The Role of Diagnosis and Decision Theory in Normative Reasoning

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Abstract

A theory of diagnosis and qualitative decision theory are able to formalize reasoning *with* norms. They are thus different from deontic logic, that formalizes reasoning *about* norms. In this paper, we compare two theories of diagnosis for normative systems: Ramos and Fiadeiro's theory of diagnosis developed for organizational process design and Tan and Van der Torre's theory of diagnosis extended with notions of qualitative decision theory. We observe several similarities.

1 Introduction

In this paper we argue that normative reasoning is more than deontic logic. Deontic logic tells you which obligations can be derived from a set of other obligations. In particular, it characterizes the logical relations between obligations. For example, in most deontic logics the conjunction $p \wedge q$ is obliged, if both p and q are obliged. However, it does not explain how norms effect the behavior of rational agents. From Op you cannot infer whether somebody will actually perform p. This is no critique on deontic logic, it is just an observation. Deontic logic was never intended to explain this effect of norms on behavior. However, If we want to explain all the different aspects of normative reasoning, then we need more formalisms than just deontic logic. In this paper we discuss two formalisms that can be used to analyze two different types of aspects of how norms effect behavior, namely the theory of diagnosis and qualitative decision theory.

Two theories that are able to formalize reasoning with norms are represented in Figure 1. A *theory of diagnosis* reasons about violations. In particular, it reasons about the past with incomplete knowledge (if everything is known than a diagnosis is completely known). Diagnostic theories have a modest purpose, because they do not support the decision-making process of the user. They do not derive decisions, they only check systems against given principles. A more expressive framework is qualitative decision theory. *Qualitative decision theory* describes how norms influence behavior. It is based on the concept of agent rationality. For example, in a normative system usually sanctions and rewards correspond with norms, and a rational agent tries to evade penalties and achieve rewards. In contrast to diagnostic theories, a (qualitative) decision theory reasons about the future. The main characteristic of qualitative decision theory is that it is goal oriented reasoning, usually for planning problems. Moreover, it combines reasoning about goals with uncertainty. This reasoning is based on the application of strategies, which can be considered as qualitative versions of the 'maximum utility' criterion.

Logical relations between obligations are an essential component of any formalism that explains the effect of norms on behavior. Hence, in this paper we also argue that deontic logic can be used as a component in the theory of diagnosis

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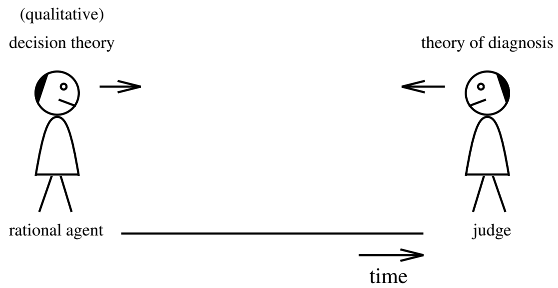

Figure 1: Reasoning with norms

as well as qualitative decision theory. Actually, we even argue for the stronger claim that the theory of diagnosis as well as qualitative decision theory can be viewed as extensions of deontic logic. In both cases the formalism contains extra principles that are added to a deontic logic basis. For example, in the case of the theory of diagnosis one of the principles that can be added to deontic logic is the parsimony principle, i.e. the assumption that as few as possible obligations are violated. There is nothing contradictory in the claim that on the one hand these formalisms explain aspects of normative behavior that deontic logic does not, whereas deontic logic is still an essential component of these theories. In the same sense physics can explain phenomena that mathematics cannot, whereas mathematics is still an essential component of physics. There are several structural similarities between preference-based deontic logic and the logics developed for diagnosis and qualitative decision theory, see e.g. [Bou94, Lan96]. The distinction between the different perspectives and deontic logic raises several important questions.

1. **Norms and dedicated theories.** The diagnosis of a normative system can use a formalism to represent norms and additional assumptions or principles to do the diagnosis. For example, Reiter's diagnosis is basically a minimization principle (called the principle of parsimony). Similarly, qualitative decision theory has a formalism for representing norms (or goals) and additional assumptions or principles to reason with them. Is such a special purpose formalism a deontic logic? How do they stand the test against the Chisholm paradox, the paradox of the gentle murderer, the problem of how to represent permissions, the problem of conflicting obligations? What are the structural similarities and distinctions between the different formalisms?

2. **Norms and preferences [Lan96].** Qualitative decision theory is based upon the concept of preference. This preference is a kind of desire, i.e. it is an endogenously motivating mechanism (coming from the agent itself). Therefore, it is not a natural candidate for dealing with normative decision-making, since a norm is by definition exogenous, in the sense that it is something the agent would not spontaneously want. How do agents work out norms in terms of gains and losses? What are the gains of observing norms? How do they learn the effects of norms and how do they reason about these effects? Which rules are implied, which ingredients enable agents to make normative decisions? In which way does a normative decider differ from an ordinary decider, if any?

3. **Norms and obligations.** A deontic logic does not derive actual but ideal behaviors. Shouldn't we distinguish the obligations derivable from a set of norms and a set of facts, from the norms itself? What is the role of so-called factual detachment in deontic logic?

In this paper we analyze structural properties of formalisms used in two dedicated theories of diagnosis, and we relate the formalisms to deontic logic. Reiter formalized in [Rei87] the model-based reasoning approach to diagnosis, and in [TvdT94a, TvdT94b, RF96b, RF96a] that theory is adapted to deontic systems by using obligations to represent the ideal behavior of a system. In Reiter's theory of diagnosis, a violation is represented by a predicate expression $Ab(c)$, where c is a component of a system to be diagnosed and Ab an abnormality predicate. For example, this violation can be derived from the system description that p is the correct behavior of a component $\neg Ab(c) \rightarrow p$ and the observation $\neg p$. In a modal deontic logic, a violation can be represented by the sentence $\neg p \wedge Op$, where the modal sentence Op is read as 'it is obligatory that p.' The typical diagnostic reasoning with normative systems is performed by a judge, who has to determine whether a suspect is guilty or not. Diagnostic reasoning has to deal with incomplete knowledge, not formalized in a deontic logic. For example, a popular additional assumption of theories of diagnosis is the so-called principle of parsimony: 'you are innocent until proven guilty.' Such a principle about incomplete knowledge is not made in deontic logic; it is an extra-logical assumption about the legal domain.

