Qualitative Argumentation

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Abstract

A key question for research in model-based, qualitative reasoning is how to predict or analyze the behavior of complex systems without resorting to completely quantitative models. One difficulty that arises is the ambiguity of results due to conflicting indications. Argumentation has long been recognized as a means for resolving issues of belief in situations characterized by incomplete, uncertain, inconsistent, and imprecise knowledge. We explore the application of a model of dialectical argumentation to the domain of qualitative reasoning. Models take the form of qualitative networks, with variables connected by strict or default, positive or negative arcs. A notion of defeat between qualitative arguments represented as paths in a network is defined. Burden of proof is specified as a flexible means of allocating risk, determining relevant argument moves, and deciding eventual outcomes. Examples are presented that illustrate the semantics of our approach.

Introduction

A basic question addressed by research in model-based qualitative reasoning is how we can predict or analyze the behavior of complex systems without resorting to completely quantitative models. One difficulty that arises from the associated loss of precision in qualitative reasoning is the ambiguity of results due to conflicting indications. In a more general setting, argumentation has long been recognized as an appropriate means for resolving issues of belief in situations characterized by incomplete, uncertain, inconsistent, and imprecise knowledge (Polya, 1968). In this paper, we explore the application of a model of dialectical argumentation to issues of ambiguity resolution in qualitative reasoning about complex systems.

Qualitative Models

Models of qualitative systems and associated argument structures will be specified in a form derived from that used for inheritance reasoning (Horty, 1994). By this approach, qualitative models of complex systems are represented as qualitative networks, being directed graphs of nodes interconnected by typed, directed links. Nodes of a qualitative network, denoted by (names in) small letters, represent the variables and parameters of the system; we will use a small letter from the end of the alphabet (e.g., x, y, z) to represent an arbitrary node of a network.

The nodes of a qualitative network are interconnected by directed links, each link connecting a pair of nodes. There are four link types, corresponding to possible combinations of strength, either strict or default, and sign, either positive or negative. The link types $=_{+}>$ and $=_{-}>$ denote strict positive and strict negative links, respectively. The meaning of a strict link $x =_{+}> y$ (or $x =_{-}> y$) is that there is a reliable (i.e., always) influence of a change in x upon variable y. A positive link means the change in y is in the same direction as the change in x, while a negative sign indicates that the direction is the opposite. A strict link is used to represent definitional relationships in system models. Link types $-_{+}>$ and $-_{-}>$ denote default positive and default negative links, respectively. The meaning of a default link $x -_{+}> y$ (or $x -_{-}> y$) is that there is an expected, but somewhat unreliable, (i.e., usually) influence of a change in x upon the value of variable y. The meanings of the signs are the same as for strict links. Default links are used to represent observed, but unexplained, regularities or tendencies in system behavior.

Default links have also been called "defeasible" (Pollock, 1987), as they can be preempted by stronger, more conclusive indications during reasoning. We use the term "default" for these links to capture the rather strong connection that is intended. We reserve the term "defeasible" for a more general, somewhat weaker influence that exists between nodes interconnected by paths containing several default links, i.e., the default relation is not transitive. We will discuss the construction of allowable qualitative arguments in the next section.

A qualitative network can serve as basis for answering questions regarding directions of change in model variables given external, input perturbations of parameters or for suggesting changes to parameters that could give rise to a desired (or observed) direction of change in a model variable. Parameters are distinguished from variables in that they have no incoming links within the given qualitative network. Impacts on parameters will be indicated by connecting a special node labeled INPUT to parameters of the network by a set of strict, positive or negative, links. A strict link from INPUT to a parameter indicates a perturbation in the value of the affected parameter in the indicated direction (i.e., positive or negative). We provide an example of a qualitative network with an associated INPUT in Figure 1. In all figures, strict links will be shown as heavy lines.

