Analysis of Conflict Dynamics by Risk Patterns

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Abstract. This paper considers the problem of extraction from data by the so called risk patterns. Risk patterns are used for analysis of dynamic changes of conflict degrees between the lower level requirements defined by participating agents who are in conflict, relative to the higher level requirements which are used to describe these patterns. The solution to this problem stems from pioneering work on this subject by Zdzisław Pawlak, which provides a basis for a complex conflict model encapsulating a decision system with complex decisions. Some specific reducts of such decision systems and their approximations are used to define risk patterns. An illustrative example of a requirements determinination for an automated lighting system is presented. The contribution of this paper is a model for analysis of conflict dynamics by means of risk patterns defined by distance reducts. The distance reducts can be extracted from data using Boolean reasoning.

Keywords: Approximation space, conflict analysis, conflict resolution, rough sets, requirements engineering, scope negotiation.

1 Introduction

Conflict analysis and resolution play an important role in government and industry where disputes and negotiations about various issues are common. To this end, many mathematical formal models of conflict situations have been proposed and studied, e.g., [4–6, 16, 17, 20]. The approach used in this paper is based on a different kind of relationship in the data. This relationship is not a dependency, but a conflict [21]. Formally, a conflict relation can be viewed as a special kind of discernibility, i.e., negation (not necessarily, classical) of indiscernibility relation which is the basis of rough set theory [19]. Thus indiscernibility and conflict are closely related from a logical point of view. It is also interesting to note that almost all mathematical models of conflict situations are strongly domain dependent.

Cost effective engineering of complex software systems involves a collaborative process of requirements identification through negotiation. This is one of the key ideas of the Win-Win [1] approach [3] used in requirements engineering. This approach also includes a decision model where a minimal set of conceptual elements, such as win conditions, issues, options and agreements, serves as an agreed-upon ontology for collaboration and negotiation defined by the Win-Win process. Conflicts arising during system requirements gathering are especially acute due to the nature of the intense collaboration between project stakeholders involved in the process. In particular, determining the scope or the extent of functionality to be developed is crucial.

Recent work in the application of rough sets to handling uncertainty in software engineering can be found in [15, 25, 23]. However, the basic assumption in all of these papers is that requirements have already been *decided* and the analysis of gathered requirements data is then performed. This paper extends the earlier work involving high-level requirements negotiation based on winning conditions [26]. In this paper, the focus is on requirements scope determination based on an analysis of the deviations to conflict degrees using risk patterns. Risk patterns are requirements that represent a certain level of risk to the entire project due to conflicts between stakeholders on certain important and necessary requirements analysis questions (negotiation parameters). The distance function that is used to derive risk patterns represents an acceptable the level of deviation (risk) for a project.

The contribution of this paper is a model for analysis of conflict dynamics by means of risk patterns defined by distance reducts. The distance reducts can be extracted from data using Boolean reasoning. We illustrate our approach in determining scope of a complex engineering system requirements.

This paper is organized as follows. An introduction to basic concepts of conflict theory is given Sect. 2. Conflicts, information systems and rough sets are discussed in Sect. 3. Extensions to the basic conflict model for conflict analysis is given in Sect. 4. Derivation of conflict degress for home lighting automation system (HLAS) requirements is given in Sect.5.1. Section 5.2 includes a method for risk pattern extraction and a discussion of the analysis of conflict dynamics with risk patterns defined by distance reducts.

2 Basic Concepts of Conflict Theory

The basic concepts of conflict theory that we use in this paper are due to [21]. Let us assume that we are given a finite, non-empty set Ag called the *universe*. Elements of Ag will be referred to as *agents*. Let a *voting function* $v : Ag \rightarrow \{-1, 0, 1\}$, or in short $\{-, 0, +\}$, be a number representing his/her voting result about some issue under negotiation, to be interpreted as *against,*

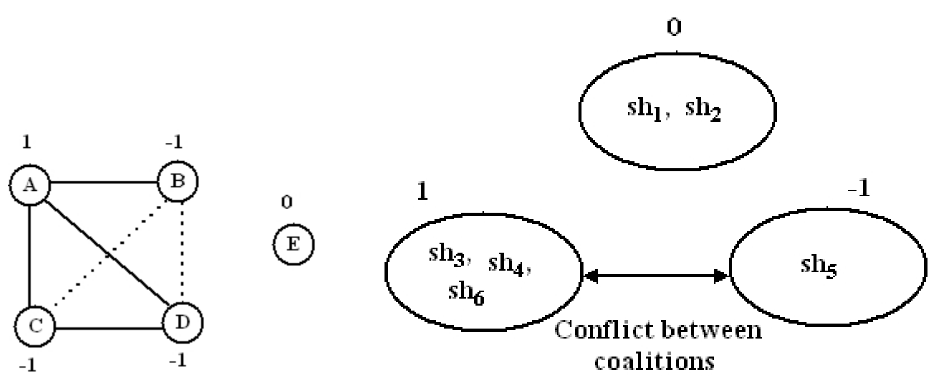
[1] See `http://sunset.usc.edu/research/WINWIN`

neutral and *favorable*, respectively. The pair $CS = (Ag, V)$, where V is a set of voting functions, will be called a *conflict situation*.