The DIagnostic framework for DEontic reasoning DIODE [TvdT94b, TvdT94a] is Reiter's theory of diagnosis [Rei87] applied to normative systems. In this paper we compare two extensions of DIODE. The first extension is DDD, Ramos and Fiadeiro's Deontic framework for Diagnosis of process Design [RF96b, RF96a]. They make a distinction between benevolent and exigent diagnoses, respectively minimal and maximal violated-norm sets (comparable to sets of broken components in Reiter's theory). Moreover, they make a distinction between structural concepts and design actions. Their deontics-based diagnosis is based on a minimal deontic logic LDD. The second extension of DIODE is Tan and Van der Torre's DIagnostic and DEcision-theoretic framework for DEontic reasoning DIO(DE)^2. The most important element of (qualitative) decision theory incorporated in DIO(DE)^2 is – besides the violation-oriented reasoning of DIODE – also goal-oriented reasoning. Deontic-based diagnosis is based on the two-phase preference-based deontic logic 2DL. Two-phase reasoning illustrates the distinction between reasoning about violated-norm sets and reasoning about diagnoses, i.e. *minimal* violated-norm sets.

We identify several similarities between the two approaches DDD and DIO(DE)^2. DIODE defines minimal violated-norm sets, based on the basic distinction between violated and non-violated norms. DDD defines also maximal violated-norm sets, based on the distinction between fulfilled and non-fulfilled norms. The exigent diagnosis corresponds to qualitative decision theory in the sense that exigent diagnosis not only reasons about the past (about incomplete knowledge) but also reasons about the future (design actions). For example, the distinction between structural concepts and design actions in DDD corresponds to the distinction between parameters and decision variables in qualitative decision theory. The theory DDD is not only used for diagnosis, but for more general decision support. Moreover, we also observe several similarities in the logics LDD and 2DL like a contingency clause (the use of consistency checks) and lack of weakening of the consequent.

The layout of this paper is as follows. In Section 2 we discuss Reiter's theory of diagnosis, the adaptation of that theory to deontic systems by using obligations to represent the ideal behavior of a system, and qualitative decision theory. In Section 3 we discuss the framework of Ramos and Fiadeiro, in Section 4 the framework of Tan and Van der Torre and in Section 5 we compare them.

2 The role of deontic logic in diagnosis and qualitative decision theory

Deontic logic formalizes reasoning *about* norms. Two important extensions of deontic logic that reason *with* norms are theory of diagnosis and qualitative decision theory. They are extensions in the sense that reasoning with norms uses a formalization of norms (although several aspects of norms may not be represented in a particular formalization of the norms). In this section we discuss the two theories that formalize reasoning with norms, and we observe a distinction in deontic logic analogous to the distinction between diagnosis and decisions.

2.1 Reiter's theory of diagnosis and DIODE

The model based reasoning approach has been studied for several years (for a survey of the topic see [DW88]). Numerous applications have been built, most of all for diagnosis of physical devices. The basic paradigm is the interaction of prediction and observation. Predictions are expected outputs given the assumption that all the components are working properly (i.e. are working according to the model of the structure and behavior of the system). If a discrepancy between the output of the system (given a particular input) and the prediction is found, the diagnosis procedure will search for defects in the components of the system (the correctness of the model is assumed).

The contribution of Reiter to the theory of diagnosis is widely accepted. His *consistency based approach* [Rei87] is the first one to model the model based reasoning approach to diagnosis. The main goal is to eliminate system inconsistency, identifying the minimal set of abnormal components that is responsible for the inconsistency. That is, reasoning about diagnosis is based on the following the assumption of diagnostic reasoning.

> **Principle of parsimony** Diagnostic reasoning is based on the conjecture that the set of faulty components is minimal (with respect to set inclusion).

Related to a diagnosis is a set of measurements. Finally, a conflict set is a minimal set of components of which at least one is broken (such sets are used in efficient diagnostic algorithms).

Definition 1 (Diagnosis) *A* system *is a pair* (COMP, SD) *where* COMP, *the* system components, *is a finite set of constants denoting the components of the system, and* SD, *the* system description, *is a set of first-order sentences. An* observation *of a system is a finite set of first-order sentences. A system to be diagnosed, written as* (COMP, SD, OBS)*, is a system* (COMP, SD) *with observation* OBS. *A* diagnosis *for* (COMP, SD, OBS) *is a minimal (with respect to set inclusion) set* $\Delta \subseteq$ COMP *such that*

$$\text{CONTEXT}_\Delta = \text{SD} \cup \text{OBS} \cup \{Ab(c) \mid c \in \Delta\} \cup \{\neg Ab(c) \mid c \in \text{COMP} - \Delta\}$$

is consistent. A diagnosis Δ *for (*COMP, SD, OBS*)* predicts *a* measurement Π *iff* $\text{CONTEXT}_\Delta \models \Pi$. *A* conflict set *for* (COMP, SD, OBS) *is a minimal (with respect to set inclusion) set* $\Delta \subseteq$ COMP *such that* CONTEXT_Δ *is inconsistent.*

The DIagnostic framework for DEontic reasoning DIODE formalizes deontic reasoning as a kind of diagnostic reasoning. Notice that DIODE is not a deontic logic (it does not describe which obligations follow from a set of obligations) and it should not be considered as such. On the other hand, since diagnosis is about violations and deontic logic is exactly for situations where violations are important [JS92], it makes sense to have a deontic framework for diagnosis like DIODE. The framework treats norms as components of a system to be diagnosed; hence the system description becomes a norms description ND. We refer to the base logic of DIODE as $\mathcal{L}_V$, and the fragment of $\mathcal{L}_V$ without violation constants as $\mathcal{L}$. We write $\models$ for entailment in $\mathcal{L}_V$. The definition of minimal violated-norm set is analogous to the definition of diagnosis. Just as we can have multiple diagnoses with respect to the same (COMP, SD, OBS), we can have multiple minimal violated-norm sets Δ with respect to (NORMS, ND, FACTS). The fact that we can have more than one minimal violation state reflects that we can have different situations that are optimal, i.e. as ideal as possible. In Section 3 we present an example that illustrates deontic diagnosis in organization scenarios.

