their individual acceptance or otherwise. The stages of a discovery dialogue may be undertaken in any order and may be repeated, subject only to certain constraints, which we have articulated in [9]. For example, the **Discuss Purpose** must precede any instance of every other stage, excepting the **Open Dialogue** and **Close Dialogue** stages.

1.3.3 Dialogue game rules

We now present examples of dialogue-game locutions which, taken together, enable a discovery dialogue to be conducted according to the model just presented. For reasons of space, we do not present all the locutions, nor all the necessary preconditions for, and the consequences of, their utterance. We continue to assume that the subject-matter of dialogues can be represented in a propositional language by lower-case Roman letters. We define *questions* as propositions with one or more free variables, and we represent these by lower-case Roman letters suffixed with a question-mark, e.g *"p?"*. We assume a Commitment Store $CS(P_i)$ exists for each agent P_i. This store contains the various propositions which the agent has publicly accepted, and each store can be viewed by all participants. Entries in the stores are of three sorts: (a) 2-tuples of the form (type, t), where t is a valid instance of type *type*, with *type* $\in$ $\{$*purpose, data item, inference mechanism, consequence, criterion, test, conclusion*$\}$; (b) 3-tuples of the form (c, t, p), where c is a consequence, t is a criterion and p a proposition; and (c) 3-tuples of the form (c_1, c_2, t), where c_1 and c_2 are consequences and t a criterion. The permitted locutions are:

open_dialogue(P_i, p): Participant P_i proposes the opening of a Discovery dialogue to consider the proposed purpose p. A dialogue can only commence with this move.

enter_dialogue(P_j, p): Participant P_j indicates a willingness to join a Discovery dialogue to consider the purpose p. All intending participants other than the mover of **open_dialogue(.)** must announce their participation with this move. Note that neither the **open_dialogue(.)** nor the **enter_dialogue(.)** move implies that the speaker accepts that p is the most appropriate formulation of the purpose, only that he or she is willing to enter into a discussion about it at this time.

propose($P_i, type, t$): Participant P_i proposes proposition t as a valid instance of type $type$, where *type* $\in$ {*purpose, data item, inference mechanism, consequence, criterion, test, conclusion*}.

assert($P_i, type, t$): Participant P_i asserts proposition t as a valid instance of type $type$, where *type* $\in$ {*purpose, data item, inference mechanism, consequence, criterion, test, conclusion*}. This is a stronger locution than **propose(.)**, and results in the tuple $(type, t)$ being inserted into $CS(P_i)$, the Commitment Store of P_i. For certain types, utterance of this locution leads to the speaker having a *burden of defence*, i.e. to provide supporting arguments or evidence for the assertion if so requested by another participant.

query(P_j,propose($P_i, type, t$)): Participant P_j requests participant P_i to provide a justification for his proposal of t as a valid instance of type $type$, where *type* $\in$ {*data item, consequence, test*}, and where $j \neq i$. Similarly, a participant may query an assertion with the command **query(**P_j,**assert(**$P_i, type, t$**))**. In response to either query, P_i must defend his proposal or assertion statement with an utterance of **show_arg(.)**.

show_arg($P_i, type, t, A$): Participant P_i presents an argument A for proposition p which is type *type* $\in$ {*data item, consequence, test*}. In the case of *data items*, the argument A is a proof from premises in the knowledge base of participant P_i and using deductive inference rules in the common logic of the dialogue. In the case of *consequences*, the argument A comprises one or more sequences of the form (D, I, C), where D is a set of *data items*, I is an inference mechanism and C is a consequence which can be drawn from D using I; all elements of this set must previously been articulated in the Agora by means of appropriate **propose(.)** or **assert(.)** locutions. In the case of *tests*, the argument A also comprises one or more sequences of the form (D, I, C), where D is a set of *data items*, I is an inference mechanism and C is a consequence which can be drawn from D using I, but these need not have been previously presented in the dialogue.

assess(P_i, c, t, p): Participant P_i asserts that when consequence c is assessed on the basis of criterion t, one may conclude proposition p. This locution inserts (c, t, p) into $CS(P_i)$.

