Reasoning with topoi – towards a rhetorical approach to non-monotonicity

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Abstract. One challenge for dialogue modelling, as well as other aspects of artificial intelligence, is the fact that human reasoning is non-monotonic. Among other things this reflects the fact that we usually do not have access to all information regarding an issue or that we have access to information and principles of reasoning which are in fact incompatible. We suggest that rather than default rules of logic, we use rhetorical rules of thumb – *topoi* – to underpin our non-logical arguments, which in rhetoric are referred to as *enthymemes*. Enthymemes and topoi are defeasible and a set of topoi accessed by one individual may be inconsistent. A rhetorical perspective highlights the importance of individual agents' point of view and goals in interaction, and in order to account for dialogue participants' individual takes on the interaction we model their information states during the course of a reasoning dialogue in Type Theory with Records.

1 INTRODUCTION

An important feature of classical logic is that if a formula is derivable from a theory (a set of formulae), then it must also be derivable from an expansion of that theory. Let us say for example that Γ is a set of formulae and A is a formula and A is a logical consequent of Γ ($\Gamma \vdash A$). Then Γ, $B \vdash A$ is true as well.

In natural reasoning however, it is often the case that we draw a conclusion which we later have to retract in the light of new information. One reason for this is that we sometimes have to consider problems about which we have limited information. To handle cases like these various types of non-monotonic logic were proposed in the early eighties in for example [29], [31] and [28]. Approaches to non-monotonic logic often suggest we represent human reasoning in terms of *defaults* as suggested in [31], with later followers such as [21]. The principle of default logic is that there are rules which are usually true, but which may in some cases be overridden by other rules. This approach seems to be adequate in cases where the non-monotonicity has to do with lack of information. However, in cases such as the "Nixon Diamond" [32] (see Section 2), we can no longer represent all accessible information as one consistent set of rules. This type of reasoning is not uncommon in conversation and other types of natural discourse, and research questions pertaining to it are sometimes addressed in conversation analysis and other approaches to dialogue. However, this research often lacks suggestions of how to represent these problems formally in a way that would make the analyses relevant for example for artificial intelligence. We propose a model inspired by rhetorical theory as introduced by Aristotle [2] and later developed in the context of natural dialogue by Ducrot, [15], [16] and Anscombre [1]. Our theory highlights the importance of point of view (essential in rhetoric) and context in natural reasoning.

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We do this by representing the resources we have at hand to underpin arguments not as a monolithic set of default rules, but as a set of *topoi*. Topoi are rules which may be contradictory within a set of resources, and which may be combined in different ways, sometimes giving rise to contradictory conclusions. In our analysis we will draw on work in dialogue semantics [19], [8], [10]. The formalism we use is Type Theory with Records (TTR), as presented for example in [8], [9], [24] which enables us to model information states as objects of structured types. This means that we get a clear and intuitive way of modelling the cognitive processes involved in rhetorical discourse which we argue are central in non-monotonic reasoning. In Section 2 we introduce two puzzles which are frequently discussed in the literature on non-monotonic reasoning. We also introduce the rhetorical concepts of *topos* and *enthymeme* and demonstrate how these concepts are relevant in natural dialogue. In Section 3. we suggest a rhetorical approach to non-monotonic reasoning. In Section 4 we use TTR to make our analysis more precise.

2 BACKGROUND

2.1 Default logic

The classic "Tweety triangle"-puzzle illustrates the principle of default reasoning. In short, the puzzle comes down to this: When we say that Tweety is a bird, and therefore Tweety flies, we draw on some rule saying that if something is a bird, then it flies. In classical logic this is expressed as in (1).

(1) $\forall x\, (\text{bird}(x) \rightarrow \text{fly}(x))$

We know however, that there are some types of birds which do not fly, like penguins and ostriches. So we also have access to rules like

(2) a. $\forall x\, (\text{penguin}(x) \rightarrow \neg\text{fly}(x))$
b. $\forall x\, (\text{penguin}(x) \rightarrow \text{bird}(x))$

This means that the rule in (14) has to be modified:

(3) $\forall x\, (\text{bird}(x) \wedge \neg\text{penguin}(x) \rightarrow \text{fly}(x))$

In most natural discourse, we allow for exceptions like this, but we do not necessarily have rules for every single exception. It would be possible to include more exceptions for other types of non-flying birds. However, this could be difficult since there might be species of birds that do not fly which we do not know of (but we know they *might* exist). Also, there might be individual birds who do not fly for various reasons. So, what we really want is a rule that expresses "under normal circumstances, birds fly" or "if we are not dealing with

an exception, then birds fly". In default logic this is usually done through *default rules* which could look like (4). (4) should be interpreted as "If x is a bird and there is nothing to contradict that x flies, then x flies.

$$(4) \quad \frac{\text{bird}(x).\ \text{fly}(x)}{\text{fly}(x)}$$

Another problem often discussed in the context of non-monotonic reasoning is the so called *Nixon Diamond* (see for example [32]). The situation described in this puzzle is the following:

(5) a. Nixon is a quaker, and quakers are pacifists
b. Nixon is a republican, and republicans are not pacifists

Since we have access to the information in (5), our theory contains rules which lead to inconsistent conclusions. If we apply (5a) and (5c) we arrive at the conclusion that Nixon is a pacifist. However, if we apply (5b) and (5d), we arrive at the opposite conclusion.