Definition 2 (DIODE) *A* normative system *is a tuple* NS = *(*NORMS, ND*) with:*

1. NORMS*, a finite set of constants denoting* norms $\{n_1, \ldots, n_k\}$,
2. ND*, the* norms description*, a set of first-order $\mathcal{L}_V$ sentences denoting* obligations $\neg V(n_i) \to (\beta \to \alpha)$.

A normative system to be diagnosed *is a tuple* NSD = (NORMS, ND, FACTS) *with:*

1. NS = *(*NORMS, ND*), a normative system, and*
2. FACTS*, a set of first-order $\mathcal{L}$ sentences that describe the facts.*

Let NSD = (NORMS, ND, FACTS) *be a normative system to be diagnosed. A* minimal violated-norm set Δ *of* NSD *is a minimal (with respect to set inclusion) subset of* NORMS *such that*

$$\text{CONTEXT}_\Delta = \text{ND} \cup \text{FACTS} \cup \{V(n_i) \mid n_i \in \Delta\} \cup \{\neg V(n_i) \mid n_i \in \text{NORMS} - \Delta\}$$

is consistent. The set of contextual obligations *of a minimal violated-norm set Δ of a normative system to be diagnosed* NSD *is* $\text{CO}_\Delta = \{\alpha \mid \alpha \in \mathcal{L}, \text{CONTEXT}_\Delta \models \alpha\}$.

Obligations are represented in DIODE analogously to the way they are represented in Anderson's reduction of so-called Standard Deontic Logic (SDL) to alethic modal logic. SDL is a normal modal system of type KD according to the Chellas classification [Che80]. It satisfies, besides the propositional tautologies, axiom **K**: $O(\alpha \to \beta) \to (O\alpha \to O\beta)$, which states that modus ponens holds within the scope of the modal operator, and axiom **D**: $\neg(O\alpha \wedge O\neg\alpha)$, which states that dilemmas are inconsistent. Anderson [And58] showed that SDL can be expressed in alethic modal logic by the translation $O\alpha =_{def} \Box(\neg V \to \alpha)$, in which V is the so-called violation constant (not a propositional variable!), together with the axiom **D**: $\Diamond\neg V$ (as usual, $\Diamond\alpha =_{def} \neg\Box\neg\alpha$). In SDL, a conditional obligation can be represented by $\beta \to O\alpha$ or by $O(\beta \to \alpha)$. The latter is according to the Anderson schema similar to $O(\beta \to \alpha) =_{def} \Box(\neg V \to (\beta \to \alpha))$. In spite of the analogy in the way obligations are represented, there are also two important distinctions between the representation of obligations in DIODE and Anderson's reduction. First, in Anderson's reduction every deontic formula is preceded by a box $\Box$. Semantically, in the theory of diagnosis distinct *models* represent distinct situations, whereas in a modal system distinct *worlds* within a model represent distinct situations. Second, in Anderson's reduction there is only one violation constant. For a further discussion see [TvdT94a]. In spite of the analogy in the representation of obligations in DIODE and Anderson's reduction, DIODE is quite different from a deontic logic. On the one hand DIODE is more than a deontic logic, because the parsimony principle adds the assumption that the set of violations of obligations is minimal. This assumption is based on the idea that people tend to comply with norms, which is an empirical assumption about the behavior of people, and which has clearly nothing to do with the logic of norms itself. On the other hand one could argue that DIODE is less than a deontic logic, because, if ND would be a deductively closed set of sentences, then the DIODE counterpart of the formula $p \to Op$ would be contained in every ND. Clearly, $p \to Op$ is not an intuitive deontic theorem, and the counterpart of this formula is also not valid in Anderson's reduction due to his box operator. Although these counter-intuitive theorems do not occur in DIODE, because ND is not deductively closed, we give another formulation at the end of this paper of DIODE in the logic 2DL, which gives a better representation of the deontic logic component in DIODE.

2.2 Qualitative decision theory

Boutilier [Bou94] develops a logic of qualitative decision theory in which the basic concept of interest is the notion of *conditional preference*. Boutilier writes $I(\alpha \mid \beta)$, read "ideally α given β," to indicate that the truth of α is preferred, given β. This holds exactly when α is true at each of the most preferred of those worlds satisfying β. Boutilier remarks that from a practical point of view, $I(\alpha|\beta)$ means that if the agent (only) knows α, and the truth of β is fixed (beyond his control), then the agent ought to ensure α. Otherwise, should $\neg\alpha$ come to pass, the agent will end up in a less than desirable β-world. Boutilier mentions that the statement can be *roughly* interpreted as "if β, do α." Moreover, Boutilier observes that the conditional logic of preferences he proposed is similar to the (purely semantic) proposal put forth by Hansson [Han71]. He concludes that 'one may simply think of $I(\alpha\,|\,\beta)$ as expressing a conditional obligation to see to it that α holds if β does.' Thomason and Horty [TH96] and Lang [Lan96] also observe the link with deontic logic when they develop the foundations for qualitative decision theory.

Boutilier [Bou94] introduces a simple model of action and ability. The atomic propositions are partitioned into *controllable* propositions, atoms over which the agent has direct influence, and *uncontrollable* propositions. He ignores the complexities required to deal with effects, preconditions and such, in order to focus attention on the structure and interaction of ability and goal determination. The consequence of this lack of an action model is that 'we should think of a rule as an *evidential rule* rather than a *causal rule*.' Moreover, Boutilier observes 'the implicit temporal aspect here; propositions should be thought of as *fluents*. We can avoid an explicit temporal representation by assuming that preference is solely a function of the truth values of fluents.' Lang [Lan96] calls controllable and uncontrollable propositions respectively decision variables and parameters. Moreover, he argues that it is necessary to distinguish not only between desires (goals) and knowledge as in [Bou94] but also between background factual knowledge (which tells which worlds are physically impossible) and contingent knowledge (which tells which of the physically possible worlds can be the actual states of affairs). This last distinction was introduced in [vdT94].

