Toward Formalizing Dialectical Argumentation

Kathleen Freeman

CIS-TR-94-19
August1994

Department of Computer and Information Science
University of Oregon

TOWARD FORMALIZING DIALECTICAL ARGUMENTATION

by

KATHLEEN FREEMAN

A DISSERTATION

Presented to the Department of Computer
and Information Science
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

August 1993

An Abstract of the Dissertation of

Kathleen Freeman for the degree of Doctor of Philosophy

in the Department of Computer and Information Science to be taken August 1993

Title: TOWARD FORMALIZING DIALECTICAL ARGUMENTATION

Approved: ______________________________

Dr. Arthur M. Farley

The construction of arguments has long been viewed as a paradigmatic example of human reasoning and, as such, is an important ability for computer programs that attempt to model intelligent behavior. We explore the use of argumentation for deriving and justifying claims in domains where knowledge is incomplete, uncertain, or inconsistent, i.e., weak theory domains. Argumentation supports a notion of proof appropriate for reasoning in weak theory domains, e.g., a claim is proved if there is plausible, irrefutable support for the claim, and there is no such support for any counter-claim.

We present elements of a theory of argumentation involving two senses of argument, argument as supporting explanation and argument as dialectical process. For argument as supporting explanation, we create argument structures that organize relevant, available support for both a claim and its negation. In dialectical argument, the format of a two-sided argument process is used to intertwine the strengths and weaknesses of support for competing claims, so arguments can be refuted and directly compared. Our account of dialectical argumentation includes a catalog of argument moves and a set of heuristics for selecting moves and thereby controlling argument generation.

This model, which has been implemented in a computer program, is a flexible environment for exploring the representation and generation of arguments. We show how the program generates reasonable arguments for a set of example problems. We give an analysis of the program, including limits of the current model of argumentation.

For artificial intelligence programs, the ability to generate arguments provides a useful technique for reasoning in real world contexts. For argumentation researchers, artificial intelligence methodology offers a new way for evaluating theories of argumentation.

ACKNOWLEDGMENTS

Thanks to my friend and adviser, Professor Art Farley, for his guidance throughout both my master's and Ph.D. programs. Working with Art is a challenge and a pleasure. He is supportive of new ideas, and has a knack for getting straight to the interesting questions. As a student, I have benefited greatly from Art's quick mind and caring attitude.

Thanks also to Professors Steve Fickas, Tom Givon, and Gene Luks for serving on the thesis committee. Steve is an extraordinarily generous teacher and researcher who always has time to talk and new and interesting ideas to share. Tom is another model for the kind of professor I'd like to be: excited about his own research and the research of others across many academic departments. Gene Luks has been an adviser and mentor since my undergraduate days at Bucknell University. He has gone out of his way for me (and many other students) more times than I can say, and as a teacher has been equal parts exacting and encouraging. I am grateful to him and his wife, Sandra, for suggesting that I come out to Oregon for graduate school, and for making me feel so at home here.

I appreciate the help and cheers from fellow graduate students and other faculty in the department and gratefully acknowledge assistance from our wonderful office staff.

Thank you to my family for their love and confidence in me through the years, and especially to my husband, Michael Hennessy. His abundant goodwill and abiding love are the mainstays of my life.

This work was supported in part by a University of Oregon Doctoral Research Fellowship, and a Tektronix Fellowship.

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

In "real world" domains, much of what is known or believed is often incomplete, uncertain, or inconsistent. As an example, consider the following "Bermuda" problem, based upon the classic example in (Toulmin, 1958):

> Usually anyone born in Bermuda can be assumed to be a British subject, unless both parents were aliens. People with British passports are generally British subjects. Statistics show that most people who are English speaking and have a Bermudan identification number were born in Bermuda. Any person with a Bermudan identification number is eligible to obtain Bermudan working papers.
>
> We have just been introduced to Harry, who speaks English, has a passport that is not a British passport, and shows us his Bermuda working papers. We would like to know whether or not Harry is a British subject.

The knowledge in this problem is inconsistent, simultaneously supporting both conflicting conclusions. It is incomplete, since knowledge that could help support one conclusion or another, such as whether or not Harry was born in Bermuda, or whether his parents were aliens, is not available. The knowledge is also uncertain, containing hedges such as "usually" and "most".

In light of these problems, how can we proceed with reasoning at all? One possibility is to resolve all of the problems, i.e., supply missing knowledge, transform uncertain into certain knowledge, for example, by explicitly mentioning exceptions to general information, and disallow inconsistent information. Unfortunately, this solution is not often realistic, due to constraints on information gathering capabilities, time, and the state of real world knowledge. Another possibility is simply to halt the reasoning process. But this is unsatisfactory, too. Certainly humans do not stop reasoning when knowledge is not complete and certain. Furthermore, there is a lot of information available; there may be enough to at least speculate about support for one or the other of the claims. It may even be enough, if not to establish a claim conclusively, to support it adequately for the current context. For example, someone choosing teams for a pick-up ball game based on whether or not a person is a British subject would need much less support for the claim than would someone attempting to establish it in a court of law. While it may not be possible to resolve incompleteness, uncertainty, and inconsistency in the knowledge, it is unhelpful to not reach any conclusion at all. We begin to explore ways to support the claim that "Harry is a British subject" under these difficult conditions.

The claim could be established if it could be shown that Harry was born in Bermuda. There is some evidence for this, as Harry speaks English, but there is no input information about whether or not Harry has a Bermuda identification number. We do know that Harry has his working papers, and it is reasonable to speculate that he was able to obtain them because he has an identification number. Reasoning in this way, while not deductive, is not irrational but considered *plausible*. Plausible inference (Polya, 1968) is appropriate for reasoning under incomplete knowledge, particularly in situations such as this one where, if we were to rely on deductive inference only, there would be no way to build a case for the claim. However, plausible inference is certainly not a panacea. The support it gives a claim is tentative, i.e., refutable. For example, if it could be shown that Harry obtained his working papers some other way, then there would be no reason to speculate that he has an identification number; the support for "identification number", as well as "born in Bermuda" and "British subject" would collapse. Even when the support cannot be immediately refuted, its tentative nature remains, and should be reflected in our certainty about its conclusion.

In light of the uncertainty in the support for the claims, and because of the possibility of inconsistency in the knowledge base, an intelligent reasoner should not stop at this point. One should explicitly look for information that would support a rival claim, e.g., "Harry is not a British subject". This would make the original claim "Harry is a British subject" controversial, and therefore even more tentative. One could try to refute the case just made by showing Harry's parents were aliens, by looking for evidence that he was not born in Bermuda, or by checking for anomalous data. A suspicious adversary might even look for evidence that Harry doesn't speak English or that he doesn't have his working papers. In the current example, there is a piece of data that does not fit: the fact that Harry is said not to have a British passport. This casts some doubt on the claim that he is a British subject.

These attempts to resolve the question of whether or not Harry is a British subject show that there is tentative support for either conclusion. However, it could be that the support for the claim "Harry is a British subject", though tentative and controversial, is enough for the particular problem solving situation. Even if it is not, the process has helped the reasoner to organize the knowledge base with respect to the claim. Structuring the support for both the original claim and its rival claim(s) is useful for justifying a decision (or lack thereof), and for comparing the support for plausible claims.

This process has highlighted some key points about reasoning under incomplete, uncertain, or inconsistent knowledge. Aspects of reasoning under these conditions, such as plausible inference and uncertainty representation, are helpful to a point, but cannot completely resolve the problems and may themselves add additional uncertainty to the knowledge. Support for claims may be tentative, and, therefore, refutable. There may be simultaneous support for conflicting claims. Yet reasoning with inconsistent knowledge is useful because it may result in enough support for a claim for a particular context; in any case, claims are evaluated with respect to both their own support and support for alternative claims. Weak links in the support for a claim are explicated, and the strength of support among alternative claims can be assessed.

An approach to reasoning is needed that addresses incompleteness, uncertainty, and inconsistency straightforwardly. There should be a variety of methods for supporting claims under these conditions. Controversy must be expected, i.e., the reasoner should look for plausible support for rival claims, and support for claims should be presumed to be refutable. Our research is about exploring the use of argumentation as a basis for deriving and justifying claims under these conditions. We discuss this approach in the remaining sections of this chapter.

Argumentation

The construction of arguments has long been viewed as a paradigmatic example of human reasoning and, as such, is an important ability for programs that attempt to model intelligent behavior. We explore the use of argumentation for reasoning in domains where knowledge is incomplete, uncertain, or inconsistent, i.e., *weak theory domains*. We contend that these factors are both pervasive and persistent; therefore, any computer program that reasons in weak theory domains must have the ability to reason under these conditions. For example, a derivation, or "proof", of a claim in such a domain could show that the claim is *dialectically valid*, i.e., there is *plausible* support for the claim, and there is no such support for any *counter-claim*.

Argumentation is a mechanism for generating a class of super-explanations: in addition to providing support for belief in a claim (as we would expect to find in a typical explanation), reasoning that counters the claim is determined, as well. Even when failing to prove a claim, argumentation is a method for locating, highlighting, and organizing relevant information in support of and counter to proposed claims, and a vehicle for comparing the merits of support for competing claims.

In the remainder of this chapter, we discuss weak theory domains in more detail, and the role played by argumentation in proving and justifying claims in weak theory domains. In the last section, we outline the research presented in the remaining chapters.

Weak Theory Domains

Since the advent of expert systems, programs written to reason like human experts in complex domains, e.g., medical diagnosis, there has been little disagreement among artificial intelligence (AI) researchers that real world knowledge is often incomplete and uncertain. Many active research areas in AI are concerned with eliminating, representing, or managing incompleteness and uncertainty, for example, default reasoning, probabilistic reasoning, non-monotonic reasoning, and case-based reasoning, to name a few. Less attention, however, has been paid to the problem of reasoning under inconsistency, which we maintain is a result of incomplete and uncertain knowledge.

Incomplete knowledge is the result of many factors, including the lack of information-gathering capabilities, combinatorial complexity of the space of possible situations, the possibility of exceptions to general rules, prevalence of changing circumstances, and imprecision in the language. These conditions are exacerbated for computers, which have access to much less knowledge than humans. To the extent that a reasoning agent doesn't know everything, or cannot represent everything it does know, knowledge will be incomplete.

When knowledge is incomplete, it will also be uncertain. For example, take the rules, "Republicans are not doves" and "Quakers are doves". Both of these are uncertain; it is easy to come up with exceptions to each rule. For example, if someone is known to be a

Quaker, the second rule could be used to derive the conclusion "dove", but tentatively, as the rule is known to have exceptions. Reasoning with uncertain knowledge can lead to inconsistencies. If someone is known to be both a Republican and a Quaker, the result will be an inconsistent knowledge base

Plausible, or non-deductive, reasoning methods that help the reasoner cope with incomplete information, such as abductive reasoning and case-based reasoning, can add additional uncertainty and inconsistency to the knowledge base. Techniques for explicitly representing and reasoning under uncertainty are helpful to a point, but may themselves be incomplete and uncertain.

For example, a standard method for representing uncertainty is to attach numeric qualifications representing certainty (probability, degree of belief) to propositions in the knowledge base (e.g., Cohen, 1985; Lea Sombe, 1990). A combining function over the numeric qualifications can then be used to reach a number that summarizes evidence for and against a claim. Decisions about rival claims can be made using a numeric comparison function.

But representing uncertainty directly, especially combining and propagating it during a reasoning process, is itself a difficult problem and an open research area. Therefore, relying on such techniques to eliminate or resolve inconsistencies that arise during the reasoning process is at best premature. As Lea Sombe (1990) put it in their comparison of formalisms for reasoning under incomplete information: "A particularly delicate problem is that of conflict resolution among several rules that lead to conflicting conclusions about a fact or about its denial. The systematic use of a combination operation in order to resolve these conflicts cannot be fully justified . . . "

Conflicting opinions from multiple experts in the domain is another possible source of inconsistency. As Buchanan &Shortliffe (1984) point out, expert systems "tend to be built precisely for those domains in which decisions are highly judgmental . . . some attention to the mechanisms of reasoning that the program uses [in addition to the decisions it reaches] may be appropriate." This is one of the goals of the research described in this paper.

In sum, we contend that any domain where knowledge is incomplete, may also contain knowledge that is inconsistent (see Figure 1). Methods for reasoning under incomplete and uncertain knowledge, while very useful, do not entirely eliminate inconsistency (they may add to it), and inconsistency in the knowledge base remains a potential problem for any agent that reasons in a weak theory domain. Argumentation, where controversy in the knowledge is presumed, is an ideal approach to reasoning under inconsistency.

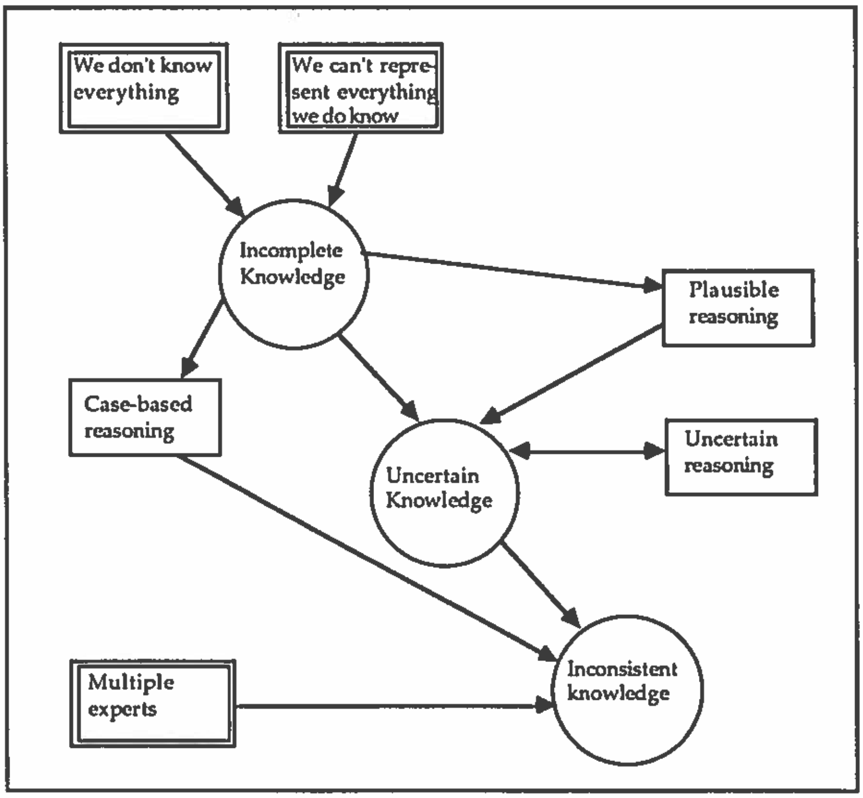


FIGURE 1. Weak theory domains.

TABLE 1. Levels of Proof for Weak Theory Domains

	support for claim	strong support	support for rival claim
beyond a reasonable doubt	yes	yes	no
dialectical validity	yes	—	no
preponderance of the evidence	yes	*	—
scintilla of evidence	yes	—	—

*stronger than support for rival claims

Levels of Proof in Weak Theory Domains

When knowledge is incomplete, uncertain, and inconsistent, a reasoner obviously cannot count on deriving claims that are deductively valid. Since claims cannot always be proved conclusively, a definition of "proof" is needed that makes sense for weak theory domains. We (and others, e.g., Barthe & Krabbe, 1982) have mentioned dialectical validity as a definition of proof that incorporates the possibility of uncertainty and inconsistency in the knowledge straightforwardly.

Other proof levels can be defined by relaxing or tightening the conditions for dialectical validity. For example, borrowing legal reasoning terminology, a claim proved *beyond a reasonable doubt* would be dialectically valid with strong, rather than simply plausible, support. A *preponderance of the evidence* proof level indicates that support for the claim is stronger than the support for any rival claim. A *scintilla of evidence* for a claim means that there is some support for the claim, regardless of support for rival claims. (See Table 1.)

These proof levels can only be obtained using a reasoning method that can refute, as well as support, claims, which includes searching for support for both a claim and its rivals. Argumentation is such a method.

Justification in Weak Theory Domains

Particularly in weak theory domains, where the conclusion reached by a reasoning agent may be only one of multiple possible, even conflicting, claims, justification of assertions is a crucial task. An observer might not even care so much about a claim per se, as in exploring the reasoning behind all possible conclusions. Argumentation, where support for a claim is evaluated on its own merits and with respect to support for other claims, supports "robust justification" for claims derived in weak theory domains. According to Kyburg (1991), ". . . argument and justification are two sides of the same coin"; Eemeren & Grootendorst (1984) write, "The purpose of argumentation is . . . to justify or refute an opinion." Even when it is not possible to prove a claim, argumentation provides partial results that highlight information in support of and counter to the claim.

Paradigmatic Model of Reasoning

Argumentation has long been studied as an important reasoning method in many areas outside artificial intelligence. It has been a topic of research in philosophy, (e.g., Rescher, 1977; Toulmin, 1958), rhetoric (e.g., Horner,1988), education (e.g., Kuhn, 1991), among others. For example, Rescher (1977) writes, ". . . disputation and debate may be taken as a paradigmatic model for reasoning in pursuit of truth. . . . There is nothing new about this approach"; and "The aim of the inquiry is to arrive at defensible results . . . [using] a heuristic method of inquiry . . . [that] pits one thesis against its rivals, with the aim of refining its formulation, uncovering its basis of rational support, and assessing its relative weight. . . . Dialectic . . . [is] a method for sifting the evidence so as to set it out systematically, in a rationally organized structure that exhibits the fabric of supporting reasons." Kuhn (1991) offers, "The major early philosophers - Plato, Socrates, Aristotle -

were all centrally concerned with thinking, and all regarded the construction of arguments as the heart of thinking . . ."

If the construction of arguments is a keystone of thinking, then this is clearly an ability that AI programs, which seek to model intelligent behavior, should have. Indeed, argumentation has recently been the subject of investigation by some AI researchers, e.g., in the areas of legal reasoning (e.g., Ashley, 1989; Marshall, 1989; Rissland, 1985), discourse analysis (e.g., Flowers, McGuire, & Birnbaum, 1982; Smolensky, et. al., 1988), default reasoning (e.g., Lenat & Guha, 1990; Loui, 1987), and others (e.g., AAAI Spring Symposium, 1991). (See Chapter V.) But as far as we know, no research has been done that explores argumentation as a general method for proving and justifying claims in weak theory domains, as in the current work.

Guide to the Rest of this Paper

In the remainder of this paper, we present the results of our work in identifying, and implementing in a computer program, a model of dialectical argumentation for deriving and justifying claims in weak theory domains. This work is motivated by a need to incorporate the ability to construct arguments, a key task of reasoning, in programs that attempt to model intelligent behavior, and to investigate an approach to reasoning that includes concepts of proving and justifying claims appropriate for weak theory domain conditions.

The approach of this research is novel in a number of aspects. Argumentation is investigated as a domain independent, comprehensive approach to reasoning in weak theory domains. The work includes a computational model of argument that incorporates a variety of techniques for reasoning under incompleteness, uncertainty, and inconsistency. The argumentation emphasis on controversy and refutation (as well as support) of claims suggests new approaches to proving and justifying claims in weak theory domains. We are interested in both the representation and generation of argument, and the computational model includes both of these. We give results for the model for a set of benchmark examples drawn from current literature in argumentation and artificial intelligence.

The remainder of this paper is organized as follows: our model of dialectical argumentation is introduced in Chapter II. Chapter II also contains an overview of DART, a computer program that implements the argument model. Chapter III presents an extended example of DART in action. Chapter IV contains an analysis of the model and its DART implementation, including limits of the current model. In Chapter V we discuss related research, in artificial intelligence and other fields where argument is studied, and in Chapter VI we offer conclusions and some speculation about future directions for this work.

CHAPTER II

MODELING DIALECTICAL ARGUMENTATION

Background and Assumptions

In this research, we make several simplifying assumptions about the type of arguments we hope to model. Of the five aspects of argumentation in classical rhetoric (invention, arrangement, style, memory, and presentation/delivery), we concentrate on invention, i.e., the process of developing a defensible proof for an assertion. Of the three types of proof in classical rhetoric (logos, ethos, pathos), we deal entirely with logos, i.e., logic reasoning (both formal and informal logic). Argumentation as studied here does not include negotiation, i.e., a claim which an arguer is attempting to establish or defeat may not be altered or changed. Persuasion per se is not a goal of argumentation, so the use of rhetorical devices intended only to persuade are not included in the model. Support for a claim will depend only on the derivation of the claim and not on issues like the fairness of the ruling or policies that would be entailed by a particular decision. Finally, arguments will have two sides only, "pro" and "con" with respect to a claim. These restrictions are intended to focus the work on the more formal aspects of argument.

Our model of argumentation is based on the following, complementary definitions of argument: (a) "the grounds . . . on which the merits of an assertion are to depend" (Toulmin, 1958), and (b) "a method for conducting controversial discussions, with one contender defending a thesis in the face of object[ions] and counterarguments made by an adversary" (Rescher, 1977). There are two senses of argument posed by these definitions. The first defines argument as a supporting explanation, i.e., an entity; the second concentrates on argument as a *dialectical* process in which two or more agents engage. Thus, the representation of arguments as structured entities and the generation of arguments as dialectical processes are both crucial to our theory.

For argument as supporting explanation, we create argument structures that organize relevant, available, plausible support for a claim, and also for its negation. Argument as dialectical process includes the tasks of supporting and refuting claims, and choosing actions referent to these tasks. In successful refutation, supporting arguments for a claim are shown to be invalid or controversial. Two sides to an argument take turns supporting and refuting claims.

Since the ability to represent arguments as supporting explanations is needed for dialectical argumentation, we describe this work first, followed by our theory of dialectical argumentation. We conclude this chapter by giving an overview of DART, a computer program that implements the argument model.

Argument as Support for a Claim

Toulmin Argument Units

We represent a supporting argument in an extended version of the form given by Toulmin in *The Uses of Argument* (1958). For Toulmin, an argument comprises *data* (i.e., evidence, grounds) said to support a *claim* (i.e., conclusion). The authority for taking the step from data to claim is called a *warrant*. The warrant may have *backing*, or justification. The data and the warrant may not be enough to establish the claim conclusively, i.e., the resultant claim may be *qualified*. The claim may be subject to *rebuttals*, special circumstances where the warrant would not hold. (See Figure 2.) Modifications to this structure are needed to (a) formalize Toulmin's ideas; (b) provide a macro structure for arguments, e.g., extended chains of support for claims, multiple

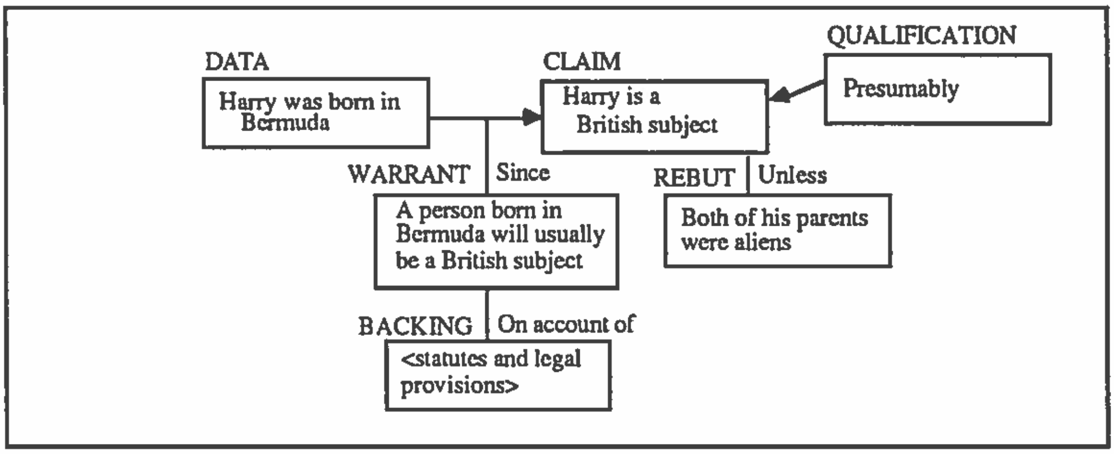


FIGURE 2. Toulmin form for representing argument as supporting explanation.

arguments for claims; and (c) explicate various sources of uncertainty, i.e., arguable points in the domain knowledge. We describe these modifications and extensions next.

Modifications to the Toulmin Format

We refer to the basic structure described above as a "Toulmin argument unit", or *tau*. In our representation of argument, the data and warrant parts of a tau are also seen as claims, and therefore can have rebuttals and qualifications. (Since all the major elements of a tau are claims, we will refer to these as data, warrant, and *conclusion*, to avoid ambiguity.) In the example, "Harry was born in Bermuda" and "A person born in Bermuda will usually be a British subject" would be viewed as claims in their own right, as well as support for "Harry is a British subject".

In our representation, all claims (not just warrants) must be supported, i.e., have backing. We define two types of backing: *atomic*, as information from outside the domain of argumentation. (This type of backing is called an "inartistic proof" in Horner, 1988.) *Tau* backing is used in cases where a conclusion is supported by data and a warrant. A claim may have multiple backings. In the example, the claim "Harry is a British subject" is supported by a tau. The claims "Harry was born in Bermuda" and "A person born in Bermuda will usually be a British subject" also need backing. The warrant would have atomic backing, given as input. All warrants have atomic backing in the current model. Support for data "Harry was born in Bermuda" might also be atomic, or this claim could be the conclusion of another tau.

An argument, then, consists of a series of qualified claims and their backings. Each claim also has an associated rebuttal. In our representation, a rebuttal is a rival claim (currently defined as the negation of the claim) and the arguments that support the rival conjecture. For example, the rebuttal for the claim "Harry is a British subject" is "Harry is not a British subject", plus its backing (and vice versa). Extenuating circumstances are represented by warrants that support the negation of a claim, for example, "A person born in Bermuda to alien parents will usually not be a British subject".

Warrants

Since warrants represent a relationship between two claims, they have a slightly different structure from other claims. In addition to qualification, backing, and rebuttal, a warrant has two propositional fields, *antecedent* and a *consequent*. The antecedent and consequent fields comprise one or more propositional clauses. If the warrant contains multiple clauses in either the antecedent or consequent, they are assumed to be conjunctive clauses.

A warrants also has two type fields associated with it. The *wtype1* field classifies the relationship between the antecedent and consequent as *explanatory (ex)* or *sign (si)*. This distinction is made in (Freeley, 1990), for example. In the next section we will see that distinguishing between explanatory and sign warrants is important for reasoners that use both deductive and plausible reasoning.

An example of an explanatory relationship is a causal link, because knowledge of the antecedent "explains" knowledge of the consequent, e.g., antecedent "fire" causes (explains) its consequent "smoke". Other explanatory relationships, in addition to cause/effect, include definition, classification, object/property, property/attribute, diagnosis/symptom, enable/effect, and action/consequent (see, e.g., Porter, 1990). A sign relationship represents a correlational link between antecedent and consequent, for example, "Summer weekends are generally rainy."

The *wtype2* field of a warrant represents the strength with which its consequent can be drawn from the given antecedent. Representing information as to the strength of the connection between warrant fields is appropriate for reasoning with incomplete or uncertain knowledge. Current types are *sufficient (s)*, *default (df)*, and *evidential (ev)*. The sufficient type is meant to represent certain relationships, e.g., definitions. Default and evidential are meant to represent two levels of uncertain knowledge, with default indicating relationships that are usually the case (e.g., "birds fly"), and evidential referring to less certain links (e.g., "persons who live in Bermuda are often British subjects"). Warrants are expected to be written in the direction that accommodates the strongest possible type. For example, for a causal relation such as that between fire and smoke, since fire causes (is default grounds for concluding) smoke, "smoke" can therefore be said to be evidential grounds for concluding "fire". In the warrant that represents this relation, "fire" should be the antecedent and "smoke" the consequent, since that is the direction of the stronger relationship.

Reasoning Types

In generating a tau backing for a claim, a warrant is applied to data to support a conclusion. For example, the warrant "A person born in Bermuda is usually a British subject" may be applied to the data "born in Bermuda" to draw the conclusion "British subject". While the antecedent and consequent indicate the normal direction of a warrant's application, warrants are used in other ways as well. For example, the above warrant could be applied to the data "British subject" to support the conclusion "born in Bermuda".

An important aspect of our model is the use of warrants in various "directions". Given a warrant with antecedent p and consequent q, we define allowable *reasoning steps* in Table 2. The last two reasoning steps are fallacies in deductive reasoning (asserting the consequent and denying the antecedent, respectively). However they are appropriate for reasoning when knowledge is incomplete. Polya (1968) discusses similar "patterns of plausible inference". He calls them "examining a ground" (MP, ABC in Table 2) and "examining a consequent" (MT, ABD in Table 2).

The MT and ABC reasoning types interact with conjunctive clauses in a warrant to generate disjunctions. For example, warrant "(X and Y)->(W and Z)" can be used with modus tollens reasoning to support the claim "not X" as follows: "(not W or not Z)->(not X or not Y)". The disjunction in the antecedent is handled by creating two warrants: "not W->(not X or not Y)" and "not Z->(not X or not Y)". The disjunction in the consequent field presents a more difficult problem. We handle it by interpreting the "or" in the consequent as an exclusive or, so the two warrants become "(not W and Y)->not X" and "(not Z and Y)->not X", to support claim "not X". That is, the current argument theory incorporates a limited form of disjunctive reasoning, but does not take on the issues of representing, reasoning with, and arguing under full disjunctive reasoning.