In order to express relations between agents, we define three basic binary relations on the universe: *agreement, neutrality*, and *disagreement*. To this end, for a given voting function v, we first define the following auxiliary function:

$$\phi_v(ag, ag') = \begin{cases} 1, & \text{if } v(ag)v(ag') = 1 \text{ or } ag = ag' \\ 0, & \text{if } v(ag)v(ag') = 0 \text{ and } ag \neq ag' \\ -1, & \text{if } v(ag)v(ag') = -1. \end{cases} \tag{1}$$

This means that, if $\phi_v(ag, ag') = 1$, agents ag and ag' have the same opinion about an issue v (*agree* on issue v); $\phi_v(ag, ag') = 0$, which means that at least one agent ag or ag' has no opinion about an issue v (is *neutral* on v), and $\phi_v(ag, ag') = -1$, which means that both agents have different opinions about an issue v (are in *conflict* on issue v). In what follows, we will define three basic relations R_v^+, R_v^0 and R_v^- on Ag^2 called *agreement, neutrality* and *disagreement* relations respectively, and defined by (i) $R_v^+(ag, ag')$ iff $\phi_v(ag, ag') = 1$; (ii) $R_v^0(ag, ag')$ iff $\phi_v(ag, ag') = 0$; (iii) $R_v^-(ag, ag')$ iff $\phi_v(ag, ag') = -1$. It is easily seen that the *agreement* relation is an *equivalence* relation. Each equivalence class of the agreement relation will be called a *coalition* with respect to v. For the conflict or disagreement relation we have: (i) not $R_v^-(ag, ag)$; (ii) if $R_v^-(ag, ag')$ then $R_v^-(ag', ag)$; (iii) if $R_v^-(ag, ag')$ and $R_v^+(ag', ag'')$ then $R_v^-(ag, ag'')$. For the neutrality relation we have: (i) not $R_v^0(ag, ag)$; (ii) $R_v^0(ag, ag') = R_v^0(ag', ag)$. In the conflict and neutrality relations there are no coalitions. In addition, $R_v^+ \cup R_v^0 \cup R_v^- = Ag^2$. All the three relations R_v^+, R_v^0 , R_v^- are pairwise disjoint. With every conflict situation $CS = (Ag, v)$ we will associate a *conflict graph*. Examples of conflict graphs are shown in Figure 1.



(a) Exemplary Conflict for some voting function, where a, B, C, D, E are agents

(b) Requirement Conflict (see $r1.1$ in Table 2)

Fig. 1. Sample Conflict Graphs

In Figure 1(a), solid lines denote conflicts, dotted line denote agreements, and for simplicity, neutrality is not shown explicitly in the graph. As one can see B, C, and D form a coalition. A conflict degree $Con(CS)$ of the conflict situation $CS = (Ag, v)$ is defined by

$$Con_v(CS) = \frac{\sum_{\{(ag,ag'):\ \phi_v(ag,ag')=-1\}} |\phi_v(ag, ag')|}{2\lceil \frac{n}{2} \rceil \times (n - \lceil \frac{n}{2} \rceil)}, \tag{2}$$

where $n = Card(ag)$. Observe that $Con(CS)$ is a measure of discernibility between agents from Ag relative to the voting function v. For a more general conflict situation $CS = (Ag, V)$ where $V = \{v_1, \ldots, v_k\}$ is a finite set of voting functions each for a different issues the *conflict degree* in CS (*tension generated by* V) can be defined by

$$Con(CS) = \sum_{i=1}^{k} Con(CS_i)/k, \tag{3}$$

where $CS_i = (Ag, v_i)$ for $i = 1, \ldots, k$.

3 Conflicts, Information Systems, and Rough Sets

There are strong relationships between the approach to conflicts and information systems as well as rough sets. In this section, we discuss examples of such relationships. The presented in this section approach seems to be promising for solving problems related to conflict resolution and negotiations (see, e.g., [11]). The application of rough sets can bring new results in the area related to conflict resolution and negotiations between agents because this makes it possible to introduce approximate reasoning about vague concepts into the area.