The simplest definition of goals is in accordance with the general maxim 'do the best thing possible consistent with your knowledge.' Boutilier [Bou94] dubbed such goals CK goals because they seem correct when an agent has *Complete Knowledge* of the world (or at least of uncontrollable atoms). But Boutilier also shows that CK-goals do not always determine the best course of action if an agent's knowledge is *incomplete*. For example, Wald's criterion is a pessimistic strategy: maximize the minimum return (see e.g. [DP95, Lan96]).

2.3 Context of justification versus context of deliberation

The distinction between the perspective of a rational agent (qualitative decision theory) and a judge (theory of diagnosis) corresponds to Thomason's distinction between the context of deliberation and the context of justification [Tho81]. Thomason distinguishes between two ways in which the truth values of deontic sentences are time-dependent. First, these values are time-dependent in the same, familiar way that the truth values of all tensed sentences are time-dependent. Second, their truth values are dependent of a set of choices or future options that varies as a function of time. If you think of deontic operators as analogous to quantifiers ranging over options, this dependency on context is a familiar phenomenon. Thus, the context of deliberation is the set of choices when you are looking for practical advice, whereas the context of justification is the set of choices for someone who is judging you.[1] The following example discussed in [Han71] illustrates that it is important to discriminate between these two contexts, because a sentence can sometimes be interpreted differently in each of them.

Example 1 *Consider the obligation 'you should not smoke if you smoke.' In the context of justification the obligation is interpreted as the identification of the fact that you are violating a rule, whereas in the context of deliberation, it is interpreted as the obligation to stop smoking. When the context is not known, it is also not known which of these two interpretations (or probably both) is meant. The two perspectives are represented in Figure 2. At the present moment in time, smoking (s) is true. The context of justification considers the moment before the truth value of s was settled, and considers whether at that moment in the past, $\neg s$ was preferred over s. The context of deliberation considers the moment the truth value of s can be changed, and considers whether at that moment in the future, $\neg s$ will be preferred over s.*

The distinction between the two interpretations of the obligation 'you should not smoke if you smoke' is as important as the distinction between Alchourrón-Gärdenfors-Makinson belief revision (or theory revision) [AGM85] and Katsuno-Mendelzon belief update [KM92] in the area of logics of belief. There is a strong analogy, because belief revision is reasoning about a non-changing world and update is reasoning about a changing world. It follows directly from Figure 2 that a similar distinction is made between respectively the context of justification and the context of deliberation, because the past is fixed, whereas the future is wide open.

[1] Thomason defines the context of justification in terms of the context of deliberation: at a certain point in time p is justification-obligatory iff at some earlier point in time p was deliberation-obligatory (in both cases p has the same time index). This is in our opinion too simple. We should make a distinction analogous to the distinction between revision and update to formalize it.

Figure 2: Contexts of normative reasoning

3 Diagnostic framework for process design

The work of Ramos and Fiadeiro should be understood as a contribution to the more general purpose to build a formal framework to support organizational process design diagnosis according to predefined process design principles. By principles they mean general rules that characterize the ideal behavior of an organization. They are interested in forms of diagnoses that report violations of such principles. The architecture of their intended framework is represented in Figure 3 (taken from [RF96b]).

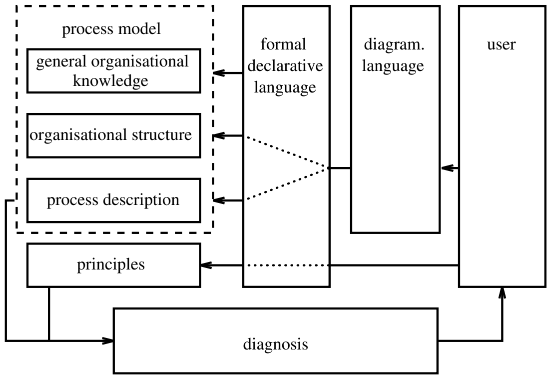

Figure 3: Architecture of Ramos and Fiadeiro's framework

The user in Figure 3 represents both the designer and the person responsible for defining general principles. As represented in Figure 3, the user (supported by a diagrammatic language) can describe the structure of the organization and design the process (process description). The diagnosis procedure uses that information, together with general organizational knowledge, to detect violations of the principles indicated by the organization (user). The translation from a diagrammatic language to a declarative formal language is necessary, because Ramos and Fiadeiro want to use logical deduction in the diagnosis procedure. The components of the process model are the following ones:

1. **Organizational structure.** The set of structural concepts that characterize an organization, e.g. *agents*, *tasks*, *hierarchies*. These concepts are independent of the processes. They describe the fixed components over which the processes should 'flow'. The structural concepts represent what is fixed in the organization in the sense that it cannot be changed as a consequence of a process (re)design.

2. **Process description.** The description of the process design, made with typical primitives used in organizational process like *assign-task*, *output-to-task* etc. Variable concepts are concepts that can be manipulated by the person that designs the process. They can be understood as 'design actions'.

3. **General organizational knowledge.** Definitions (e.g. *available*, *informed*) and rules common to all organizations (e.g. *if a task is assigned to a collective agent, all the members of the collective agent are assigned to that task*).

4. **Principles.** General rules that characterize the ideal behavior of an organization. Each organization decides which rules should be used. Usually the rules that guide the design are general rules. For example, '*no employee can be assigned to a control task if the decision to control is assigned to an agent up in the hierarchy.*'

The following example of [RF96b] illustrates the design of an order delivering process, and is adapted from [CL92]. In Chen and Lee's framework for the evaluation of internal accounting control procedures, the idea of having general principles guiding organizational diagnosis is already present. However, this framework is not supported by a theory of diagnosis. For instance, it does not deal with either alternative or minimal diagnoses.