2.2 Enthymemes and topoi

Aristotle's *Rhetoric* does not deal with logic, but with the logic-like type of reasoning which frequently occurs in dialogue and other spoken discourse. This type of reasoning is, by and large, non-monotonic. Aristotle presents rhetoric as an art in some ways parallel to logic, and many rhetorical concepts are coined as counterparts of similar concepts in logic. A central concept in the Aristotelian theory of logical deduction is the *syllogism*. In the *Prior Analytics* [3] Aristotle defines the syllogism as

> An argument (*logos*) in which, certain things having been supposed, something different from the things supposed results of necessity because these things are so

"certain things having been supposed" refers to the set of premises, and, being in the plural, "the things supposed" indicates, according to[23], that there must be more than one premise. The rhetorical correlate of the syllogism - the deductive type of proof - in rhetoric is the *enthymeme*. The conclusion of an enthymeme does not - in contrast to that of a syllogism - need to follow of necessity. Neither is there a need for the set of premises to consist of more than one premise. These are differences regarding to formal requirements, but there are also other ways in which syllogisms and enthymemes differ, mainly having to do with subject matter. While logical arguments should deal with general statements, enthymemes deal with particular cases. This means that in logic we argue for or against a general claim about the world, whereas in rhetoric we seek to persuade someone of something regarding a particular case. This means that premises stating that something is usually the case could be acceptable in rhetoric but not in syllogistic reasoning. An example of an enthymeme from the *Rhetoric* is the following:

$$(6) \quad \frac{\text{one ought not be envied}}{\text{one should not be educated}}$$

The persuasive quality of the enthymeme in (6) is probably not evident to many of us. In Aristotle's time however, it was presumably clear – at least clear enough for Aristotle to choose it as an example in his *Rhetoric* [2]. Presenting an argument in this way – drawing on a set of non-necessary assumptions – is possible because the members of an audience, just like people who take part in a conversation, have knowledge of and beliefs regarding the world around them. In this case Aristotle expected the audience to recognise, based on experience and previous input, that educated people are usually envied, so when they hear the argument, they add their belief regarding educated people to the argument and may, if the argument is wisely chosen in the context, find it reasonable.

In order to have effect the enthymeme needs to draw on some commonly recognised notion which supplies the information lacking in the set of premises. This notion Aristotle refers to as the *topos* of the enthymeme. Some topoi may be applied to various subjects – common topoi – while others are specific to a particular subject. For Aristotle all topoi and enthymemes are not equally acceptable and he discourages use of fallacious topoi and modes of reasoning in rhetoric, on normative grounds as well as on the grounds of not being caught out with a fallacious argument. On the other hand, the Rhetoric provides tools to reason with whichever means the speaker thinks he can get away with – what is emphasised is the importance of adapting to the audience, and this could potentially include fallacious topoi and sophistic argumentation. One example of a fallacy that often occurrs in spontaneous discussions is the *fallacy of the converse*, the fallacy of inferring the converse of the original statement. For example, we might all agree that if Sam is a boxer, he is strong, but the converse – if Sam is strong then he is a boxer – does not hold. However, this type of reasoning still occurs in discourse (for an example see the dialogue excerpt discussed in [6]) and in some contexts this way of reasoning might even be efficient. Two thousand years after Aristotle, a more pragmatic concept of topos was made the centre of a linguistic theory presented in [15], [16], to an extent in collaboration with [1]. The theory is based on the idea that there is always a link between two utterances A and C where one of them is an assertion or a suggestion, exhortation, etc. and the other an assertion which functions as a support for the first. This link sanctions the interpretation of A and C as an argument. This link is referred to by Ducrot and Anscombre as *topos*. [16] argues that topoi are notions which are *common*, that is they are assumed or taken for granted in a community, even before the conversation takes place in which they are employed. They are also *general* in the sense that one topos can be employed in various arguments, in various situations.The opposite, that different topoi may be employed in similar situations is also true. [1] argues that when we say *Give a coin to the porter, he carried the bags all the way here*, there is an obvious connection between the first and second proposition expressed in the utterance. However, the connection between carrying luggage and getting a tip is not linguistic. Instead it is the common place principle that work should be rewarded, which is generally recognised, at least in western society. Interestingly, argues [1], there are other, equally acceptable principles that would lead to an opposite conclusion, such as principles that porters get paid to carry luggage already, and you should not get a tip for doing your job. Anscombre also makes the important observation that topoi, contrary to logical rules, do not constitute a monolithic system. Instead the system of topoi consists of principles which may be combined in different ways, like logical rules, but which do not necessarily fit together in a specific situation. [1] suggests that this is because topoi are part of ideology – ways in which we perceive the world – and ideologies are not monolithic. Therefore, a principle like *opposites attract* and *birds of a feather flock together* may co-exist not only in one community, but in the set of topoi of one individual. Another important aspect of topoi according to Ducrot, is that they are *gradual*, that is if I say "it's warm today, let's go to the beach", the topos - that warm weather makes the beach an attractive destination, is more true the warmer it is, and less true the less warm

it is. A consequence of this would be that an enthymeme evoking a topos may be more or less convincing, depending on the context of utterance.