TABLE 2. Reasoning Types

warrant	data	conclusion	reasoning step
p -> q	p	q	modus ponens (MP)
p -> q	not q	not p	modus tollens (MT)
p -> q	q	p	direct abduction (ABD)
p -> q	not p	not q	contrapositive abduction (ABC)

When deductive and plausible reasoning types are present in the same system, as they are in this model, care must be taken to avoid inappropriate reasoning combinations, as Pearl (1987), for example, has discussed. For example, if the reasoner knows that "rain causes wet grass" and "sprinkler on causes wet grass", an unrestricted combination of modus ponens and abductive reasoning would allow the reasoner to derive the conclusion "sprinkler on" from the data "rain". This is unacceptable, though reasoning from data "wet grass" to "sprinkler on" (i.e., abductively) is reasonable in isolation.

To permit the generation of acceptable conclusions, while blocking generation of unacceptable ones, the reasoning types interact with the warrant type fields. Modus ponens/abduction combinations are not permitted for two explanatory warrants, unless both warrants are "evidential". The justification for this is that the data field of the explanatory warrant being used with modus ponens reasoning already explains its conclusion, and, therefore, abductive reasoning, which essentially is speculation about a plausible explanation, or cause, for a claim, is irrelevant in this context. In the above example, as "rain" explains how the grass came to be wet there is no reason to speculate "sprinkler on" as another explanation for the wet grass.

However, when the warrants are evidential, or at least one warrant is "sign", then the reasoning combination is permitted. For example, concluding "wet grass" from data "Thursday" and the correlational relationship "On Thursdays, the grass is generally wet", does not provide an explanation as to how or why the grass came to be wet. In this case, it is appropriate to continue along the reasoning chain using abductive reasoning, to hypothesize an explanation ("sprinkler on" or "rain") for the wet grass on Thursdays.

This is also appropriate for evidential, explanatory warrants. If, for example, "high humidity" or "grey skies" were evidential data for conclusion "rain" (i.e., "high humidity ->rain"; "grey skies ->rain"), it seems reasonable to conclude "grey skies" starting from data "high humidity". This is because "high humidity" gives only a partial cause for conclusion (using modus ponens reasoning) "rain", i.e., there is still room to speculate as to additional (partial) causes, e.g., "grey skies".

Qualifications

Qualifications are needed to capture the support for claims reached as a result of arguments using uncertain knowledge and plausible reasoning. We use the following qualifications: *strong(s)*, *usual (!-)*, *credible (+)*, and *unknown (?)*. The first three are ranked in decreasing order of support; the last indicates a lack of (known) support.[1]

The qualification on a claim is that associated with its strongest supporting argument. The qualifications on input data and warrants are given as atomic backing at input time and remain unchanged thereafter, unless better support is derived from a tau backing. The qualification on any claim resulting from a tau backing is the least of the qualifications associated with the warrant application: the qualification(s) on the data support, the qualification on the warrant, and the qualification derived from the warrant type and reasoning step applied ("link qualification", see Table 3).

TABLE 3. Link Qualifications

warrant type	reasoning step	link qualification
$->_s$	MP, MT	strong
$->_s$	ABD, ABC	credible
$->_{df}$	MP, MT	usual
$->_{df}$	ABD, ABC	credible
$->_{ev}$	MP, MT	credible
$->_{ev}$	ABD, ABC	credible

[1] As we discuss in Chapter 5, the issue of representing, combining, and propagating uncertainty is a research area in it own right. Here, we choose a simple representation that covers our needs with respect to the argumentation model, but avoids the complexity and commitments that would come with implementing one or another of the current methods for representing uncertainty.

This weak link approach to propagating support for claims and its appropriateness for plausible reasoning is discussed in (Pollock, 1991) and (Rescher, 1976). Rescher (1976) appeals to tradition: "[Plausible reasoning] bases its approach on the traditional modal principle that the conclusion of a piece of reasoning takes its status from that of the 'weakest' premis[e] (*pars deterior*)." Pollock (1991) argues that human reasoning must make use of a "weakest link principle for defeasible arguments", or something like it, as other methods for propagating uncertainty seem too complex for everyday reasoning.

Figure 3 shows the new representation of the argument given in Figure 2, with the modifications and extensions to the Toulmin format described in this section.

Dialectical Argumentation

In the previous section, we described a representation for arguments as supporting explanations. The representation, based on the standard Toulmin format, includes non-deductive reasoning types, qualified claims, explanatory and correlational warrants, and sufficient, default, and evidential warrants. These features are appropriate for representing and reasoning about knowledge that is incomplete or uncertain. They also explicate uncertainty in the support for a claim, i.e., arguable points. However, having only a structural model does not capture the procedural character of argumentation. In this section, based upon the representation just outlined, we expand our model of argumentation to include argument as a dialectical process, where arguments supporting alternative claims are refuted and defended in turn. In the dialectical format, the strengths and weaknesses of support for competing claims are explicitly highlighted and directly compared.

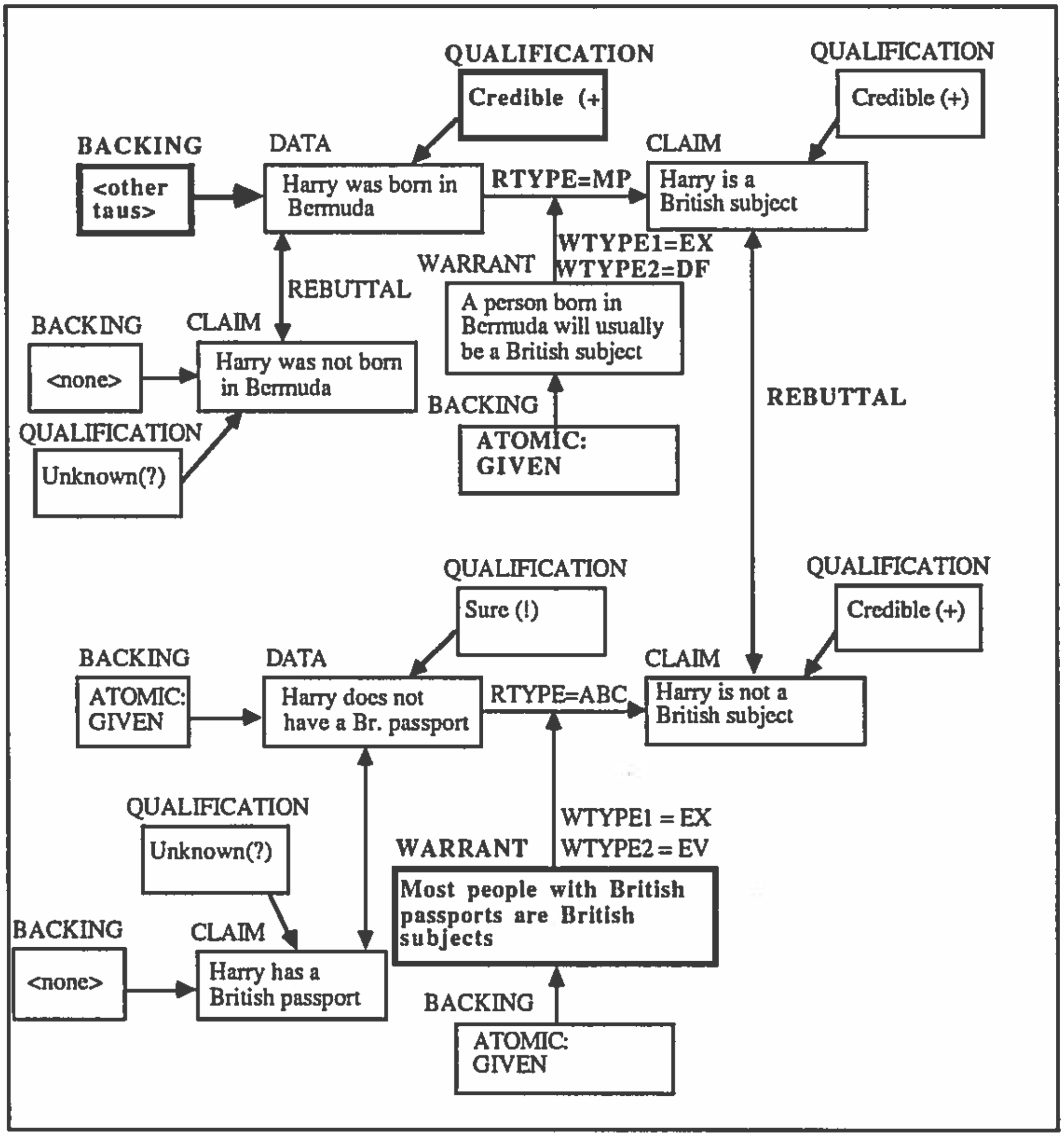


FIGURE 3. Modified Toulmin form for representing argument as supporting explanation.

Definitions

Generating dialectical arguments results in the intertwining of the argument structures that support a claim and its negation. We expand the qualification field for a claim to summarize the support for both the claim and its negation. For example, given the argument slice shown in Figure 3, the qualification for the claim "Harry is a British subject" would be "++", since there is some support for both the claim and its negation. The qualification for "Harry has a British passport" would be "?!". Using this representation of the qualification, we define several terms for our theory of dialectical argumentation.

Support for the input claim is *Side-1 support* and support for the negation of the claim is *Side-2 support*. Support for a claim is *consistent*, for mutually exclusive conjectures, if there is support on one side of the claim and no support on the other side, i.e., the qualification slot for one side only contains a "!", "!-", or "+". A claim that is not consistent is *controversial*. A claim qualification is *terminal* when there are no argument moves available that could change its qualification.

With these definitions, we now define the set of proof levels (see Chapter I) in terms of our model. A *dialectically valid (dv)* claim is one with terminal, consistent support. When a claim has terminal support, either consistent or controversial, that is stronger than the support for its negation (if any), the claim is proved with a *preponderance of the evidence (pe)*. When there is terminal support for a claim, either consistent or controversial, regardless of the strength of the support, the claim is proved with a *scintilla of evidence (se)*. Finally, burden of proof level *beyond a reasonable doubt (brd)* is support for a claim that is both dialectically valid and strong (i.e., qualified as sure or usual).

The burden of proof in an argument is always on Side-1 to establish support for the input claim, where support is defined with respect to one of the proof levels. A claim with a qualification that supports Side-1 is a *Side-1 check*, else it is a *Side-2 check*. A claim that is a terminal check for a side is a *winner* for that side.

Generating Dialectical Argument

We define the primary tasks of dialectical argumentation to be (a) supporting a claim; and (b) refuting a claim or its supporting arguments. Tasks are implemented by argument moves. Thus, dialectical argumentation can be described as a process of two sides alternatively moving through a search space of qualifications for a claim, seeking a winner (check) qualification for their own side, and thereby undoing the check qualification achieved by the other side. Progress through the state space is achieved and constrained by argument moves. Move selection is driven by a heuristic evaluation process that is based on the possibility of strong progress toward a check qualification for the side and argument coherence.

Dialectical argument begins in a stylized fashion, with Side-1 attempting to find support for its claim. If there is no support, the argument ends, and Side-1 concedes the claim. (This does not mean that the negation of the claim has been established; to do this requires another argument, where the input claim is the negation of the current claim.) If Side-1 is able to find support for the claim, control is given to Side-2, which tries to refute the argument or claim(s) established by Side-1. A side executes argument moves in order, until one succeeds or there are no more moves. When a move is successful, and the qualification on the input claim becomes a check for the current side, the current side gives control of the argument to the other side, to attempt to refute the refutations. A side chooses moves until it achieves a check qualification or has no more moves. When there are no more moves, the current side concedes the argument and the argument ends.

Generating Argument Structures

Finding support for a claim results in the generation of the argument structures described earlier in this chapter. Given a claim, search for support proceeds in a goal-directed fashion by looking for backing for the claim. If a claim is already in the data base with atomic backing, then the task is done. If a claim is already in the data base with tau backing, the backing is checked to ensure that it does not loop (i.e., no claim is being used to support itself in the argument) or contradict (i.e., no negation of a claim is being used to support the claim) claims further up the argument tree. If the claim has no backing, or has non-reusable tau backing, then tau backing for the claim is generated by searching for warrants that are relevant to the claim, i.e., contain the claim in their antecedent or consequent fields. Loops and contradictions are pruned during this process.

Argument generation continues recursively, with searching for backing for claims from the "other side" of a relevant warrant. The process grounds out when a claim is supported in the data base. Then a new tau structure is generated for each warrant that supports a claim, and the qualification and backing fields of the claims are updated to reflect the new support.

Dialectical Argument Moves

In this section, we focus our attention on refuting a claim or its supporting arguments. We begin to give operational meaning to the tasks of dialectical argumentation by defining them in terms of the argument moves needed to implement them (see Table 4).

We distinguish two types of refutation: (a) *undercutting* and (b) *rebutting* (following Pollock, 1987, though not exactly). Undercutting is accomplished by finding weaknesses in purported support for a claim. With respect to the structure of a tau, undercutting questions the sufficiency of the data support and the link fields (i.e., warrant type and

TABLE 4. Dialectical Argument Moves

ARG TASKS	MOVES	GIVEN	SHOW	SUCCESS C IS -
support C	(a) support	C	X->C ^ X C->X ^ X ~C->X ^ ~X X ->~C ^ ~X	supported supported supported supported
refute C undercut C	(b) invalid data	X->C ^X		controversial
	(c) exception	X->$_{df}$C ^X	X^Y->~C ^Y	not supported
	(d) inapplicable evidence	X->~C ^~X	Y->s~C ^Y	not supported
	(e) unneeded explanation	C->X ^X	Y->X ^Y	not supported
	(f) missing evidence	X->$_{ev}$C ^X	Y->$_{ev}$C ^~Y	controversial
	(g) conflicting evidence	X->$_{ev}$C ^X	Y->$_{ev}$~C ^Y	controversial
rebut C	(h) reductio ad absurdum	C	C->...->Z ^~Z	controversial
	(i) support rival claim	C	X->~C ^X	controversial

reasoning type). Questioning the data that supports a conclusion amounts to attempting to refute the data-claim of the tau, moving the argument a step back. Following up on less than certain warrant and/or reasoning types in the support for a claim leads to argument moves that: (a) search for exceptions to default rules; (b) attempt to show that weak evidence is irrelevant in the face of other, strong evidence; (c) try to find alternative explanations for data, defeating claims that had been hypothesized as explanations for the same data using abductive reasoning; (d) search for missing evidence, or evidence for a rival claim, to emphasize that the evidence given in support of a claim is insufficient.

If an undercutting move is successful, it can result in the withdrawal of an argument. This in turn leaves the conclusion of the argument unsupported. For example, in the Bermuda problem the claim "id#" can be hypothesized as an explanation for data "wp". Since the problem contains additional knowledge, i.e., "special skills" and "special skills->df wp", "wp" can be shown to be otherwise explainable, and should be withdrawn as support for "id#". The qualification of the claim "id#" would change from "+|?" to "?|?" as a result of this undercutting argument.

Also in Table 4 we see that some methods for which undercutting a claim may result in support for a rival claim. These leave the original argument as it was, but highlight its inadequacies. As a result, its conclusion may become controversial or unsupported.

In contrast, rebutting moves attack a claim without regard for its supporting arguments. In a successful rebuttal, support for a rival claim is found. As a result, the original claim becomes controversial. We identify two rebutting argument moves: (a) reductio ad absurdum; and, more generally, (b) establishing alternative arguments for rival conjectures.

Heuristics for Dialectical Argument

When a side is in control of the argument, it must select which argument move to apply. Heuristics, guidelines for ordering argument moves, determine the course of the actual argument. Some researchers have suggested that the rules for generating sequences of moves constitute, with argument-as-supporting-explanation and argument-as-dialectical-process, a third "sense" of argument (Cox & Willard, 1982). The current model includes heuristics for controlling argument generation. They are meant to reflect two goals: generate the strongest argument possible (for each side), and generate a coherent argument, i.e., the arguments of each side are responsive to the arguments put forward by the other side.

Heuristics are used to order both the moves that implement a dialectical argumentation task, and the warrants that implement a particular move. Argument moves are currently ordered according to the following criteria: (a) moves that can defeat a tau, and therefore result in the withdrawal of support from a claim, are preferred over moves that can only cause the tau's claim to become controversial; (b) specific moves are preferred over general ones, for example, "find evidence to support not C, to conflict with current evidential support X for C" is given priority over "find (any) support for not C"; (c) moves that attack taus closer to the root, or top level claim, of the argument are given priority over moves farther down the argument tree; and (d) undercutting moves are given priority over rebutting moves. For example, to refute the argument "$X\text{-}{>}_{ex/ev/mp}Y\text{-}{>}_{ex/df/mp}C$", the move "find exception (to refute tau Y->C)" is preferred over the "find missing/conflicting evidence (to refute tau X->C)" moves, since an exception can defeat a tau, while the evidence moves can only make a tau controversial. The "find missing/conflicting evidence" moves would be preferred to "question data support Y" because the former are more specific rules. "Question data support Y" would be preferred to "rebut C", because the undercutting move responds to an argument of the other side (not just the top claim).

Warrants are currently ordered according to the following criteria: (a) strong reasoning types (modus ponens and modus tollens) are preferred over weak reasoning types; (b) strong warrant types are preferred over weaker warrant types; and (c) warrants where the data support part already has consistent support or where nothing is known about its support are preferred over warrants where the data support is controversial, or negated. For example, to support claim "C", the warrant "X->$_{ex/ev}$C" would be rated above "C ->$_{ex/ev}$Y", because it would use modus ponens rather than abductive reasoning. But "Z ->$_{ex/df}$C" would be preferred to it, because the default warrant type is stronger than the evidential warrant type. And "X->$_{ex/ev}$C", where nothing is yet known about X, would be ranked above "Q->$_{ex/ev}$C" where the current qualification for "Q" is "?+", i.e., "not Q" is supported.

These heuristics anticipate to some extent the moves that the other side may use to try to refute this tau, should this warrant turn out to actually support the claim. That is, strong reasoning types cannot be refuted, while weaker ones can. Warrant type *sure* cannot be refuted; warrant type *default* can only be refuted by an exception move; while evidential warrants are refuted by both conflicting evidence and missing evidence moves. Similarly, weaker reasoning types allow more opportunities for rebuttals. Controversial or negated data can support a claim controversially at best, while consistently supported data or data where nothing is known about the support will be, at least immediately, less susceptible to the question data support argument move.

Heuristics can be arbitrarily complex and use a large amount of knowledge (e.g., domain knowledge, argument knowledge, etc.). The heuristics of the current model are not meant to be the final word on controlling argument generation; we include them to begin to explore the role of heuristics in dialectical argumentation. We find they generate reasonable, effective, generally coherent arguments, as we demonstrate later.

DART: Implementing the Argumentation Model

DART (Dialectical Argumentation), a computer program written in Common Lisp, implements the model of dialectical argumentation described in the previous sections. Given a warrants base and data base, a claim to prove, and a proof level, DART generates a dialectical argument as a side effect of its attempt to prove the input claim. The argument is represented internally in the program and at output using the modified Toulmin representation described earlier in this chapter. In this section we give a general overview of DART; a detailed example of DART in action is given in Chapter III.

The program user is responsible for providing DART with an application file containing the warrants base, initial data base, and claim. The user may also specify a proof level and allowable reasoning types and warrant types at input time, otherwise DART will use default values. The default burden of proof level is dialectical validity, and default reasoning and warrant types are "all" (i.e., MP, MT, ABD, and ABC for reasoning; ex, and all subcategories of ex, and si warrants; s, df, ev warrants). If the user does restrict reasoning or warrant types, this has the consequence of limiting the warrants available to the argument generation routines. For example, DART could be restricted to use only deductive reasoning over sufficient warrants. Then, even if a claim could be supported by an evidential warrant, and this would be useful with respect to the proof level, the warrant would not be used.

The user must be alert to possible interactions between warrant and reasoning type restrictions and the proof level. For example, restricting reasoning types to non-deductive ones (i.e., ABD and ABC), then setting the proof level to beyond a reasonable doubt sets the argument generator an impossible task. In this situation, no argument would be found to support the input claim, because no argument could meet all the input constraints simultaneously. In other situations, the user may find the flexibility at input time useful, for example, restricting the use of evidential warrants would effectively shrink the size of the warrants base, making argument generation more efficient, as well as cause the program to generate only strong arguments (with respect to warrant strength), which may be desirable in a particular context.

In generating an argument, DART uses the format of a two-sided argument, as described earlier in this chapter. Figure 4 shows important DART modules. The main components of DART are the Find_Support and Refute modules, and we discuss these next, as well as rules for turntaking during argumentation.

Find Support

The architecture of Find_Support is similar to that of most rule-based systems (see Figure 5). The goal of the Find_Support module is to establish support for an input claim (or claims). If there is no current support for the input claim, Find_Support attempts to generate support. This is accomplished in the "matching" step; the warrants base is searched for warrants that could provide support for the claim. The matcher examines warrants for all reasoning type possibilities, i.e., support for claim C could be supplied by warrant "X->C" using modus ponens, by "not C->X" using modus tollens, by "C->X" using abduction, and by "X->not C" using the abduction-contrapositive reasoning type.

Potentially supportive warrants are checked for allowable reasoning types and warrant types. They are also checked to ensure that support from the warrant would not conflict with or repeat support further up the argument chain. For example, say a side in the argument wishes to find support for the claim "C", and the warrants base contains a

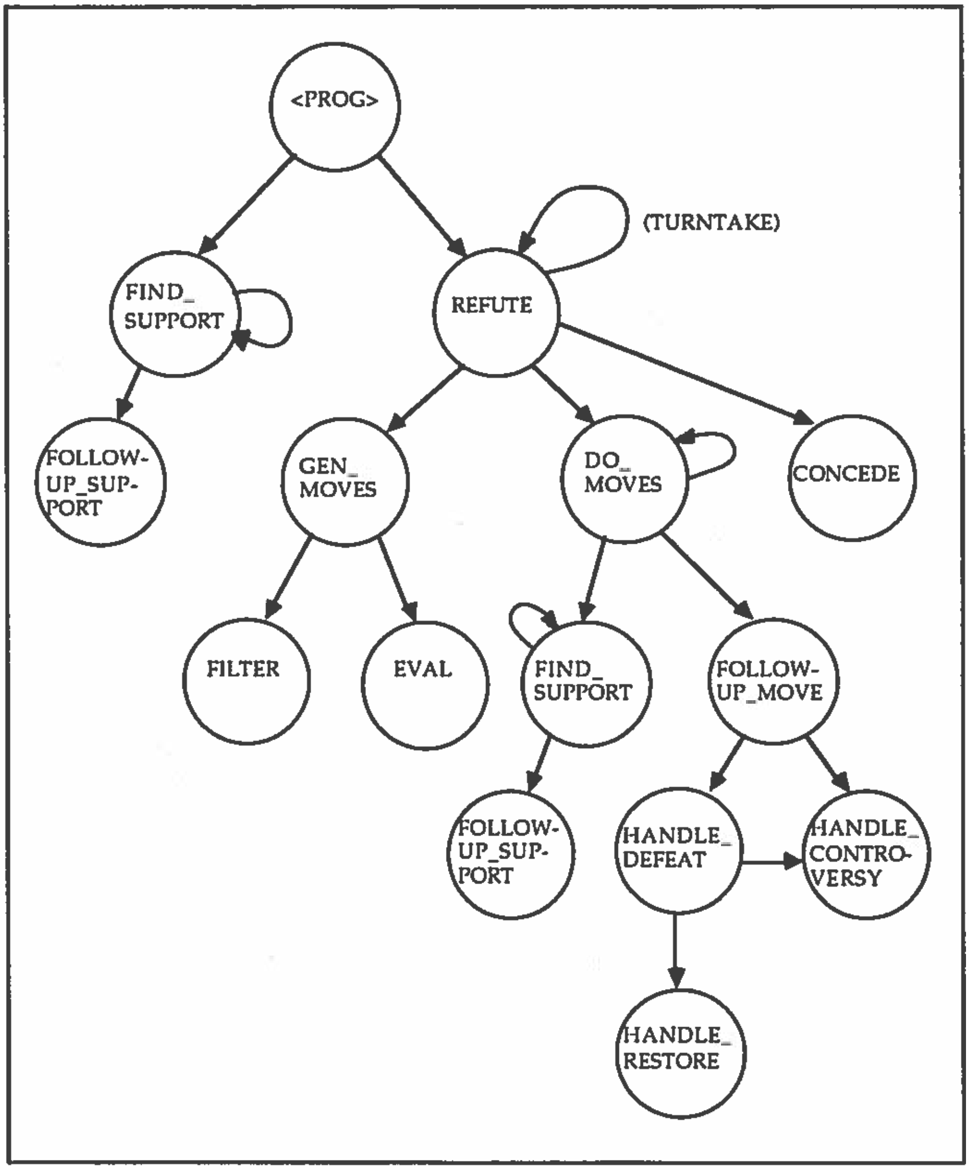


FIGURE 4. DART main modules.

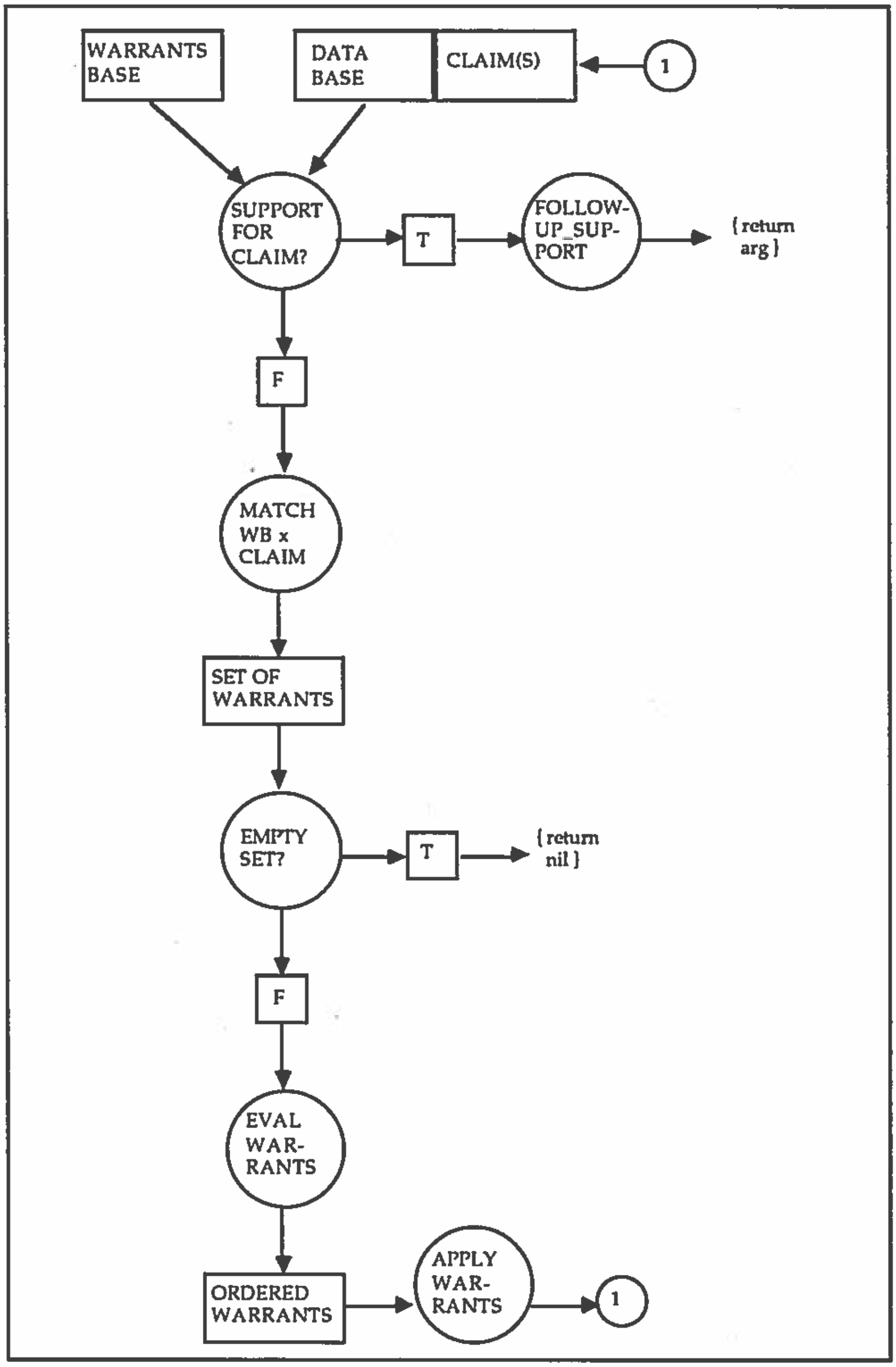


FIGURE 5. Find support module.

warrant "X->$_{ex/ev}$C", a potentially supportive warrant. However, if the user has specified that only default warrants are permitted, or that modus ponens reasoning is not permitted, then this warrant cannot be used. Or, if "C" is itself being used to support or help support the claim "not X", then "X->C" cannot be used, as it would cause the argument to be internally inconsistent (i.e., "X->C->...->not X"). If the warrant does pass all the constraint checks, it is added to a conflict set of warrants.