An information system is a table rows of which are labeled by *objects* (*agents*), columns by *attributes* (*issues*) and entries of the table are *values of attributes* (*votes*), which are uniquely assigned to each agent and attribute, i.e. each entry corresponding to row x and column a represents opinion of an agent x about issue a. Formally an *information system* can be defined as a pair $S = (U, A)$, where U is a nonempty, finite set called the *universe*; elements of U will be called *objects* and A is a nonempty, finite set of *attributes* [19]. Every attribute $a \in A$ is a total function $a : U \to V_a$, where V_a is the set of *values* of a, called the *domain* of a; elements of V_a will be referred to as *opinions*, and $a(x)$ is opinion of agent x about issue a. The above given definition is general, but for conflict analysis we will need its simplified version, where the domain of each attribute is restricted to three values only, i.e., $V_a = \{-1, 0, 1\}$, for every a, meaning *disagreement, neutral* and *agreement* respectively. For the sake of simplicity we will assume $V_a = \{-, 0, +\}$. Every information system with the above mentioned restriction will be referred to as a *situation*.

We now observe that any conflict situation $CS = (Ag, V)$ can be treated as an information system where $Ag = \{ag_1, \ldots, ag_n\}$ and $V = \{v_1, \ldots, v_k\}$ with the set of objects Ag (*agents*) and the set V of attributes (*issues*).

The discernibility degree between agents ag and ag' in CS can be defined by

$$disc_{CS}(ag, ag') = \frac{\sum_{\{i:\ \phi_{v_i}(ag,ag')=-1\}} |\phi_{v_i}(ag, ag')|}{k}, \tag{4}$$

where $ag, ag' \in Ag$. Now, one can consider reducts of CS relative to the discernibility degree defined by $disc_{CS}$. For example, one can consider agents ag, ag' as discernible if

$$disc_{CS}(ag, ag') \geq tr,$$

where tr a given threshold.[2] Any reduct $R \subseteq V$ of CS is a minimal set of voting functions preserving all discernibility in voting between agents that are at least equal to tr. All voting functions from $V - R$ are dispensable with respect to preserving such discernibility between objects. In an analogous way, one can consider reducts of the information system CS^T with the universe of objects equal to $\{v_1, \ldots, v_k\}$ and attributes defined by agents and voting functions by $ag(v) = v(ag)$ for $ag \in Ag$ and $v \in V$. The discernibility between voting functions can be defined, e.g., by

$$disc_{CS^T}(v, v') = |Con(CS_v) - Con(CS_{v'}|, \tag{5}$$

and makes it possible to measure the difference between voting functions v and v', respectively. Any reduct R of CS^T is a minimal set of agents that preserves the differences between voting functions that are at least equal to a given threshold tr.

4 Complex Conflict Model

In this section we present an extension of the conflict model and we outline an approach to conflict resolution based on such a model. We assume that agents in the complex conflict models are represented by conflict situations $s = (Ag, v)$, where Ag is the set of lower level agents and v is a voting function defined on Ag for $v \in V$. Hence, agents in the complex conflict model are related to groups of lower level agents linked by a voting function. The voting functions in the complex conflict models are defined on such conflict situations. The set of the voting functions for the complex conflict model is denoted by A. In this, way we obtain an information system (U, A), where U is the set of situations. Observe that any situation $s = (Ag, v)$ can be represented by a matrix

$$[v(ag)]_{ag \in Ag}, \tag{6}$$

where $v(ag)$ is is the result of votiung by the agent $ag \in Ag$. We can extend the information system (U, A) to the decision system (U, A, d) assuming, e.g., that

[2] To compute such reducts one can follow a method presented in [29] assuming that any entry of the discernibility matrix corresponding to (ag, ag') with $disc_{CS}(ag, ag') < tr$ is empty and the remaining entries are families of all subsets of V on which the discernibility between (ag, ag') is at least equal to tr [6].

$d(s) = Con_v(s)$ for any $s = (Ag, v)$. For the constructed decision system (U, A, d) one can use, e.g., the introduced above function (2) to measure the discernibility between compound decision values which correspond to conflict situations in the constructed decision table. The reducts of this decision table relative to decision have a natural interpretation with respect to conflicts.