Example 2 (Delivering order) *To avoid frauds in organizational accounting procedures, some control rules are often used. In Figure 4, the process is designed in order to (partially) fulfill those rules (principles). The process is as follows. The stock manager receives an order (from a salesman, for example), fills up an internal delivery order (IDO) and sends the IDO to agent 1, assigned to the task of verifying the IDO. After receiving the same order the accounting department fills up the invoice and also sends it to agent 1. Agent 1 checks if the values of the IDO and the invoice are the same, stores the invoice in the invoice file and sends the IDO to agent 2, assigned to the task of filling up the outgoing delivery order (ODO). After filling up the ODO agent 2 sends it to the client together with the goods.*

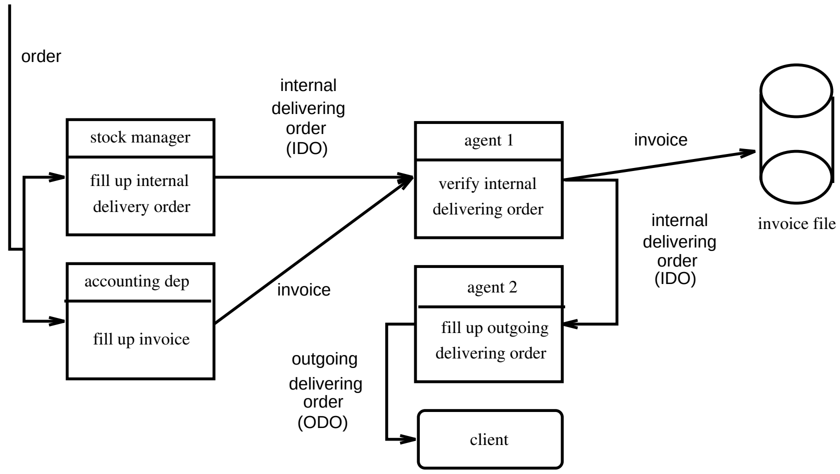

Figure 4: Ideal order delivering process

Agent 1 is involved in the process in order to avoid a potential fraud between the stock manager and the client, because agent 1 checks if the goods in the IDO matches the values in the invoice. In the process design in Figure 4 one general rule, to ensure that the document is not manipulated by other agents, is fulfilled: 'all documents must go straight to the control agent after they are created.*'* *Two other rules that apply to the process are* 'an agent should not control a superior in the hierarchy' *and* 'socially-close agents should not control each other.*'* *For example, the stock manager should not be a superior of agent 1 and agent 2 should not be socially-close to the stock manager.*

We give a simple formalization of this example in a propositional language, which suffices for our purpose of illustrating DDD. *Instead of formalizing the three generic rules as first-order obligations, we formalize several consequences (instances) of these generic rules as propositional obligations. Let us assume the following organization structure: John, Ann and Phil are agents of the organization, Phil is socially-close to John and the stock manager is hierarchical superior than John. The obligations are (a) the output of the task verify-IDO must go to the task fill-up-ODO, (b) we must not assign Phil to the task fill-up-ODO, because socially close agents should not be involved in this process, (c) we must not assign John to the task verify-IDO, because one agent should not control a superior in the hierarchy, and (d) the output of the task fill-up-invoice must go to the task verify-IDO. Using the violation constants of* DIODE, *we represent the four obligations by* $\neg V_1 \rightarrow a$, $\neg V_2 \rightarrow b$, $\neg V_3 \rightarrow c$ *and* $\neg V_4 \rightarrow d$, *respectively. An instance of the general organisational knowledge is that if the output of task verify-IDO goes to fill-up-ODO and Phil is not assigned to fill-up-ODO, then Phil does not receive the ODO, which is represented by* $a \wedge b \rightarrow e$. *Finally, facts (design) are that Ann is agent 1, Phil is agent 2, John is not assigned to the task verify-IDO and that Phil receives the ODO, i.e.,* $c \wedge \neg e$. *Notice that one of the first or second obligation is violated, the third obligation is fulfilled, and nothing is know about the fourth obligation.*

In the following section we show how we can reason about this delivering order example in the deontic framework for diagnosis of process design, based on Reiter's theory of diagnosis.

3.1 DDD Deontic framework for diagnosis of (organizational) process design

Minimal diagnoses have proven to be adequate for detecting violations of obligations. However, for the purpose of process design diagnosis, it is not sufficient to capture cases of unfulfilled obligations. This particularity of process design lead Ramos and Fiadeiro in [RF96b] to propose a more general diagnosis, one that distinguishes between potential, benevolent and exigent diagnosis. The following example criticizes the principle of parsimony for organizational process design.

Example 3 (Delivering order, continued) *If it is important that the invoice goes straight to the task verify-IDO, then a design that does not commit itself with the output of the invoice must be avoided. Indeed, if the principle is not enforced, it is possible that, during the implementation of the process in the organization, the invoice goes straight to the invoice file. To avoid this undesired situation, the diagnosis should alert to the 'incompleteness' of the design. When it is important to ensure that all obligations are fulfilled, and not only detect violations of obligations, the principle of parsimony is much too* benevolent *(it is like the assumption of the fulfillment of obligations in the absence of information). In that case an approach based only on minimal diagnosis is not adequate and an* exigent *diagnosis (where unfulfilled obligations are detected) is more suitable.*

In order to deal with diagnoses that are not minimal, Ramos and Fiadeiro extend the representation of obligations by assuming that norms are completely described. With this new approach, more useful information can be obtained for process design, keeping at the same time all the results of model based reasoning. When a set of norms is translated to DDD, the following two assumptions are made to incorporate fault knowledge. The underlying assumption of 'innocent until proven guilty' is not always the right one; sometimes 'guilty until proven innocent' is preferred. So-called fault knowledge (see e.g. [dKMR90]) describes the consequences of broken components, in general $\beta \wedge Ab(c) \rightarrow \gamma$. Hence, with fault knowledge from the abnormality of a component new information can be derived. If the rules from the system description SD are represented by $\beta \wedge \neg Ab(c) \rightarrow \alpha$, then there is no fault knowledge. In that case, the maximal diagnosis is simply the set of all components. Obviously, for any reasonable definition of a maximal diagnosis, fault knowledge has to be added.

- **Assumption 1** As a rule, each (conditional) obligation of a premise set corresponds to a separate norm. A set of obligations is translated to a set of norms.
- **Assumption 2** Every norm description completely describes an obligation. Thus, a conditional obligation 'α should be the case if β is the case' is represented in DDD by the norm description $\neg V(n_i) \leftrightarrow (\beta \rightarrow \alpha)$. The conditional obligation can be read in DDD as 'if the norm n_i is not violated, then and only then if β is the case then α is the case.' The sentence is logically equivalent with $V(n_i) \leftrightarrow (\neg\alpha \wedge \beta)$, which explains why $V(n_i)$ is called a *violation constant*.