If the conflict set is empty when the matcher finishes checking the warrants base, Find_Support has failed to find support for the claim, and returns nil. If the conflict set is not empty, each warrant is evaluated, and the set is heuristically ordered, currently according to the criteria given in earlier in this chapter. The data support part of the next warrant (e.g., "X", when "X->C" is being used to support "C") then becomes the new claim, and Find_Support calls itself recursively.

Warrant ordering heuristics implement an informed depth first search. Breadth first search is avoided due to the risk of combinatorial explosion. It is hoped that the heuristics direct the depth first search to minimize the risk of exponential search. Although it is not part of the current program, once one warrant is chosen to implement a move, it may be desirable to switch to another warrant. For example, a side may have chosen between two default warrants that could both support a claim using modus ponens reasoning. If it turns out that the left hand side of the chosen warrant is only (possibly) supported by evidential warrants, the side may want to backtrack and try the other default warrant, rather than continue down the current support chain. This would hopefully result in the generation of the strongest possible support for a claim, all the way down to its data support, a goal which the current heuristics aim for but only partially achieve.

When the proposition part of the input claim to Find_Support is already supported in the data base, Find_Support generates an argument structure ("Followup_Support"), in the format of the modified Toulmin representation. The support for the current claim is propagated along a warrant to become data support for another claim, and so on along the argument chain. A tau structure is generated to record the link between each data support and claim combination. The qualification and backing fields of each claim in the argument are updated to reflect the new support. The argument chain originates with the current claim (i.e., the one supported in the data base) and continues up the argument to the claim that was input to the original call to Find_Support.

For example, when Find_Support is called for claim "C", and the warrants base contains "X->C" and "Y->X", and the data base contains a claim node showing that "Y" has atomic backing, then the argument structure generated by Find_Support would include three claims ("X", "Y", and "C") and two taus (one that is backing for "X" based on data support "Y", and one that is backing for "C" based on data support "X").

Turntaking

At the beginning of the argument generation process, Find_Support is called by Side-1 to generate support for the argument's top level (input) claim. If this initial call to Find_Support is successful, the qualification on the top level claim of the argument becomes a Side-1 check with respect to the input proof level, and control of the argument is given to Side-2. Side-2's task is then to obtain a check qualification for its side; this is accomplished by refuting the current argument established by the other side. If Side-2 succeeds in obtaining a check qualification, control is given to Side-1 to attempt to refute the refutation. Turntaking continues in this manner until one side concedes the argument.

Refute

The architecture for the Refute module for dialectical argumentation can also be represented using a rule-based system framework (see Figure 6). The input to the Refute module is the current argument, i.e., the claim node of the top level argument claim, including its qualification and backing. From the backing for the top claim node Refute can access he entire current argument structure.

The most recent addition to the argument, the part just generated by the other side, is used by the Refute matcher. The matcher matches the new claims and their tau backings to a table of argument moves, i.e., for each new tau that contributes to the support of the claim that the current side wishes to refute, DART generates argument moves that will, if successful, refute the tau. (See Table 5 for a list of moves and the taus they refute.) Some moves attempt to exploit weak points in the tau, e.g., weak warrant and reasoning types. A move that is generated for every tau is to question the data support field of the tau, since if the data support can be shown to be controversial, the claim it purports to support will also be controversial. A rebuttal move for the top claim is also generated.

TABLE 5. Implementing Moves for Dialectical Argument

CLAIM/ BACKING	ARGUMENT MOVE	IMPLEMENT USING
X->C	invalid data	rebut X
$X\text{->}_{df}C$	exception	find MP support for not C
$X\text{->}_{abc}C$	inapplicable evidence	find MP, MT support for not C
$X\text{->}_{abd}C$	unneeded explanation	find MP support for X
$X\text{->}_{ev}C$	missing evidence	find ABC, evidential support for not C
$X\text{->}_{ev}C$	conflicting evidence	find evidential support for not C
<any>->C	rebut	find support for not C

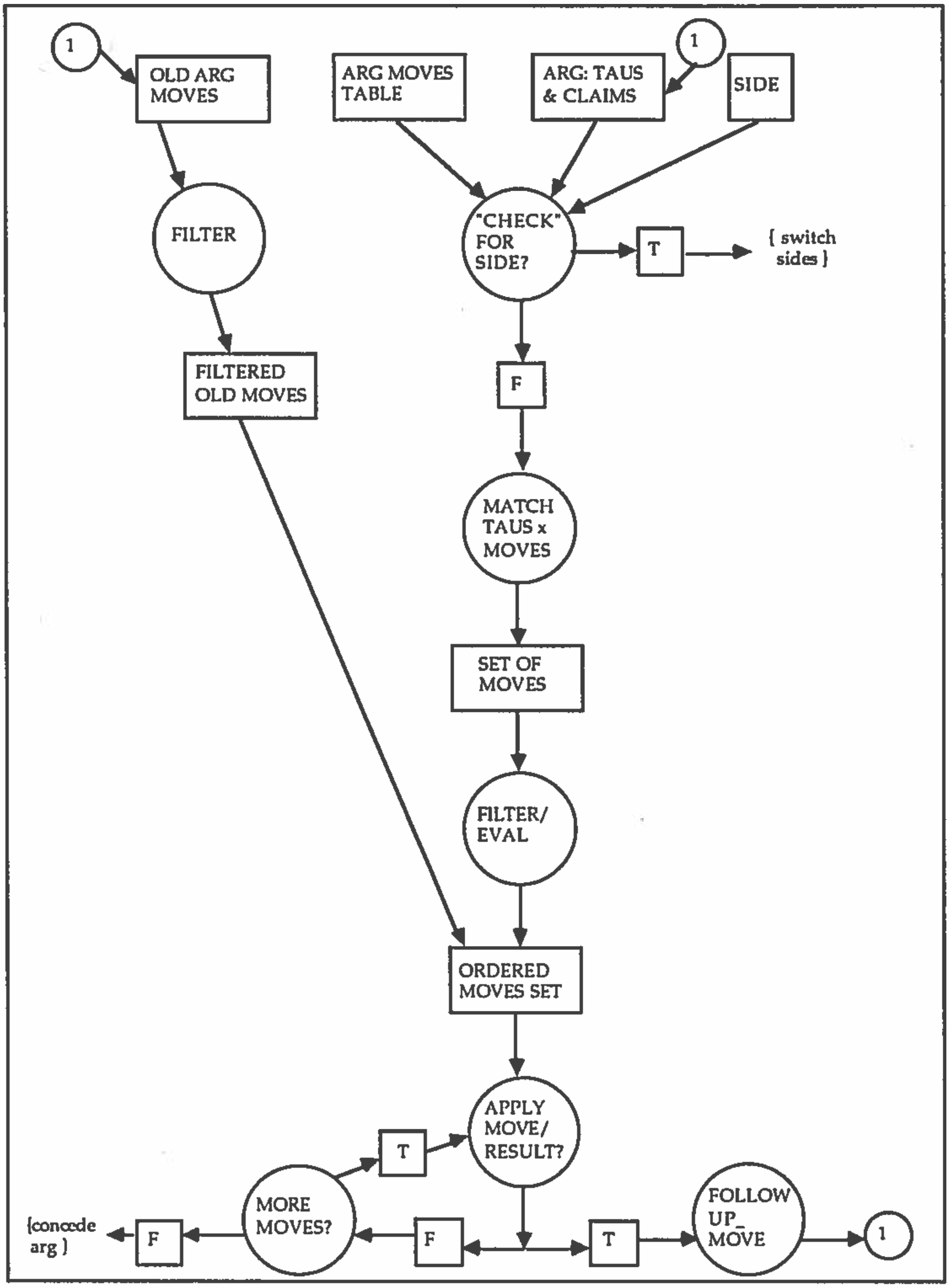


FIGURE 6. Refute module.

For example, to refute the tau "$X \rightarrow_{ex/df/mp} C$", the Refute matcher will generate argument moves "find exception to X support for C" (the warrant is vulnerable because it is only a default), "question data support X", and "rebut C".

The moves are filtered with respect to the burden of proof level, as well as input reasoning and warrant type constraints. For the example above, when the burden of proof level is "scintilla of evidence", and the current side is Side-2, the only move of the three generated that would survive the filtering process would be the "find exception" move. This is because to win the overall argument, Side-2 must actually force the withdrawal (i.e., defeat) Side-1's argument, and "find exception" is the only move that can cause that to happen. If "modus ponens" were not an allowable reasoning type, then the "find exception" move would be filtered, too, since it is eventually implemented using modus ponens reasoning. (See Table 5.)

After filtering, the surviving moves are evaluated, and the set is ordered, currently according to the criteria given earlier in this chapter. Since arguments have two sides, moving through the argument moves search space is similar to game-playing. Moves are always forward from the current state, and progress is not toward one overall goal, since each side has its own goal, which opposes the goal of the other side. Although they are not part of the current program, game-playing search techniques such as minimax and alpha-beta cutoff could be appropriately generalized for argumentation.

Unlike most games, in argumentation there is no reason why a side might not make more than one successful move, or even try all of its moves, during one turn. This would be tantamount to a breadth first search of the argument space, and therefore subject to combinatorial explosion. The current approach, which, as in Find Support, is a heuristically-informed depth first search, is potentially more efficient (though we have not tested this for the example arguments). Also, the state of the argument "game" does not entirely change with every move. Thus, some argument moves not chosen by the side during its current turn may still be available in later turns. Since moves are not lost, there is not the danger of failure due to taking the wrong branch of the argument tree. In the worst case, more of the search space (as usual, subject to combinatorial explosion) will be covered before the argument ends.

The ordered set of new moves is added to the ordered set of moves that were generated in response to previous argument segments, but haven't yet been used (if any). Old moves are checked for continued relevance, i.e., they are filtered if the tau they would have refuted has since been defeated or the claim of the tau is no longer connected to the current argument. New moves are given priority over old moves, supporting argument coherency.

After generating, filtering, and ordering argument moves, the side is finally ready to refute the current argument. Moves are attempted in order; all moves are applied using the Find_Support module. The attempted move, and its result, are given as program output. If a move is not successful, the side tries the next move. If there are no more moves, the side concedes the argument.

If the move is successful, Refute updates the current argument structure ("Followup_Move"). Find_Support will have updated the current argument from its data base support up to the claim that Find_Support was originally called for. The updating that remains is to propagate the move results from the current claim up the argument tree to the root, i.e., the top level claim. For example, say the original argument was "X->$_{ex/ev/mp}$Y ->$_{ex/ev/mp}$C", and the last move was "question data support Y". If the call to Find_Support was successful (for example, using warrant "Q->not Y"), then Find_Support will have created a tau showing new data support "Q" for claim "not Y", and will also have updated the qualification and backing fields of claim node "not Y". Refute must now propagate this result up the argument tree, i.e., to claim node "C".

A successful refutation will either defeat a tau, or cause it to be controversial. When a tau is defeated, it is removed from the current argument structure, as are any taus that depended on the defeated tau for support. If the defeated tau was itself a defeater tau, then the taus that were removed at that time are restored to the current argument. When a tau is shown to be controversial, its claim becomes controversial. This will in turn cause each tau supported by that claim to be controversial, and so on to the root of the argument. This is the case in the above example. Showing "Y" to be controversial makes the tau "Y->C" controversial, and its claim, "C", therefore becomes controversial. A new tau ("Y->$_{ex/cv/abc}$not C") is generated to record this, and the qualification and backing fields for claim node "not C" are updated accordingly. Thus, at the end of a successful refute move, taus will have been added, removed, and/or restored, and new claim qualifications propagated to the top argument claim. Followup_Move results are given as program output.

At this point, the Refute module tests the qualification of the top claim to see if it is "check" for the current side. If it is a check qualification, control of the argument is turned over to the other side. If it is not a check qualification, current side executes the next move, or concedes the argument if there are no more moves.

CHAPTER III

AN EXTENDED EXAMPLE OF DART IN ACTION

To further describe the operations of the DART argumentation modules, we present an extended example of DART in action. DART output is given for a version of the Bermuda problem, for each of the four proof levels. For arguments generated by DART for other example problems, see the Appendix.

Example Input

We give information for an extended version of the Bermuda example of Chapter I. Anyone born in Bermuda can be assumed to be a British subject, unless both parents were aliens. Statistics show that most people who speak English and have Bermuda identification numbers were born in Bermuda. Having a Bermuda identification number makes one eligible to obtain Bermuda working papers, as does having special working skills, unless there are already enough workers with the special skill. Having a high school education is highly correlated with having Bermuda working papers. Most people who have a British passport, or pay taxes in Bermuda, or live in Bermuda, are British subjects.

This knowledge can be represented by the following input warrants:

```
(w1 ((british passport))  -->  ex ev  ((british subject)) (!? GIVEN))
(w2 ((bermuda born))  --> ex df  ((british subject)) (!? GIVEN))
(w3 ((english speaking)(bermuda id#))  --> si ev  ((bermuda born)) (!? GIVEN))
(w4 ((bermuda id#))  --> ex df  ((working papers)) (!? GIVEN))
(w5 ((bermuda born)(alien parents))  --> ex df  ((not british subject)) (!? GIVEN))
(w6 ((special skills))  --> ex df  ((working papers)) (!? GIVEN))
(w7 ((special skills)(quota met))  --> ex df  ((not working papers)) (!? GIVEN))
(w8 ((pays Bermuda taxes))  --> ex ev  ((british subject)) (!? GIVEN))
(w9 ( (lives in Bermuda))  --> ex ev  ((british subject)) (!? GIVEN))
(w10 ((high school education))  --> si df  ((working papers)) (!? GIVEN))
```

We also have some information about an individual, Harry: he completed high school in Bermuda, lives in Bermuda, and pays Bermuda taxes. He has one passport, that is not a British passport, speaks English, and has special work skills, though the quota for working papers for Harry's special skills has been met. We would like to know whether or not Harry is a British subject.

This knowledge can be represented by the following input claims:

```
(d1 (english speaking) (!? OBSERVED))
(d2 (british passport) (?! GIVEN))
(d3 (special skills) (!? GIVEN))
(d4 (quota met) (!? GIVEN))
(d5 (pays Bermuda taxes) (!? GIVEN))
(d6 (lives in Bermuda) (!? GIVEN))
(d7 (high school education) (!? GIVEN))
(claim (british subject) (?? NIL))
```

Argument Output

Dialectical Validity

In the first example, the burden of proof, borne by Side 1, is dialectical validity. The argument starts with Side-1 attempting to generate support for the input claim, "british subject".

```
Starting argument...
Side 1 is looking for support for (BRITISH SUBJECT)
Burden of proof on side 1 is dialectical validity.
```

As the claim is not already supported, the warrant base is searched for warrants that can be used to provide tau support for the claim. A conflict set of warrants is generated, and warrants are checked for compliance with constraints, including input reasoning types and warrant types. In addition, the data support part of the warrant may not repeat or contradict any claims that are already part of the argument chain being developed. The conflict set of available warrants is then heuristically ordered according to the criteria given in Chapter II.

Here, warrant W2 is preferred over the other warrants because it is a default, rather than evidential, warrant. Warrants W8 and W9 are preferred over W1, because using W1 would mean using data support "British passport", and "not British passport" is supported in the current data base.

```
Looking for support for claim (BRITISH SUBJECT)
Check warrant(s) (W2 W8 W9 W1) for support for (BRITISH SUBJECT).

    Trying W2 with ((AND (BERMUDA BORN)))
    to support (BRITISH SUBJECT).

    Looking for support for claim (BERMUDA BORN)
    Check warrant(s) (W3) for support for (BERMUDA BORN).

        Trying W3 with ((AND (ENGLISH SPEAKING) (BERMUDA ID\#)))
        to support (BERMUDA BORN).

        Looking for support for claim (ENGLISH SPEAKING)
        Support found in data base for (ENGLISH SPEAKING)

        Looking for support for claim (BERMUDA ID\#)
        Check warrant(s) (W4) for support for (BERMUDA ID\#).

            Trying W4 with ((AND (WORKING PAPERS)))
            to support (BERMUDA ID\#).

            Looking for support for claim (WORKING PAPERS)
            Check warrant(s) (W10) for support for (WORKING PAPERS).

                Trying W10 with ((AND (HIGH SCHOOL EDUCATION)))
                to support (WORKING PAPERS).

                Looking for support for claim (HIGH SCHOOL EDUCATION)
                Support found in data base for (HIGH SCHOOL EDUCATION)

                Support found for warrant W10
            Support found for warrant W4
        Support found for warrant W3
    Support found for warrant W2
```

Side-1 has found support for the claim, and generates an argument in support in the modified Toulmin format:

Claim ((BRITISH SUBJECT)) is supported by ((BERMUDA BORN))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t226
Claimnode qualification is: (+ ?)

Claim ((BERMUDA BORN)) is supported by
((BERMUDA ID\#) (ENGLISH SPEAKING))
Warrant id: W3 - Wtype1: SI - Wtype2: EV - Rtype: MP
New tau id: #:\t225
Claimnode qualification is: (+ ?)

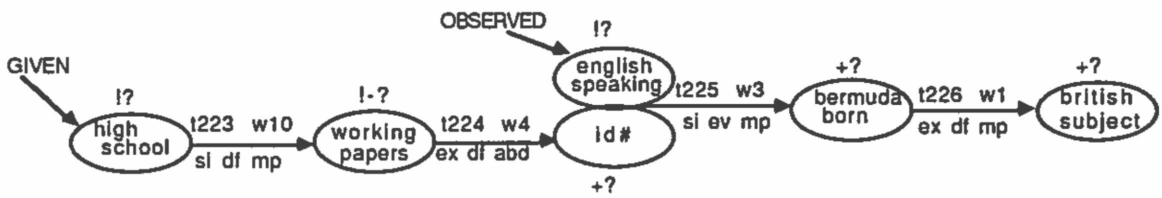
Claim ((BERMUDA ID\#)) is supported by ((WORKING PAPERS))
Warrant id: W4 - Wtype1: EX - Wtype2: DF - Rtype: ABD
New tau id: #:\t224
Claimnode qualification is: (+ ?)

Claim ((WORKING PAPERS)) is supported by
((HIGH SCHOOL EDUCATION))
Warrant id: W10 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t223
Claimnode qualification is: (!- ?)

Claim (HIGH SCHOOL EDUCATION) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (ENGLISH SPEAKING) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

This argument can be graphically represented as follows:



In sum, there is some support for the claim that Harry is a British subject, because there is support for the claim that he was born in Bermuda. Side-1 makes the argument that Harry was born in Bermuda based on the information that he speaks English, and on an argument that he has a Bermuda identification number. "English speaking" was provided in the input data base; Bermuda identification number is speculated as an explanation for Harry's having his working papers, since one way of obtaining working papers is to have an identification number. Though we were not told directly that Harry has his working papers, having one's working papers is strongly correlated with having at least a high school education, which Harry does indeed have.

Though there is support for the top claim, it is qualified as credible, rather than strong. The reason for this is that Side-1 has made use of evidential rules as well as abductive reasoning in generating the support for "British subject". We can also see in this argument the effect of declaring a warrant to be a "sign", rather than an "explanatory" warrant: Since a "high school education" is only correlated with (i.e., does not provide an explanation for) "working papers", Side-1 was able to use modus ponens followed by abductive reasoning to reason from "high school education" to "id#". This would not have been possible if the warrant used with modus ponens had been an explanatory one: with an explanation already provided for "working papers", no further speculation as to how Harry obtained them (i.e., via an "id#") would have been permitted.

Since Side-1 has achieved a Side-1 check qualification on the top claim, control of the argument is given to Side-2, to attempt to refute Side-1's support for the claim. Side-2 proceeds as follows:

```
-----------------------------------------------------------------**Side 2 is next.
```

First, argument moves that can be used to refute Side-1's argument are collected, including moves generated but not used by Side-2 in previous turns. Since this is Side-2's first turn, there are no old moves:

Usable moves from before are:
<None>

Next, new moves are generated, based on Side-1's last argument in support of the top claim. Moves are generated tau by tau, and seek to expose weak reasoning types, warrant types, and data support:

Possible NEW argument moves are

Find exception for rule (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
Refuted tau would be #:\t226

Question data: find support or bolster (AND (NOT BERMUDA BORN))
Refuted tau would be #:\t226

Look for evidence that supports (AND (NOT BERMUDA BORN))
to refute (AND (BERMUDA ID\#) (ENGLISH SPEAKING)) evidence for
(AND (BERMUDA BORN))
Refuted tau would be #:\t225

Look for evidence, other than (AND (BERMUDA ID\#) (ENGLISH SPEAKING)),
that would support (AND (BERMUDA BORN)) but is unavailable.
Refuted tau would be #:\t225

Question data: find support or bolster
(OR (NOT BERMUDA ID\#) (NOT ENGLISH SPEAKING))
Refuted tau would be #:\t225

Look for another explanation for (AND (WORKING PAPERS))
to show (AND (BERMUDA ID\#)) is an unneeded explanation.
Refuted tau would be #:\t224

Question data: find support or bolster (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t224

Find exception for rule
(AND (HIGH SCHOOL EDUCATION)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t223

Question data: find support or bolster (AND (NOT HIGH SCHOOL EDUCATION))
Refuted tau would be #:\t223

Find support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

In the current example, moving from the root (top claim) to the leaf nodes of the argument, Side-2 generates argument moves for each tau. An exception move is generated for the first tau, since being born in Bermuda is only support-by-default for the claim "British subject". In addition, the data support "Bermuda born" will be investigated, in case it turns out to be controversial. Next, find missing evidence and conflicting evidence moves are generated. Evidence that would support "Bermuda born", and is known not to be the case (i.e., is "missing"), tends to refute the current evidence, since evidence is expected to accumulate in support of a claim. Conflicting evidence, or evidence that supports the negation of the claim (i.e., "not Bermuda born") would also obviously refute the claim. Again, the supposed data support is also questioned, in case it is controversial. An "unneeded explanation" move is generated to respond to the tau using abductive reasoning. That is, "id#" is supported because it explains how Harry came to obtain his working papers. If another explanation for working papers were provided, this tau would be defeated. As usual, a move is also generated to investigate whether "working papers" is itself a controversial item. Finally, an exception move is generated since the final tau uses default reasoning, and a move to question the data support for the tau is generated.

The generated moves have already been checked for compliance with input reasoning type and warrant type constraints; next, further checking is done and moves are filtered that are not strong enough to achieve the qualification needed to refute with respect to the input burden of proof level. For dialectical validity, Side-2 needs only to show that support for the top claim is controversial, so all of the generated moves are retained:

When the burden of proof is dialectical validity, usable NEW argument moves are <all moves>.

Next, the conflict set of argument moves is heuristically ordered, according to the criteria given in Chapter II. For the current example, the result of sorting the moves is as follows:

New argument moves, in sorted order, are:

Find exception for rule (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
Refuted tau would be #:\t226

Look for another explanation for (AND (WORKING PAPERS))
to show (AND (BERMUDA ID\#)) is an unneeded explanation.
Refuted tau would be #:\t224

Find exception for rule
(AND (HIGH SCHOOL EDUCATION)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t223

Look for evidence that supports (AND (NOT BERMUDA BORN))
to refute (AND (BERMUDA ID\#) (ENGLISH SPEAKING)) evidence for
(AND (BERMUDA BORN))
Refuted tau would be #:\t225

Look for evidence, other than (AND (BERMUDA ID\#) (ENGLISH SPEAKING)),
that would support (AND (BERMUDA BORN)) but is unavailable.
Refuted tau would be #:\t225

Question data: find support or bolster (AND (NOT BERMUDA BORN))
Refuted tau would be #:\t226

Question data: find support or bolster
(OR (NOT BERMUDA ID\#) (NOT ENGLISH SPEAKING))
Refuted tau would be #:\t225

Question data: find support or bolster (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t224

Question data: find support or bolster (AND (NOT HIGH SCHOOL EDUCATION))
Refuted tau would be #:\t223
Find support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

Side-2 now attempts each move in turn, until a successful move results in a Side-2 check qualification on the top claim, or until there are no more moves.

Next move for side 2 is:
Find exception for rule (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))

Looking for support for claim (NOT BRITISH SUBJECT)
Check warrant(s) (W5) for support for (NOT BRITISH SUBJECT).

Trying W5 with ((AND (BERMUDA BORN) (ALIEN PARENTS)))
to support (NOT BRITISH SUBJECT).

Looking for support for claim (BERMUDA BORN)
Support found in data base for (BERMUDA BORN)

Looking for support for claim (ALIEN PARENTS)
No warrant support found.

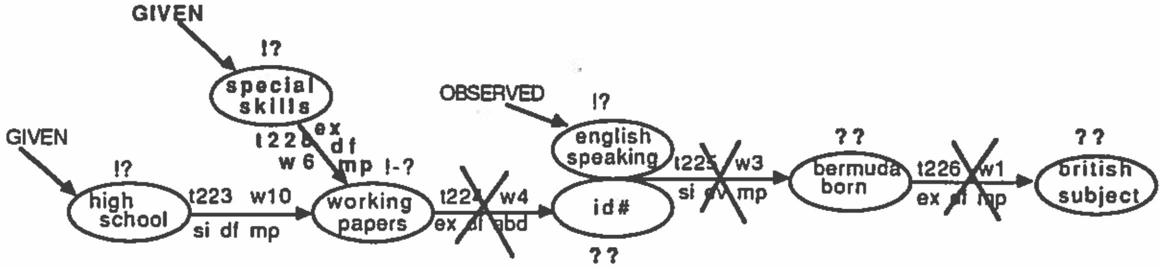
No support found.

move failed

An exception warrant was found, and support for the default part ("Bermuda born") was quickly confirmed. But no support was found for the exception part of the warrant ("alien parents"), and the move failed. Side-2 continues with the next move:

```
Next move for side 2 is:
Look for another explanation for (AND (WORKING PAPERS))
to show (AND (BERMUDA ID\#)) is an unneeded explanation.

Looking for support for claim (WORKING PAPERS)
Check warrant(s) (W6) for support for (WORKING PAPERS).

    Trying W6 with ((AND (SPECIAL SKILLS)))
    to support (WORKING PAPERS).

    Looking for support for claim (SPECIAL SKILLS)
    Support found in data base for (SPECIAL SKILLS)

Support found for warrant W6

Claim ((WORKING PAPERS)) is supported by ((SPECIAL SKILLS))
Warrant id: W6 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t228
Claimnode qualification is: (!- ?)

Claim (SPECIAL SKILLS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t228: ((AND (SPECIAL SKILLS))->(WORKING PAPERS))
*makes tau #:\t224: ((AND (WORKING PAPERS))->(AND (BERMUDA ID\#)))
*defeated -       UNNEEDED-EXPL.

Tau #:\t225:
(AND (BERMUDA ID\#) (ENGLISH SPEAKING)) -> (AND (BERMUDA BORN))
is withdrawn.

Tau #:\t226: (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
is withdrawn.

Qualification for claim (BRITISH SUBJECT) is (? ?)
```

Graphically represented, the argument now looks as follows:



Side-2 has succeeded in providing an alternative explanation for how Harry obtained his working papers, defeating the support for "id#". The support for "id#" was therefore withdrawn, as were the taus further up the argument tree that depended on "id#" for their support. Since its supporting argument was defeated, the qualification for "British subject" reverts to unknown. This is a check for Side-2, and control is returned to Side-1, to attempt to defend the claim against this refutation.

Once again, a conflict set of argument moves is generated, filtered, and sorted:

--**Side 1 is next.
Usable moves from before are:
<None>

Possible NEW argument moves are
Find exception for rule (AND (SPECIAL SKILLS)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t228

Question data: find support or bolster (AND (NOT SPECIAL SKILLS))
Refuted tau would be #:\t228

Find support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

When the burden of proof is dialectical validity, usable NEW argument moves are

Find exception for rule (AND (SPECIAL SKILLS)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t228

Find support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

New argument moves, in sorted order, are:

Find exception for rule (AND (SPECIAL SKILLS)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t228

Find support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

Since Side-2's argument uses a default tau, Side-1 generates an exception move, along with the usual question data support move and support top claim move. Note that the question data move is filtered: this is because showing that special skills is controversial can at best show that the top claim is controversial, but for dialectical validity, Side-1 must provide non-controversial support for the top claim. Thus, the move is rejected as too weak. Side-1 attempts the moves in order:

Next move for side 1 is:
Find exception for rule (AND (SPECIAL SKILLS)) -> (AND (WORKING PAPERS))

Looking for support for claim (NOT WORKING PAPERS)
Check warrant(s) (W7) for support for (NOT WORKING PAPERS).

Trying W7 with ((AND (SPECIAL SKILLS) (QUOTA MET)))
to support (NOT WORKING PAPERS).