The described decision table can be, e.g., used in conflict analysis. We would like to illustrate this possibility. First, let us recall some notation. For $B \subseteq A$ we denote by $Inf_B(s)$ the B-signature of the situation s, i.e., the set $\{(a, a(s)) : a \in A\}$. Let $INF(B) = \{Inf_B(s) : s \in U\}$. Let us also assume that for any $B \subseteq A$ there is given a similarity relation $\tau_B \subseteq INF(B) \times INF(B)$[3]. In terms of these similarity relations, one can consider a problem of conflict analysis. This is the searching problem for the tolerance reducts [30] $B \subseteq A$ preserving the deviation of conflict degree defined by A and τ_A on the tolerance classes (defined by situations) to a degree at least $1 - tr$.

5 Analysis of Conflict Dynamics

In this section, we consider the problem of extraction of risk patterns from data (requirements) of a complex software system. These risk patterns will then be used for analysis of dynamic changes of conflict degrees between project stakeholders. A stakeholder is one who has a share or an interest in the requirements for a systems engineering project. A typical system requirements engineering process leads to conflicts between project stakeholders. Conflict graphs are used to analyze conflict situations, reason about the degree of conflict and explore coalitions. Let Ag be represented by the set SH (stakeholders). Let V denote the set of requirements. Let $CS = (SH, V)$ where $SH = \{sh_1, \ldots, sh_n\}$ and $V = \{v_1, \ldots, v_k\}$. A complete example of the problem of achieving agreement on high-level system requirements for a home lighting automation system described in [14] can be found in [26].

5.1 Example: Determining Conflict Degrees of System Requirements

As a part of requirements scope negotiation, several parameters need to be determined: level of effort, importance of a requirement, stability, risk, testability to name a few. In this paper, we consider the following negotiation parameters: *Level of effort (E)* which is a rough estimate of development effort (High, Medium, Low), *Importance* (I) which determines whether a requirement is essential to the project (High, Medium, Low), *Stability* (S) of a requirement which indicates its volatility (Yes, Perhaps, No), *Risk* (R) which indicates whether the requirement is technically achievable (High, Medium, Low) *Testability* (T) indicating whether a requirement is testable (Yes, No). Specifically, the example illustrates the high level functionality (R1) of Custom Lighting Scene [26] to be

[3] We assume that the family $\{\tau_B\}_{B \subseteq A}$ is satisfying some natural conditions [30].

included in release of V1.0 of HLAS System. The negotiation parameter values (conditions) assessed by the development team for R1 are given in Table 1. The decision values for the decision $Conflict\ Degree$ will be defined below.

Table 1. Scope Negotiation

Negotiation Parameters						
$R1$	E	I	S	R	T	$Conflict\ Degree$
$r1.1$	M	H	N	L	Y	0.3
$r1.2$	M	H	N	L	Y	0.44
$r1.3$	H	M	N	M	Y	0.2
$r1.4$	L	H	Y	L	Y	0
$r1.5$	M	H	P	H	Y	0.67
$r1.6$	M	L	P	H	N	0.89

Assume that R1 includes the following specifications (objects): $r1.1$ - ability to control up to a maximum of 20 custom lighting scenes throughout the residence, $r1.2$ - each scene provides a preset level of illumination (max. of 3) for each lighting bank, $r1.3$ - maximum range of a scene is 20 meters, $r1.4$ - activated using Control Switch, $r1.5$ - activated using Central Control Unit, and $r1.6$ - Ability to control an additional 2 lighting scenes in the yard. The decision attribute is a compound decision denoting the conflict degree which is a result of a matrix given in Table 2.

The voting results of the members drawn from a stakeholders list SH is given in Table 2. The stakeholder list is comprised of builders, electrical contractors and the marketers. Every stakeholder votes on each of the requirements. An algorithm for determining win agreements can be found in [26]. The conflict graph $CS_{r1.1} = (SH, r1.1)$ can be presented in a simplified form as a graph with nodes represented by coalitions and edges representing conflicts between coalitions as shown in Fig. 1(b). From this graph, one can compute the conflict degree using using Eqn. 2 where $Con(CS_{r1.1}) = 0.3$. The degree of conflict for the remaining requirements are $Con(CS_{r1.2}) = 0.44$, $Con(CS_{r1.3}) = 0.2$, $Con(CS_{r1.4}) = 0$, $Con(CS_{r1.5}) = 0.67$, and $Con(CS_{r1.6}) = 0.89$.