Ramos and Fiadeiro propose the following deontic framework for diagnosis of (organizational) process design DDD. They discriminate between minimal and maximal violated-norm sets.

Definition 3 (DDD) *A* normative system *is a* DIODE *tuple* NS = (NORMS, ND) *where* ND*, the* norms description*, is a set of completely described conditional obligations* $\neg V(n_i) \leftrightarrow (\beta \rightarrow \alpha)$*. Let* NSD = (NORMS, ND, FACTS) *be a normative system to be diagnosed and* CONTEXT_Δ *the context of a set of norms* $\Delta \subseteq$ NORMS*. A* potential diagnosis Δ *of* NSD *is a subset of* NORMS *such that* CONTEXT_Δ *is consistent. A* benevolent (exigent) diagnosis Δ *is a minimal (maximal) subset (with respect to set inclusion) of* NORMS *such that* CONTEXT_Δ *is consistent. The* implicit violation set Δ *of* NSD *is a minimal subset (with respect to set inclusion) of* NORMS *such that* CONTEXT_Δ *is inconsistent.*

The set of potential diagnosis can be ordered by set inclusion, of which the benevolent and exigent diagnosis are respectively the lower and upper bounds. Diagnostic reasoning is not restricted to the minimal elements of the graph, but to all elements. Moreover, for the benevolent diagnosis we have the additional information supplied by the implicit obligation sets and the contextual obligations. This is illustrated by the example of the delivering order in DDD, see [RF96b] for a full discussion of this example in DDD.[2]

Example 4 (Delivering order, continued) *Consider the following normative system:*

1. NORMS = $\{n_1, n_2, n_3, n_4\}$, *and*
2. ND = $\{\neg V(n_1) \leftrightarrow a, \neg V(n_2) \leftrightarrow b, \neg V(n_3) \leftrightarrow c, \neg V(n_4) \leftrightarrow d\}$.

[2] As remarked in [dKMR90], with the representation of fault knowledge it is no longer possible to compute all consistent sets of normal and abnormal components based on minimal diagnosis: not all supersets of minimal sets are consistent. In Reiter's minimal diagnosis that property holds. Indeed, in Figure 5.a, only the sets in italics are consistent if we adopt the complete description of norms.

The set of potential diagnoses of FACTS = $\{a \wedge b \rightarrow e, c \wedge \neg e\}$ *is represented in Figure 5. We have* FACTS $\models \neg a \vee \neg b$ *and* FACTS $\cup$ ND $\models V(n_1) \vee V(n_2)$*. Moreover, we have* FACTS $\cup$ ND $\models \neg V(n_3)$*. There is one exigent diagnosis,* $\{V(n_1), V(n_2), V(n_4)\}$*, and two benevolent diagnoses,* $\{V(n_1)\}$ *and* $\{V(n_2)\}$*. The implicit violation set is* $\{V(n_1), V(n_2)\}$*, which means that either the first or the second norm has to be violated.*

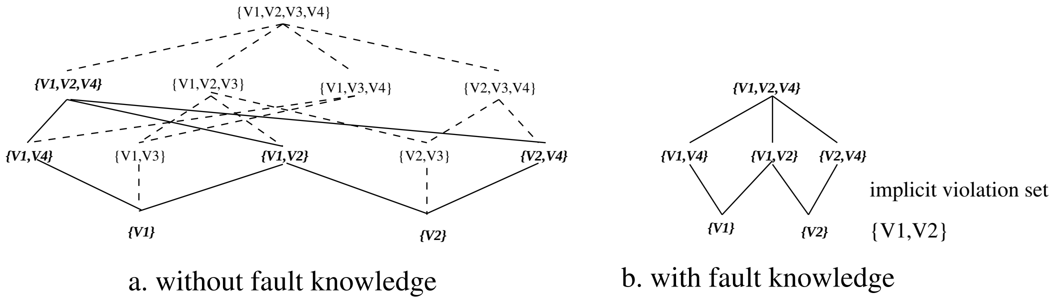

Figure 5: Consistent sets of violations

3.2 DDD[2] Deontic framework for Diagnosis for process Design based on Deontic logic

In [RF96a] Ramos and Fiadeiro show how a theory of diagnosis can use deontic logic. Ramos and Fiadeiro use dyadic deontic logic to represent conditional obligations.[3] With the dyadic operator, Chisholm's paradox for conditional obligations does not occur. Dyadic obligations $O(\alpha \mid \beta)$ are read as 'α is obligatory in the context β.' They have the following desiderata for the dyadic logic.

1. Conditional obligation, thus not $O(\alpha|\beta) \leftrightarrow O(\beta \rightarrow \alpha)$. For example, if there is a rule *'if an order form is send to a supplier, then a copy of the order form should be send to the department store'* $O(c|o)$ and neither c and o nor their negations can be derived, then an exigent diagnosis should not contain the violation of the obligation. The situation is avoided if we only consider violations of *actual* obligations in a diagnosis, because with actual obligations, if o cannot be derived, then the violation will never appear in a diagnosis. Thus a normal modal system like SDL and Anderson's reduction to alethic modal logic is insufficient.

2. Contraposition $O(\alpha|\beta) \leftrightarrow O(\neg\beta|\neg\alpha)$. For example, if there is the rule $O(c|o)$ and $\neg c$ can be derived and $\neg o$ cannot be derived, then an exigent diagnosis should contain the violation of the obligation.

3. No weakening of the consequent. Consider the rule of inference RM : if $\vdash \beta \rightarrow \alpha$ then $O\beta \rightarrow O\alpha$. Assume the following rule: *if one agent sends a document to other, then the second receives the document.'* Notice that A sending a document to B is more specific than B receiving it because it can be send by anyone. Furthermore, assume the obligation *'Ann is obliged to send a budget to John'* and the fact *'Ann does not send the budget'* (thus John does not receive it). Given rule RM, the diagnosis will report two violations. However only one violation really occurs. Thus a normal modal system like SDL and a non-normal modal system like Chellas minimal deontic logic are insufficient.