Looking for support for claim (SPECIAL SKILLS)
Support found in data base for (SPECIAL SKILLS)

Looking for support for claim (QUOTA MET)
Support found in data base for (QUOTA MET)

Support found for warrant W7

Claim ((NOT WORKING PAPERS)) is supported by
((QUOTA MET) (SPECIAL SKILLS))
Warrant id: W7 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t229
Claimnode qualification is: (!- !-)

Claim (QUOTA MET) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (SPECIAL SKILLS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t229:
*((AND (QUOTA MET) (SPECIAL SKILLS))->(NOT WORKING PAPERS))
*makes tau #:\t228: ((AND (SPECIAL SKILLS))->(AND (WORKING PAPERS)))
*defeated - EXCEPTION.

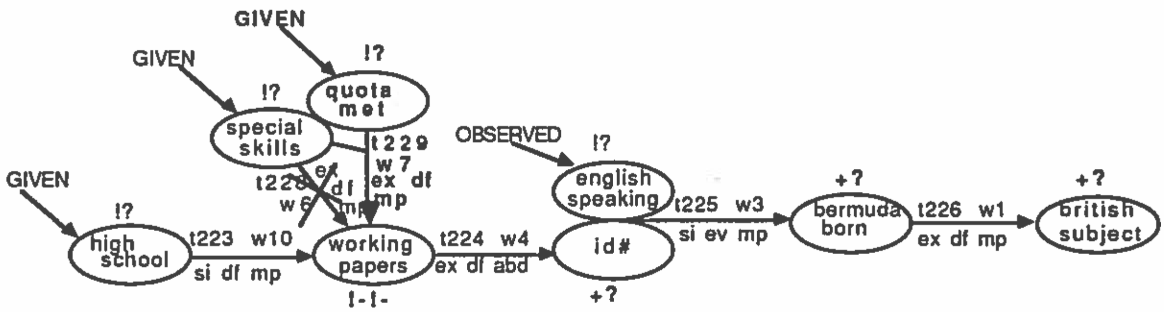
Tau #:\t224: (AND (WORKING PAPERS)) -> (AND (BERMUDA ID\#))
is restored.

Tau #:\t225:
(AND (BERMUDA ID\#) (ENGLISH SPEAKING)) -> (AND (BERMUDA BORN))
is restored.

Tau #:\t226: (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
is restored.

Qualification for claim (BRITISH SUBJECT) is (+ ?)

The graphical representation of the current argument is as follows[2]:



Side-1 succeeds on the first move: "special skills" does not provide an explanation for "working papers" after all, because the exception to the default rule holds in this case, i.e., the quota has been met. Side-1 has defeated Side-2's defeater argument, so Side-2's argument is removed, while the argument that had been removed is reinstated. The top claim is supported once again, and control of the argument returns to Side-2.

--**Side 2 is next.
Usable moves from before are:

Find exception for rule
(AND (HIGH SCHOOL EDUCATION)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t223

---

[2]In the graphical format, all claims are printed as positive propositions. The link between claims indicates how the claim is actually being used, i.e., "X —>Y" is "X supports Y"; "X ▬▬>Y" is "X supports not Y"; "X - - ->Y" is "not X supports Y"; and "X ===>Y" is "not X supports not Y".

Look for evidence that supports (AND (NOT BERMUDA BORN))
to refute (AND (BERMUDA ID\#) (ENGLISH SPEAKING)) evidence for
(AND (BERMUDA BORN))
Refuted tau would be #:\t225

Look for evidence, other than (AND (BERMUDA ID\#) (ENGLISH SPEAKING)),
that would support (AND (BERMUDA BORN)) but is unavailable.
Refuted tau would be #:\t225

Question data: find support or bolster (AND (NOT BERMUDA BORN))
Refuted tau would be #:\t226

Question data: find support or bolster
(OR (NOT BERMUDA ID\#) (NOT ENGLISH SPEAKING))
Refuted tau would be #:\t225

Question data: find support or bolster (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t224

Question data: find support or bolster (AND (NOT HIGH SCHOOL EDUCATION))
Refuted tau would be #:\t223

Possible NEW argument moves are

Find exception for rule
(AND (QUOTA MET) (SPECIAL SKILLS)) -> (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t229

Question data: find support or bolster
(OR (NOT QUOTA MET) (NOT SPECIAL SKILLS))
Refuted tau would be #:\t229

Find support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

When the burden of proof is dialectical validity, usable NEW argument moves are
<all moves>.

New argument moves, in sorted order, are:

Find exception for rule
(AND (QUOTA MET) (SPECIAL SKILLS)) -> (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t229

Question data: find support or bolster
(OR (NOT QUOTA MET) (NOT SPECIAL SKILLS))
Refuted tau would be #:\t229

Find support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

Side-2 has many choices for moves this time, including moves generated in response to Side-1's most recent argument, as well as moves generated to respond to previous arguments that haven't yet been used.

Next move for side 2 is:
Find exception for rule
(AND (QUOTA MET) (SPECIAL SKILLS)) -> (AND (NOT WORKING PAPERS))

Looking for support for claim (WORKING PAPERS)
No warrant support found.

move failed

Next move for side 2 is:
Question data: find support or bolster
(OR (NOT QUOTA MET) (NOT SPECIAL SKILLS))

Looking for support for claim (NOT QUOTA MET)
No warrant support found.

Looking for support for claim (NOT SPECIAL SKILLS)
No warrant support found.

move failed

Next move for side 2 is:
Find support for (AND (NOT BRITISH SUBJECT))

Looking for support for claim (NOT BRITISH SUBJECT)
Check warrant(s) (W5 W1 W2 W8 W9) for support for (NOT BRITISH SUBJECT).

Trying W5 with ((AND (BERMUDA BORN) (ALIEN PARENTS)))
to support (NOT BRITISH SUBJECT).

Looking for support for claim (BERMUDA BORN)
Support found in data base for (BERMUDA BORN)

Looking for support for claim (ALIEN PARENTS)
No warrant support found.

Trying W1 with ((AND (NOT BRITISH PASSPORT)))
to support (NOT BRITISH SUBJECT).

Looking for support for claim (NOT BRITISH PASSPORT)
Support found in data base for (NOT BRITISH PASSPORT)

Support found for warrant W1

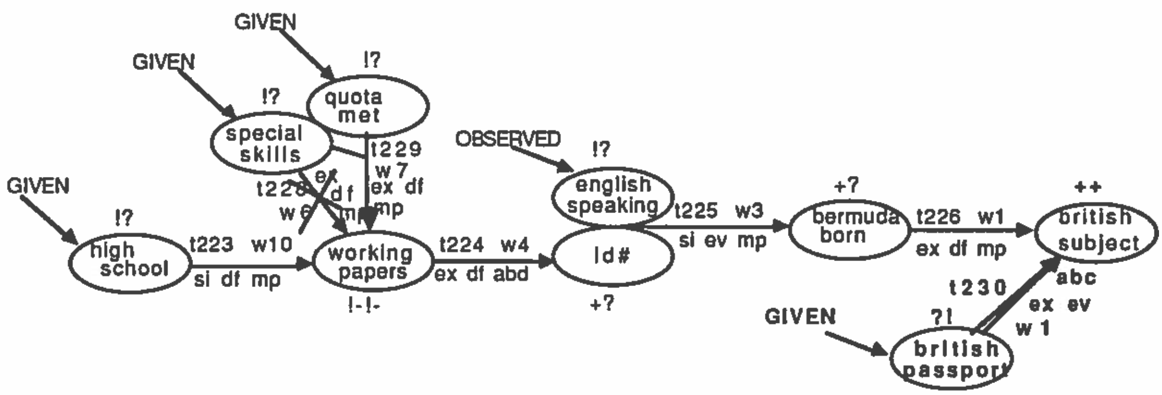
Claim ((NOT BRITISH SUBJECT)) is supported by ((NOT BRITISH PASSPORT))
Warrant id: W1 - Wtype1: EX - Wtype2: EV - Rtype: ABC
New tau id: #:\t230
Claimnode qualification is: (+ +)

Claim (NOT BRITISH PASSPORT) is already supported.
Backing is GIVEN
Claimnode qualification is: (? !)

Tau #:\t230: ((AND (NOT BRITISH PASSPORT))->(NOT BRITISH SUBJECT))
makes top claim: (BRITISH SUBJECT) controversial - FS.

Qualification for claim (BRITISH SUBJECT) is (+ +)

The graphical representation of the current argument is as follows:



Side-2 does not succeed in refuting Side-1's last argument directly, but does manage to refute the top claim by bringing in new evidence, Harry's lack of a British passport. Since having a British passport is evidence for "British subject", this missing evidence tends (via the contrapositive of abductive reasoning) to support the counter-claim. The support is weak, but it is enough, and Side-1 takes control of the argument.

---**Side 1 is next.
Usable moves from before are:
<None>

Possible NEW argument moves are

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t230

Look for evidence that supports (AND (BRITISH SUBJECT))
to refute (AND (NOT BRITISH PASSPORT)) evidence for
(AND (NOT BRITISH SUBJECT))
Refuted tau would be #:\t230

Look for evidence, other than (AND (NOT BRITISH PASSPORT)),
that would support (AND (NOT BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t230

Question data: find support or bolster (AND (BRITISH PASSPORT))
Refuted tau would be #:\t230

Bolster support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

When the burden of proof is dialectical validity, usable NEW argument moves are

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t230

New argument moves, in sorted order, are:

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t230

Since Side-2's argument is weak in both its warrant type and reasoning type, Side-1 is able to generate many argument moves. But the burden of proof on Side-1 is so strong that only the one move that can defeat Side-2's support outright is usable.

Next move for side 1 is:
Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.

Looking for support for claim (BRITISH SUBJECT)
No warrant support found.

move failed

Since the move failed, and Side-1 has no more argument moves, the argument ends with a Side-2 check qualification, and Side-1 is forced to concede the argument:

Side 1 has no more argument moves.
Side 2 wins.
Claim (BRITISH SUBJECT) was NOT established.
Burden of proof on side 1 was: dialectical validity

Preponderance of the Evidence

We can see in the above example that some evidence favoring the claim "British subject" was never used, since Side-2 was able to establish irrefutable support for the negation of the claim. Once the claim became controversial, there was no point in continuing the argument, and Side-1 conceded. In the next example, Side-1 has a lighter burden of proof, preponderance of the evidence.

The argument is generated to the point where it ended in the previous section, with only one difference. When it was Side-1's turn to defend the top claim against Side-2's "special skills" refutation, three argument moves were generated: "find exception for rule (special skills) -> (working papers)"; "question data: find support for (not special skills)"; and "find support for (British subject)". When the burden of proof was dialectical validity, the "question data" move was filtered, since it could not defeat Side-2's argument. When the burden of proof is preponderance of the evidence, that move is not filtered, since even a controversial claim can win for preponderance of the evidence. Recall that Side-1 succeeded on that turn using the "find exception" move, so the "question data" move was cached for possible use in a later turn.

We join the argument after Side-2 has successfully generated an argument for its top claim, "not British subject", based on the support "not British passport", causing the qualification for the top claim to become controversial (i.e., the current qualification on

"British subject" is "++"). Side-1 is given control of the argument, and generates the following argument moves:

```
Usable moves from before are:
<None>

Possible NEW argument moves are

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t273

Look for evidence that supports (AND (BRITISH SUBJECT))
to refute (AND (NOT BRITISH PASSPORT)) evidence for
(AND (NOT BRITISH SUBJECT))
Refuted tau would be #:\t273

Look for evidence, other than (AND (NOT BRITISH PASSPORT)),
that would support (AND (NOT BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t273

Question data: find support or bolster (AND (BRITISH PASSPORT))
Refuted tau would be #:\t273

Bolster support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

----------------------------------------------------------------
When the burden of proof is preponderance of the evidence,
usable NEW argument moves are
<all moves>.

----------------------------------------------------------------
New argument moves, in sorted order, are:

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t273

Look for evidence that supports (AND (BRITISH SUBJECT))
to refute (AND (NOT BRITISH PASSPORT)) evidence for
(AND (NOT BRITISH SUBJECT))
Refuted tau would be #:\t273

Look for evidence, other than (AND (NOT BRITISH PASSPORT)),
that would support (AND (NOT BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t273
```

Question data: find support or bolster (AND (BRITISH PASSPORT))
Refuted tau would be #:\t273

Bolster support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

Where we might have expected to see the "question data: find support for (not special skills)" move included in the list of old argument moves, it has been filtered, since the tau it would refute (i.e., "special skills" support for "working papers") has been defeated in the meanwhile. Also, we again see the difference between burden of proof levels: when burden of proof was dialectical validity, Side-1 had only one usable move, the first move listed above. Since even controversial claims can still win preponderance of the evidence arguments, all of the newly generated moves may be used in the current argument. Side-1 attempts each move in turn:

Next move for side 1 is:
Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BRITISH PASSPORT))
for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.

Looking for support for claim (BRITISH SUBJECT)
No warrant support found.

move failed

Next move for side 1 is:
Look for evidence that supports (AND (BRITISH SUBJECT))
to refute (AND (NOT BRITISH PASSPORT)) evidence for
(AND (NOT BRITISH SUBJECT))

Looking for support for claim (BRITISH SUBJECT)
Check warrant(s) (W8 W9 W1) for support for (BRITISH SUBJECT).

Trying W8 with ((AND (PAYS BERMUDA TAXES)))
to support (BRITISH SUBJECT).

Looking for support for claim (PAYS BERMUDA TAXES)
Support found in data base for (PAYS BERMUDA TAXES)

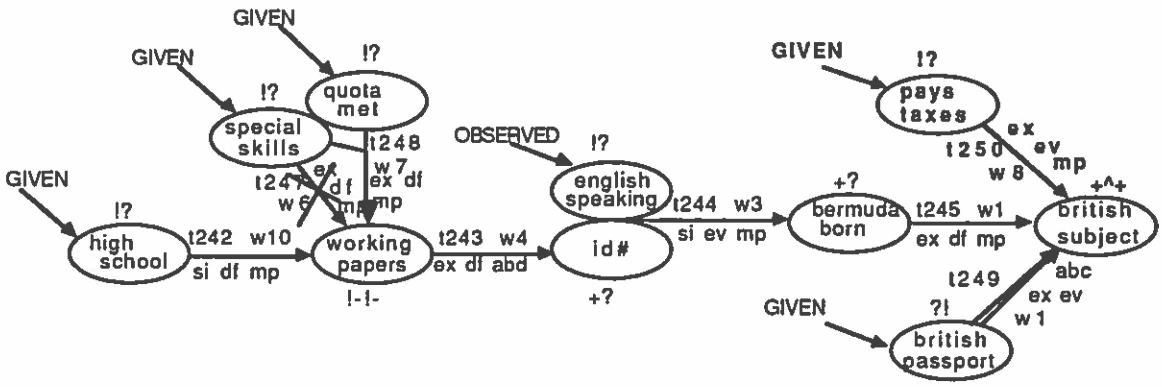
Support found for warrant W8

Claim ((BRITISH SUBJECT)) is supported by ((PAYS BERMUDA TAXES))
Warrant id: W8 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t274
Claimnode qualification is: (+^ +)

Claim (PAYS BERMUDA TAXES) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t274: ((AND (PAYS BERMUDA TAXES))->(BRITISH SUBJECT))
*makes tau #:\t273:
*((AND (NOT BRITISH PASSPORT))->(AND (NOT BRITISH SUBJECT)))
*controversial - CONFLICTING-EV.

Qualification for claim (BRITISH SUBJECT) is (+^ +)



Evidence supporting the top claim is found to refute Side-2's evidence for the negation of the top claim. The qualification on "British subject" becomes (+^ +), where the annotation on the first field of the qualification means that the positive proposition has more evidential support than the negative proposition. Since the proof level is preponderance of the evidence, that is all Side-1 needs, and control of the argument is returned to Side-2.

---**Side 2 is next.
Usable moves from before are:

Find exception for rule
(AND (HIGH SCHOOL EDUCATION)) -> (AND (WORKING PAPERS))
Refuted tau would be #:\t266

Look for evidence that supports (AND (NOT BERMUDA BORN))
to refute (AND (BERMUDA ID\#) (ENGLISH SPEAKING)) evidence for
(AND (BERMUDA BORN))
Refuted tau would be #:\t268

Look for evidence, other than (AND (BERMUDA ID\#) (ENGLISH SPEAKING)),
that would support (AND (BERMUDA BORN)) but is unavailable.
Refuted tau would be #:\t268

Question data: find support or bolster (AND (NOT BERMUDA BORN))
Refuted tau would be #:\t269

Question data: find support or bolster
(OR (NOT BERMUDA ID\#) (NOT ENGLISH SPEAKING))
Refuted tau would be #:\t268

Question data: find support or bolster (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t267

Question data: find support or bolster (AND (NOT HIGH SCHOOL EDUCATION))
Refuted tau would be #:\t266

Possible NEW argument moves are

Look for evidence that supports (AND (NOT BRITISH SUBJECT))
to refute (AND (PAYS BERMUDA TAXES)) evidence for
(AND (BRITISH SUBJECT))
Refuted tau would be #:\t274

Look for evidence, other than (AND (PAYS BERMUDA TAXES)),
that would support (AND (BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t274

Question data: find support or bolster (AND (NOT PAYS BERMUDA TAXES))
Refuted tau would be #:\t274

Bolster support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

When the burden of proof is preponderance of the evidence,
usable NEW argument moves are
<all moves>.

New argument moves, in sorted order, are:

Look for evidence that supports (AND (NOT BRITISH SUBJECT))
to refute (AND (PAYS BERMUDA TAXES)) evidence for
(AND (BRITISH SUBJECT))
Refuted tau would be #:\t274

Look for evidence, other than (AND (PAYS BERMUDA TAXES)),
that would support (AND (BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t274

Question data: find support or bolster (AND (NOT PAYS BERMUDA TAXES))
Refuted tau would be #:\t274

Bolster support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP

Side-2 attempts the new moves in order, but Side-2 does not succeed in refuting Side-1's most recent argument. Side-2 now attempts to refute old Side-1 arguments, and finds:

Going to old argument moves-- ...

Looking for support for claim (NOT BERMUDA BORN)
Check warrant(s) (W3) for support for (NOT BERMUDA BORN).

Trying W3 with
((AND (NOT ENGLISH SPEAKING)) (AND (NOT BERMUDA ID\#)))
to support (NOT BERMUDA BORN).

Looking for support for claim (NOT ENGLISH SPEAKING)
No warrant support found.

Looking for support for claim (NOT BERMUDA ID\#)
Check warrant(s) (W4) for support for (NOT BERMUDA ID\#).

Trying W4 with ((AND (NOT WORKING PAPERS)))
to support (NOT BERMUDA ID\#).

Looking for support for claim (NOT WORKING PAPERS)
Support found in data base for (NOT WORKING PAPERS)

Support found for warrant W4
Support found for warrant W3

Claim ((NOT BERMUDA BORN)) is supported by ((NOT BERMUDA ID\#))
Warrant id: W3 - Wtype1: SI - Wtype2: EV - Rtype: ABC
New tau id: #:\t276
Claimnode qualification is: (+ +)

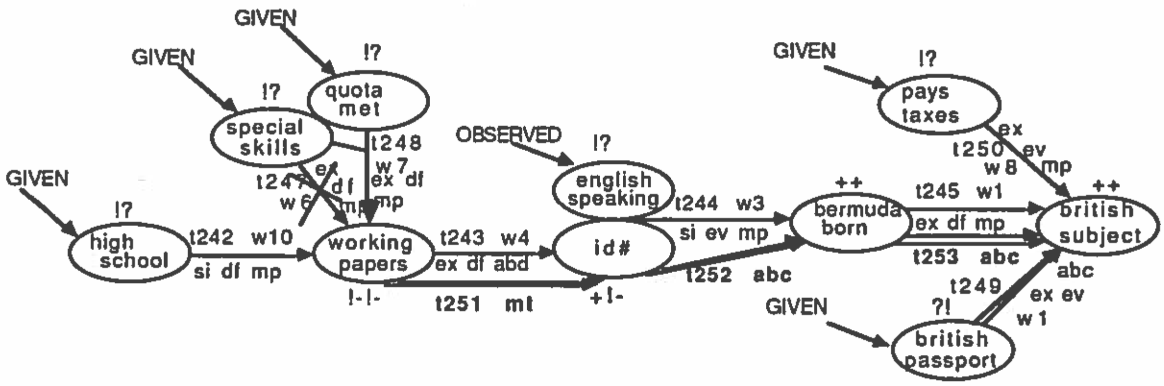
Claim ((NOT BERMUDA ID\#)) is supported by ((NOT WORKING PAPERS))
Warrant id: W4 - Wtype1: EX - Wtype2: DF - Rtype: MT
New tau id: #:\t275
Claimnode qualification is: (+ !-)

Claim (NOT WORKING PAPERS) is already supported.
Backing is ((QUOTA MET) (SPECIAL SKILLS))
Claimnode qualification is: (!- !-)

*Tau #:\t276: ((AND (NOT BERMUDA ID\#))->(NOT BERMUDA BORN))
*makes tau #:\t269: ((AND (BERMUDA BORN))->(AND (BRITISH SUBJECT)))
*controversial - FS-OR-BOLSTER.

Claim (AND (NOT BRITISH SUBJECT)) is supported by
(AND (NOT BERMUDA BORN))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t277
Claimnode qualification is: (+ +)

Qualification for claim (BRITISH SUBJECT) is (+ +)



Side-2 succeeds in making "Bermuda born" controversial, and therefore "British subject" (evenly) controversial. The support for "not Bermuda born" is actually based on work Side-1 had done early in the argument, when it used the exception "special skills" and "quota met" to show that Harry would not have been able to obtain "working papers" on account of his "special skills". Note that the exception rule may be overstated here, i.e., "special skills" and "quota met" intuitively seem to support only the weaker conclusion, that Harry did not obtain his working papers by the default means of "special skills", rather than the stronger conclusion that Harry does not have his working papers. (The same could be said for more well known exceptions, e.g., if we know a bird is not a flying bird, should we say that it does not fly, or just that it does not fly on account of its being a bird, and whether or not it flies at all is still unknown.)

Given the current representation, Side-2 now takes the exception argument to its logical conclusion, that is, whether or not Harry has "working papers" is controversial, and so, therefore, is his having "id#", and "Bermuda born", and, therefore, "British subject". Side-2 has evened up the controversy, and control of the argument is given to Side-1.

```
---------------------------------------------------------------**Side 1 is next.
Usable moves from before are:

Look for evidence, other than (AND (NOT BRITISH PASSPORT)),
that would support (AND (NOT BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t273

Question data: find support or bolster (AND (BRITISH PASSPORT))
Refuted tau would be #:\t273

-----------------------------------------------------------
New argument moves, in sorted order, are:

Find strong support for (AND (BRITISH SUBJECT))
to show that weak evidence (AND (NOT BERMUDA BORN))
 for claim (AND (NOT BRITISH SUBJECT)) is irrelevant.
Refuted tau would be #:\t277

Find strong support for (AND (BERMUDA BORN))
to show that weak evidence (AND (NOT BERMUDA ID\#))
for claim (AND (NOT BERMUDA BORN)) is irrelevant.
Refuted tau would be #:\t276

Find exception for rule
(AND (NOT WORKING PAPERS)) -> (AND (NOT BERMUDA ID\#))
Refuted tau would be #:\t275

Look for evidence that supports (AND (BERMUDA BORN))
to refute (AND (NOT BERMUDA ID\#)) evidence for
(AND (NOT BERMUDA BORN))
Refuted tau would be #:\t276

Look for evidence, other than (AND (NOT BERMUDA ID\#)),
that would support (AND (NOT BERMUDA BORN)) but is unavailable.
Refuted tau would be #:\t276

Question data: find support or bolster (AND (BERMUDA BORN))
Refuted tau would be #:\t277
```

Question data: find support or bolster (AND (BERMUDA ID\#))
Refuted tau would be #:\t276

Question data: find support or bolster (AND (WORKING PAPERS))
Refuted tau would be #:\t275

Bolster support for (AND (BRITISH SUBJECT))
Refuted tau would be TOP

The moves fail until the following:

Next move for side 1 is:
Bolster support for (AND (BRITISH SUBJECT))

Looking for support for claim (BRITISH SUBJECT)
Check warrant(s) (W9 W1) for support for (BRITISH SUBJECT).

Trying W9 with ((AND (LIVES IN BERMUDA)))
to support (BRITISH SUBJECT).

Looking for support for claim (LIVES IN BERMUDA)
Support found in data base for (LIVES IN BERMUDA)

Support found for warrant W9

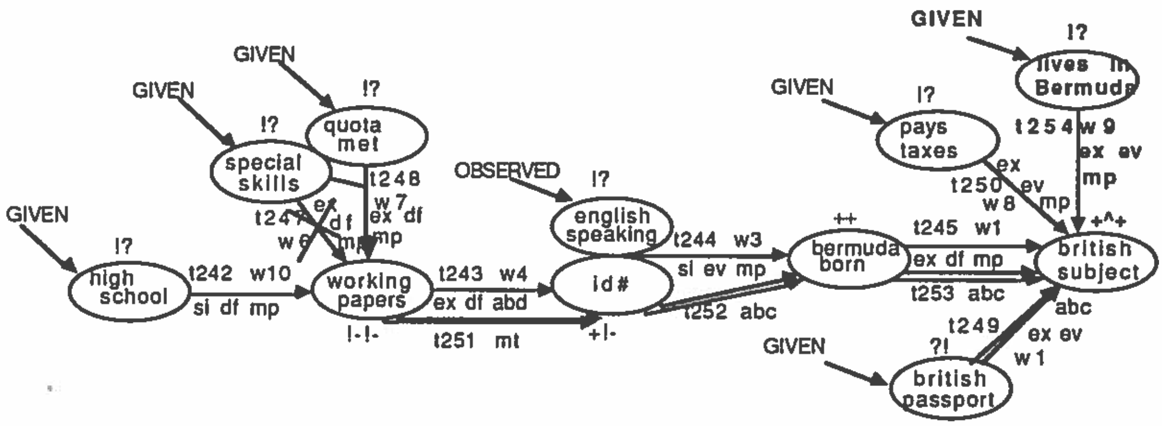
Claim ((BRITISH SUBJECT)) is supported by ((LIVES IN BERMUDA))
Warrant id: W9 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t278
Claimnode qualification is: (+^ +)

Claim (LIVES IN BERMUDA) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t278: ((AND (LIVES IN BERMUDA))->(BRITISH SUBJECT))
*makes top claim: (NOT BRITISH SUBJECT) controversial - BOLSTER.

Qualification for claim (BRITISH SUBJECT) is (+^ +)

The argument can be graphically represented as follows:



Side-1 succeeds in finding additional evidence for the claim "British subject", and Side-2 once again takes control of the argument:

```
------------------------------------------------------------------**Side 2 is next.
Usable moves from before are:

Question data: find support or bolster
(OR (NOT BERMUDA ID\#) (NOT ENGLISH SPEAKING))
Refuted tau would be #:\t268

Question data: find support or bolster (AND (NOT WORKING PAPERS))
Refuted tau would be #:\t267

Question data: find support or bolster (AND (NOT HIGH SCHOOL EDUCATION))
Refuted tau would be #:\t266

--------------------------------------------------------------
New argument moves, in sorted order, are:

Look for evidence that supports (AND (NOT BRITISH SUBJECT))
to refute (AND (LIVES IN BERMUDA)) evidence for (AND (BRITISH SUBJECT))
Refuted tau would be #:\t278

Look for evidence, other than (AND (LIVES IN BERMUDA)),
that would support (AND (BRITISH SUBJECT)) but is unavailable.
Refuted tau would be #:\t278

Question data: find support or bolster (AND (NOT LIVES IN BERMUDA))
Refuted tau would be #:\t278

Bolster support for (AND (NOT BRITISH SUBJECT))
Refuted tau would be TOP
```

Side-2 tries all of its remaining moves, with no success, and concedes the argument.

Claim "British subject" is proved for the preponderance of the evidence proof level.

Side 2 has no more argument moves.
Side 1 wins.
Claim (BRITISH SUBJECT) was established.
Burden of proof on side 1 was: preponderance of the evidence.

Scintilla of Evidence

This is the easiest proof level to achieve for an input claim. Side-1 need only show that there is some irrefutable support for the claim, regardless of the support for any rival claim. For this burden of proof level, Side-2's moves will be limited in much the same way that Side-1's moves were for dialectical validity. That is, it is not enough for Side-2 merely to show the input claim is controversial; to win the argument, Side-2 must actually defeat any support for the claim that Side-1 is able to generate. From the above examples, we know that Side-2 will be unable to accomplish this, so here we include only a minimal trace of the argument generation process.

Starting argument...
Side 1 is looking for support for (BRITISH SUBJECT)
Burden of proof on side 1 is a mere scintilla of evidence.

Claim ((BRITISH SUBJECT)) is supported by ((BERMUDA BORN))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t293
Claimnode qualification is: (+ ?)

Claim ((BERMUDA BORN)) is supported by
((BERMUDA ID\#) (ENGLISH SPEAKING))
Warrant id: W3 - Wtype1: SI - Wtype2: EV - Rtype: MP
New tau id: #:\t292
Claimnode qualification is: (+ ?)