5.2 Risk Patterns

Risk patterns are defined by specific reducts (and their approximations) of the complex conflict model. The complex conflict model encapsulates a decision system with complex decisions where the decision is equal to the conflict degree. The conflict degree derived as a result of voting is essentially a subjective value used in the decision column of Table 1. To determine which requirements should be included in product release version V1.0, negotiation must occur at two levels, namely, voting and decision table. Conflict degrees are defined by (6) (see

Table 2. Voting Results for R1

Voting Results						
Stakeholder	$r1.1$	$r1.2$	$r1.3$	$r1.4$	$r1.5$	$r1.6$
sh_1	0	1	-1	0	-1	-1
sh_2	0	1	0	0	-1	-1
sh_3	1	-1	0	1	1	-1
sh_4	1	1	0	1	1	-1
sh_5	-1	0	1	1	1	1
sh_6	1	1	-1	1	0	1

Section 4). In this section, we assume that the distance between conflict degrees considered in the previous section is defined by equation (5) (see Section 3).

Now, one can consider reducts of this decision table relative to a fixed distance δ between decision values (see Table 1). Such reducts are called the distance reducts [36]. Let $DT = (U, A, d)$ be a (consistent) decision table [19] and let δ be a distance function between decisions from V_d. Any minimal set $B \subseteq A$ satisfying the following condition:

$$\delta(d(x), d(y)) \geq tr \wedge non(xIND(A)y) \longrightarrow non(xIND(B)y) \tag{7}$$

where $IND(A), IND(B)$ are indiscernibility relations relative to A, B respectively [19] and tr is a given threshold is called (d, tr)-reduct of DT.

One can use an approach presented in [29] and define modified discernibility reducts making it possible to compute such reducts using Boolean reasoning method. Any such reduct B defines a set of risk patterns. They are obtained by taking the values of attributes from B on any object x from DT, i.e.,

$$\bigwedge_{a \in B} (a = a(x)). \tag{8}$$

From the distance reduct definition, the deviation of the decision on the set of objects satisfying formula (8) in DT, i.e., on the set

$$\| \bigwedge_{a \in B} (a = a(x)) \|_{DT} = \{y \in U : a(y) = a(x) \text{ for } a \in B\} \tag{9}$$

is at most tr. Alg. 1 gives the basic steps that need to be followed to find a risk pattern.

Algorithm 1: Algorithm for determining risk patterns

Input : $DT = (U, A, d)$ - consistent decision table
Output: Risk Patterns x in DT defined by $B \subseteq A$ satisfying equation 9
for $(all\ x,\ y \in DT)$ **do**
  select $x,\ y$ such that $\delta(d(x), d(y)) \geq\ tr$;
  compute reduct B satisfying (7);
end

Now, one can analyze the dynamics of conflict degree changes by dropping conditions from defined risk patterns. Excluding certain conditions may cause small changes to the deviation of decisions, while excluding other conditions can lead to a substantial increase in the decision deviation. In other words, different sets of negotiation parameters can lead to differing deviations in conflict degrees. As a result, the team is able to evaluate the effect of the different sets of negotiation parameters on the overall risk to the project.

One can use information maps introduced in [35] for visualization of these dynamical changes of risk patterns. This approach can be applied to the decision table represented in Table 1 in which the values of decisions are conflict degrees of issues (requirements) $r1.1, \ldots, r1.6$ defined by stakeholder voting. In this way, one can obtain a method making it possible to visualize the risk patterns with different degrees of the conflict degree deviation showing how the higher level features reflect the conflict degrees assigned to the lower level requirements by stakeholders.

For example, if we assume $tr = 0.3$ we obtain the following discernibility function for the distance reducts of the decision table represented in Table 1:

$$(S \vee R) \wedge (E \vee S). \tag{10}$$

Hence, we obtain two reducts $\{S\}$ and $\{E, R\}$. One can see that the deviation of the conflict degree on the indiscernibility classes defined by $\{S\}$ or $\{E, R\}$ is at most 0.24 and 0.22, respectively. However, if we exclude certain conditions the deviation increases, e.g., for the indiscernibility class defined by E and $r1.1$, the deviation is 0.59 and for the indiscernibility class defined by R and $r1.1$ is 0.44.

The distance reducts can be generalized by adding a requirement that the reduced set of attributes should not only preserve the discernibility between objects but to preserve it to a degree (at least equal to a given threshold). In this case one can use reducts proposed in [28].

6 Conclusion

This paper introduces rough set based requirements scope determination using a complex conflict model with risk patterns. In other words, the complex conflict model provides the ability to (i) define a level of conflict that is acceptable, (ii) determine the equivalent set of requirements based on a specified set of negotiation parameters tailored to a specific project, (iii) select requirements to be included in the system with a measure indicating the extent to which standards (risk) for release parameters have been followed, (iv) analyze the risk pattern dynamics when some higher level objective negotiation parameters are excluded.

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