4. Design action and context. Dyadic obligations $O(\alpha|\beta)$ have two components. First, the *design action* (α) that indicates what the designer should do. Second, *the context* (β) that describes the situation in which the design action should be done.

5. No structural variables in the scope of the modal operator. It is assumed that it makes no sense to have obligations that oblige a process designer to act in the structure of the organisation. This is formalized by the contingency clause $\neg struct(\alpha)$, as explained below. It follows from that assumption that, whatever the context, any obligation where the action is represented by a structural concept is not valid. For example, the following rule *'if the task approve-budget is assigned to John, then John must be the Head of Department (HD)'* $O(h|a)$ is not valid because John being or not being the HD is not an design action (it is a part of the structure of the organisation). The rule should be: '*if John is not the HD, then he cannot be assigned to the task approve-budget*' $O(\neg a \mid \neg h)$.

[3] A deontic logic describes besides obligations also permissions. However, the 'organization' does not say : you are permitted to do ... ! That makes no sense in design. The diagnosis is not going to check if the permissions are 'fulfilled', because it is a designer problem. The designer is permitted to do anything except violating the rules.

Ramos and Fiadeiro make a distinction between structural and action variables (4). The basic idea is the following, inspired by Castañeda's distinction between assertions and actions [Cas81]. The modal language of deontic logic gives us the opportunity – not present in Reiter's first order theory of diagnosis – to distinguish between structural variables which are fixed *within a model*, and variables which are allowed to vary within the model. For a structural variable p, we have $\Box p \vee \Box\neg p$. Hence, we have $p \rightarrow \Box p$: if the structural variable is true in the actual world, it is true in all worlds. Notice that $\Box p$ should be read as p is a structural concept, not as p is necessarily true (as in Anderson's proposal). Moreover, they restrict the scope of the deontic operator to action variables (5). Hence, we add the clause $\neg struct(\alpha)$ to an obligation for α. This is a formalization of von Wright's contingency principle, because we have $Op \rightarrow \Diamond\neg p$ and $Op \rightarrow \Diamond p$. The contingency clause $\neg struct(\alpha)$ is a kind of consistency check. Von Wright remarks that 'the last may be regarded as a version of the principle, commonly associated with the name of Kant, that 'Ought implies (entails) Can' [vW71, p.163].

In [RF96a] the following logic LDD is proposed. It is defined in terms of a monadic minimal modal logic, and thereby we have trivially soundness and completeness of the logic. The modal operator I is a technical trick to avoid the problems of Chellas' standard modal operators. The interested reader is referred to [RF96a] for further details.[4]

Definition 4 **(LDD)** *Consider a bimodal logic with $\Box$ and I. The logic is the smallest set of formula that contains the propositional tautologies and the following axioms and is closed under the following rules of inference.*

MP: $\frac{\alpha\rightarrow\beta,\alpha}{\beta}$
Nes: $\frac{\vdash\alpha}{\vdash\Box\alpha}$
RE: $\frac{\alpha_1\leftrightarrow\alpha_2}{I\alpha_1\leftrightarrow I\alpha_2}$
K: $\Box(\beta\rightarrow\alpha)\rightarrow(\Box\beta\rightarrow\Box\alpha)$
T: $\Box\alpha\rightarrow\alpha$
$\neg I\bot$
$\neg I\top$
$\Box\alpha\rightarrow I\alpha$

The logic LDD *is extension of the bimodal logic with the following definitions.*

$$struct(\alpha) =_{def} \Box\alpha\vee\Box\neg\alpha$$
$$O(\alpha|\beta) =_{def} I(\beta\leftrightarrow\alpha)\wedge\neg I(\neg\alpha\wedge\beta)\wedge\neg struct(\alpha)$$

Definition 5 **(Semantics LDD)** *Kripke models $M=\langle W,R_1,R_2,V\rangle$ for* LDD *consist of W a set of worlds, $R_1(w,w')$ a binary reflexive accessibility relation, $R_2(w,W')$ an accessibility relation that gives a nonempty set of sets of worlds ($\neq W$) for each world (we write either $R_1(w,w')$ and $R_2(w,W')$, or $w'\in R_1(w)$ and $W'\in R_2(w)$), such that for all $W'\in R_2(w)$ we have $W'\subset R_1(w)$, and V a valuation function for the propositions in the worlds. We have:*

$M,w\models\Box p$ *iff for all w' such that $R_1(w,w')$ we have $M,w'\models p$*
$M,w\models Ip$ *iff there is a W' such that $R_2(w,W')$ and $W'=\{w'\in R_1(w)\mid M,w'\models p\}$.*

The logic is not closed under conjunction, weakening of the consequent, etc. The following proposition shows that LDD has the desired properties.

Proposition 1 *The logic* LDD *validates the following theorems.*

$$\neg O(\top|\beta)$$
$$\neg O(\bot|\beta)$$
$$(\beta\wedge struct(\beta)\wedge O(\alpha|\beta))\rightarrow O(\alpha|\top)$$
$$(struct(\alpha_2)\wedge O(\alpha_1\wedge\alpha_2|\beta))\rightarrow O(\alpha_1|\beta)$$
$$(\neg struct(\beta)\wedge O(\alpha|\beta))\rightarrow O(\neg\beta|\neg\alpha)$$

The logic LDD *does not validate the following theorem (the first desideratum of the list at the beginning of this section).*

$$(\neg struct(\beta\rightarrow\alpha)\wedge O(\alpha|\beta))\rightarrow O(\beta\rightarrow\alpha|\top)$$

Proof *The two theorems $\neg O(\top\mid\beta)$ and $\neg O(\bot\mid\beta)$ follow directly from the clause $\neg struct(\alpha)$. The two theorems $(\beta\wedge struct(\beta)\wedge O(\alpha\mid\beta))\rightarrow O(\alpha\mid\top)$ and $(struct(\alpha_2)\wedge O(\alpha_1\wedge\alpha_2\mid\beta))\rightarrow O(\alpha_1\mid\beta)$ follow from $\alpha\wedge$*

[4] In this paper, we have simplified the formalization. In [RF96a], the dyadic operator is defined directly in the semantics: $O(\alpha\mid\beta)$ is true iff in all ideal designs $\alpha\leftrightarrow\beta$ and in ideal designs it is not the case that $\beta\wedge\neg\alpha$.