Claim ((BERMUDA ID\#)) is supported by ((WORKING PAPERS))
Warrant id: W4 - Wtype1: EX - Wtype2: DF - Rtype: ABD
New tau id: #:\t291
Claimnode qualification is: (+ ?)

Claim ((WORKING PAPERS)) is supported by ((HIGH SCHOOL EDUCATION))
Warrant id: W10 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t290
Claimnode qualification is: (!- ?)

Claim (HIGH SCHOOL EDUCATION) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (ENGLISH SPEAKING) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

---**Side 2 is next.

Claim ((WORKING PAPERS)) is supported by ((SPECIAL SKILLS))
Warrant id: W6 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t295
Claimnode qualification is: (!- ?)

Claim (SPECIAL SKILLS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t295: ((AND (SPECIAL SKILLS))->(WORKING PAPERS))
*makes tau #:\t291: ((AND (WORKING PAPERS))->(AND (BERMUDA ID\#)))
*defeated - UNNEEDED-EXPL.

Tau #:\t292:
(AND (BERMUDA ID\#) (ENGLISH SPEAKING)) -> (AND (BERMUDA BORN))
is withdrawn.

Tau #:\t293: (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
is withdrawn.

Qualification for claim (BRITISH SUBJECT) is (? ?)

---**Side 1 is next.

Claim ((NOT WORKING PAPERS)) is supported by
((QUOTA MET) (SPECIAL SKILLS))
Warrant id: W7 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t296
Claimnode qualification is: (!- !-)

Claim (QUOTA MET) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (SPECIAL SKILLS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t296:
*((AND (QUOTA MET) (SPECIAL SKILLS))->(NOT WORKING PAPERS))
*makes tau #:\t295: ((AND (SPECIAL SKILLS))->(AND (WORKING PAPERS)))
*defeated - EXCEPTION.

Tau #:\t291: (AND (WORKING PAPERS)) -> (AND (BERMUDA ID\#))
is restored.

Tau #:\t292:
(AND (BERMUDA ID\#) (ENGLISH SPEAKING)) -> (AND (BERMUDA BORN))
is restored.

Tau #:\t293: (AND (BERMUDA BORN)) -> (AND (BRITISH SUBJECT))
is restored.

Qualification for claim (BRITISH SUBJECT) is (+ ?)

--**Side 2 is next.

Side 2 has no more argument moves.
Side 1 wins.
Claim (BRITISH SUBJECT) was established.
Burden of proof on side 1 was: a mere scintilla of evidence.

The argument begins in the usual fashion, with Side-1 supporting the claim "british subject" based on "Bermuda born". In its first refutation attempt, Side-2 succeeds in defeating that original argument. However, Side-1 then successfully defends its argument, i.e., defeats Side-2's defeating argument, and restores its support for the top claim. Side-2 is unable to defeat this argument another time, and concedes the argument. Claim "british subject" is proved for the "scintilla of evidence" burden of proof level.

Beyond a Reasonable Doubt

This is the most difficult proof level to achieve. The input claim must be established with strong, consistent support. As we saw in the dialectical validity example, this will not be possible for the claim "British subject" using the input data and warrants. The argument is given in its entirety here.

Starting argument...
Side 1 is looking for support for (BRITISH SUBJECT)
Burden of proof on side 1 is beyond a reasonable doubt.

Looking for support for claim (BRITISH SUBJECT)
Check warrant(s) (W2) for support for (BRITISH SUBJECT).

Trying W2 with ((AND (BERMUDA BORN)))
to support (BRITISH SUBJECT).

Looking for support for claim (BERMUDA BORN)
No warrant support found.

No support found.

side 1 loses
Burden of proof on side 1 was: beyond a reasonable doubt.

The only warrant strong enough to establish the claim is W2, with data "Bermuda born". But there are no warrants strong enough to establish "Bermuda born" strongly, and Side-1 must concede the argument before it really even starts.

CHAPTER IV

EVALUATING DART

Contributions

Computational Model of Argumentation

We have just described DART, a computational model for representing and generating arguments. DART incorporates features appropriate for reasoning in weak theory domains, including plausible inference, a simple method for representing and propagating uncertainty, levels of proof, and a presumption of controversy, possibly persistent, in the knowledge base. Argument as supporting explanation and dialectical argumentation are both included in the model. Argument representation is based on the classic Toulmin format; argument generation uses a variety of argument moves and a set of heuristics for selecting moves and thereby controlling argument generation. Though heuristics are currently built in to the model, they are represented in a modular fashion that makes them easy to remove, or change. Users may manipulate other argument features, including allowable reasoning and warrant types, as well as the input proof level. The model also specifies rules for turntaking during the argument process and conceding the argument. Program output for both argument-as-process and argument-as-product is given.

With respect to reasoning in weak theory domains, the program has yielded good results, in that it generates reasonable arguments for a wide variety of sample problems in many domains (see Chapter III; Appendix). These demonstrate some of the advantages of the argumentation approach for reasoning in weak theory domains. We review some of these next.

As in the Bermuda example just presented, the inclusion of plausible as well as deductive reasoning means DART is able to generate (additional) support for claims, overcoming some of the limitations of incomplete knowledge. Many of the examples in the Appendix also make use of plausible inference types, e.g., Kahane, 1988; Ryan, 1984; and others. DART is able to recreate the arguments given for these critical reasoning situations. For example, one of the problems given in (Ryan, 1984) describes two men: Socrates, who was both wise and just, and Cleon, who was wise but not just. In response to the question, "Are wise persons just?", DART is able to generate an argument in support of the claim "just" stemming from the data "wise", citing Socrates as an example of a wise person who was just. This argument involves abductive reasoning to get from "wise" to "Socrates". The counter-argument points out this weakness in Side-1's argument. There is another example of a wise person, namely, Cleon, and he was not just. The final argument shows that the claim "wise persons are just" is controversial.

The distinctions recorded in the warrant type fields in DART constrain inappropriate combinations of deductive and plausible inference, as shown in the Appendix example taken from (Pearl, 1987). The example deals with an inappropriate modus ponens, abduction combination; it is discussed in Chapter II.

DART's weakest link method for representing and propagating uncertainty provides a simple way of recording uncertainty from both domain knowledge and plausible reasoning types. The weakest link method is both appropriate for plausible reasoning (see Chapter II) and easily accommodated to incorporate additional sources of uncertainty in the knowledge. Representing uncertainty gives DART a rough measure for argument analysis and comparison, particularly when there is support for competing claims.

Because of its ability to refute as well as build support for claims, claims in DART are derived "robustly", i.e., the reasoning process does not stop until support for a claim has been tested by defeater or controversy-causing moves. Weak links in the support for a claim are explicated and the possibility of inconsistency is not overlooked. Thus, the reasoner, while reasoning under weak theory domain conditions, is able to avoid generating fallacious (final) results, i.e., results that overstate or inappropriately reach a conclusion. (For example, see see results in the Appendix for Prakken, 1991; Ryan, 1984; and the extension of Pearl, 1987.)

In addition to robust derivation of claims, argumentation supports robust justification of claims. Every claim reached by DART's argumentation process is attached to backing, i.e., an argument that supports the claim. Each claim is also attached to the backing for its negation. Output from the dialectical process itself, presented as a sequence of intertwined arguments as supporting explanations (the user may also choose to include relevant argument moves in the output), gives further information about DART's reasoning mechanisms, including its attempts to refute claim support. Thus, justification for accepting, or not accepting, a claim is always available.

Burden of Proof

The argumentation model implemented in DART includes the concept of burden of proof. Side-1 always bears the burden of proof, i.e., to win an argument, Side-1 must establish the input claim to a specified proof level. (Side-2 wins by foiling this attempt.) Levels of proof are defined with respect to weak theory domain conditions, incorporating differing strengths in support for claims, and the possibility of simultaneous support for rival claims. Since not all claims need to be proved to the same level, the argumentation model accepts the proof level as input, and then uses it to help control argument generation. In the Bermuda problem, it was shown that a proof level of beyond a reasonable doubt meant that the input claim was conceded immediately, while a proof level of preponderance of the evidence resulted in both sides having to collect all the evidence for the claim they could. The Appendix examples from (Poole, 1989) and (Lea Sombe, 1990), among others, show how proof levels affect argument generation and outcome.

In (Poole, 1989) we are given the information that Quakers are generally doves, and Republicans are generally hawks (i.e., not doves). Furthermore, someone who is a hawk is highly likely to support the star wars project; someone who is a Quaker can be presumed to be religious; and hawks and doves alike are usually politically motivated. Nixon is both a Republican and a Quaker. Is he a dove?

DART's results match the example output for the claim "dove": it is controversial, with the inconsistency stemming from conflicting input data "Republican" and "Quaker". Though controversial, the claim would be proved in DART for the "scintilla of evidence" proof level.

However, when the claim is "star wars", results diverge a bit. Again, the claim is controversial for both DART and Poole, since it relies on data "not dove", which is itself controversial. For DART, this means that the qualification on "support star wars" is inconsistent; in Poole's example, the claim appears in one of two possible extensions generated from the input data. But in DART, the claim, though controversial, will be established for proof level "preponderance of the evidence". This is because "supports strong wars" is strongly supported, using modus ponens reasoning, by "Republican" and "not dove", while "not supports star wars" follows only weakly, using abduction-contrapositive reasoning, from "Quaker" and "dove". (This in turns stems from the rules given in the original knowledge base; there is a rule that explicitly supports "supports star wars", but none that explicitly supports its negation.) At proof level "preponderance of the evidence", DART is able to make a non-random choice between inconsistent outcomes, based on its analysis of the arguments that support each option.

Issues for Reasoning under Uncertainty

DART has proved to be a useful framework for the exploration of argument and reasoning in weak theory domains. Limits on combining deductive and plausible reasoning, the role of defeater moves, particularly exceptions to rules, in uncertain reasoning, the representation and propagation of uncertainty, undercutting and rebutting moves, and case-based and rule-based reasoning are all current issues in AI research that were highlighted in the process of generating arguments for the set of example problems. Each of these has been discussed elsewhere in this paper, in light of the argumentation approach to reasoning. Another issue involves the extent of controversy in the knowledge base. We continue with the example from (Poole, 1989) described above, for the claim "religious".

For Poole, "religious" is an example of a claim where there is an argument that supports it, and there is no argument that opposes it. However, for DART, "religious" is controversial. In both systems, "religious" is obviously supported by "Quaker". However, DART is also able to generate support for "not religious", based on support for "not Quaker", based on support for "not dove", stemming from input "Republican". This argument includes both modus tollens and abduction-contrapositive reasoning.

The difference between the DART output and the original example raises interesting issues about the status of input claims and how wide-ranging an effect the sources of inconsistency should have on the reasoning process. On the one hand, it may seem odd that "Quaker", which was given as non-controversial input, should be seen as controversial. On the other hand, it seems correct that "religious" should be controversial. Unlike "supports star wars", it is not directly involved in the "dove/not dove" controversy. However, its supporting argument does rely on support, namely, "Quaker", that is at the source of the "dove/not dove" controversy. Hence, "religious" should not escape the consequences of being involved with the inconsistent "Republican/Quaker" input. The current model of argumentation adopts a questioning stance toward all claims and searches aggressively for inconsistency in the knowledge base.

As for "support star wars", "religious", though controversial, can be established for proof level "preponderance of the evidence", since the argument opposed includes a weak reasoning type.

Summary

In sum, our investigation of argumentation as an approach to reasoning in weak theory domains, and the DART program that implements this approach, have proven useful in a number of ways. Argumentation is a domain independent, comprehensive approach to reasoning that expects and handles incompleteness, uncertainty, and inconsistency in the domain knowledge. The ability to refute support for claims, including defeating support for a claim, and finding support for a rival claim, is explicitly included in a dialectical argumentation approach to reasoning. The argumentation emphasis on controversy and refutation supports the concept of proof levels, which can be used to inform decision-making under inconsistent knowledge.

The computational model of argument provides an exploratory framework that is useful for AI researchers investigating issues of argumentation and reasoning in weak theory domains, and for argumentation researchers for analyzing theories of argument.

Using DART to examine the current argumentation model has also revealed a number of limitations in the model. These limitations are the subject of the next section. Possible additions to the model to address some of the limitations, as well as extensions to the current framework, are discussed in Chapter VI.

Limitations

Warrant-establishing Arguments

Although in the modified Toulmin structure for representing arguments, warrants, along with the data support and conclusion fields, are claims (i.e., qualified, with backing and possible rebuttals) all generated arguments are "warrant-using", rather than "warrant-establishing" (Toulmin, 1958) arguments. That is, aside from their representation, warrants are not really treated as claims. Warrants are given at input, with atomic backing and a qualification. After that, they are not directly questioned as other claims in an argument are. For example, given the tau, "Harry was born in Bermuda and someone born in Bermuda will generally be a British subject, therefore, Harry is almost certainly a British subject", DART attempts to argue about the data support, "Harry was born in Bermuda", and the conclusions, "Harry is almost certainly a British subject", but the warrant "Someone born in Bermuda will generally be a British subject" is not directly refuted.

This is a simplification in the model, as warrants and warrant-establishing arguments are more complex than other claims and warrant-using arguments. Toulmin describes warrant-establishing arguments as "Such arguments . . . in which the acceptability of a novel warrant is made clear by applying it successively to a number of cases in which both 'data' and 'conclusion' have been independently verified. In this type of argument the warrant . . . is novel . . . the word 'induction' can be used to refer to warrant-establishing arguments." (Toulmin, 1958) Inductive reasoning is of course an important research area in its own right, one which we have avoided getting involved with at this time.

The "Distinction" Argument Move

There is another, related restriction on the types of arguments being generated by the current model. In his analysis of dialectical argument, Rescher (1977) defines "distinction" to be a primary argument move. By this he means something very close to the "find exception" (to a default warrant) move in our model, though (possibly) with the difference that the distinction move involves generating the exception warrant "on the fly". As we discussed in the previous section, the current model does not allow for directly questioning or generating warrant-claims. This inability means that the model is not able to implement the full distinction move, or generate arguments of the type found in some court cases. For example, (Marshall, 1989) presents a case involving the constitutionality of a policy that allows police to use deadly force in the apprehension of a fleeing felon. Starting from the warrant "If a person is a fleeing felon then the use of deadly force against that person is acceptable", much of the ensuing argument revolves around refining the warrant through the use of the distinction move; for example, what if the fleeing felon were not dangerous? are all fleeing felons inherently dangerous? what if the felon were armed? what if the felon were violent? what if the violence were aimed only at property?

If these distinctions (exceptions) were included in the knowledge base before the argument generation process started, they would be included in an argument generated by DART; if not, the default status of the initial warrant would be noted, and its conclusion qualified appropriately, but an argument of the type described here would not be possible. As with warrant-establishing arguments, this simplification was used to avoid difficult reasoning and knowledge representation questions in the prototype argumentation model.

Limited Disjunction

Another limitation that restricts the size of the argument space is the limited disjunction restriction. Recall that claims, when they include more than one clause, are assumed to contain conjunctions; similarly, the data base is an implicit conjunction across all the (singleton) claims therein. As with the other restrictions, this is meant to simplify reasoning and knowledge representation in the prototype. (Also, disjunctive reasoning is generally not found or discussed in the literature on uncertainty, argumentation, or expert systems.) The argumentation space is affected, since some classical argument moves rely on disjunctive reasoning, e.g., reasoning about dilemmas. For example, with disjunctive reasoning, the warrants "X->Z" and "Y->W", and the data "X or Y", the conclusion "Z or W" could be drawn. If neither "Z" nor "W" were acceptable to the other side of the argument, it is faced with a dilemma. The classical response is two-pronged: one may "go between the horns" of the dilemma or "grasp the dilemma by the horns". In the former response, the arguer tries to show that "X or Y" is not an exhaustive list of possibilities, e.g., the current situation should be described as "X or Y or Q", where "Q" supports an acceptable conclusion. In the latter response, one would essentially argue about the warrant, e.g., show "not Y->W" or "not X->Z". Without full disjunctive reasoning and warrant-establishing arguments, dilemmas cannot be generated or refuted in the current model.

Case-based Reasoning

Some research in argumentation has centered around case-based reasoning, most notably, (Ashley, 1989). The current model uses rule-based, rather than case-based, reasoning. Case-based reasoning is still a relatively new and unsettled area in AI research. Our goal was to concentrate on argumentation, rather than on reasoning issues per se. However, running the model on applications that were built for a case-based reasoner (see Appendix examples from Ashley, 1989 and Marshall, 1989) has yielded some interesting points of contrast between rule-based and case-based reasoning.

Cases, unlike rules, may contain features that do not actively contribute to the conclusion of the case, i.e., the conclusion was reached (the case was decided) regardless of, or even despite, those presence of those features. In addition, matching a new data situation to an old case involves defining "similar" with respect to the matching process, e.g., allowing a partial match. The implication is that the representation and matching of cases can be more complex than the representation and matching of rules. The representation of cases should include "despite" and "irrelevant" features, and the matching process should include (at least) partial matching. Obviously either of these issues can get arbitrarily complex, e.g., features might be weighted to help drive the matching process, and so on.

The ability to represent irrelevant features might prove to be useful for rule representation. Some exception warrants could be represented as containing data that is irrelevant to the conclusion of the warrant. For example, in the problem discussed in Chapter III, "special skills and quota met" seems to operate less as support for the conclusion "not working papers", than to be simply irrelevant to, i.e., no longer a factor in, any conclusion about working papers.

Another interesting point about case-based reasoning and similarity is brought out in the example from (Marshall, 1989). The original argument is given as "Since a motor home has wheels, a motor home is mobile, so a motor home can be classified as an automobile, therefore, a motor home is exempted from the fourth amendment requirement (regarding search and seizure)". But the argument generator described in this paper would not generate this argument. This is due to the restriction against having modus ponens reasoning followed by abductive reasoning for default, explanatory warrants. That is, the warrants "wheels->$_{ex/df}$mobile", and "automobile->$_{ex/df}$mobile" would not be combined to generate "wheels ->mobile->automobile", as the motor home feature "mobile", having been already explained by "wheels", would not need to be "explained" again (via abductive reasoning) by speculating that the motor home is a kind of automobile.

Another argument in this style might be "rain->wet grass->sprinkler on->helps vegetables grow", i.e., rain causes wet grass, and in that way is similar to a sprinkler, so rain, like a sprinkler, must help vegetables grow. When "rain" and "sprinkler" were seen as multiple explanations (causes) for the same effect (wet grass), then the "rain->wet grass->sprinkler" argument is unacceptable (as shown in Chapter II). However, this same argument slice appears to be useful from a similarity-based reasoning perspective.

In this chapter, we have described contributions and some limitations of the current model of argumentation. Many of the limitations touch on topics that are active research areas in their own rights, leading to the possibility of extensions to the current model to incorporate results from other research areas.

CHAPTER V

RELATED RESEARCH

Our research in modeling argument builds on other research in argumentation from both inside and outside artificial intelligence. Also, since we have chosen to explore argumentation as a method for reasoning in weak theory domains, this work overlaps somewhat with work in AI on reasoning under uncertainty. We discuss these related areas in the following sections.

Argumentation

There has been a great deal of investigation of argument outside AI, in philosophy, rhetoric, education, and critical reasoning. The idea that argumentation is a key reasoning technique is discussed in (Freeley, 1990; Kahane, 1988; Kuhn, 1991; Rescher 1977) and elsewhere. Our view of argument as a combination of explanation, or proof, on the one hand, and moves and heuristics for generating dialectical argument, on the other, is based on two senses of argument found in this body of literature. Our representation of argument structure extends Toulmin's (1958) well known data-warrant-claim model of argument (see Chapter II). Our model of dialectical argument overlaps with work by (Freeley, 1990; Kahane, 1988; Lumer, 1988; Pollock, 1992; and Rescher, 1977). The current work has been greatly inspired by Rescher's work, especially his emphasis on the relationship between dialectical argumentation and plausible reasoning, or "rational controversy". His research on each of these topics (Rescher, 1976; Rescher, 1977) supports our emphasis on the suitability of plausible reasoning for reasoning under inconsistency, the central role of dialectical argumentation for plausible reasoning, and the importance of justification in dialectical reasoning.

The starter set of argument moves listed in this paper (see Chapter II) was inspired by the uncertain areas in the domain knowledge that are highlighted by the tau structure, e.g., weak reasoning and warrant types. But the moves can also be classified according to the organization of argument moves given in (Freeley, 1990), as "tests of evidence" (i.e., missing evidence; conflicting evidence; invalid data support) and "tests of reasoning" (i.e., unneeded explanation; inapplicable evidence). These moves, along with the "deny" (Rescher, 1977) moves (i.e., rebut; exception) can be classified according to the fallacies they address, using the categorization in (Kahane, 1988): "questionable premise" (invalid data), "invalid inference" (unneeded explanation; inapplicable evidence); and "suppressed evidence" (missing evidence; conflicting evidence; exception; rebut).

Our description of the primary tasks of dialectical argumentation is also found in this literature, probably most closely in (Lumer, 1988): "First, one tries to convince the other by means of argumentation, then the other tries to convince the first by means of another argument for a counter-thesis; or he criticizes the arguments of the first . . ." Lumer (1988) also gives a partial definition of disputation as a specification of players, argument moves, and rules for generating a sequence of moves. As we have seen, our model includes each of these.

Pollock has been working toward a general framework for defeasible reasoning (Pollock, 1987; Pollock, 1991; Pollock, 1992). His framework includes two types of support for a claim and two types of support defeaters. Support can be *prima facie*, i.e., creating a (defeasible) presumption in favor of a conclusion, or *conclusive*, i.e., logically entail its conclusion. Defeaters can be *rebuttals*, i.e., reasons (support) for denying a conclusion, or *undercutting*, i.e., reasons for withdrawing the current support for a conclusion. Pollock also advocates the weakest link principle for propagating reason strength. Thus, our model fits into Pollock's framework, though there is a bit of difference in our use of the terms "rebutting" and "undercutting". This is because it turned out that some undercutting moves, i.e., moves that attempt to break the link between data support and a claim, turn out to also be rebuttal moves, i.e., support the negation of the claim. For example, the move "show inapplicable evidence", when successful, generates (a particular type of) support for a rival claim in order to cut the link between the original support and its claim. For example, "not quaker->$_{abc/df}$not dove" would be shown to be inapplicable (irrelevant) when faced with the strong support "Pacifist Party member->$_{mp/df}$dove". To differentiate between undercutting and rebutting moves, we have defined undercutting moves to be moves that attack the other side's argument for a claim and *may* result in support for the negation of the claim, and rebutting moves as moves that generate support for a rival claim, regardless of support for the original claim.

There is much in Pollock's framework that we do not implement, for example, some rules of inference for argument formation (e.g., dilemmas) and his concept of levels of argument, but these may be grounds for future work. Our model is concerned with some areas that Pollock does not emphasize, e.g., combining deductive and plausible reasoning, an explicit model of the representation and generation of dialectical argument, and results for a set of benchmark examples.

In sum, there is a rich body of argumentation literature from many fields. It is mainly our "computer-oriented approach" to modeling argument that differentiates us from this other work. At least one investigator (Hample, 1982) has called for more formality in argumentation research: "[modeling arguments] will be beneficial in several respects . . . models yield a precise and clear understanding of the exact character of the theories they serve". One of the goals of the current work is to employ the computer as a modeling tool to achieve this effect. Our program is an implementation of a small part of a general theory of argumentation.

AI and Argumentation

AI researchers have also undertaken work in argumentation, and recently work in this area seems to be on the rise (e.g., AAAI Spring Symposium, 1991). Most AI work in argumentation has been done in contexts other than reasoning per se, e.g., natural language processing (e.g., Flowers, McGuire, & Birnbaum, 1982; Reichman-Adar, 1984; Smolensky, et. al., 1988), software engineering and design (e.g., Conklin, 1988; Lee, 1991), and legal reasoning (e.g., Ashley, 1989; Marshall, 1989; Rissland, 1985). Much of this work is mainly concerned with argument analysis and representation, while other work is mainly concerned with argument generation. We briefly describe some of the important contributions of previous research in AI and argumentation.

Argument research in the context of natural language processing has been done by (Flowers, McGuire, & Birnbaum, 1982; Reichman-Adar, 1984; and Smolensky, et. al., 1988). Flowers, McGuire, & Birnbaum (1982) point out that an argumentation program needs knowledge of a domain, knowledge of reasoning methods, and knowledge about argumentation. In our model these correspond respectively to the warrants and data bases; the Find_Support module, with its knowledge of plausible reasoning, representing and propagating uncertainty, and proof levels; and the Refute module, with its knowledge of argument moves and heuristics. They propose representing arguments using graphs of belief nodes connected by support and attack relations. They give three general ways for attacking an argument: attack the data support, attack the claim directly, and attack the link between the data and the claim. These are similar to categorizations from general argument literature and the moves in the current work can be straightforwardly categorized in this way. They also describe a task important for natural language processing but not for our more restricted form of argument, that of responding to ad hominem attacks. This type of argument move, along with other strictly rhetorical (as opposed to logical) moves are omitted from our model altogether.

Reichman-Adar (1984) presents a design for a discourse analysis program with "issue context spaces" with slots for claim, topic, and supporting context spaces. Debative discourse includes slots for protagonists, antagonists, counter-claims, and supports. This interesting but high level description of argument representation has not been implemented, so it is difficult to have a precise understanding of argument representation and generation in this framework.

The EUCLID program described in (Smolensky, et. al., 1988) is meant to support logical discourse among human users, i.e., "give users the expressive and analytic power necessary to elevate the effectiveness of their own reasoned argumentation". In EUCLID, as in the current model, an argument is represented as a recursive structure where argument claims are supported by complex entities (arguments) that are claims themselves. Claims are linked by labelled arcs that represent a relationship between claims, e.g., "support", "attack". An interesting contribution of this work is the Argument Representation Language (ARL), a set of primitive types and predicates for formally describing argument structure. ARL incorporates high-order structures which are combinations of simpler argument structures. High level structures can be used to represent argument by analogy and summations of arguments. In contrast, the Toulmin structure does not include any mechanism for summarizing parts of an argument.

Work similar to this, though in the domain of software engineering and design, has been done by (Conklin, 1988) and (Lee, 1991). Conklin (1988) describes the IBIS tool, which is mean to capture important design process decisions. It supports dialog (including argumentation) during system design. Design issues are represented as nodes in a network, and connected by arcs that represent relations such as "challenges", "specializes", "evidence", etc. However, as in EUCLID, it is the users of IBIS who are actually generating the arguments; IBIS supports this by promoting structured discussion of the issues. Similarly, the work described in (Lee, 1991) attempts an explicit representation of design rationale, including the pros and cons of alternative designs, represented in an argument space. He discusses the Toulmin format for representing the argument space and finds, as we did, that the high level description given by Toulmin needs to be more precise and to be extended to handle macro-argument structures. He also decides, as we did, and as is the case in ARL, that every part of a Toulmin structure should be a claim, so claims are both support for and supported by other claims.

Other work that investigates the Toulmin format for argument representation is presented in (Marshall, 1989) and (Storrs, 1991). They confirm the conclusion that work is needed to formalize Toulmin's description of an argument. Storrs (1991) suggests that there are four kinds of data support: (a) axioms, or hard facts; (b) assumptions, i.e., best guesses or simplifications; (c) commonsense knowledge; and (d) local context knowledge. As this work is concerned only with representing arguments, it is not clear whether these data labels would be useful for defining argument moves. Marshall (1989), using examples from the legal reasoning domain, describes a hypertext implementation of the Toulmin format, for users to represent and analyze arguments. She suggests that ". . . pursu[ing] . . . understanding argument as a process" is an important task for argumentation research.

Other work in the legal reasoning domain has been done by Ashley (1989) and Rissland (1985). Rissland gives a "preliminary taxonomy of argument moves", as well as strategies to be implemented via the moves. As her focus is legal, case-based reasoning, where the intent of each arguer is to win the argument (rather than to locate and organize all relevant domain knowledge, for example), some of the moves are irrelevant to our work, e.g., "obfuscating", where facts are added or deleted "to trick the opposition". However two moves from her set of argument moves are found in our model: "bolstering" and "mooting". The bolstering move is meant to strengthen support for a side, as DART does, for example, when it is trying to accumulate evidence in support of a claim. Mooting is a move to show another argument is inconsequential or irrelevant, as the "show inapplicable evidence" move does in DART. Rissland also makes a helpful distinction between argument "tactics" and "strategies", where tactics apply to local move sequencing operations, while argument strategies have to do with overall argument goals, and may be implemented in a series of moves. All the heuristics in our current model would be classified as tactics; investigating argument strategies would be an interesting subject for further investigation.

HYPO, the program described in (Ashley, 1989), generates three-ply arguments about domain knowledge that is represented mainly as legal cases; the argument is about whether a new case should be decided for the plaintiff or the defendant. This work is unusual compared to most of the other work described here in that HYPO actually generates an argument about the new case. Arguments always consist of the same three steps: (a) one side looks for cases similar to the input case (that support the desired conclusion for the side), and uses the best ones as support for the same conclusion for the new case; (b) the other side attempts to "distinguish" the input case from the supporting cases, i.e., show they are not really similar to the supporting case, or the other side may look for counterexamples, cases similar to the new case that were decided for the other side; and (c) the original side gets a chance to respond to the other side's counterexamples, using the distinguishing move. Thus, DART is very much in the spirit of HYPO, in that all claims are seen as arguable, and arguments for and against a claim are generated using the format of a two-sided argument. However the specifics of DART, for example, rules rather than cases, explicit analysis of the representation of argument, exploration of a variety of argument moves, and heuristic generation of argument, differentiate the current work from HYPO.