2.3 Topoi as rhetorical resources

Our view of rhetorical reasoning and natural situated reasoning in general, is that arguments in natural dialogue are always, or as good as always, enthymematic. These arguments work because they are underpinned by topoi which are established in the *rhetorical resources* of an individual through interaction with the world including other agents. The notion of rhetorical resources is inspired by work on other types of linguistic resources, such as [14], [25], [13], [9]. The leading idea of this work is that linguistic agents have various language resources available which they can use to construct a particular language suitable to the purposes of the dialogue at hand. An important part of a theory of resources, is that resources are dynamic and may be affected by speech events occurring during the course of a dialogue. Our view, discussed in more detail in [6], is that linguistic agents do not have one monolithic collection of resources, but rather that different resources can be applied in different domains and situations. Resources can be local to one particular dialogue as we struggle to make sense of what our dialogue partners are saying or to convey concepts for which we do not yet have linguistic expressions. Certain ad hoc resources may not survive a particular conversation. Others may be limited to a small set of interlocutors or particular subject matter. They may progress to be part of our more general linguistic resources which we feel we can use with any speaker of the language. In fact, this perspective on topoi is very much in line with the view of topoi in [16] and [1], who emphasise that a system of topoi - even that accessed by one individual - will most likely include conflicting propositions. This would present a problem in classical logic, and for any monolithic logical system, like various non-monotonic logics. For a system of topoi, however, it does not.

3 A RHETORICAL PERSPECTIVE ON NON-MONOTONICITY

This far, we have sketched a picture of how enthymemes and topoi interact so that an enthymematic argument uttered by a person A, may tap into a topos recognised by B, or, if B does not recognise the topos, causes B to tentatively establish a topos that would support the argument. An agent's knowledge base is expanded with more and more ways in which people reason, and the agent continuously re-evaluates, specifies and generalises her topoi and thus develops resources that are compatible with input. In this respect the work on default logic in [22] presents a view similar to ours. In [22] discusses an example of reasoning between parents and children regarding age, homework and tv-watching. Principles like "Kids at least nine years old get to watch tv after dinner" are obviously non-necessary in nature, just like topoi. They might be overruled by other rules such as "Kids get to watch tv if they have done their homework." However, just like in real legislation, in a system of common law principles we cannot have contradicting principles or rules. We argue that in ordinary reasoning it is often not the case that sets of applicable rules are completely non-contradictory, or organised hierarchically with general rules as defaults, and more specified rules overruling the default according to some principle of probability. Instead, we argue that the principles underpinning arguments are not necessarily hierarchical (even though some might be more commonly appealed to than others), and not necessarily consistent, even within one individual or context.

So it seems to us that if we want to account for how conversational agents make inferences in natural language, or how some inferences (even logical inferences) may be more acceptable or appropriate than others, we benefit from focusing on the agent's point of view rather than facts about the world (or at least facts about the world other than those constituted by agents' beliefs and opinions about the world). Agents involved in interaction may have different takes on a situation or type of situation either because they have access to different information or different rules of thumb according to which they process that information, or because their goals differ. This seems to be very relevant to many of the problems addressed in the literature on non-monotonic reasoning – particularly puzzles of the "Nixon diamond" variety where two contradicting conclusions may be drawn based on a seemingly acceptable set of rules. We therefore suggest that we look at these problems differently – from a rhetorical perspective in a dialogue setting.

Let's consider an authentic dialogue example, first presented in [33]. The context of (7) is that two colleagues are on their way to work, and one of them (A) suggests to the other (B) that they choose Walnut Street rather than some other possible option.

(7) a. A: Let's walk along Walnut Street
b. A: It's shorter

(7) can be seen as an enthymematic argument where A tries to persuade B that Walnut Street should be chosen on account of being shorter (than some other possible option). In terms of default reasoning we could say that the rule (7) is based on may be represented as in (8)

(8) $$\frac{\text{shorter}(x).\ \text{preferable}(x)}{\text{preferable}(x)}$$

Of course this example differs from the Tweety example in that it has to do with taste or opinion, whereas "Tweety" has to do with facts. Still it could be argued that we may very well consider (8) a default rule if we perceived that the rule "the shorter route is preferable" to be true in most cases, but that there may be exceptions to this rule, such as "if it is not very crowded" or "if it is not a short cut through the park and it is the middle of the night". However, In the case of "Tweety" one agent may assert that Tweety can fly, since she does not have the information that Tweety is a penguin, only that he is a bird, drawing on the default rule that birds fly. In the "Walnut Street" case however, we do not only have to worry about the exceptions to the default rule that short routes are preferable when choosing a route, we also have to consider the purpose or goal associated with the walk. In some contexts "longer routes are preferable" would be the default, such as a context where the goal is to get some exercise. Moreover in a single context, agents may have different opinions regarding the purpose of the walk.

If we imagine the Tweety-scenario as a dialogue situation where a speaker A claims: "Tweety flies – he's a bird!", A has expressed an enthymeme

(9) $$\frac{\text{Tweety is a bird}}{\text{Tweety flies}}$$

A's argument is underpinned by a topos saying that if we have a situation where something is a bird, we can assume that we also have

a situation where that something flies. Let us then imagine that another speaker, B says in reply to A "No, Tweety can't fly – he's a penguin!", evoking a topos saying that if we have a situation where something is a penguin, then we have a situation where this something does not fly. The topos about penguins could be considered more reliable, and A would have to reconsider her judgement about Tweety. [21] suggests that this is due to that the rule saying that penguins do not fly is more specific than the one saying that birds do fly. The reason that it is more specific is that penguins are a type of bird, but birds are not a type of penguins, and a topos stating that is probably also evoked in a conversation like this.