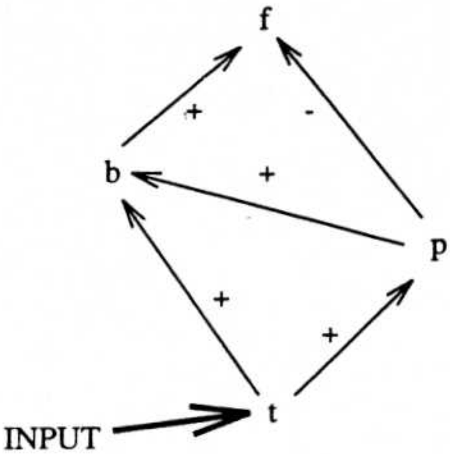

Figure 1.

Qualitative Arguments

Given a qualitative network modeling a complex system, we are interested in defining the notion of arguments for and against claims regarding changes in values of variables relative to a given input perturbation. An *qualitative argument* is a directed path in a qualitative network. We denote an argument P consisting of the path a,b,c,d,e as P(a,b,c,d,e); if node u immediately precedes node v in an argument path, then u is directly connected to v by a link of the qualitative network. An argument from a start node x to a finish node y through an intermediate, possibly empty, sequence of nodes π is denoted as P(x,π,y). Which directed paths form arguments and with what strengths and signs will be defined by argument construction rules given below.

We characterize an argument in terms of strength and sign. We introduce defeasible strength for arguments between nodes connected by paths involving more than one default link; defeasible arguments capture a qualitative relationship that is weaker than that established by either strict (always) or default (usually) links. If $P(x,\pi,y)$ is a defeasible positive argument, it represents the notion that "it is reasonable to believe that a change in x will result in a change in y in the indicated direction". If this path begins at a node INPUT, we are saying that "the given input perturbation set could reasonably be expected to result in the corresponding change in y". Distinguishing between strict, default, and defeasible argument strengths will allow us to capture, in a straightforward manner, certain reasoning results that seem intuitively correct. This will be demonstrated by examples presented later in the paper.

Allowable arguments in an inheritance network, with associated strengths and signs, are defined recursively, in the "backward direction" from a given goal node. Links in the network form direct arguments, as defined by the following argument construction rule:

Rule R1: (direct arguments)
- A. Given $x =_+> y$, $P(x,\epsilon,y)$ is a strict positive argument.
- B. Given $x =_-> y$, $P(x,\epsilon,y)$ is a strict negative argument.
- C. Given $x -_+ > y$, $P(x,\epsilon,y)$ is a default positive argument.
- D. Given $x -_- > y$, $P(x,\epsilon,y)$ is a default negative argument.

In the above rule, x refers to an arbitrary variable or parameter node x or INPUT; the symbol ϵ represents the empty sequence of nodes. We extend an argument by adding a new element as start node, creating a compound argument. We consider only acyclic compound arguments, defined by the following rule:

Rule R2: (compound arguments)
- A. If $P(x,\pi,y)$ is a strict positive argument not containing z, then
  - (i) given $z =_+> x$, $P'(z,x,\pi,y)$ is a strict positive argument;
  - (ii) given $z -_+ > x$, $P'(z,x,\pi,y)$ is a default positive argument;
  - (iii) given $z =_-> x$, $P'(z,x,\pi,y)$ is a strict negative argument;
  - (iv) given $z -_- > x$, $P'(z,x,\pi,y)$ is a default negative argument.
- B. If $P(x,\pi,y)$ is a strict negative argument not containing z, then
  - (i) given $z =_+> x$, $P'(z,x,\pi,y)$ is a strict negative argument;
  - (ii) given $z -_+ > x$, $P'(z,x,\pi,y)$ is a default negative argument;
  - (iii) given $z =_+> x$, $P'(z,x,\pi,y)$ is a strict positive argument;
  - (iv) given $z -_+ > x$, $P'(z,x,\pi,y)$ is a default positive argument.
- C. If $P(x,\pi,y)$ is a default positive argument not containing z, then
  - (i) given $z =_+> x$, $P'(z,x,\pi,y)$ is a default positive argument;

(ii) given $z -_+> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument;
(iii) given $z =_-> x$, $P'(z, x, \pi, y)$ is a default negative argument;
(iv) given $z -_-> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument.