In sum, AI and argumentation is a fertile research area, and many contributions from previous work can be mapped to parts of our model of argumentation. The current works adds to these contributions in (a) its emphasis on both argument-as-supporting-explanation and argument-as-dialectical-process; (b) its domain independent model of argument; (c) implementation of the theory in a computer program, with results for a wide variety of example problems; and (d) analysis of argumentation with respect to the task of reasoning in weak theory domains.

The last point brings us into the realm of work in AI and reasoning under uncertainty. As we are investigating argumentation as a general approach to reasoning in weak theory domains, it is worthwhile to mention similarities and differences between this approach and other, better established approaches to reasoning in weak theory domains. (Helpful surveys of these approaches can be found in Dubois & Prade, 1989 and Lea Sombe, 1990.) This is the topic of the next section.

Reasoning under Uncertainty

Argumentation is a general approach to incomplete or uncertain reasoning that expects inconsistency in addition to, indeed perhaps as a result of, incompleteness and uncertainty in the knowledge, and handles it by generating arguments both for and against a claim. An argumentation approach emphasizes decision justification, where justification for a claim includes both providing plausible support for a claim and defending it with respect to support for other plausible claims.

In contrast, other work in uncertain reasoning has tended to focus on uncertainty per se rather than on inconsistency, and emphasize decision making (i.e., resolving uncertainty) rather than decision justification. However there are many important results and insights from this very active research area, and we summarize the ones most relevant to our own work next.

(Lea Sombe, 1990) is a survey of various logics that have been and are being developed to handle uncertainty in the domain knowledge, e.g., default logic, non-monotonic modal logics, conditional logics, fuzzy logic, etc. This overview shows that this is very much an open research area. Most of the methods use numerical representations of uncertainty; many of these suffer from "the matter of the semantics of the weighted production rules, particularly on conflict resolution". But another school of thought "deeply distrusts numbers", mainly because they summarize, too succinctly, reasons for believing or disbelieving a claim. Once summarized, the reasons become inaccessible, i.e., it is not possible to reason "about" (in contrast to with, or under) uncertainty. However, as Lea Sombe (1990) points out, "There is no opposition between reasoning with uncertain information and reasoning about uncertainty."

We include both of these in our model of argumentation. We believe that a method for explicitly representing, combining, and propagating uncertainty is important for reasoning in weak theory domains. Theoretically, any method for doing this could be used in our model of argument. However we chose to define a new, simple method (see Chapter II) for three reasons: (a) to avoid ideological commitments to one particular method or another at this stage of argument modeling; (b) to keep the representation of uncertainty as simple as possible, so as to not be distracted from issues more central to modeling argument; and

(c) it does not appear that any of the methods (of the ones described in Lea Sombe, 1990, for example) implements uncertainty representation appropriately for our model, i.e., uses weakest link propagation of uncertainty or incorporates uncertainty that arises from plausible reasoning.

We also believe (along with Cohen 1985, for example) that it is important to be able to reason about, as well as under, uncertainty, i.e., methods for reasoning under uncertainty should include the ability to justify belief or disbelief in a claim. We have maintained that generating arguments for and against a claim is an excellent method for justifying claims reached by uncertain reasoning. An argument in support of a claim highlights sources of uncertainty in the domain knowledge and the reasoning process and, as a structured object, is itself subject to further argumentation, i.e., supports reasoning about uncertainty. Thus arguments seem to implement one of the goals given in (Cohen, 1985) for "endorsements", i.e., symbolic representations of reasons for believing or disbelieving propositions: they "allow one to distinguish different kinds of uncertainty, and to tailor reasoning to what is known about uncertainty." Arguments differ from endorsements in that they are altogether a different kind of structured object, and have their roots in a long line of research in reasoning. However, it may be that endorsements are compatible with our current model of argumentation. Though the semantics of endorsements are not clear (as Cohen himself points out), it seems that they are not too unlike atomic backing for a claim, for example, or a warrant type field. For example, in Cohen's program, the rule endorsement "too general" is used to tell the reasoner that multiple rules of this type working together can support a claim, but none should be used on its own. It is conceivable that the Find_Support module of DART could use endorsements in this same way; furthermore the Refute module could have argument moves aimed at specific endorsements.

Other work in AI and reasoning under uncertainty has to do with inference processes, or what we have been calling plausible reasoning. As we discussed (Chapter II), Pearl (1987) points out the dangers of mixing what he calls "causal" and "evidential" rules in the same chain of reasoning, e.g., if the rule "rain->(causes)wet grass" is fired, the rule "wet grass->(is evidence for)sprinkler on" should then be blocked from firing. He proposed to do this by blocking causal/evidential combinations during reasoning. Poole (1989) handles this problem in a system that combines abductive ("explanatory") and deductive ("predictive") inference. Data is represented as observations and conjectures; observations need to be explained (i.e., trigger abductive reasoning), while conjectures are used to predict (i.e., trigger deductive reasoning). As there is no way to get from a conjecture to an explanation, inappropriate modus ponens/abduction reasoning combinations do not arise. As we have seen, our model of argumentation, which also combines plausible and deductive reasoning, addresses this problem by blocking some inference combinations for most explanatory warrants. As in Poole's program, reverse causal rules need not explicitly appear in the warrants base. Furthermore, warrant type fields are consulted before an inference combination is blocked, as it may be appropriate for some warrants.

Some research in reasoning under uncertainty is concerned with inconsistencies that can arise during default reasoning (i.e., the "multiple extensions problem"). The main thrust of this work (e.g., Horty, 1987; Loui, 1987; Simari & Loui, 1992) is to develop methods for resolving the inconsistency, usually by invoking a specificity defeater principle, i.e., the conclusion of a more specific rule defeats the conclusion of a more general rule. Our model uses a simple version of this principle when exception warrants are used to defeat default warrants. Extensions to the model could include additional specificity defeater argument moves. However, we note that, in domains (e.g., legal reasoning, design, etc.) where inconsistency is considered a feature, or at least a given, rather than a problem, the approach to argumentation described in this paper offers a way to reason about, rather than simply under, (persistent) inconsistency.

Finally, the work in default reasoning that is closest in spirit to our own is found in the Cyc project (e.g., Guha, 1990; Lenat & Guha, 1990). Guha (1990) writes, "The basic ideas is as follows. When determining whether some proposition P is true, one constructs arguments for and against that proposition and decides one way or another after comparing these arguments, where an argument for proposition P is similar to a proof for P, but is non-monotonic." Cyc also has an Argumentation Axiom that seems close to the preponderance of evidence proof level: ". . . if we have an acceptable [i.e., not known to be invalid] argument for P and there isn't any 'better' argument for not P, then we would like to accept P as a theorem." The preference criteria for comparing two arguments include inferential distance (i.e., specificity), causal arguments, etc.

This work, as far as it goes, is very similar to the current research. The current research offers a more developed model of argumentation that includes representation of argument structures, and moves and heuristics for dialectical argumentation, none of which is present in Cyc. Indeed, Guha (1990) goes on to say that ". . . an important task [for future work] is to develop a rich theory of arguments, their basic types and properties . . ."

In sum, the current work, along with other AI work in reasoning under uncertainty, presumes the existence of uncertainty in the domain knowledge. In our model dialectical argumentation is viewed as a useful, general technique for deriving and justifying claims in light of the problems that arise from reasoning in weak theory domains, particularly inconsistency.

CHAPTER VI

CONCLUSIONS

Modeling dialectical argumentation is a rich area for future work. We outline ideas for interesting research directions, then summarize the main points of this paper.

Directions for Future Research

Many ideas for future work involve extending the current model for dialectical argumentation. We give an overview of some of these ideas, followed by a brief discussion for other directions for the research, e.g., formalizing the model, and exploring user interface capabilities for the model.

Ideas for extending the current model can be classified into two main areas: additions to argument representation and additions to argument generation. As we discussed in Chapter V, there has been interesting research in argumentation representation, particularly the Argument Representation Language (ARL). The current representation could be recast or at least supplemented with ARL primitives and argumentation combination operators. Since DART generates as well as represents arguments, it would be interesting to investigate new argument moves that might be suggested by ARL primitives.

There are many possibilities for adding to the current account of dialectical argumentation, including more argument moves, refinement of heuristics for move selection, and new heuristics for implementing argument strategies (in contrast to tactics, see Chapter V). For example, another plausible inference pattern given in (Polya, 1968) is "successive verification of several consequences", which could be implemented in DART as searching for as much abductive support for a claim as possible. Other argument moves might be suggested by exploring the subcategories of the "explanatory" warrant type. For example, an "enable/effect" warrant appears to be amenable to different moves than a "cause/effect" warrant. If an expected effect of a particular cause has not happened, that is a strong argument against the cause, while the lack of an expected effect would not be nearly so strong an argument against the enabler in an "enable/effect" relationship.

The refinement of heuristics for ordering argument moves is another fertile area for investigation. Currently, moving through the argument space is a matter of searching for a check qualification on the input claim (for one's own side). But since argument is a two-sided process, it might also be important to explicitly check for, and avoid, argument states that, although good for one's own side, are particularly vulnerable to refutation by the other side. In other words, argumentation resembles game-playing, and techniques such as a minimax search and alpha beta cutoffs may prove useful in an argumentation context.

In addition to heuristics for selecting the next move, more global heuristics, to implement higher level argument strategies, could be used. A strategy suggested in (Lorenz, 1978) calls for defenses (against attacks) to be made in the reverse order of the attacks, i.e., the last attack made should be the first attack answered, and defenses need not be constructed by a side until the side is done making all of its attacks. The "direct refutation" strategy given in (Rieke & Sillars, 1984) calls for a side (in one turn) to do a point by point review of each of the other side's claims, attacking each in turn.

It would be interesting to explore adding cases and case-based reasoning to the current model of argument. We discussed some differences between case and rule-based reasoning in Chapter IV; the model would have to be modified to include the representation and matching of cases in the data base, as well as to integrate the combination of case and rule-based reasoning in a single system. Some work in this area has been done by (Rissland & Skalak, 1989).

There is also the issue of scaling up the prototype model. This could be explored by attempting to generate dialectical arguments for large applications, e.g., extant expert systems, for various proof levels and perhaps with various sets of heuristics, and evaluating the output for issues for representing and generating large arguments.

Any of these additions to the model would be enhanced by a graphical, interactive user interface. Argumentation is a familiar concept to humans, and therefore provides a useful metaphor for the user interface for programs that reason in weak theory domains. Issues to be considered for graphical output include presentation of the process of argumentation, and how to summarize arguments (representation and generation) in a useful manner. Issues for an interactive user interface are more complex, and could include defining a language for user interaction, for argument analysis and generation.

Finally, there is the possibility of formalizing the model. Now that a prototype computational model for argumentation has been built, it may be appropriate to be more formal about the generation of dialectical argument. Barthe & Krabbe (1982), for example, describe a system of "formal dialectics", and there is also a body of research on "paraconsistent logic", or the logic of inconsistency (e.g., Priest, 1988; Priest, et. al., 1989; Rescher & Brandom, 1980) that may be a source of ideas for the next generation of the model.

Summary

The main contribution of the research described in this paper is a computational model of dialectical argumentation that exhibits reasonable behavior when applied to benchmark examples from argumentation and AI research. This work was motivated by the need to incorporate the ability to construct arguments, a key task of dialectical reasoning, in programs that attempt to model intelligent behavior. Argumentation is investigated as a general technique for reasoning under incomplete, uncertain, and inconsistent knowledge.

Argumentation, which expects controversy and includes the task of refuting, as well as supporting, claims, provides the foundation for a new approach to proving and justifying claims in weak theory domains. Deriving deductively valid claims may not be possible under weak theory domain conditions. We defined dialectical validity as plausible, irrefutable, consistent support for a claim. Claims are evaluated on their own merits and with respect to support for other claims. The conditions for dialectical validity can be relaxed and constrained to define additional proof levels. Proof levels can be used to inform decision-making for alternative claims.

We described two senses of argument: argument as support for a claim (i.e., product) and argument as a dialectical process. We described some of the knowledge needed for argumentation, including a structure for representing argument as support for a claim, and moves and heuristics for the generation of dialectical argument. Arguments are represented using a format based on Toulmin's structure of argument. We gave more precise descriptions of the major elements of the Toulmin structure, and incorporated knowledge needed for reasoning in weak theory domains, e.g., plausible inference types, the representation and propagation of uncertainty, and proof levels, into the Toulmin format. We gave a specification of dialectical argumentation that comprises the major elements of dialectical argument: argument moves, heuristics for move selection and control of argument generation, rules for turntaking between the two sides of the argument, and implementation of differing burdens of proof for conceding an argument. Argument moves are based on our representation of argument, as well as discussions of reasoning fallacies and responsive moves from the argumentation literature.

We described the DART program, a computational model of dialectical argumentation. DART implements a comprehensive, domain independent approach to reasoning in weak theory domains that combines the model elements given above: deductive and plausible inference for reasoning under incomplete knowledge, a weakest link method for propagating uncertainty, and proof levels, a Toulmin format for argument representation, and a catalog of argument moves, set of heuristics for selecting moves, and rules for turntaking and conceding arguments, for reasoning under and about inconsistency.

We presented program output for a set of example problems drawn from the literature in argumentation, AI and argumentation, and AI and reasoning under uncertainty. For some examples, DART recreates the original arguments given for the example. In other cases, DART is able to give more detailed output, due to its use of plausible inference, uncertainty representation, and proof levels. For all the examples, program output includes argument output of both the process and products of dialectical argumentation that can be used to justify accepting or not accepting a claim. DART output across the benchmark examples also raises some issues for reasoning in weak theory domains, including the uses and limits of plausible and deductive inference, and the extent of controversy in a knowledge base.

Finally, the theory and computational model of argument described in this paper provide an exploratory framework for further investigation of argumentation. We have suggested some directions for future research, including extending and formalizing the knowledge needed for reasoning in weak theory domains, particularly knowledge for the representation and generation of argument, evaluating the model for medium or large applications, and adding interactive input/output capability for an argumentation-based user interface.

For artificial intelligence programs, the ability to generate arguments provides a useful technique for reasoning in real world contexts. For argumentation researchers, artificial intelligence methodology offers a new way for evaluating theories of argumentation.

APPENDIX

In this appendix, we discuss the argumentation approach to reasoning in weak theory domains for thirteen additional example problems. The examples are drawn from literature in argumentation, and artificial intelligence research. For each example, we briefly describe the problem, then give the DART representation of the problem information and highlights of the DART argumentation process.

EXAMPLE 1

We give DART output for a the example problem given in (Lea Sombe, 1990). The knowledge is represented by the following warrants and data:

```
(w1 ((student)) --> si df ((young)) (!? GIVEN))
(w2 ((young)) --> si df ((single)) (!? GIVEN))
(w2a ((single)) --> si ev ((young)) (!? GIVEN))
(w3 ((student)(has children)) --> ex df ((not single)) (!? GIVEN))
(w4 ((cohabitant)) --> si df ((young)) (!? GIVEN))
(w5 ((cohabitant)) --> ex s ((not married)(not single)) (!? GIVEN))
(w6 ((single)) --> ex s ((not cohabitant)(not married)) (!? GIVEN))
(w7 ((married)) --> ex s ((not single)(not cohabitant)) (!? GIVEN))

(d1 (student) (!? GIVEN))
(d2 (has children) (!? OBSERVE))
(claim (single) (?? NIL))
```

That is, students are generally young, and young people are generally single, and vice versa. A student who is a parent is generally not single. People who are cohabitating are also usually young. Finally, by definition, the states of cohabitating, single, and married are mutually exclusive. We added the "si" and "ex" values; since most of the relationships expressed in the warrants seems to be correlational, most of the warrants are classified as sign, or correlational, information.

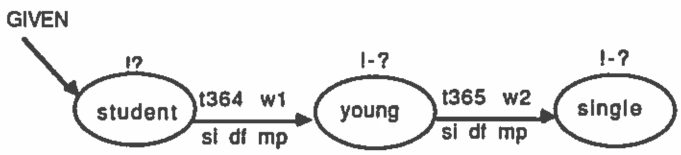
There is information that there is a student (Lea) who is a parent; the question is whether her marital status is single. DART generates an argument with the default proof level, dialectical validity.

Starting ARG...
Side 1 is looking for support for (SINGLE)
Burden of proof on side 1 is dialectical validity.

Claim ((SINGLE)) is supported by ((YOUNG))
Warrant id: W2 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t365
Claimnode qualification is: (!- ?)

Claim ((YOUNG)) is supported by ((STUDENT))
Warrant id: W1 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t364
Claimnode qualification is: (!- ?)

Claim (STUDENT) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



Side-1 finds support for the claim "single", stemming from the knowledge that Lea is a student, and therefore (by default) young, and therefore (again by default) single.

---**Side 2 is next.

. . . Next move for side 2 is:
Find support for (AND (NOT SINGLE))

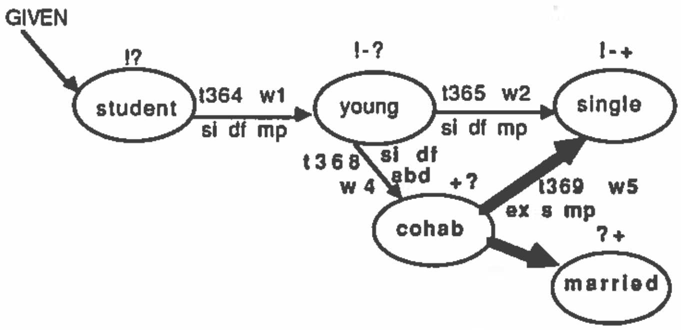
Claim ((NOT MARRIED) (NOT SINGLE)) is supported by ((COHABITANT))
Warrant id: W5 - Wtype1: EX - Wtype2: S - Rtype: MP
New tau id: #:\t369
Claimnode qualification is: (!- +)

Claim ((COHABITANT)) is supported by ((YOUNG))
Warrant id: W4 - Wtype1: SI - Wtype2: DF - Rtype: ABD
New tau id: #:\t368
Claimnode qualification is: (+ ?)

Claim (YOUNG) is already supported.
Backing is ((STUDENT))
Claimnode qualification is: (!- ?)

Tau #:\t369: ((AND (COHABITANT))->(NOT SINGLE))
makes top claim: (SINGLE) controversial - FS.

Qualification for claim (SINGLE) is (!- +)



Side-2 is able to show that a young person might be cohabitating, rather than single, causing the claim to become controversial. Side-1 is not able to defeat Side-2's argument, and concedes the claim.

---**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (SINGLE) was NOT established.
Burden of proof on side 1 was: dialectical validity

Although Side-1 lost the argument, so far, at least, it looks like it has the stronger support for the claim. We run DART again, to try to establish the claim by a preponderance of the evidence.

Starting ARG...
Side 1 is looking for support for (SINGLE)
Burden of proof on side 1 is preponderance of the evidence.

Claim ((SINGLE)) is supported by ((YOUNG))
Warrant id: W2 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t375
Claimnode qualification is: (!- ?)

Claim ((YOUNG)) is supported by ((STUDENT))
Warrant id: W1 - Wtype1: SI - Wtype2: DF - Rtype: MP
New tau id: #:\t374
Claimnode qualification is: (!- ?)

Claim (STUDENT) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Side-1 once again puts forth its strong support for the claim.

--**Side 2 is next.

. . . Next move for side 2 is:
Find support for (AND (NOT SINGLE))

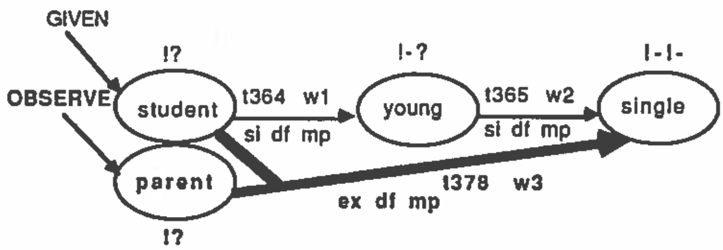
Claim ((NOT SINGLE)) is supported by ((HAS CHILDREN) (STUDENT))
Warrant id: W3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t378
Claimnode qualification is: (!- !-)

Claim (HAS CHILDREN) is already supported.
Backing is OBSERVE
Claimnode qualification is: (! ?)

Claim (STUDENT) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Tau #:\t378: ((AND (HAS CHILDREN) (STUDENT))->(NOT SINGLE))
makes top claim: (SINGLE) controversial - FS.

Qualification for claim (SINGLE) is (!- !-)



This time, Side-2 skips the argument about Lea cohabitating, since it is not strong enough to defeat Side-1 when the burden of proof is preponderance of the evidence. But Side-2 does manage to find strong support for the claim "not single", using the knowledge that Lea is a parent. Control of the argument returns to Side-1.

--**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (SINGLE) was NOT established.
Burden of proof on side 1 was: preponderance of the evidence.

Side-1 concedes the argument; there is strong support for both the input claim and its negation.

In the (Lea Sombe, 1990) example, there is some question about whether or not Lea is a parent, i.e., she may or may not have children. In DART, this could be represented in either of two ways: "has children" could be qualified with a "+?" (rather than "!?"), or DART could be rerun with the same claim but with "not has children" in the data base. In the former case, "single" would be established by a preponderance of the evidence, though not with dialectical validity. This is because Side-2's case in the preponderance of the evidence argument is based on strong support for "has children". When there is only credible support for "has children", then Side-2's case will not reach the "usual" qualification it needs to defeat Side-1. However, Side-2 will still have its original "cohabitant" argument available, as well as the weaker "has children" argument, and Side-1 will therefore be unable to achieve the consistent support it would need to establish its claim when the proof level is dialectical validity.

If the "has children" information were replaced with "not has children", Side-1 would win on preponderance of the evidence but not on dialectical validity. We can see why from the discussion above: Side-1 has its strong argument; Side-2 no longer has the "has children" argument, but it does still have the "cohabitant" argument. Side-2's argument is weaker than Side-1's, but Side-1 will not be able to defeat it altogether.

We can contrast the DART output with the results given in (Lea Sombe, 1990) for this knowledge base using default logic. In default logic, "maybe has children" is translated to "has children" in one data base, and "not has children" in another data base (i.e., same as the "latter case", above). From the two data bases come three extensions, i.e., conflicting sets of results. "Student" and "young" are in every extension. "Single" is in the extension based on the "not has children" information. When "has children" is included in the data base, one extension has "single", and other extension has "not single".

This is similar to what DART tells us, though DART gives more information, i.e., the entire argument rather than just the claims (extensions), and also additional arguments for additional proof levels and reasoning types. For DART, as in default logic, all of the arguments contain "single" and "young". DART and default logic also give similar results when "has children" is part of the input knowledge, i.e., there is support both for and against the claim "single". DART is also able to show that this is the case for different proof levels. Default logic gives a different result than DART when "not has children" is in the input knowledge base. For default logic, based on this information, there is support only for Lea's being single. For DART, there is still a controversy, because there is some support, via the abductive reasoning type, for Lea's cohabitating with someone, rather than being single. The support is weak, so DART's results concur with the default logic results when the proof level is preponderance of the evidence, but for dialectical validity the claim is still controversial.

EXAMPLE 2

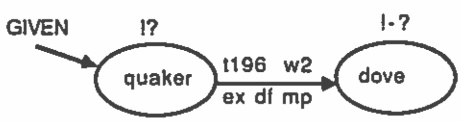
We give DART output for a an example problem given in (Poole, 1989) (and elsewhere). The knowledge is represented by the following warrants and data:

```
(w1 ((republican)) --> ex df ((not dove)) (!? GIVEN))
(w2 ((quaker)) --> ex df ((dove)) (!? GIVEN))
(w3 ((not dove)) --> ex df ((supports star wars)) (!? GIVEN))
(w4 ((not dove)) --> ex df ((politically motivated)) (!? GIVEN))
(w5 ((dove)) --> ex df ((politically motivated)) (!? GIVEN))
(w6 ((quaker)) --> ex df ((religious)) (!? GIVEN))

(d1 (republican) (!? GIVEN))
(d2 (quaker) (!? GIVEN))
(claim (dove) (?? NIL))
```

That is, someone who is a Quaker will usually be a dove, and someone who is a Republican will usually be a hawk (not a dove). Someone who is a hawk will usually support the "star wars" project. Both hawks and doves are politically motivated, and Quakers can usually be assumed to be religious. The initial data base contains information that someone is both Republican and a Quaker. The question is whether or not such a person will be a dove.

The default proof level is dialectical validity.

```
Starting ARG...
Side 1 is looking for support for (DOVE)
Burden of proof on side 1 is dialectical validity.

Claim ((DOVE)) is supported by ((QUAKER))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t196
Claimnode qualification is: (!- ?)

Claim (QUAKER) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)
```



---**Side 2 is next.

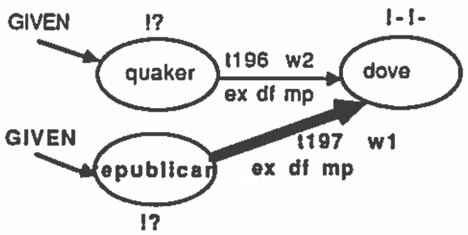
. . . Next move for side 2 is:
Find support for (AND (NOT DOVE))

Claim ((NOT DOVE)) is supported by ((REPUBLICAN))
Warrant id: W1 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t197
Claimnode qualification is: (!- !-)

Claim (REPUBLICAN) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Tau #:\t197: ((AND (REPUBLICAN))->(NOT DOVE))
makes top claim: (DOVE) controversial - FS.

Qualification for claim (DOVE) is (!- !-)



--**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (DOVE) was NOT established.
Burden of proof on side 1 was: dialectical validity

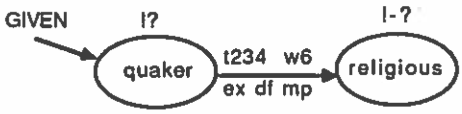
The input claim is controversial; there is support for both the claim and its negation.

In his discussion of this example, Poole is concerned not only with the "dove" and "not dove" claims, but also with other possible claims: "supports star wars", "politically motivated", and "religious", and well as "dove and not dove" and "dove or not dove". He suggests four ways of handling the results of reasoning from an inconsistent knowledge base such as the one given here: if p and q, mutually exclusive propositions, can both be reasoned to, then a system might predict, i.e., claim (1) either p or q but not both; (2) neither p nor q; (3) p or q; or (4) nothing, reasoning should stop when the inconsistency is detected. For the current example, option (1) leads to two possibilities: either (politically motivated, not dove, supports star wars, and religious), or (politically motivated, dove, and religious). The only claim established when option (2) is enforced is "religious". Option (3), or the "membership in all extensions" option, would permit all claims that appear in any extension, in this case, "politically motivated" and "religious", along with "(not dove and supports star wars) or (dove)". Option (4) leads to no claims at all.

We can analyze DART in terms of Poole's prediction proposals. Options (2) and (4) essentially do not reason under inconsistency, and therefore are contrary to the spirit of our argumentation model. DART does not explicitly generate multiple extensions, but would generate either of the extensions given in Option (1) if "dove" or "not dove" were included in the input knowledge base. But since they are not, and the claim "dove" is controversial, DART's output is closest in spirit to Option (3), above.

For the proof level dialectical validity, DART's output is similar to the "membership in all extensions" output given above. DART does not represent the disjunction, which leaves "politically motivated" and "religious". But for DART, unlike for Poole's system, "religious" is controversial. "Religious" is controversial in DART for the same reason that "support star wars" is controversial, i.e., it is embroiled in the "dove"/"not dove" controversy. Here is the argument generated by DART:

```
Starting ARG...
Side 1 is looking for support for (RELIGIOUS)
Burden of proof on side 1 is dialectical validity.

Claim ((RELIGIOUS)) is supported by ((QUAKER))
Warrant id: W6 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t234
Claimnode qualification is: (!- ?)

Claim (QUAKER) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)
```



---**Side 2 is next.

. . . Next move for side 2 is:
Question data: find support or bolster (AND (NOT QUAKER))

Claim ((NOT QUAKER)) is supported by ((NOT DOVE))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MT
New tau id: #:\t237
Claimnode qualification is: (! !-)

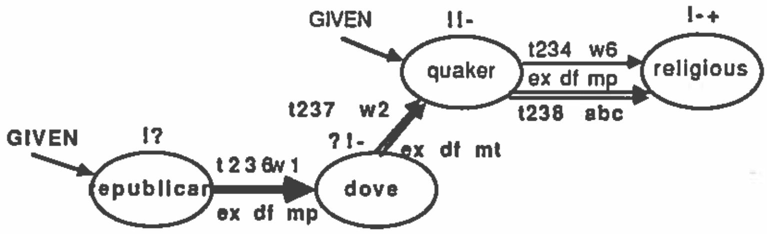
Claim ((NOT DOVE)) is supported by ((REPUBLICAN))
Warrant id: W1 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t236
Claimnode qualification is: (? !-)

Claim (REPUBLICAN) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t237: ((AND (NOT DOVE))->(NOT QUAKER))
*makes tau #:\t234: ((AND (QUAKER))->(AND (RELIGIOUS))) controversial -
*FS-OR-BOLSTER.