4 FORMAL ANALYSIS

We will now develop the analysis in the previous section by suggesting how the reasoning going on in some of the examples we have mentioned may be represented formally. We will use a gameboard style semantics cast in Type Theory with Records (TTR). [8], [13], [9], [19] [10]. The notion of *Dialogue Gameboard* is inspired by game metaphors in language philosophy, for example those suggested by Wittgenstein [4] and Lewis [27], and an important feature of Ginzburg's theory of dialogue semantics – KoS – which has been developed over the last fifteen years in for example [17], [18], with a current take presented [19]. One development of the dialogue gameboard is presented in [26] who propose an information state update approach to dialogue modelling. Gameboard style dialogue semantics cast in TTR can be found in [19], [12]. However, in none of these works are any suggestions about how to handle rhetorical phenomena. Thus the version of the gameboard presented here is modified to be able to account for enthymemes and topoi. They are also altered in some other respects compared to earlier versions.

Our focus is particularly on how individual agents draw on individual (and sometimes distinct) resources in the shape of sets of topoi. We will therefore use separate gameboards for each agent, representing their respective information states.

4.1 A dialogue gameboard for rhetorical reasoning

The gameboard is divided into "shared" and "private" [2]. Shared information is information which the agent whose information state is represented believes to be shared, and which has in some way been referred to in a dialogue, or is necessary for a dialogue contribution to be interpreted in a relevant way. For example, although a topos may be of central relevance in the dialogue, it does not appear on the gameboard, as part of an agent's shared information state, until it has been made explicit, or until something has been said which has caused it to be accommodated. Under "private" we find two fields - *agenda* and *topoi*. The agenda keeps track of the next dialogue move (or moves) an agent intends to make. Each label in the information state (such as "shared", "agenda" or "topoi") is of a type, which is stated after the colon. The type of the agenda is a list of *MoveTypes*.

(10)
$$\begin{bmatrix} \text{private:} \begin{bmatrix} \text{agenda:list}(\textit{MoveType}) \\ \text{topoi:list}(\textit{Rec}\rightarrow\textit{RecType}) \end{bmatrix} \\ \text{shared:} \begin{bmatrix} \text{eud:list}(\textit{Rec}\rightarrow\textit{RecType}) \\ \text{L-M:}\textit{Rec} \\ \text{topoi:list}(\textit{Rec}\rightarrow\textit{RecType}) \end{bmatrix} \end{bmatrix}$$

[2] The dialogue gameboard presented here is a simplified version of that presented in [5]

Sometimes a type is made up of more than one field, for example the type of an agent's private information state in (10). We refer to such structured types as *record types*. On the gameboard we also may have items representing actual situations, not just types of situations. For example, the latest utterance that has been made in the dialogue, "LU". These may also be made up of several fields, and we refer to them as *records*.

The private topoi which an agent may draw on to produce or interpret enthymematic arguments have the type of list of dependent types, in this case functions from records to record types. Let's say for example, that we have a situation S_1 where something, let's call it obj_1, is judged to be a bird at a perceiving event p_1. We represent S_1 as the record in (11).

(11) $S_1 = \begin{bmatrix} \text{x} & = \text{obj}_1 \\ \text{c}_{\text{bird}} & = \text{p}_1 \end{bmatrix}$

S_1 is of type T_1, the type where an object is a bird.

(12) $T_1 = \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{bird}}\text{:bird(x)} \end{bmatrix}$

When we encounter – or imagine – a situation where an object obj_1 is a bird, we know that we will also have a type of situation where that object flies. Let's call it T_2.

(13) $T_2 = \left[\text{c}_{\text{fly}}\text{:fly}(\text{obj}_1)\right]$

Now, we can represent the topos that if something is a bird, then it flies, or simply "birds fly" as function (14) from record to record type.

(14) $\lambda r\text{:} \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{bird}}\text{:bird(x)} \end{bmatrix} \left(\left[\text{c}_{\text{fly}}\text{:fly}(r.\text{x})\right]\right)$

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The eud (enthymeme under discussion), under "shared", represents enthymematic arguments which have been made explicit in the discourse or which have been accommodated. The type of the eud is the same as that of the topoi, that is, a list of functions from records to record types. The field L-M (latest move) keeps track of the last utterance made, in terms of speaker, move type and utterance content. Finally, in addition to private topoi we also have "shared topoi" on the gameboard. Shared topoi are principles of reasoning that an agent has to accommodate for an argument to make sense. These may be readily available to the agent or tentatively accepted for the sake of the argument. Sometimes we want to make fields in the gameboard *manifest*. This means that we require the value associated with the label to be a particular object of the type represented.

4.2 Reasoning with topoi

In Section 2.1 we discussed two classic "puzzles" often used as examples in literature on non-monotonic logic. We will now illustrate this account by describing how these examples could play out in a dialogue where enthymematic arguments are underpinned by rhetorical resources in the form of topoi modelled in TTR. Situating these examples in a dialogue setting emphasises the importance of point of view in non-monotonic reasoning.

4.2.1 *The Tweety triangle*

Let's assume that A and B need to agree on whether Tweety flies or not, and the following exchange takes place:

(15) a. A: Tweety flies – he's a bird!

b. B: No, he doesn't – he's a penguin!