D. If $P(x, \pi, y)$ is a default negative argument not containing z, then
(i) given $z =_+> x$, $P'(z, x, \pi, y)$ is a default negative argument;
(ii) given $z -_+> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument;
(iii) given $z =_-> x$, $P'(z, x, \pi, y)$ is a default positive argument;
(iv) given $z -_-> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument.

E. If $P(x, \pi, y)$ is a defeasible positive argument not containing z, then
(i) given $z =_+> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument;
(ii) given $z -_+> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument;
(iii) given $z =_-> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument;
(iv) given $z -_-> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument.

F. If $P(x, \pi, y)$ is a defeasible negative argument not containing z, then
(i) given $z =_+> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument;
(ii) given $z -_+> x$, $P'(z, x, \pi, y)$ is a defeasible negative argument;
(iii) given $z =_-> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument;
(iv) given $z -_-> x$, $P'(z, x, \pi, y)$ is a defeasible positive argument.

In rule R2, z represents either an arbitrary node of the network or INPUT. Unless otherwise specified, a variable subargument, such as π, can be empty, i.e., equal to ϵ. The sign of an argument corresponds to the multiplicative influence of the signed links along its path in the qualitative network. Of importance is how the strength of an argument is impacted by adding new links. Put simply, an argument path with one default link is of default strength; a path with more than one default link is of defeasible strength. A strict argument contains only strict links. An argument starting with INPUT is said to be *grounded*.

For example, given the network in Figure 1, we find three grounded arguments with respect to variable f, as follows: a negative, defeasible argument P_1(INPUT,t,p,f) and two positive, defeasible arguments P_2(INPUT,t,p,b,f) and P_3(INPUT,t,b,f).

We see that there are both positive and negative arguments regarding the conclusion that variable f increases as parameter t is perturbed upward. This is an example of the ambiguity that often arises in qualitative analyses of complex systems. From an argumentation perspective, we can restate this situation as arguments standing in a conflicting relationship to one another. Various definitions of conflict relationships between arguments have been given previously (Pollock, 1987; Loui, 1987; Sartor, 1993; Horty, 1994; Farley, 1996). Here, two arguments with the same start and finish nodes, $P(x, \pi_1, y)$ and $P'(x, \pi_2, y)$, *directly conflict* if they differ in sign. More generally, two arguments *conflict* if one directly conflicts with a subargument of the other, i.e., one argument is of the form $(\pi_1, x, \pi_2, y, \pi_3)$, the other is the form (x, π, y), where (x, π, y) and (x, π_2, y) are of opposite sign. In our example, we have the following pairs of conflicting, grounded arguments: (P_1, P_2) and (P_1, P_3).

Are there methods for resolving qualitative ambiguities, now that they are viewed as conflicts between qualitative arguments? One helpful notion is that of defeat between arguments. Certain pairs of arguments may stand in a stronger form of conflict relationship. In such cases, one argument will be said to defeat the other. Defeat between conflicting arguments is determined by comparing their respective strengths. To make this possible, we define a strict argument to be stronger than a default argument, which in turn is stronger than a defeasible argument.

One argument A *defeats* another argument B iff argument B is of the form $(\pi_1, x, \pi_2, y, \pi_3)$, A is of the form (x, π, y), argument A and the subargument (x, π_2, y) are of opposite sign, and A is of greater strength than the subargument (x, π_2, y) of B. In other words, an argument that conflicts with another argument and is of greater strength than the subargument with which it directly conflicts defeats the other argument. In our example from Figure 1, the argument P_4(p,ϵ,f) defeats argument P_2.

Defeating arguments are of course vulnerable to being defeated themselves. In addition, there is a vulnerability associated with intermediate nodes of defeating arguments. If argument $A(\pi_1, x, \pi_2, v, \pi_3)$, where π_1 is a sequence of one or more nodes, is defeated by an argument $B(x, \pi, y)$, where π is a sequence of one or more nodes, then the set of arguments starting at nodes of π_1 and ending at nodes of π that only pass through nodes of A and B constitutes the set of *vulnerable arguments* for the defeat relation between A and B. The vulnerable arguments associated with a defeat are those that start prior to the beginning of the defeating argument and end at intermediate nodes of the defeating argument. Finally, we say that an argument A *ultimately defeats* an argument B in a qualitative network Q only if A defeats B, A is not defeated, and none of the associated vulnerable arguments are defeated.