Claim (AND (NOT RELIGIOUS)) is supported by (AND (NOT QUAKER))
Warrant id: W6 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t238
Claimnode qualification is: (!- +)

Qualification for claim (RELIGIOUS) is (!- +)



---**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (RELIGIOUS) was NOT established.
Burden of proof on side 1 was: dialectical validity

"Religious" is supported by "quaker", but "quaker" is shown to be controversial as a result of the "dove"/"not dove" controversy; this in turn makes "religious" controversial. Modus tollens and abductive-contrapositive reasoning are used, and neither of these reasoning types is used in Poole's system, hence only DART shows "religious" to be controversial.

In DART, as in Poole's system, "politically motivated" is not controversial. An argument is generated, and as this claim is the consequence of two warrants where the antecedents are negations of each other, the "abc" arguments are defeated by "mp" arguments, and the claim is established. (Since its support is strong, it is actually proved "beyond all reasonable doubt".) In sum, DART with proof level dialectically validity roughly corresponds to Poole's "appears in all extensions" option, though without the disjunctive claim, and without "religious", which DART finds to be controversial.

If the problem is considered for "preponderance of the evidence", more claims are established. We can see from the arguments given above that "dove" will not be proved, but "supports star wars" and "religious" both will be, as the evidence in support of those claims is stronger than the evidence against. (This stems from the warrants available in the knowledge base. Both claims are consequences of explicit warrants, i.e., can be - and are - established using strong reasoning types, while their negations can only be established weakly, using the same warrants with weak reasoning types.) When the proof level is "scintilla of evidence", all claims can be established; for "beyond a reasonable doubt", as we have already seen, only "politically motivated" can be proved.

EXAMPLE 3

We give DART output for an example problem given in (Pearl, 1987), and show how DART addresses a concern raised there about including mixed reasoning types in a single system (see Chapter II; also Appendix Example 6). The knowledge is represented by the following warrants and data:

```
(w1 ((rain)) --> ex df ((wet grass)) (!? GIVEN))
(w2 ((sprinkler)) --> ex df ((wet grass)) (!? GIVEN))
(w3 ((wet grass)) --> ex df ((wet shoes)) (!? GIVEN))

(d1 (rain) (!? GIVEN))
(claim (sprinkler) (?? NIL))
```

Rain and sprinklers both cause the grass to become wet; wet grass in turn causes wet shoes. We are told it has rained; we'd like to know whether the sprinkler was on.

```
Starting ARG...
Side 1 is looking for support for (SPRINKLER)
Burden of proof on side 1 is dialectical validity.

side 1 loses
Burden of proof on side 1 was: dialectical validity
```

There is no way to conclude "sprinkler" from rain, as modus ponens/abductive reasoning combinations are blocked for multiple causes. As there is no other knowledge relevant to the claim, Side-1 quickly concedes the argument.

EXAMPLE 4

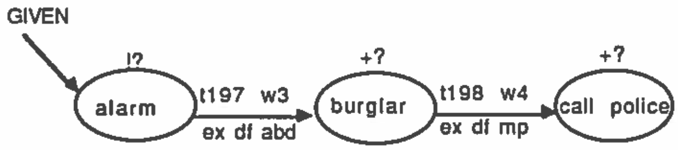
We obtained this problem from Prof. Bruce D'Ambrosio at Oregon State University. We use it here to illustrate points about hypothetical reasoning and "policy" arguments. Input knowledge is as follows:

```
(w1 ((earthquake))  --> ex ev ((radio report)) (!? GIVEN))
(w2 ((earthquake))  --> ex df ((set off alarm)) (!? GIVEN))
(w3 ((burglar))  --> ex df ((set off alarm)) (!? GIVEN))
(w4 ((burglar))  --> ex df ((call police)) (!? GIVEN))
(w5 ((not burglar)(call police)) --> ex df ((not keep police happy)) (!? GIVEN))

(d1 (set off alarm) (!? GIVEN))
(d2 (keep police happy) (!? GIVEN))
(claim (call police) (?? NIL))
```

An alarm has gone off, and the question is whether or not to call the police. If the alarm was caused by a burglar, the police should be called. But if the alarm was caused by an earthquake, the police will not be happy to have been needlessly disturbed. The "policy" that it is better to have the police happy is represented by including d2 in the input knowledge, i.e., "keep police happy" is not something we believe, as other data is, but something that we'd like to be the case. In general, DART is not concerned with policy arguments, but this representation works for this problem. Side-1 generates the following argument in favor of calling the police:

```
Starting ARG...
Side 1 is looking for support for (CALL POLICE)
Burden of proof on side 1 is dialectical validity.

Claim ((CALL POLICE)) is supported by ((BURGLAR))
Warrant id: W4 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t198
Claimnode qualification is: (+ ?)

Claim ((BURGLAR)) is supported by ((SET OFF ALARM))
Warrant id: W3 - Wtype1: EX - Wtype2: DF - Rtype: ABD
New tau id: #:\t197
Claimnode qualification is: (+ ?)
```

Claim (SET OFF ALARM) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



The support for the claim is weak, because it is speculative, but the claim is a credible one.

Side-2 is given control of the argument, and considers the options:

--**Side 2 is next.
New argument moves, in sorted order, are:

Find exception for rule (AND (BURGLAR)) -> (AND (CALL POLICE))
Refuted tau would be #:\t206

Look for another explanation for (AND (SET OFF ALARM))
to show (AND (BURGLAR)) is an unneeded explanation.
Refuted tau would be #:\t205

Question data: find support or bolster (AND (NOT BURGLAR))
Refuted tau would be #:\t206

Question data: find support or bolster (AND (NOT SET OFF ALARM))
Refuted tau would be #:\t205

Find support for (AND (NOT CALL POLICE))
Refuted tau would be TOP

There are no known exceptions to the "if burglar then call police" warrant, so Side-2 goes on to the next move:

Next move for side 2 is:
Look for another explanation for (AND (SET OFF ALARM))
to show (AND (BURGLAR)) is an unneeded explanation.

Looking for support for claim (SET OFF ALARM)
Check warrant(s) (W2) for support for (SET OFF ALARM).

Trying W2 with ((AND (EARTHQUAKE)))
to support (SET OFF ALARM).

Looking for support for claim (EARTHQUAKE)
Check warrant(s) (W1) for support for (EARTHQUAKE).

Trying W1 with ((AND (RADIO REPORT)))
to support (EARTHQUAKE).

Looking for support for claim (RADIO REPORT)

No warrant support found.
No support found.
No support found.

move failed

Side-2 sees that an earthquake might have triggered the alarm, but is unable to find any evidence of an earthquake, and the move fails. This is an example where hypothetical reasoning would be useful, to let the user know about the possible defeater, to inform the user as to knowledge that it would be helpful to have.

The rest of the undercutting moves result in failure as well, and Side-2 finally comes to the rebuttal move: is there any support at all for not calling the police?

Next move for side 2 is:
Find support for (AND (NOT CALL POLICE))

Looking for support for claim (NOT CALL POLICE)
Check warrant(s) (W5 W4) for support for (NOT CALL POLICE).

Trying W5 with ((AND (NOT BURGLAR) (KEEP POLICE HAPPY)))
to support (NOT CALL POLICE).

Looking for support for claim (NOT BURGLAR)
Check warrant(s) (W3) for support for (NOT BURGLAR).

Trying W3 with ((AND (NOT SET OFF ALARM)))
to support (NOT BURGLAR).

Looking for support for claim (NOT SET OFF ALARM)

No warrant support found.
No support found.

Trying W4 with ((AND (NOT BURGLAR)))
to support (NOT CALL POLICE).

Looking for support for claim (NOT BURGLAR)
Check warrant(s) (W3 W5) for support for (NOT BURGLAR).

Trying W3 with ((AND (NOT SET OFF ALARM)))
to support (NOT BURGLAR).

Looking for support for claim (NOT SET OFF ALARM)

No warrant support found.

Trying W5 with ((AND (NOT KEEP POLICE HAPPY)))
to support (NOT BURGLAR).

Looking for support for claim (NOT KEEP POLICE HAPPY)

No warrant support found.
No support found.
No support found.

move failed

Side-2 finds, using W5 and modus tollens reasoning, that the policy of keeping the police happy means that they should not be called when there is no burglar. However, there is no evidence at all to support there not being a burglar. Side-2 concedes the argument.

Side 2 has no more arg moves.
Side 1 wins.
Claim (CALL POLICE) was established.
Burden of proof on side 1 was: dialectical validity

If Side-1 were really serious about not wanting to call the police unless there were a burglar, the proof level should be set to "beyond a reasonable doubt"; then Side-1 would not have been able to make a case for "call police".

EXAMPLE 5

We give DART output for an example problem from (Ashley, 1988). The warrants represent a subset of the legal cases that are part of HYPO's knowledge base. We point out differences between case and rule-based reasoning, both in the knowledge base and during reasoning (see Chapter V).

```
(Speedry_Chemical_Products
 ((disclosure in negotiations with defendant)) --> ex df ((not plaintiff)) (!? GIVEN))
(Space_Aero
 ((competitive advantage gained)
  (common employee transferred product tools)
  (security measures adopted)
  (disclosure in negotiations with defendant)) --> ex df ((plaintiff)) (!? GIVEN))
(Automated_Systems
 ((vertical knowledge)
  (disclosure in negotiations with defendant) --> ex df ((not plaintiff)) (!? GIVEN))
(Yokana
 ((secrets voluntarily disclosed)
  (common employee transferred product tools) --> ex df ((not plaintiff)) (!? GIVEN))
(Sunbeam
 ((secrets voluntarily disclosed) --> ex df ((not plaintiff)) (!? GIVEN))
(Data_General
 ((disclosures subject to restriction)
  (secrets voluntarily disclosed) --> ex df ((plaintiff)) (!? GIVEN))

(d1 (secrets voluntarily disclosed) (!? GIVEN))
(d2 (disclosures subject to restriction) (!? GIVEN))
(d3 (common employee transferred product tools) (!? GIVEN))
(claim (plaintiff) (?? NIL))
```

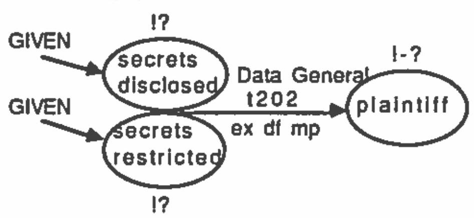
Using warrants to represent cases is a straightforward task to a point; the features of the case become the left hand side of the warrant, and the decision in the case is the right hand side of the warrant. However, the warrant representation does not distinguish between features that support the decision, and features that are irrelevant or even opposed to the decision. This means that the argumentation matching process is unable to ignore features that do not contribute strongly to the conclusion, and heuristic evaluation does not have the information it would need to choose a case that includes "despite" features, in order to mitigate the effect of a "despite" feature in the current fact situation. DART argues in the usual way:

Starting ARG...
Side 1 is looking for support for (PLAINTIFF)
Burden of proof on side 1 is preponderance of the evidence.

Claim ((PLAINTIFF)) is supported by ((SECRETS VOLUNTARILY DISCLOSED) (DISCLOSURES SUBJECT TO RESTRICTION))
Warrant id: DATA_GENERAL - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t202
Claimnode qualification is: (!- ?)

Claim (SECRETS VOLUNTARILY DISCLOSED) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (DISCLOSURES SUBJECT TO RESTRICTION) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



The Data General case is cited in support of the plaintiff. It is a good case to cite, since it shares two of the three features of the current fact situation. However, if the features of Data General were a superset of those of the input case (particularly if many of the extra features were despite, or irrelevant ones), it would an even better case for the plaintiff to cite, but it would not be found in the absence of a partial matching mechanism. The argument continues:

---**Side 2 is next.

. . . Next move for side 2 is:
Find support for (AND (NOT PLAINTIFF))

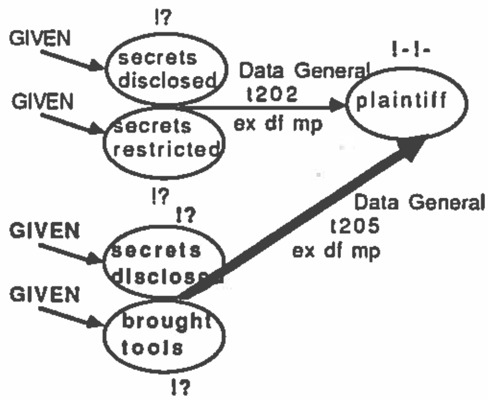
Claim ((NOT PLAINTIFF)) is supported by ((COMMON EMPLOYEE TRANSFERRED PRODUCT TOOLS) (SECRETS VOLUNTARILY DISCLOSED))
Warrant id: YOKANA - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t205
Claimnode qualification is: (!- !-)

Claim (COMMON EMPLOYEE TRANSFERRED PRODUCT TOOLS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (SECRETS VOLUNTARILY DISCLOSED) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Tau #:\t205: ((AND (COMMON EMPLOYEE TRANSFERRED PRODUCT TOOLS) (SECRETS VOLUNTARILY DISCLOSED))->(NOT PLAINTIFF))
makes top claim: (PLAINTIFF) controversial - FS.

Qualification for claim (PLAINTIFF) is (!- !-)



--**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (PLAINTIFF) was NOT established.
Burden of proof on side 1 was: preponderance of the evidence.

The defendant is also able to cite a case, Yokana, to support its side. Since Side-1 is unable to find stronger support for the plaintiff, the argument ends. Although DART is able to make a reasonable argument using warrants to represent legal cases, this example highlights some of the additional functionality that would be needed to really implement case-based arguments.

EXAMPLE 6

This problem, taken from (Marshall, 1989), shows how the restrictions on modus ponens/abductive reasoning combinations (Chapter II; Chapter V; Appendix Example 3) inhibit an attempt to show two things are similar (and therefore should be treated the same way under the law). The knowledge is represented by the following warrants and data:

```
(w1 ((wheels)) --> ex df ((mobile)) (!? GIVEN))
(w2 ((automobile)) --> ex df ((mobile)) (!? GIVEN))
(w3 ((automobile)) --> ex df ((searchable)) (!? GIVEN))
(w4 ((trunk)) --> ex df ((not searchable)) (!? GIVEN))
(w5 ((motor home)) --> ex ev ((trunk)) (!? GIVEN))
(w6 ((motor home)) --> ex df ((wheels)) (!? GIVEN))

(d1 (motor home) (!? GIVEN))
(claim (searchable) (?? NIL))
```

These are the stripped-down facts of a Supreme Court case regarding whether a motor home, parked in a parking lot, was exempt from constitutional restrictions on search and seizure. The argument in support of this position is given in (Marshall, 1989) as: a motor home has wheels, so a motor home is mobile, so a motor home can be classified as an automobile, so a motor home, like an automobile, is exempt from fourth amendment restrictions. DART output for this example is as follows:

```
Starting ARG...
Side 1 is looking for support for (SEARCHABLE)
Burden of proof on side 1 is dialectical validity.

Looking for support for claim (SEARCHABLE)
Check warrant(s) (W3 W4) for support for (SEARCHABLE).

    Trying W3 with ((AND (AUTOMOBILE)))
    to support (SEARCHABLE).

    Looking for support for claim (AUTOMOBILE)
    Check warrant(s) (W2) for support for (AUTOMOBILE).

        Trying W2 with ((AND (MOBILE)))
        to support (AUTOMOBILE).

        Looking for support for claim (MOBILE)
```

No warrant support found.
No support found.

Trying W4 with ((AND (NOT TRUNK)))
to support (SEARCHABLE).

Looking for support for claim (NOT TRUNK)
Check warrant(s) (W5) for support for (NOT TRUNK).

Trying W5 with ((AND (NOT MOTOR HOME)))
to support (NOT TRUNK).

Looking for support for claim (NOT MOTOR HOME)
Check warrant(s) (W6) for support for (NOT MOTOR HOME).

Trying W6 with ((AND (NOT WHEELS)))
to support (NOT MOTOR HOME).

Looking for support for claim (NOT WHEELS)
Check warrant(s) (W1) for support for (NOT WHEELS).

Trying W1 with ((AND (NOT MOBILE)))
to support (NOT WHEELS).

Looking for support for claim (NOT MOBILE)

No warrant support found.
No support found.
No support found.
No support found.
No support found.

side 1 loses
Burden of proof on side 1 was: dialectical validity

Side-1 tries to prove that the motor home can be searched, by showing that it is (like) an automobile, because it is mobile. However the warrant that could show this, i.e., "wheels -> mobile" is inhibited due to the modus ponens/abductive reasoning restriction. That is, since the fact "mobile" has already been "explained" by "wheels" (and "motor home"), it is not appropriate to speculate (via abductive reasoning) about another "explanation" for "mobile", i.e., "automobile". Of course, in this example, the modus ponens/abduction combination would serve a different purpose: to show that two objects share a common property, and therefore are "similar" (and might or should share other properties, in this example, being "searchable").

Side-1 tries another route, to show that a motor home is not (like) a trunk, which is definitely not exempt from fourth amendment restrictions, but that fails, and Side-1 concedes the argument.

EXAMPLE 7

We give DART output for another example from (Marshall, 1989). Here, there is no attempt to show similarity between objects; DART deals straightforwardly with a knowledge base containing inconsistent information:

```
(w1 ((fleeing) (burglar))  --> ex s ((fleeing felon)) (!? GIVEN))
(w2 ((fleeing felon))  --> ex df ((deadly force is reasonable)) (!? GIVEN))
(w3 ((another office available)) --> ex ev
                    ((non-violent apprehension possible)) (!? GIVEN))
(w4 ((non-violent apprehension possible)  --> ex ev
                    ((not deadly force is reasonable)) (!? GIVEN))
(w5 ((fleeing felon))  --> ex s ((not state violation)) (!? GIVEN))
(w6 ((not state violation))  --> ex df ((deadly force only deterrent)) (!? GIVEN))
(w7 ((deadly force only deterrent))  --> ex df
                    ((deadly force is reasonable)) (!? GIVEN))

(d1 (burglar) (!? GIVEN))
(d2 (fleeing) (!? GIVEN))
(d3 (unarmed) (!? GIVEN))
(d4 (non-violent) (!? GIVEN))
(d5 (private residence) (!? GIVEN))
(d6 (unoccupied) (!? GIVEN))
(d7 (ten dollars) (!? GIVEN))
(d8 (officer available) (!? GIVEN))
(d9 (another officer available) (!? GIVEN))
(claim (deadly force is reasonable) (?? NIL))
```

That is, when in pursuit of a fleeing felon, the use of deadly force is reasonable. Deadly force is also reasonable when it is the only deterrent to flight. However, when non-violent apprehension is possible, the use of deadly force is not reasonable. A fleeing burglar is, by definition, a fleeing felon; a fleeing felon is, by definition, not in violation of any state code. In this circumstance, the use of deadly force would usually be the only deterrent to flight. The presence of more than one officer is an indication that a non-violent apprehension of a criminal is possible.

The current situation involves an unarmed, non-violent burglar, fleeing from an unoccupied, private residence. Less than ten dollars was stolen. There are at least two officers available to stop the burglar. Is the use of deadly force reasonable in these circumstances? DART generates the following argument:

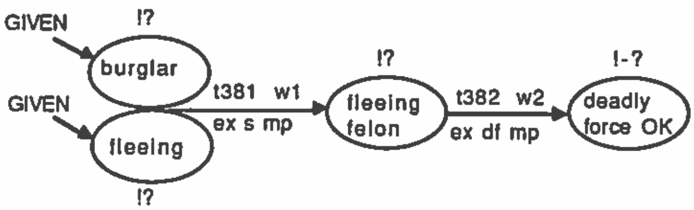
Starting ARG...
Side 1 is looking for support for (DEADLY FORCE IS REASONABLE)
Burden of proof on side 1 is dialectical validity.

Claim ((DEADLY FORCE IS REASONABLE)) is supported by ((FLEEING FELON))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t382
Claimnode qualification is: (!- ?)

Claim ((FLEEING FELON)) is supported by ((BURGLAR) (FLEEING))
Warrant id: W1 - Wtype1: EX - Wtype2: S - Rtype: MP
New tau id: #:\t381
Claimnode qualification is: (! ?)

Claim (BURGLAR) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (FLEEING) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



Side-1 makes its argument for the reasonableness of deadly force based on the rule that it is appropriate to use deadly force to stop a fleeing felon, and the individual involved is a fleeing felon. Side-2 responds:

---**Side 2 is next.

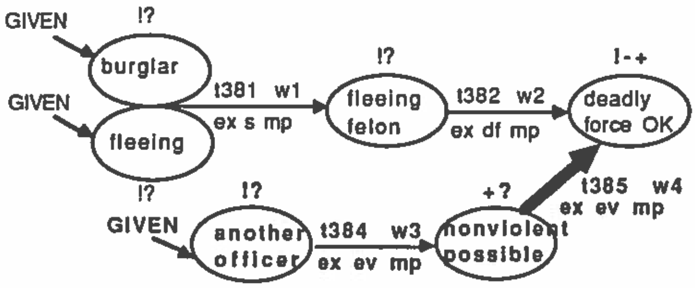
Next move for side 2 is:
Find support for (AND (NOT DEADLY FORCE IS REASONABLE))

Claim ((NOT DEADLY FORCE IS REASONABLE)) is supported by ((NON-VIOLENT APPREHENSION POSSIBLE))
Warrant id: W4 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t385
Claimnode qualification is: (!- +)

Claim ((NON-VIOLENT APPREHENSION POSSIBLE)) is supported by
((ANOTHER OFFICER AVAILABLE))
Warrant id: W3 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t384
Claimnode qualification is: (+ ?)

Claim (ANOTHER OFFICER AVAILABLE) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Tau #:\t385: ((AND (NON-VIOLENT APPREHENSION POSSIBLE))->(NOT
DEADLY FORCE IS REASONABLE))
makes top claim: (DEADLY FORCE IS REASONABLE) controversial - FS.



Side-2 points out that there are exceptions (represented in the knowledge base as competing warrants) to the simple rule used by Side-1. Here, Side-2 is able to show that non-violent apprehension of the felon might have been possible; therefore, the use of deadly force was not reasonable. Side-1 is unable to defeat this argument, and concedes the claim:

--**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (DEADLY FORCE IS REASONABLE) was NOT established.
Burden of proof on side 1 was: dialectical validity

Side-1 would have won if the proof level had been preponderance of the evidence. (In that case, Side-2 would not have even generated its argument, as it was too weak from the beginning, relying on an evidential warrant.) It is also interesting to note that much of the knowledge in the input data base was not used anywhere in the argument, because there were no warrants to match it. This is the kind of knowledge that the judges in the case made use of to draw distinctions (see Chapter IV).

EXAMPLE 8

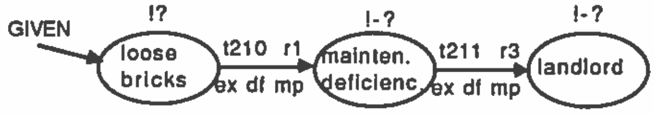
This problem, which demonstrates default and (rule-based) legal reasoning, is from (Prakken, 1991). The knowledge is represented by the following warrants and data:

```
(r1 ((loose bricks)) --> ex df ((maintenance deficiency)) (!? GIVEN))
(r2 ((loose bricks)(near road)) --> ex df ((danger)) (!? GIVEN))
(r3 ((maintenance deficiency)) --> ex df ((landlord responsible)) (!? GIVEN))
(r4 ((maintenance deficiency)) --> ex df ((not tenant responsible)) (!? GIVEN))
(r5 ((danger)) --> ex ev ((tenant responsible)) (!? GIVEN))
(r6 ((danger)) --> ex df ((not landlord responsible)) (!? GIVEN))
(r7 ((loose bricks)(near road)(seldom used)) --> ex df ((not danger)) (!? GIVEN))

(d1 (loose bricks) (!? GIVEN))
(d2 (near road) (!? GIVEN))
(d1 (seldom used) (!? GIVEN))
(claim (landlord responsible) (?? NIL))
```

That is, loose bricks in a rental unit are usually a maintenance deficiency, and taking care of maintenance deficiencies is the responsibility of the landlord, not the tenant. However, if the loose bricks are near a road, they constitute a danger, in which case the tenant, rather than the landlord, is responsible for the problem. However, loose bricks near a road that is seldom used should not be considered a danger. In this case, there were loose bricks, near a road, and the road was rarely used. Is the landlord responsible? DART output for this example is as follows:

```
Starting ARG...
Side 1 is looking for support for (LANDLORD RESPONSIBLE)
Burden of proof on side 1 is dialectical validity.

Claim ((LANDLORD RESPONSIBLE)) is supported by
((MAINTENANCE DEFICIENCY))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t211
Claimnode qualification is: (!- ?)

Claim ((MAINTENANCE DEFICIENCY)) is supported by ((LOOSE BRICKS))
Warrant id: R1 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t210
Claimnode qualification is: (!- ?)
```

Claim (LOOSE BRICKS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



--**Side 2 is next.

. . . Next move for side 2 is:
Question data: find support or bolster (AND (NOT MAINTENANCE DEFICIENCY))

Claim ((NOT MAINTENANCE DEFICIENCY)) is supported by ((TENANT RESPONSIBLE))
Warrant id: R4 - Wtype1: EX - Wtype2: DF - Rtype: MT
New tau id: #:\t216
Claimnode qualification is: (!- !-)

Claim ((TENANT RESPONSIBLE)) is supported by ((DANGER))
Warrant id: R5 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t215
Claimnode qualification is: (!- ?)

Claim ((DANGER)) is supported by ((NEAR ROAD) (LOOSE BRICKS))
Warrant id: R2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t214
Claimnode qualification is: (!- ?)

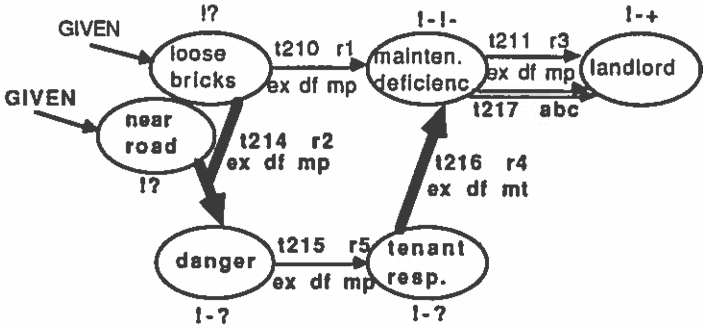
Claim (NEAR ROAD) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (LOOSE BRICKS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t216:
*((AND (TENANT RESPONSIBLE))->(NOT MAINTENANCE DEFICIENCY))
*makes tau #:\t211: ((AND (MAINTENANCE DEFICIENCY))->
*(AND (LANDLORD RESPONSIBLE))) controversial - FS-OR-BOLSTER.

Claim (AND (NOT LANDLORD RESPONSIBLE)) is supported by (AND (NOT MAINTENANCE DEFICIENCY))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t217
Claimnode qualification is: (!- +)

Qualification for claim (LANDLORD RESPONSIBLE) is (!- +)



--**Side 1 is next.

. . . Next move for side 1 is:
Find exception for rule (AND (NEAR ROAD) (LOOSE BRICKS)) ->
(AND (DANGER))

Claim ((NOT DANGER)) is supported by ((SELDOM-USED) (NEAR ROAD)
(LOOSE BRICKS))
Warrant id: R7 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t218
Claimnode qualification is: (? !-)

Claim (SELDOM-USED) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (NEAR ROAD) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Claim (LOOSE BRICKS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t218: ((AND (SELDOM-USED) (NEAR ROAD) (LOOSE BRICKS))->
*(NOT DANGER))
*makes tau #:\t214: ((AND (NEAR ROAD) (LOOSE BRICKS))->(AND (DANGER)))
*defeated - EXCEPTION.

Claim (AND (NOT TENANT RESPONSIBLE)) is supported by (AND (NOT
DANGER))
Warrant id: R5 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t219
Claimnode qualification is: (? +)

Claim (AND (MAINTENANCE DEFICIENCY)) is supported by (AND (NOT
TENANT RESPONSIBLE))
Warrant id: R4 - Wtype1: EX - Wtype2: DF - Rtype: ABD
New tau id: #:\t220
Claimnode qualification is: (!- ?)

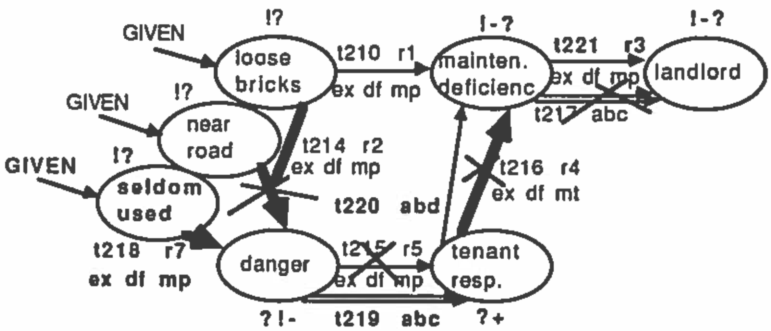
Claim (AND (LANDLORD RESPONSIBLE)) is supported by (AND (MAINTENANCE DEFICIENCY))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t221
Claimnode qualification is: (!- ?)