If we think of the exchange in (15) as two enthymematic arguments, A and B are obviously appealing to different topoi. A's argument is underpinned by a topos saying that if something is a bird, then it flies, corresponding to a sentence with the bare plural "birds fly". We represent this topos as a dependent type as in (16): Record types representing contextually relevant individuals which are accessed during a dialogue are reminiscent of Heim's [20] file cards representing referents of definite noun phrases, and Recanati's mental files [30].

(16) $\begin{bmatrix} \text{x=Tweety:}\mathit{Ind} \\ \text{c}_{\text{bird}}\text{:bird(x)} \end{bmatrix}$

Let us now consider the information state of A before this exchange. The project which A has in mind is to agree on whether Tweety flies or not. On this topic A has access to a set of relevant resources – the topos in (14), which is loaded onto private topoi on the game board, and a Tweety type like the one in (16).

The topos (14) on A's gameboard together with the accessed Tweety type pushes the type of an assertion that Tweety flies onto the agenda. When A has uttered the whole of (15a) – "Tweety flies" – this item is popped off the agenda[3]. However, the topos is still on A's private gameboard, and pushes another item on the agenda, the type of an assertion that Tweety is a bird, as shown in Figure 1. When A has uttered (15b) expects the enthymeme "Tweety is a bird, therefore, Tweety flies" and the topos "birds fly" to be accommodated. We could imagine a few different scenarios here: No 1: B does not recognise the topos at all (which seems unlikely). She could then make a clarification request along the lines of "what do you mean he's a bird – what does that have to do with flying?", questioning the relevance of the premise, to which A could reply by pointing to the topos he has in mind – "Birds fly". B could then agree or disagree to this. If B disagrees, A would have to provide some evidence that birds do indeed fly, at least most of the time. If B agrees, she could evaluate the argument and possibly object, but in this case not to the topos that birds fly, but to the argument that Tweety flies. However, we assume that B has access to the topos "birds fly", and thereby is able to accommodate the enthymeme "Tweety is a bird, therefore he flies". Thus, B recognises the topos, and it is loaded onto B's shared topoi, and the enthymeme "Tweety is a bird, therefore Tweety flies" is loaded onto eud. This means that, B agrees that this enthymeme is indeed under discussion. B then evaluates the enthymeme by searching her resources for the type "Tweety". We assume that B's Tweety-type looks like (17):

(17) $\begin{bmatrix} \text{x=Tweety:}\mathit{Ind} \\ \text{c}_{\text{bird}}\text{:bird(x)} \\ \text{c}_{\text{penguin}}\text{:penguin(x)} \end{bmatrix}$

[3] Note that corresponding items will be pushed on *Latest Utterance* for A and B, and on *beliefs* for A. For convenience we do not represent that here.

Note that the type in (17) might have many other constraints, such as "black and white", "eats fish", etc. However, we restrict ourselves now to those aspects of B's Tweety-type which are relevant for this dialogue. Now, B continues the evaluation by searching her resources for a topos which is relevant to the enthymeme on one hand and to the type of Tweety on the other. She finds such a topos, namely "If something is a penguin, then it is a bird". According to this principle, represented in (18), "penguin" is a subtype of "bird".

(18) $\lambda r\text{:} \begin{bmatrix} \text{x:}\mathit{Ind} \\ \text{c}_{\text{penguin}}\text{:penguin(x)} \end{bmatrix} \left(\left[\text{c}_{\text{bird}}\text{:bird}(r.\text{x})\right]\right)$

B also accesses a topos which says that penguins do not fly, (19):

(19) $\lambda r\text{:} \begin{bmatrix} \text{x:}\mathit{Ind} \\ \text{c}_{\text{penguin}}\text{:penguin(x)} \end{bmatrix} \left(\left[\text{c}_{\neg\text{fly}}\text{:}\neg\text{fly}(r.\text{x})\right]\right)$

Now B may compare the topos which was evoked and accommodated by A's enthymematic argument with the topoi she herself has access to. On the one hand is "birds fly", on the other "penguins do not fly" and "penguins are birds". The two later topoi may be composed. To do that we first need to talk about fixed-point types for topoi. If ε_1 is the topos in (18), then a fixed-point type for ε_1 is a type T such that $a : T$ implies $a : \varepsilon_1(a)$. Such a type can be obtained by merging the domain type and the result type adjusting the references to r in the dependencies, as in (20).

(20) $\begin{bmatrix} \text{x:}\mathit{Ind} \\ \text{c}_{\text{penguin}}\text{:penguin(x)} \\ \text{c}_{\text{bird}}\text{:bird(x)} \end{bmatrix}$

We will refer to this type as $\mathcal{F}(\varepsilon_1)$. We may combine (20) and (19), which we call ε_2. Note that $\mathcal{F}(\varepsilon_1)$ is a subtype of the domain type of ε_2. This is a condition which must be fulfilled in order to be able to compose ε_1 with ε_2. The composition of ε_1 and ε_2, $\varepsilon_1 \circ \varepsilon_2$, is

(21) $\lambda r\text{:} \begin{bmatrix} \text{x:}\mathit{Ind} \\ \text{c}_{\text{bird}}\text{:bird(x)} \\ \text{c}_{\text{penguin}}\text{:penguin(x)} \end{bmatrix} \left(\left[\text{c}_{\neg\text{fly}}\text{:}\neg\text{fly}(r.\text{x})\right]\right)$

Now B has access to two topoi which are relevant for evaluating Tweety's ability to fly, one which says that Tweety can fly because he is a bird, and one which says he cannot fly because he is a penguin. Since the domain type in (21) is more specified, or restricted, than the one in (14), (21) constitutes a stronger argument as long as it is applicable to Tweety. So, B has evaluated the enthymeme under discussion and does not agree. An item is pushed on her agenda to refute A's argument (the assertion "Tweety can't fly") followed by the assertion "He's a penguin!" (22) represents B's information state after this utterance. The topos B would expect A to accommodate is at least (19), since that is what is needed to make the enthymeme coherent. In 4.2.1 we see B's information state after having uttered (15b).