compare(P_i, c_1, c_2, t): Participant P_i asserts that consequence c_1 is better or equal to consequence c_2 when they are compared on the basis of criterion t. Each of c_1, c_2 and t must previously been articulated in the Agora by means of the appropriate **propose(.)** or **assert(.)** locutions. This locution inserts (c_1, c_2, t) into $CS(P_i)$.

recommend(P_i, $conclusion, a$): Participant P_i proposes proposition a as a recommended conclusion. This locution inserts $(conclusion, a)$ into $CS(P_i)$.

accept(P_j, $locution$): Participant P_j indicates agreement with the prior locution, *locution*, uttered by another participant. If the prior locution resulted in a change to that speaker's commitment store then the **accept(.)** locution similarly alters $CS(P_j)$.

contest(P_j, $locution$): Participant P_j indicates disagreement with the prior locution, *locution*, uttered by another participant. The **contest(.)** locution is the obverse of **accept(.)** and has no impact on $CS(P_j)$.

retract(P_i, $locution$): Participant P_i indicates retraction of her prior utterance of the locution *locution*. If the prior locution resulted in an insertion into $CS(P_i)$, then the **retract(.)** locution deletes it.

withdraw_dialogue(P_i, p): Participant P_i announces her withdrawal from the Discovery dialogue to consider the governing question p.

We now demonstrate that the dialogue game locutions we have defined can be used to undertake a Discovery dialogue in accordance with the formal model we have proposed.

Proposition 1: *Each of the ten stages of the formal model of discovery dialogues presented in section 3.2 can be executed by judicious choice of these dialogue-game locutions.*
Proof. We consider each stage in turn:

1. A dialogue opens with the locution **open_dialogue**(P_i, p) and at least one utterance of **enter_dialogue**(P_j, p), with $j \neq i$.
2. The Discuss Purpose stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **contest(.)** and **retract(.)**, in each case with the type *purpose*.
3. The Share Knowledge stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **query(.)**, **show_arg(.)**, **contest(.)** and **retract(.)**, in each case with the type *data item*.
4. The Discuss Mechanism stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **contest(.)** and **retract(.)**, in each case with the type *inference mechanism*.
5. The Infer Consequences stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **query(.)**, **show_arg(.)**, **contest(.)** and **retract(.)**, in each case with the type *consequence*.
6. The Discuss Criteria stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **contest(.)** and **retract(.)**, in each case with the type *criterion*.
7. The Assess Consequences stage consists of utterances of **assess(.)**, **compare(.)**, **agree(.)**, **contest(.)** and **retract(.)**.
8. The Discuss Tests stage consists of utterances of **propose(.)**, **assert(.)**, **accept(.)**, **contest(.)** and **retract(.)**, in each case with the type *test*.

9. The Propose Conclusions stage consists of the **recommend**(P_i, $action, a$) locution, possibly followed by utterances of **accept**(P_j, $action, a$).
10. Participants may exit a dialogue, by means of the **withdraw_dialogue**(P_i, p) locution, at any time. The dialogue itself closes once the second-last participant utters this locution. □

In addition to defining the permitted locutions, we have specified commencement, combination, commitment and termination rules for this game [9]. These rules have been specified to accord with principles of joint mutual inquiry between consenting participants proposed by Hitchcock in [5].

1.4 Conclusion

This paper has proposed a formal argumentation system for chance discovery in domains where knowledge is distributed between autonomous agents. Our approach has led us to propose a new type of dialogue, which we call a chance discovery dialogue, for arguments in this domain. We have proposed a formal model for the conduct of discovery dialogues, and presented the locutions and rules for a dialogue game undertaken in accordance with this model.

We are currently considering a number of further research lines, in particular the question of whether discovery dialogues can be automated. We are exploring the use of evolutionary computational approaches to enable fully automated dialogues to be conducted. For example, it may be possible to use a genetic algorithm to generate candidate discoveries which are then processed through the dialogue-game described above. Those which are accepted by the participants to the discussion may be considered the fittest survivors and so form the basis for a subsequent generation of discoveries, which are discussed in subsequent dialogues.[1]

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