Burden of Proof

A qualitative claim is a statement regarding the influence of one element (i.e., variable, parameter, or INPUT perturbation) of a qualitative network on another variable of the network. A positive claim will be denoted as $x_+ > y$, while $x_- > y$ will denote the negative claim. Each grounded argument $P(INPUT, \pi, y)$ supports a positive or negative claim regarding the direction of influence of a specified input perturbation set on variable y of the model.

To determine the ultimate acceptability of a qualitative claim, we must decide which type of error, either of commission (i.e., false positive acceptance of a claim) or of omission (i.e., false negative rejection of a claim), we are more willing to accept. We would like to adjust this allocation of risk depending upon estimated consequences of wrongly accepting or rejecting a qualitative claim between a particular model element and a given variable.

We provide the ability to allocate risk in a flexible manner by specifying a burden of proof. A burden of proof is a parameter to the argument process, not a property of the reasoning system. One domain in which the notion of burden of proof has long been applied is that of legal reasoning. A different burden of proof may be mandated at each stage of a legal process or for a different type of legal action. For example, arguments sufficient to indict someone need not be as convincing as those needed to convict someone. When considering conviction in criminal cases, we are more concerned about errors of commission (i.e., a finding of guilt when not guilty) and, thus, place a high burden of proof on the side arguing for guilt.

There are two aspects to the specification of a burden of proof: (i) which side of a claim (positive or negative) bears the burden and (ii) what level of proof is required for acceptance of the claim. The first aspect addresses whether one is more concerned about accepting false positives, where the burden is placed on the claim of interest, or false negatives, where the burden is placed on the claim of opposite sign. Sometimes, we want a good argument supporting a claim before accepting it, where the risk associated with wrongly accepting the claim is perceived to be high. On other occasions, where accepting a claim has potentially high value and little perceived risk, we demand a good argument against the claim (i.e., of opposite sign) before denying its acceptance.

The second aspect of burden of proof, that of proof level, addresses the issue of what is considered to be a good, or sufficient, argument. Proof level will be based upon the following notions of defendable and justifiable arguments. A defendable argument is an argument that is not ultimately defeated by any other argument of a given qualitative network and INPUT perturbation. A justifiable argument is a defendable argument with the added condition that every argument that conflicts with it is ultimately defeated.

We now define the following three proof levels:

scintilla of evidence (se): there exists a defendable argument supporting the claim;

preponderance of evidence (pe): there exist more defendable arguments supporting the claim than its negation;

dialectical validity (dv): there exists a justifiable argument supporting the claim.

Winning a scintilla of evidence argument for a claim merely requires that some argument for the claim can be defended against all attacks. In a dialectical context, this means that only defeating arguments can be considered by the side opposing the claim; a conflicting argument of lesser or equal strength is irrelevant. Preponderance of evidence requires a means for assessing relative strengths of sets of conflicting, defendable arguments. We state that having a greater number of defendable arguments for a claim represents a stronger case. Under preponderance of evidence, if the opposing side finds an equally strong argument, this can not be ignored; the argument must be counteracted, either by defeating it or by finding a new argument of equal strength. Finally, dialectical validity requires not only that some argument be defendable but also that any conflicting argument be defeated, even though that argument is not any greater in strength.

We can now define the semantics associated with a given qualitative network Q and INPUT perturbation in terms of the sets of claims acceptable under differing burdens of proof. Given network Q and a perturbation set as links from INPUT, we denote by D(Q, INPUT) the set of defendable, grounded arguments. Similarly, we denote by J(Q, INPUT) the set of justifiable, grounded arguments. By our definitions, J(Q, INPUT) is a subset of D(Q, INPUT).

We denote by C(Q, INPUT, L) the set of claims that are acceptable with proof level L, given Q and INPUT. The set C(Q, INPUT, L) is derived from sets D(Q, INPUT) and J(Q, INPUT), as per our definitions above. A claim c is an element of C(Q, INPUT, se) iff there exists an argument for c as claim in D(Q, INPUT). A claim c is an element of C(Q, INPUT, pe) iff there exists more arguments for claim c in D(Q, INPUT) than there are arguments for the complement of c in D(Q, INPUT). A claim c is an element of C(Q, INPUT, dv) iff there exists an argument for claim c in J(Q, INPUT).