Let's assume that A accommodates this topos. A then has to evaluate the latest enthymeme under discussion in relation to the enthymeme he himself produced, and the activated topoi. If A has access to the same type for Tweety as B has, or at least a type which shares the

Figure 1. The type of A's information state after the first part of utterance (15a)

$$\left[\begin{array}{l}\text{private:}\left[\begin{array}{l}\text{agenda=}\left[\begin{array}{l}\text{[e:}\textit{Assertion}\\ \text{cnt=}\left[\text{e:bird(Tweety)}\right]\text{:}\textit{RecType}\end{array}\right]\text{:list(}\textit{MoveType}\text{)}\\ \text{topoi= [}\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{bird}}\text{:bird(x)}\end{array}\right](\left[\text{c}_{\text{fly}}\text{:fly}(r.\text{x})\right])\text{]:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}\end{array}\right]\\ \text{shared:[]}\end{array}\right]$$

Figure 2. The type of B's information state after utterance (15b)

$$\left[\begin{array}{l}\text{private:}\left[\begin{array}{l}\text{agenda= [] :list(}\textit{MoveType}\text{)}\\ \text{topoi= [}\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{bird}}\text{:bird(x)}\\ \text{c}_{\text{penguin}}\text{:penguin(x)}\end{array}\right](\left[\text{c}_{\neg\text{fly}}\text{:}\neg\text{ fly}(r.\text{x})\right])\text{] :list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}\end{array}\right]\\ \text{shared:}\left[\begin{array}{l}\text{eud=[}\lambda r\text{:}\left[\begin{array}{l}\text{x=Tweety:}\textit{Ind}\\ \text{c}_{\text{bird}}\text{:bird(x)}\\ \text{c}_{\text{penguin}}\text{:penguin(x)}\end{array}\right](\left[\text{c}_{\neg\text{fly}}\text{:}\neg\text{ fly}(r.\text{x})\right])\text{]:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}\\ \text{L-M:}\left[\begin{array}{l}\text{e:}\textit{Assertion}\\ \text{c}_{\text{actor}}\text{:actor(e,}B\text{)}\\ \text{c}_{\text{addressee}}\text{:e,}A\\ \text{cnt=e:bird(Tweety):}\textit{RecType}\\ \text{c}_{\text{cnt}}\text{:content(e,cnt)}\end{array}\right]\\ \text{topoi=[}\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{penguin}}\text{:penguin(x)}\end{array}\right](\left[\text{c}_{\neg\text{fly}}\text{:}\neg\text{ fly}(r.\text{x})\right])\text{]:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}\end{array}\right]\end{array}\right]$$

constraint that Tweety is a penguin, and topos which says that penguin is a subtype of bird, A will be able to evaluate B's argument and his own argument in the light of B's argument, and come to the conclusion that B's argument is stronger since it is more specific (c.f. [21]). However, if a third person would enter the discussion and say that Tweety actually flies, since he has a pair of artificial wings, both A and B would have to reevaluate their position. The type of *Bird who is a penguin who has artificial wings* is more specific than *Bird* or *Penguin-bird*', and therefore a topos stating that someone who has artificial wings flies would be stronger, in case the constraint "has artificial wings" is in the Tweety-type.

4.2.2 The Nixon Diamond

The Nixon diamond-puzzle is slightly different from the "Tweety triangle". In the the case of Tweety we have a topos suggesting an entailment relationship between "penguin" and "bird". This means that, according to the topos, "penguin" is a subtype of "bird". The consequence of this is that the default rules "birds fly" and "penguins do not fly" are hierarchical. In the case of the Nixon diamond there is no suggested entailment relation between "quaker" and "republican". Instead the problem arises from the possibility to draw incompatible inferences from the known information.

One way to think about this problem is in terms of blocking inferences – if we know that Nixon is both a republican and a quaker, and if we start out by applying the default rule that quakers are pacifists, we would be blocking the inference that Nixon is not a pacifist. We suggest instead that we consider this problem from a rhetorical perspective in a dialogue setting. In natural discussions of this type we sometimes agree on the principles according to which we may reason, that is, share topoi. However, we might value these topoi differently. This might be because we already have clear opinions regarding the conclusion and the dialogue is aimed at justifying our respective positions rather than using default rules to reach a conclusion. So, let us imagine again a conversation, this time between two people discussing whether Nixon is (or was) a pacifist or a non-pacifist. We disregard the fact that there might be other more relevant evidence in this discussion – the best arguments the dialogue participants are able to come up with are the following:

(22) a. A: Nixon is not a pacifist! - he's a republican!
b. B: He's a pacifist - he's a Quaker!