Tau #:\t215: (AND (DANGER)) -> (AND (TENANT RESPONSIBLE))
is withdrawn.

Tau #:\t216: (AND (TENANT RESPONSIBLE)) -> (AND (NOT MAINTENANCE DEFICIENCY))
is withdrawn.

Tau #:\t217: (AND (NOT MAINTENANCE DEFICIENCY)) -> (AND (NOT LANDLORD RESPONSIBLE))
is withdrawn.

Qualification for claim (LANDLORD RESPONSIBLE) is (!- ?)



--**Side 2 is next.

Side 2 has no more arg moves.
Side 1 wins.
Claim (LANDLORD RESPONSIBLE) was established.
Burden of proof on side 1 was: dialectical validity

EXAMPLE 9

We give DART output for an example from a critical reasoning text (Kahane, 1988) to show that it generates reasonable output for an "everyday reasoning" problem. The argument given in the text is: since identical twins have the same genes, and identical twins do not score the same on IQ tests, then the environment must play some part in determining IQ. In DART, some knowledge that is implicit in this argument must be made explicit; knowledge is represented by the following warrants and data:

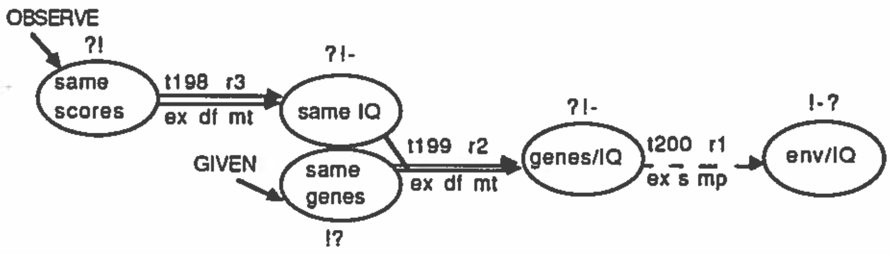
```
(r1 ((not genes completely determine iq)) --> ex s
        ((environment partially determines iq)) (!? GIVEN))
(r2 ((genes completely determine iq) (same genes)) --> ex df
        ((same iq)) (!? GIVEN))
(r3 ((same iq)) --> ex df ((same testscores)) (!? GIVEN))

(d1 (same genes) (!? GIVEN))
(d2 (not same testscores) (!? OBSERVE))
(claim (environment partially determines iq) (?? NIL))
```

In addition to the data about twins, DART contains three warrants that link the data with conclusions that support the top claim. DART then generates the following argument:

```
Starting ARG...
Side 1 is looking for support for (ENVIRONMENT PARTIALLY DETERMINES IQ)
Burden of proof on side 1 is dialectical validity.

Claim ((ENVIRONMENT PARTIALLY DETERMINES IQ)) is supported by
((NOT GENES COMPLETELY DETERMINE IQ))
Warrant id: R1 - Wtype1: EX - Wtype2: S - Rtype: MP
New tau id: #:\t200
Claimnode qualification is: (!- ?)

Claim ((NOT GENES COMPLETELY DETERMINE IQ)) is supported by
((NOT SAME IQ) (SAME GENES))
Warrant id: R2 - Wtype1: EX - Wtype2: DF - Rtype: MT
New tau id: #:\t199
Claimnode qualification is: (? !-)

Claim ((NOT SAME IQ)) is supported by ((NOT SAME TESTSCORES))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: MT
New tau id: #:\t198
Claimnode qualification is: (? !-)
```

Claim (NOT SAME TESTSCORES) is already supported.
Backing is OBSERVE
Claimnode qualification is: (? !)

Claim (SAME GENES) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



--**Side 2 is next.

Side 2 has no more arg moves.
Side 1 wins.
Claim (ENVIRONMENT PARTIALLY DETERMINES IQ) was established.
Burden of proof on side 1 was: dialectical validity

This is the same argument as the one given in (Kahane, 1988), with the warrant links between data and conclusions explicitly rather than implicitly represented. Modus tollens reasoning plays an important part in the argument.

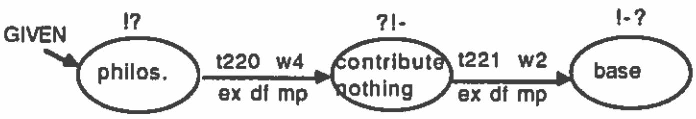
EXAMPLE 10

We give DART output for an example problem in (Ryan, 1984), for a demonstration of DART argumentation generation capabilities for a simple, inconsistent knowledge base. The knowledge is represented by the following warrants and data:

```
(w1 ((followers of art))  --> ex df ((not base)) (!? GIVEN))
(w2 ((contribute nothing))  --> ex df ((base)) (!? GIVEN))
(w3 ((philosophers)) --> ex df ((followers of art)) (!? GIVEN))
(w4 ((philosophers)) --> ex df ((contribute nothing)) (!? GIVEN))
(w5 ((cynics)) --> ex df ((philosophers)) (!? GIVEN))
(w6 ((cynics)) --> ex df ((contribute nothing)) (!? GIVEN))

(d1 (philosophers) (!? GIVEN))
(claim (base) (?? NIL))
```

Followers of art are not base, unlike those who contribute nothing to society. Philosophers are both followers of art and contribute nothing to society. Cynics, a particular school of philosophers, contribute nothing. Are philosophers base? DART generates the following argument:

```
Starting ARG...
Side 1 is looking for support for (BASE)
Burden of proof on side 1 is dialectical validity.

Claim ((BASE)) is supported by ((CONTRIBUTE NOTHING))
Warrant id: W2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t221
Claimnode qualification is: (!- ?)

Claim ((CONTRIBUTE NOTHING)) is supported by ((PHILOSOPHERS))
Warrant id: W4 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t220
Claimnode qualification is: (!- ?)

Claim (PHILOSOPHERS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)
```



--**Side 2 is next.

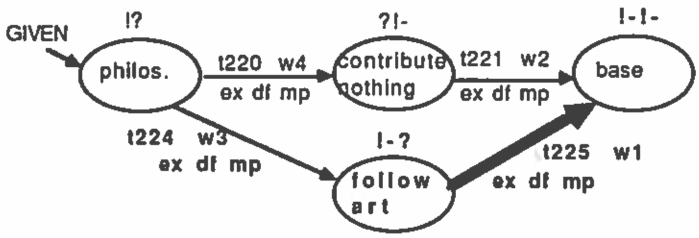
. . . Next move for side 2 is:
Find support for (AND (NOT BASE))

Claim ((NOT BASE)) is supported by ((FOLLOWERS OF ART))
Warrant id: W1 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t225
Claimnode qualification is: (!- !-)

Claim ((FOLLOWERS OF ART)) is supported by ((PHILOSOPHERS))
Warrant id: W3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t224
Claimnode qualification is: (!- ?)

Claim (PHILOSOPHERS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

Tau #:\t225: ((AND (FOLLOWERS OF ART))->(NOT BASE))
makes top claim: (BASE) controversial - FS.



--**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (BASE) was NOT established.
Burden of proof on side 1 was: dialectical validity

Side-1 has another argument it could make, namely, that the philosophers might be cynics, and cynics are base. However, in light of Side-2's irrefutable argument, the additional argument would not help Side-1 for proof levels dialectical validity or beyond a reasonable doubt. Neither would it help for preponderance of the evidence, since the remaining argument is weaker than the one Side-1 has already given. For scintilla of evidence, Side-1 already has a strong enough argument.

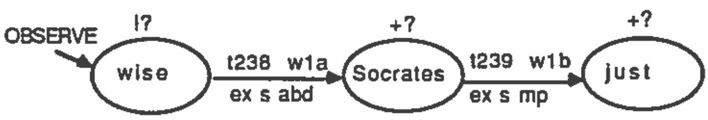
EXAMPLE 11

We give DART output for another example in (Ryan, 1984), to show a DART argument that highlights abductive reasoning. The knowledge is represented by the following warrants and data:

```
(w1a ((Socrates)  --> ex s ((wise)) (!? GIVEN))
(w1b ((Socrates))  --> ex s ((just)) (!? GIVEN))
(w2a ((Cleon)) --> ex s ((wise)) (!? GIVEN))
(w2b ((Cleon)) --> ex s ((not just)) (!? GIVEN))

(d1 (wise) (!? OBSERVE))
(claim (just) (?? NIL))
```

Here we are told about Socrates, a person who was both wise and just, and Cleon, who was also wise, but not just. In general, should it be said that wise persons are just? DART generates the following argument:

```
Starting ARG...
Side 1 is looking for support for (JUST)
Burden of proof on side 1 is dialectical validity.

Claim ((JUST)) is supported by ((SOCRATES))
Warrant id: W1B - Wtype1: EX - Wtype2: S - Rtype: MP
New tau id: #:\t239
Claimnode qualification is: (+ ?)

Claim ((SOCRATES)) is supported by ((WISE))
Warrant id: W1A - Wtype1: EX - Wtype2: S - Rtype: ABD
New tau id: #:\t238
Claimnode qualification is: (+ ?)

Claim (WISE) is already supported.
Backing is OBSERVE
Claimnode qualification is: (! ?)
```



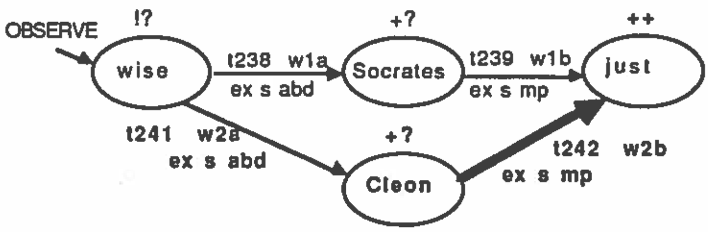
---**Side 2 is next.

Claim ((NOT JUST)) is supported by ((CLEON))
Warrant id: W2B - Wtype1: EX - Wtype2: S - Rtype: MP
New tau id: #:\t242
Claimnode qualification is: (+ +)

Claim ((CLEON)) is supported by ((WISE))
Warrant id: W2A - Wtype1: EX - Wtype2: S - Rtype: ABD
New tau id: #:\t241
Claimnode qualification is: (+ ?)

Claim (WISE) is already supported.
Backing is OBSERVE
Claimnode qualification is: (! ?)

Tau #:\t242: ((AND (CLEON))->(NOT JUST))
makes top claim: (JUST) controversial - FS.



---**Side 1 is next.

Side 1 has no more arg moves.
Side 2 wins.
Claim (JUST) was NOT established.
Burden of proof on side 1 was: dialectical validity

Socrates is cited as an example of someone who was both wise and just. However, Side-2 has a counterexample in Cleon, and Side-1 must concede the argument.

EXAMPLE 12

We give DART output for an example from (Cohen, 1985), and contrast argument with endorsements. Knowledge is represented by the following warrants and data:

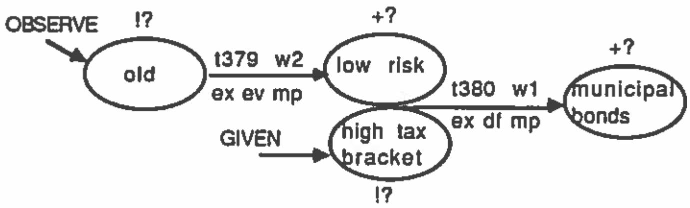
```
(w1 ((high tax bracket) (low risk tolerance)  --> ex df ((municipal bonds)) (!? GIVEN))
(w2 ((old))  --> ex ev ((low risk tolerance)) (!? GIVEN))
(w3 ((requires a lot of money relative to capital)) --> ex ev
                                                    ((low risk tolerance)) (!? GIVEN))

(d1 (old) (!? OBSERVE))
(d1 (requires a lot of money relative to capital) (!? GIVEN))
(d1 (high tax bracket) (!? GIVEN))
(claim (municipal bonds) (?? NIL))
```

Municipal bonds are usually indicated if an investor is in a high tax bracket and has a low risk tolerance. Being old is an indication of low risk tolerance, as is requiring a lot of money relative to the ability of capital to produce it. The current situation involves someone who is old, requires a lot of money relative to their capital, and is in a high tax bracket. Would municipal bonds be a good investment for such a person?

Reasoning from input data and warrants to the claim is straightforward; DART generates the following argument:

```
Starting ARG...
Side 1 is looking for support for (MUNICIPAL BONDS)
Burden of proof on side 1 is preponderance of the evidence.

Claim ((MUNICIPAL BONDS)) is supported by
((LOW RISK TOLERANCE) (HIGH TAX BRACKET))
Warrant id: W1 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t380
Claimnode qualification is: (+ ?)

Claim ((LOW RISK TOLERANCE)) is supported by ((OLD))
Warrant id: W2 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t379
Claimnode qualification is: (+ ?)

Claim (OLD) is already supported.
Backing is OBSERVE
Claimnode qualification is: (! ?)
```

Claim (HIGH TAX BRACKET) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)



---**Side 2 is next.

Side 2 has no more arg moves.
Side 1 wins.
Claim (MUNICIPAL BONDS) was established.
Burden of proof on side 1 was: preponderance of the evidence.

Cohen (1985) uses this problem to show how endorsements can affect reasoning. In his example, warrants w2 and w3 are both endorsed as "too general". Therefore, neither of them on their own could be used to conclude "low risk tolerance", but both of them together could be (as would be possible here). DART represents "too general" by setting the type of the warrant to evidential only. But there is nothing to stop DART from then using one warrant at a time to support the "low risk tolerance" claim, though the claim is qualified as credible to reflect its weaker backing. If DART needed additional evidence to support "low risk tolerance", for example, if Side-2 had evidence against, then the other evidential warrant could have been used. Since the claim was not controversial, the extra evidence was not used in this example.

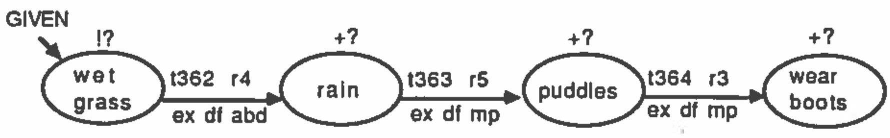
EXAMPLE 13

This problem is an extension of the problem given in Appendix C: When there are puddles, one should generally wear boots. Rain causes puddles and wet grass; thunder is evidence of rain. Sprinklers, like rain, cause wet grass. If a sprinkler were on, that would indicate that it is not winter. It is not winter; there is thunder and the grass is wet. Would it be a good idea to wear boots? This information is represented in DART as follows:

```
(r1 ((sprinkler))  --> ex ev ((not winter)) (!? GIVEN))
(r2 ((sprinkler))  --> ex df ((wet grass)) (!? GIVEN))
(r3 ((puddles)) --> ex df ((wear boots)) (!? GIVEN))
(r4 ((rain)) --> ex df ((wet grass)) (!? GIVEN))
(r5 ((rain)) --> ex df ((puddles)) (!? GIVEN))
(r6 ((thunder)) --> ex ev ((rain)) (!? GIVEN))

(d1 (wet grass) (!? GIVEN))
(d2 (not winter) (?! GIVEN))
(d3 (thunder) (!? GIVEN))
(claim (wear boots) (?? NIL))
```

The argument generated by DART shows an argument around abductive reasoning, and an example of bolstering a claim. Proof level is preponderance of the evidence.

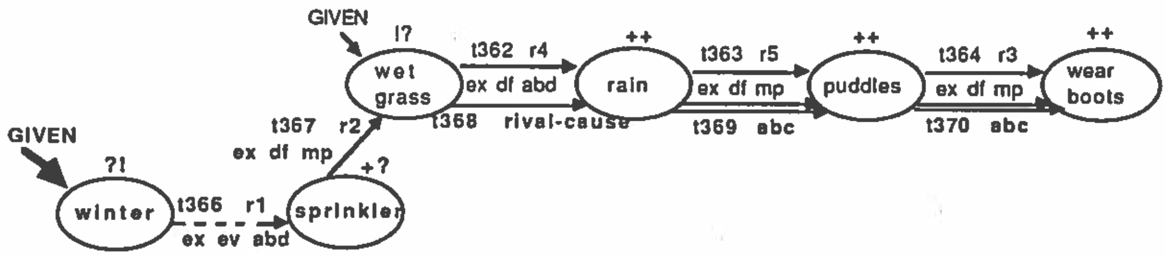
```
Starting ARG...
Side 1 is looking for support for (WEAR BOOTS)
Burden of proof on side 1 is preponderance of the evidence.

Claim ((WEAR BOOTS)) is supported by ((PUDDLES))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t364
Claimnode qualification is: (+ ?)

Claim ((PUDDLES)) is supported by ((RAIN))
Warrant id: R5 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t363
Claimnode qualification is: (+ ?)

Claim ((RAIN)) is supported by ((WET GRASS))
Warrant id: R4 - Wtype1: EX - Wtype2: DF - Rtype: ABD
New tau id: #:\t362
Claimnode qualification is: (+ ?)

Claim (WET GRASS) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)
```



Side-1 finds weak support for wearing boots, stemming from the wet grass, which might have been caused by rain, in which case there would also be puddles, in which case one should wear boots. Side-2 is given a chance to respond:

```
----------------------------------------------------------------**Side 2 is next.

... Next move for side 2 is:
Look for another explanation for (AND (WET GRASS))
to show (AND (RAIN)) is an unneeded explanation.

Claim ((WET GRASS)) is supported by ((SPRINKLER))
Warrant id: R2 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t367
Claimnode qualification is: (! ?)

Claim ((SPRINKLER)) is supported by ((NOT WINTER))
Warrant id: R1 - Wtype1: EX - Wtype2: EV - Rtype: ABD
New tau id: #:\t366
Claimnode qualification is: (+ ?)

Claim (NOT WINTER) is already supported.
Backing is GIVEN
Claimnode qualification is: (? !)

*Tau #:\t367: ((AND (SPRINKLER))->(WET GRASS))
*makes tau #:\t362: ((AND (WET GRASS))->(AND (RAIN))) controversial -
*UNNEEDED-EXPL.

Claim (AND (NOT RAIN)) is supported by (AND (WET GRASS))
Warrant id: R4 - Wtype1: EX - Wtype2: DF - Rtype: RIVAL-CAUSE
New tau id: #:\t368
Claimnode qualification is: (+ +)

Claim (AND (NOT PUDDLES)) is supported by (AND (NOT RAIN))
Warrant id: R5 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t369
Claimnode qualification is: (+ +)

Claim (AND (NOT WEAR BOOTS)) is supported by (AND (NOT PUDDLES))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: ABC
New tau id: #:\t370
Claimnode qualification is: (+ +)
```

Qualification for claim (WEAR BOOTS) is (+ +)



Side-2 counters by pointing out that the wet grass could have been caused by a sprinkler, rather than rain; since it is not winter, the sprinkler might have been on. Support for "sprinkler" is not strong enough to defeat "rain", but it is enough to make "rain", and therefore the entire argument up to "wear boots", controversial. Side-1 responds:

---**Side 1 is next.

. . . Next move for side 1 is:
Question data: find support or bolster (AND (RAIN))

Claim ((RAIN)) is supported by ((THUNDER))
Warrant id: R6 - Wtype1: EX - Wtype2: EV - Rtype: MP
New tau id: #:\t371
Claimnode qualification is: (+^ +)

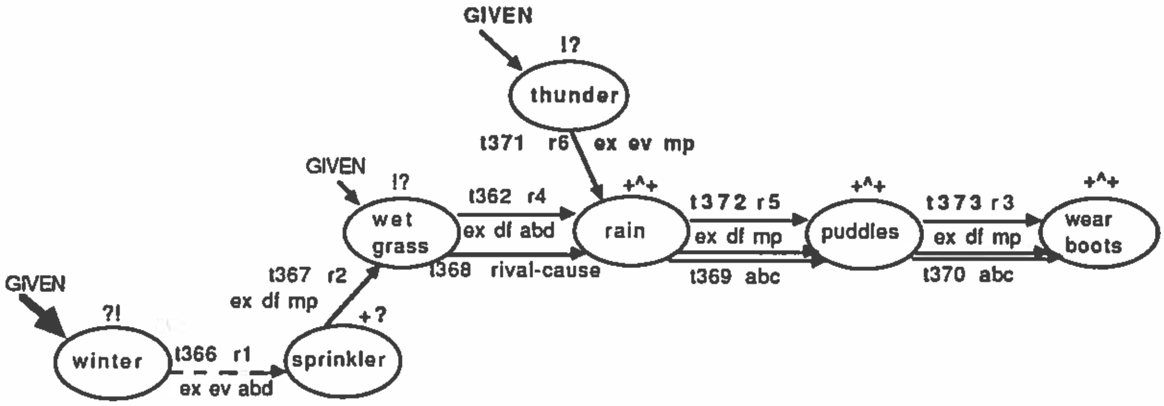
Claim (THUNDER) is already supported.
Backing is GIVEN
Claimnode qualification is: (! ?)

*Tau #:\t371: ((AND (THUNDER))->(RAIN))
*makes tau #:\t369: ((AND (NOT RAIN))->(AND (NOT PUDDLES))) controversial -
*FS-OR-BOLSTER.

Claim (AND (PUDDLES)) is supported by (AND (RAIN))
Warrant id: R5 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t372
Claimnode qualification is: (+^ +)

Claim (AND (WEAR BOOTS)) is supported by (AND (PUDDLES))
Warrant id: R3 - Wtype1: EX - Wtype2: DF - Rtype: MP
New tau id: #:\t373
Claimnode qualification is: (+^ +)

Qualification for claim (WEAR BOOTS) is (+^ +)



Side-1 defends its argument by bolstering its support for rain; there was thunder, which is evidence for rain. The preponderance of the evidence is with Side-1 again.

---**Side 2 is next.

Side 2 has no more arg moves.
Side 1 wins.
Claim (WEAR BOOTS) was established.
Burden of proof on side 1 was: preponderance of the evidence.

BIBLIOGRAPHY

Ashley, K. (1988). Modelling legal argument: reasoning with cases and hypotheticals (COINS Tech Report 88-01). Amherst, MA: University of Massachusetts, Department of Computer Science.

Ashley, K. (1989). Toward a computational theory of arguing with precedents. *Proceedings of the Second International Conference on Artificial Intelligence and Law*. 93-102.

Barth, E.M. & Krabbe, E.C.W. (1982). *From axiom to dialog: a philosophical study of logics and argumentation*. Berlin, NY: Walter de Gruyter.

Buchanan, B. & Shortliffe, E. (1984). *Rule-based expert systems*. Reading, MA: Addison-Wesley.

Cohen, P. (1985). *Heuristic reasoning about uncertainty: an artificial intelligence approach*. Los Altos, CA: Morgan Kaufmann Publishers, Inc.

Conklin, J. (1988). Design rationale and maintainability (Report STP-249-88). Microelectronics and Computer Technology Corporation.

Cox, J. R. & Willard, C. A. (Eds.). (1982). *Advances in argumentation theory and research*. Carbondale: Southern Illinois University Press.

Dubois, D. & Prade, H. (1989). Handling uncertainty in expert systems - pitfalls, difficulties, remedies. In E. Hollnagel (Ed.), *The reliability of expert systems* (pp. 64-118). West Sussex: Ellis Horwood Limited.

Flowers, M., McGuire, R., & Birnbaum, L. (1982). Adversary arguments and the logic of personal attacks. In W. Lehnert & M. Ringle (Eds.), *Strategies for natural language processing* (pp. 275-294). Hillsdale, N.J.: Erlbaum Associates.

Freeley, A. (1990). *Argumentation and debate: Critical thinking for reasoned decision making* (7th ed.). Belmont, CA: Wadsworth Publishing Company.

Guha, R. (1990). The representation of defaults in Cyc. *Proceedings of the Eighth National Conference on Artificial Intelligence*. 608-614.

Hample, D. (1982). Modeling argument. In J. R. Cox & C. A. Willard (Eds.), *Advances in argumentation theory and research* (pp. 259-284). Carbondale: Southern Illinois University Press.

Horner, W. (1988). *Rhetoric in the classical tradition*. New York: St. Martin's Press.

Horty, J., Thomason, R., & Touretzky, D. (1987). A skeptical theory of inheritance in nonmonotonic semantic networks. *Proceedings of the Sixth National Conference on Artificial Intelligence*. 358-363.

Kahane, H. (1988). *Logic and contemporary rhetoric* (5th ed.). Belmont, CA: Wadsworth Publishing Co.

Kuhn, D. (1991). *The skills of argument.* Cambridge: Cambridge University Press.

Kyburg, H. (1991). How to settle an argument. *Proceedings of the AAAI Spring Symposium on Argumentation and Belief.* 116-121.

Lea Sombe (1990). Reasoning under incomplete information in artificial intelligence. *International Journal of Intelligent Systems, 5*, 323-472.

Lee, J. (1991). DRL: A task-specific argumentation language. *Proceedings of the AAAI Spring Symposium on Argumentation and Belief.* 122-132.

Lenat, D. & Guha, R. (1990). Cyc: a mid-term report. *AI Magazine, 11*, 32-59.

Lorenz, K. (1978). On the criteria for the choice of rules of dialogic logic. In E. Barthe & J. Martens (Eds.), *Argumentation: approaches to theory formation* (pp. 145-157). Amsterdam: John Benjamins B.V.

Loui, R. (1987). Defeat among arguments: a system of defeasible inference. *Computational Intelligence, 3*, 100-106.

Lumer, C. (1988). The disputation - a special type of cooperative argumentation dialogue. *Argumentation, 2*, 441-464.

Marshall, C. (1989). Representing the structure of a legal argument. *Proceedings of the Second International Conference on Artificial Intelligence and Law.* 121-127.

Pearl, J. (1987). Embracing causality in formal reasoning. *Proceedings of the Sixth National Conference on Artificial Intelligence.* 369-373.

Pollock, J. (1987). Defeasible reasoning. *Cognitive Science, 11*, 481-518.

Pollock, J. (1991). A theory of defeasible reasoning. *International J of Intelligent Systems, 6*, 33-54.

Pollock, J. (1992). How to reason defeasibly. *Artificial Intelligence, 57*, 1-42.

Polya, G. (1968). *Mathematics and plausible reasoning* (2nd ed.) (vol. II). Princeton, NJ: Princeton University Press.

Poole, D. (1989). Explanation and prediction: an architecture for default and abductive reasoning. *Computational Intelligence, 5*, 97-110.

Porter, B., Bareiss, R., & Holte, R. (1990). Concept learning and heuristic classification in weak theory domains. *Artificial Intelligence, 45*, 229-263.

Prakken, H. (1991). A tool in modelling disagreement in law: preferring the most specific argument. *Proceedings of the Third International Conference on Artificial Intelligence and Law.* 165-174.

Priest, G. (1988). *Beyond consistency.* Hamden, Munchen, Wien: Philosophia Verlag.

Priest, G., Rowtley, R., & Norman, J. (1989). *Paraconsistent Logic: essays on the inconsistent.* Hamden, Munchen, Wien: Philosophia Verlag.

Proceedings of the AAAI Spring Symposium on Argumentation and Belief. (1991). Stanford University: Stanford, California.

Reichman-Adar, R. (1984). Extended person-machine interface. *Artificial Intelligence, 22.*

Rescher, N. (1976). *Plausible Reasoning.* Assen/Amsterdam, The Netherlands: Van Gorcum.

Rescher, N. (1977). *Dialectics: A controversy-oriented approach to the theory of knowledge.* Albany: State University of New York Press.

Rescher, N. & Brandom, R. (1980). *The logic of inconsistency.* Oxford: Basil Blackwell.

Rieke, R. & Sillars, M. (1984). *Argumentation and the decision making process.* Glenview, Illinois: Scott, Foresman and Company.

Rissland, E. (1985). Argument moves and hypotheticals. In C. Walter (Ed.), *Computing power and legal reasoning.* St. Paul: West Publishing Co.

Rissland, E. & Skalak, D. (1989). Interpreting statutory predicates. *Proceedings of the Second International Conference on Artificial Intelligence and Law.* 46-53.

Ryan, E. (1984). *Aristotle's theory of rhetorical argumentation.* Montreal: Bellarmin.

Simari, G. & Loui, R. A mathematical treatment of defeasible reasoning and its implementation. *Artificial Intelligence, 53*, 125-157.

Smolensky, S., Fox, B., King, R., & Lewis, C. (1988). Computer-aided reasoned discourse, or, how to argue with a computer. In R. Guindon (Ed.), *Cognitive science and its applications for human-computer interaction.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Storrs, G. (1991). Extensions to Toulmin for capturing real arguments. *Proceedings of the AAAI Spring Symposium on Argumentation and Belief.* 195-204.

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

van Eemeren, F. & Grootendorst, R. (1984). *Speech acts in argumentative discussions: a theoretical model for the analysis of discussions directed towards solving conflicts of opinion.* Dordrecht, Holland; Cinnaminson, U.S.A.: Foris Publications.