The three proof levels defined above create a hierarchy of acceptable claims based on set inclusion. For any Q and INPUT, C(Q, INPUT, se) contains C(Q, INPUT, pe), which contains C(Q, INPUT, dv). Only C(Q, INPUT, se) can contain contradictory claims, i.e., claims between the same model elements with opposite signs.

Examples

We now turn our attention to a number of examples that demonstrate general principles of our approach and illustrate the impact that burden of proof has upon argumentation semantics. Looking back to the example of Figure 1, both positive and negative claims can win only scintilla of evidence arguments; there is exactly one defendable, defeasible argument supporting each claim.

In Figure 2, we find the argument P_1(INPUT,e,d,b,a) of defeasible strength for a positive input perturbation to e resulting in a positive change in a. However, this argument is defeated by argument P_2(d,c,a), a negative argument of default strength defeating subargument P_3(d,b,a) of P_1. As a result, the only grounded, defendable argument is the negative argument P_4(INPUT,e,d,c,a). While it is only of defeasible strength, it is not attacked by any other defendable argument. Thus, the negative claim INPUT $_-$ > a prevails for all three burdens of proof.

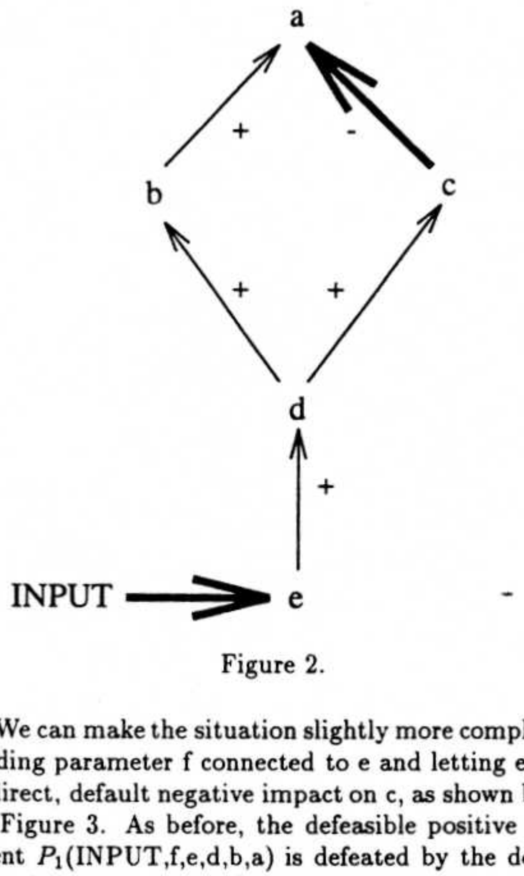

Figure 2.

We can make the situation slightly more complex by adding parameter f connected to e and letting e have a direct, default negative impact on c, as shown below in Figure 3. As before, the defeasible positive argument P_1(INPUT,f,e,d,b,a) is defeated by the default negative argument P_2(d,c,a). This time, however, the defeasible negative argument P_3(INPUT,f,e,d,c,a) is defeated by the default negative argument P_4(e,ϵ,c), which defeats subargument P_5(e,d,c) of P_3. By defeating P_5, argument P_4 reinstates P_1; it defeats a vulnerable argument associated with the defeat of P_1 by P_2. The only other defendable, grounded argument in this example is P_6(f,e,c,a), which is a defeasible positive argument.

Thus, we see that for the network of Figure 3, the claim INPUT $_+$ > a is acceptable up through a burden of proof of dialectical validity. In the previous two examples, if we did not consider the structure of the arguments involved and their conflict interactions, the qualitative indications would be ambiguous. By considering defeat relations among arguments, we see there is a clear prediction for direction of influence according to our argumentation semantics.