Initially in this conversation, A has in mind a type of Richard Nixon which may be restricted in a number of ways, but it has at least the restriction "republican". A also has access to a topos regarding republicans which says that republicans are non-pacifists.

(23) $$\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{republican}}\text{:republican(x)}\end{array}\right](\left[\text{c}_{\text{not\_pacifist}}\text{:not\_pacifist}(r.\text{x})\right])$$

In Figure 3. we see A's information state just before she produces the utterance (22a). On the agenda are two ordered items – the type of an assertion that Nixon is a republican (which is the support of the argument) and the type of an assertion that he is a non-pacifist (the claim).

When A has uttered the first part of (22a) the first item is popped off the agenda, and a corresponding item is pushed on L-M. After the second part of (22a) has been uttered, an enthymeme is pushed onto A's dialogue gameboard, as seen below in Figure 4.

Now, A expects B to recognise the topos (23), and thereby accommodate and eventually accept the enthymeme under discussion in Figure 4. Let us assume that B is familiar with the topos and easily accommodates the enthymeme it underpins. In order to evaluate the enthymeme he has to access his "Nixon type". This type has, among others, the constraint "quaker". However, B cannot deny (we assume) that Nixon is also a republican. Therefore the type he accesses has at least the constraints shown in (24)

Figure 3. The type of A's information state before utterance "Nixon is not a pacifist – He's a republican"

$$\begin{bmatrix} \text{private:} & \begin{bmatrix} \text{agenda=[} \begin{bmatrix} \text{e:}\textit{Assertion} \\ \text{cnt=}\left[\text{e:}\neg\ \text{pacifist(Nixon)}\right] \text{:}\textit{RecType} \end{bmatrix}, \begin{bmatrix} \text{e:}\textit{Assertion} \\ \text{cnt=}\left[\text{e:republican(Nixon)}\right] \text{:}\textit{RecType} \end{bmatrix} \text{]:list(}\textit{MoveType}\text{)} \\ \text{topoi=[}\lambda x\text{:} \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{republican}}\text{:republican}(r.\text{x}) \end{bmatrix} (\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\ \text{pacifist}(r.\text{x})\ \right])\text{]:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)} \end{bmatrix} \\ \text{shared:} & [] \end{bmatrix}$$

Figure 4. The type of A's information state after utterance "He's not a pacifist"

$$\begin{bmatrix} \text{private:} & \begin{bmatrix} \text{agenda=[ ] :list(}\textit{MoveType}\text{)} \\ \text{topoi=} \left[\lambda r\text{:} \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{republican}}\text{:republican(x)} \end{bmatrix} (\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\ \text{pacifist}(r.\text{x})\right])\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)} \end{bmatrix} \\ \text{shared:} & \begin{bmatrix} \text{eud=} \left[\lambda r\text{:} \begin{bmatrix} \text{x=Nixon:}\textit{Ind} \\ \text{c}_{\text{republican}}\text{:republican(x)} \end{bmatrix} (\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\text{pacifist}(r.\text{x})\right])\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)} \\ \text{L-M:} \begin{bmatrix} \text{e:}\textit{Assertion} \\ \text{c}_{\text{actor}}\text{:actor(e,}A\text{)} \\ \text{c}_{\text{addressee}}\text{:addressee(e,}B\text{)} \\ \text{cnt=}\left[\text{e:republican(Nixon)}\right]\text{:}\textit{RecType} \\ \text{c}_{\text{cnt}}\text{:content(e,cnt)} \end{bmatrix} \\ \text{topoi=} \left[\lambda r\text{:} \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{republican}}\text{:republican(x)} \end{bmatrix} (\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\ \text{pacifist}(r.\text{x})\right])\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)} \end{bmatrix} \end{bmatrix}$$

(24) $\begin{bmatrix} \text{x=Nixon:}\textit{Ind} \\ \text{c}_{\text{quaker}}\text{:quaker(x)} \\ \text{c}_{\text{republican}}\text{:republican(x)} \end{bmatrix}$

For some reason, either because B wants to argue that Nixon is a pacifist, or because "quaker" is simply a more salient quality of Nixon for him than "republican", the topos which is pushed onto B's private topoi is (25)

(25) $\lambda r \begin{bmatrix} \text{x:}\textit{Ind} \\ \text{c}_{\text{quaker}}\text{:quaker(x)} \end{bmatrix} (\left[\text{c}_{\text{pacifist}}\text{:pacifist}(r.\text{x})\right])$

B now has to take into account on the one hand two topoi – one saying that republicans are a subtype of non-pacifists, and one saying that quakers are a subtype of pacifists – on the other the type of an individual who is both a quaker and a republican. Since his "Nixon type" and topoi are incompatible, B, in order to make his point, has to generalise his Nixon type. On private topoi at this stage we would thus find one topos saying that republicans are non-pacifists and one saying that quakers are pacifists. The topos saying that quakers are pacifists pushes two items onto the agenda - the type of an assertion claiming that Nixon is a pacifist and the type of an assertion supporting this claim.

After having uttered (22b), B's take on the state of the dialogue is that there are two enthymemes under discussion - Nixon is a quaker and therefore a pacifist, and Nixon is a republican and therefore a non-pacifist respectively. B also assumes that topoi underpinning both arguments have been evoked in the dialogue. We see B's information state at this point in 4.2.2. Since "pacifist" and "non-pacifist" are incompatible, A and B have to evaluate the arguments based on how general they take the rules expressed in the topoi are and whether they think that one of the rules is more committing than the other. One could for example say that if someone is a quaker, that person has to be a pacifist, otherwise he would no longer be a quaker, while being a republican could mean nothing more than having voted for a republican candidate – not necessarily embracing all political views typically taken by republicans. It would also be possible to reason in favour of the conclusion that Nixon is a non-pacifist in a similar way. Traditionally problems like the Nixon diamond are treated either sceptically (no inference is accepted) or credulously (all inferences are accepted). Often the sceptical approach is chosen in order to avoid incompatible inferences. However, if we think of situations where this kind of problem would occur, it seems that the credulous approach is closer to human reasoning. The rhetorical approach that we suggest represent something of a middle ground since it allows agents to reason with inconsistent topoi and topoi leading to inconsistent conclusions.

5 DISCUSSION

In this paper we have considered a rhetorical perspective on two puzzles which are well known from the literature on non-monotonicity. These are associated with problems, particularly in the context of modelling human-like language behaviour. For example, solutions to the Tweety-puzzle normally involve a closed world assumption, and in the Nixon-puzzle we are faced with the problem of having to introduce inconsistent rules. We have suggested that it might be beneficial to assume a rhetorical and dialogical perspective on problems of non-monotonic reasoning. In this perspective, the question is often not which conclusion to reach but how to argue for a specific standpoint, or against another. This type of reasoning is well accounted for in rhetoric, for example by Aristotle who, in his work on rhetoric, related rhetorical arguments, enthymemes, to logical arguments. The topoi which underpin enthymemes have in common with default rules that they are defeasible. However, there is no claim that a set of topoi has to constitute a single coherent logical system, even in the resources of one agent. In the light of new information, we simply add another topos to our rhetorical resources and choose the one that best suits our purpose. We also suggested how to model rhetorical reasoning based on the resources available to particular agents. We did this using dialogue gameboards cast in TTR, which enables us to use underspecified types that may be gradually refined, as illustrated in our analysis of the Tweety-Puzzle.

Figure 5. The type of B's information state before utterance (22b), "Nixon is a pacifist – He's a quaker"

$$\left[\begin{array}{l}
\text{private:} \left[\begin{array}{l}
\text{agenda=[} \left[\begin{array}{l}\text{e:}\textit{Assertion}\\ \text{cnt=}\left[\text{e:pacifist(Nixon)}\right]\text{:}\textit{RecType}\end{array}\right], \left[\begin{array}{l}\text{e:}\textit{Assertion}\\ \text{cnt=}\left[\text{e:quaker(Nixon)}\right]\text{:}\textit{RecType}\end{array}\right] \text{] :list(}\textit{MoveType}\text{)}\\
\text{topoi=} \left[\begin{array}{l}\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{republican}}\text{:republican(x)}\end{array}\right](\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\text{pacifist}(r.\text{x})\right]),\\ \lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{quaker}}\text{:quaker(x)}\end{array}\right](\left[\text{c}_{\text{pacifist}}\text{:pacifist}(r.\text{x})\right])\end{array}\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}
\end{array}\right]\\
\text{shared:} \left[\begin{array}{l}
\text{eud=} \left[\lambda r\text{:}\left[\begin{array}{l}\text{x=Nixon:}\textit{Ind}\\ \text{c}_{\text{republican}}\text{:republican(x)}\end{array}\right](\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\text{pacifist}(r.\text{x})\right])\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}\\
\text{L-M:} \left[\begin{array}{l}\text{e:}\textit{Assertion}\\ \text{c}_{\text{actor}}\text{:actor(e,}A\text{)}\\ \text{c}_{\text{addressee}}\text{:addressee(e,}B\text{)}\\ \text{cnt=}\left[\text{e:non-pacifist(Nixon)}\right]\text{:}\textit{RecType}\\ \text{c}_{\text{cnt}}\text{:content(e,cnt)}\end{array}\right]\\
\text{topoi=}\left[\lambda r\text{:}\left[\begin{array}{l}\text{x:}\textit{Ind}\\ \text{c}_{\text{republican}}\text{:republican(x)}\end{array}\right](\left[\text{c}_{\neg\text{pacifist}}\text{:}\neg\text{pacifist}(r.\text{x})\right])\right] \text{:list(}\textit{Rec}\rightarrow\textit{RecType}\text{)}
\end{array}\right]
\end{array}\right]$$

6 FUTURE WORK

We have not addressed the issue of how an agent's information state is updated based on the previous state. In future work we plan to include update rules which are formally similar to enthymemes, that is, functions from records to record types. When we model existing data, we know which enthymemes the agents use and we may formulate topoi which would result in the observed dialogue behaviour. However, if we were modeling an agent capable of interpreting and producing new dialogue contributions, other issues arise. For example, we would want to develop the relation between topoi accommodated and beliefs that are committed in the interaction, in order to limit the possibilitites to argue inconsistently. Also, we would have to introduce a mechanism that lets the agent choose between available topoi. This could be for example organising topoi according to strength, similar to the prioritised defaults in [7]. Another interesting possibility would be to combine a rhetorical approach to non-monotonicity with the probabilistic type theory presented in [11]. This approach might also enable us to model how new topoi are acquired.

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