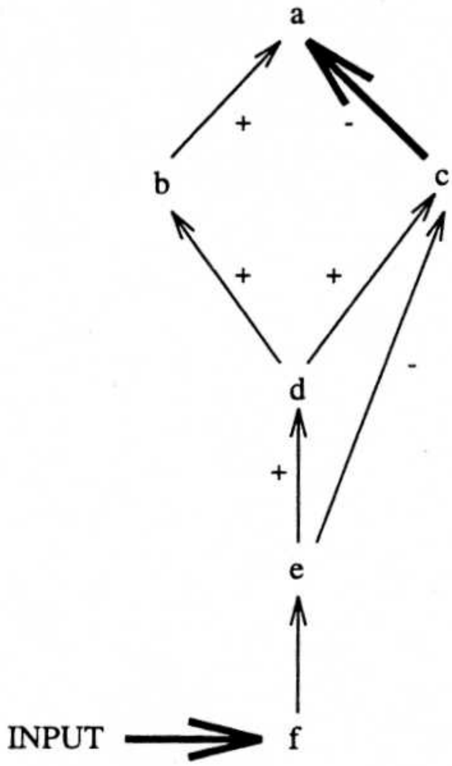

Figure 3.

We can create more ambiguous situations, such as the one presented in Figure 4. Here no arguments are defeated. As a result, there are three grounded, defendable arguments: P_1(INPUT,e,b,a), P_2(INPUT,e c,a) and P_3(INPUT,e,d,a). Argument P_1 indicates a negative influence, while P_2 and P_3 indicate positive. The claim INPUT $_-$ > a is acceptable with a burden of proof of scintilla of evidence. However, by being able to outweigh the set of arguments available for the negative claim, the claim INPUT $_+$ > a can win arguments up through a burden of proof of preponderance of evidence.

Recall that scintilla of evidence is the only burden of proof for which both positive and negative claims can be considered acceptable. Use of scintilla of evidence is appropriate for situations where there is little perceived risk in making errors of commission. Scintilla of evidence allows acceptance of a claim even when the

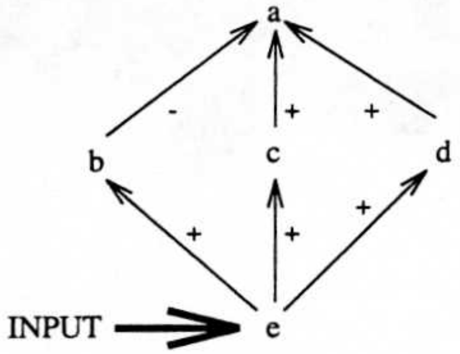

Figure 4.

other side has more arguments in its favor, as long as there exists a defendable argument for the claim. If any arc in Figure 4 were made strict, the argument containing it would become dominant. The associated claim would win arguments up through dialectical validity.

Economic reasoning is frequently based upon incomplete, imprecise models of complex interactions among markets (Farley and Lin, 1990). Thus, this domain is particularly well-suited to application of qualitative argumentation. We present a qualitative network designed to allow macroeconomic reasoning about the interactions between product and money markets in Figure 5, where the nodes are defined as follows:

PD: Product Demand
PS: Product Supply
EPD: Excess PD
P: Price
MD: Money Demand
MS: Money Supply
EMD: Excess MD
IR: Interest Rate

We have only two parameters in our model, MS and PS; the two market cycles are negative in sign, indicating their qualitative stability. The links from PD and PS (MD and MS) to EPD (EMD) are strict as EPD (EMD) is the defined to be the difference between the other two variables. Suppose we consider the impact that an increase to these parameters would have upon variable MD. For a perturbation of PS there is only one allowable, defeasible argument P_1(INPUT,PS,EPD,P,MD), which is of negative sign, so the negative claim would win arguments under all burdens of proof.

For a perturbation of MS there are two defeasible arguments P_2(INPUT,MS,EMD,IR,MD) and P_3(INPUT,MS,EMD,IR,PD,EPD,P,MD), both of which are positive. Suppose we perturb both PS and MS upward at the same time. At first blush, it appears that the two positive arguments P_2, P_3 would outweigh the single negative argument P_1, allowing

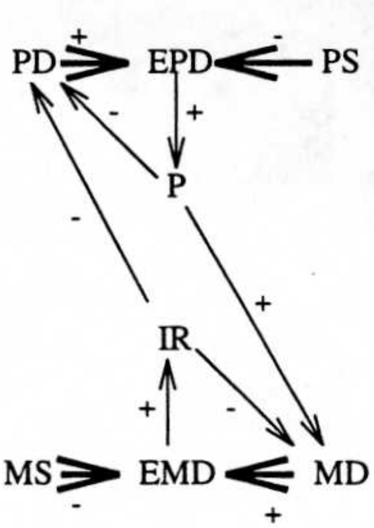

Figure 5.

the positive claim to be accepted up through preponderance of evidence, while the negative claim could only win scintilla of evidence arguments. However, the argument P_4(INPUT,PS,PD) would be of default strength and, therefore, defeat argument P_3. As such, both positive and negative claims can only muster one defendable, defeasible argument and are only accepted under the minimal, scintilla of evidence burden of proof.

Argument Process

Now that we have defined a structure for arguments as acyclic paths in a qualitative network and characterized several important properties of and relationships between arguments, we describe a process whereby we can decide whether to accept a claim or not. The decision will be made through a process of dialectical argumentation under a given burden of proof. The process model presented here is based upon a model of dialectical argumentation described earlier (Freeman, 1993; Farley and Freeman, 1995), modified and adapted to the circumstances of qualitative argumentation.

A dialectical argument has two sides, where Side-1 argues in favor of an input claim and Side-2 against the claim, i.e., in support of its negation. The argument process begins with Side-1 attempting to find a grounded argument for the input claim. Search for a supporting argument proceeds from the goal node toward the INPUT node in a backward-directed manner, according to the argument construction rules given above. If no support can be found, the argument ends with a loss for Side-1; all burdens of proof require Side-1 to find at least one grounded, defendable argument.

Subsequently, the two sides alternate as active side of the argument. A side remains active until it succeeds in creating a check condition or runs out of moves and must concede the argument. A *check condition* for a side S is a situation such that, if the other side can not successfully respond, side S wins the argument. Except for the initial situation, when Side-1 must generate a grounded argument for the claim, the active side is faced with a set of check arguments for the other side, i.e., arguments responsible for the other side holding the check condition.

When active, a side selects an argument move to apply from a set of possible moves. For this, a side can apply one of two primitive functions that search the qualitative network for relevant arguments. The first is *find-arguments (x, y, s, Q)*, which searches for argument paths from node x to node y of sign s in qualitative network Q. The function returns a list of argument paths in order of decreasing strength (i.e., the empty list if no such paths exist). The other function, *find-conflicting-arguments(A, Q)*, finds arguments that conflict with argument A in network Q, being equivalent to the union of directly conflicting arguments for each pair of nodes in A. This function is implemented by calls to the function *find-arguments* with parameters being pairs of nodes from argument A and the complement of the sign of the corresponding subargument in A. Defeating and rebutting (i.e., conflicting, but not defeating) arguments can be recognized in the process.

Whether an argument is adequate to generate a check condition for the active side depends upon the burden of proof specified. For example, under a burden of proof of dialectical validity, Side-2 can consider both defeating and rebutting arguments in response to Side-1's arguments. If Side-2 finds a conflicting argument, Side-1 must defeat Side-2's response or propose a completely new argument for its claim; otherwise, it must concede the argument. Side-2 can continue posing counterarguments, all of which Side-1 must defeat if it is to prevail under a burden of dialectical validity.

If the burden of proof is preponderance of evidence, then Side-2 must generate a counterargument of strength equal to that proposed by Side-1. If it can do this, Side-1's finding another argument in favor of the claim is sufficient to regain its check condition. As long as Side-1 can come up with more arguments of strength greater than or equal to those that Side-2 produces, it will prevail. If the burden of proof is merely scintilla of evidence, Side-2 can only consider defeating arguments in response to Side-1's arguments. Side-1 need not defeat rebuttals to win the argument under this burden of proof; it must merely defend some argument against defeat; if Side-2 can defeat an argument, Side-1 can abandon it in favor of another supporting the input claim.

We can characterize burden of proof in terms of where it places the "burden of defeat", i.e., which side must defeat the other's arguments. In the case of scintilla of evidence, the burden of defeat is on Side-2; while under a burden of proof of dialectical validity, the burden of defeat is on Side-1. Under preponderance of evidence, neither side takes on the burden of defeat. This is a free for all, where piling up more arguments of equal strength in favor of the given claim is sufficient.

We see that burden of proof plays several roles in the process of dialectical argumentation: (i) as basis for deciding the relevance of arguments found by the active side; (ii) as basis for deciding the sufficiency of the outcome of an active side's move; (iii) as basis for determining that an argument is over; and (iv) as basis for determining whether a claim is accepted or not. With scintilla of evidence or dialectical validity as burden of proof, the argument process may be shortened significantly due to the burden of defeat borne by one side of the argument.

Discussion

We have previously applied our framework for argumentation to the domains of legal reasoning and nonmonotonic inheritance (Farley and Freeman, 1995; Freeman and Farley, 1996; Farley, 1996). The current effort is most closely related to the work on inheritance reasoning, where inheritance arguments were defined to be paths in inheritance networks. The semantics of links in an inheritance network and the set of allowable arguments differ somewhat from those defined here for qualitative argumentation; the definitions of argument defeat and burden of proof are adopted directly.

More generally, an argument framework consists of three main elements:

(i) a logic for generating allowable, consistent arguments from background knowledge;

(ii) a definition of defeat between pairs (or sets) of arguments;

(iii) a decision process for determining which side prevails in a given argument (what claims are acceptable from given background information).

It is the second two aspects that distinguish argumentation from theorem proving and extend the applicability of the underlying logic from generating allowable, consistent arguments to making decisions in real-world contexts.

Under the approach for arguing about the implications of qualitative models presented here, we accept any acyclic path in a given qualitative nework as an allowable argument. In terms of defeat, we only considered comparisons between the predictability or reliability of opposing impacts upon a chosen variable, as determined by subpaths of differing arguments. We did not consider the possible magnitudes of impacts or the summation of impacts over several paths when defining defeat between arguments. We could extend our model to include these considerations. Each edge could be labeled by a coefficient capturing the relative impact that a unit change in the variable at the tail of a directed arc would have in terms of units of the variable at the head of the arc. Combining this impact label with the types we are currently using would allow us to capture the notion of expected impact on the variable at the head. Impact coefficient labels could be specified in qualitative or quantitative form. The presence of these labels would not alter the general framework we have defined, but would require a new specification of argument strength propagation and comparison.

The issue of representing additive effects in qualitative networks is more significant. In such networks, there can be two reasons that differing paths reach a given variable in the network. One is that each path represents an alternative explanation of a possible direction of change. Our argumentation semantics defined above reflects this view. The other reason is that each path represents a separate term of an additive or multiplicative impact on the variable. In this case, we would need to consider these paths as a single argument and develop appropriate definitions for strength computation and defeat determination. Our argumentation framework provides a structure within which to address this added complexity.

Conclusion

This paper reports results of an initial study applying notions developed previously in the field of argumentation to issues arising in qualitative reasoning about complex systems. The domain of qualitative reasoning is well-suited for the application of argumentation, as qualitative reasoning contexts are often characterized as being dependent upon incomplete, imprecise, uncertain, often conflicting indications. Dialectical argumentation provides a method for considering both sides of a qualitative claim and making a decision as to its acceptability based upon an appropriate allocation of risk by assigning burden of proof.

We have modified our previous Scheme implementation for the inheritance reasoning domain to perform the qualitative argumentation outlined in this paper. This implementation determines sets of claims acceptable for each of the three burdens of proof by computing the sets of justifiable and defendable arguments. The next steps for our research will be to reimplement the argumentation system in terms of the dialectical argument process described above and to use this to explore problem solving and diagnostic reasoning over complex qualitative networks modeling interesting, real-world systems. One example domain would be economics, as we have illustrated, where impacts among variables are often not well understood, giving rise to non-strict links in the resultant models.

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