$struct(\alpha) \rightarrow \Box\alpha$. The theorem $(\neg struct(\beta) \wedge O(\alpha \mid \beta)) \rightarrow O(\neg\beta \mid \neg\alpha)$ follows from $(I(\beta \leftrightarrow \alpha) \wedge \neg I(\neg\alpha \wedge \beta)) \rightarrow (I(\neg\alpha \leftrightarrow \neg\beta) \wedge \neg I(\neg\neg\beta \wedge \neg\alpha))$. For a countermodel of $(\neg struct(\beta \rightarrow \alpha) \wedge O(\alpha \mid \beta)) \rightarrow O(\beta \rightarrow \alpha \mid \top)$, consider $W = \{w_0, w_1, w_2, w_3, w_4\}$ with $w_1 = \{\neg a, \neg b\}; w_2 = \{a, b\}; w_3 = \{\neg a, b\}; w_4 = \{a, \neg b\}$, $R_1(w_0, w_1); R_1(w_0, w_2); R_1(w_0, w_3); R_1(w_0, w_4); R_2(w_0, \{w_1, w_2\})$. We have $M, w_0 \models I(a \leftrightarrow b)$ because $W' = \{w_1, w_2\}$, we have $M, w_0 \models I(\neg a \wedge b)$ because we do not have $R_2(w_0, \{w_3\})$, and we have $M, w_0 \not\models I((b \rightarrow a) \leftrightarrow \top)$ because we do not have $R_2(w_0, \{w_1, w_2, w_4\})$.

The logic LDD is used for deontics-based diagnosis.[5]

Definition 6 (Deontics-based diagnosis) *An obligation system is a tuple* OS = (OBL, STRUCT) *with:*

1. OBL*, a finite set of modal sentences denoting conditional obligations $O(\alpha|\beta)$,*
2. STRUCT*, a set of expressions denoting which variables are structural $\Box p \vee \Box\neg p$.*

An obligation system to be diagnosed is a tuple OSD = (OBL, STRUCT, FACTS) *with:*

1. OS = (OBL, STRUCT)*, an obligation system, and*
2. FACTS*, a finite set of propositional sentences.*

The actual obligation set AO *is the set of obligations (without logical equivalents):*

$$\text{AO} = \{O_a\alpha \mid \text{OBL} \cup \text{FACTS} \cup \text{STRUCT} \models O(\alpha|\beta) \wedge \beta\}$$

A potential diagnosis Δ is a subset of the actual obligation set AO *such that*

$$\text{CONTEXT}_\Delta = \text{OBL} \cup \text{FACTS} \cup \text{STRUCT} \cup \{\neg\alpha \mid O_a\alpha \in \Delta\} \cup \{\alpha \mid O_a\alpha \in \text{AO} - \Delta\}$$

is consistent.

Deontics-based diagnosis is illustrated by the following example.

Example 5 (Delivering order, continued) *Consider the following additional rule to the initial example in Example 2: 'if an ODO is sent to a client, a copy of the ODO should be sent to the department store' ($O(g|f)$). Since the condition of the obligation does not hold (it is not 'designed' yet), there is no actual obligation of g (send a copy of ODO to the department store). Consider the following obligation system to be diagnosed* (OBL, STRUCT, FACTS) *with*

1. OBL = $\{O(a|\top), O(b|\top), O(c|\top), O(d|\top), O(g|f)\}$,
2. STRUCT = $\emptyset$,
3. FACTS = $\{a \wedge b \rightarrow e, c \wedge \neg e\}$.

The actual obligation set is AO = $\{O_a a, O_a b, O_a c, O_a d\}$ *and the set of potential diagnoses is similar to the previous representation in* DDD *in Example 4.*

4 Diagnostic and decision-theoretic framework

The work of Tan and Van der Torre should be understood as a contribution to a more general purpose to build a formal framework to support drafting of bureaucratic procedures, in particular international trade procedures [BLWW95]. For example, in [RTvdT96] it is shown how to extend the Petri net formalism to represent different types of behavior, in particular normative behavior. This extension is motivated by the use of Petri nets to model bureaucratic procedures, which contain normative aspects like obligations and permissions. It is important that violations of obligations, i.e. sub-ideal states, are represented explicitly in the modeling of procedures, because in most procedures it is described explicitly what is considered as ill-behavior, and how this will be punished (the corresponding sanction). However, the representation of violations and sub-ideal behavior in Petri nets is not very satisfactory, see [RTvdT96]. The modeling of violations of bureaucratic procedures explains Tan and Van der Torre's interest in theories of diagnosis.

[5] We have simplified the deontics-based diagnosis a bit. The obligation system that consists of the single obligation $O(a|b)$ and facts $b \wedge \neg a$ will report that a is a violation. But in [RF96a] the user is informed that if he changes b to $\neg b$, then the violation will disappear.

4.1 DIODE with applicable norms

In DIODE, there is no distinction between fulfilling a dyadic obligation, and inapplicability of a dyadic obligation. For example, for an obligation $O(\alpha \mid \beta)$ we have $\neg V(n) \leftrightarrow (\beta \rightarrow \alpha)$, which is logically equivalent with $\neg V(n) \leftrightarrow (\neg\beta \vee (\beta \wedge \alpha))$. A solution is to add applicability information. For example, for an obligation $O(\alpha \mid \beta)$ we have $\neg V(n) \leftrightarrow (\beta \rightarrow \alpha) \wedge A(n) \leftrightarrow \beta$. Thus, the underlying logic is extended with an applicability predicate similar to the violation predicate. Now, first we determine the applicable obligations by minimizing the $A(n)$. Secondly, for applicable obligations we can have minimal or maximal sets.

Definition 7 **(DIODE with applicable norms)** *A* normative system *is a* DIODE *tuple* NS = (NORMS, ND) *where* ND, *the* norms description, *is a set of* conditional obligations $\neg V(n_i) \leftrightarrow (\beta \rightarrow \alpha) \wedge A(n) \leftrightarrow \beta$. *Let* NSD = (NORMS, ND, FACTS) *be a normative system to be diagnosed. The* active norms Δ_a *of* NSD *is a minimal subset of* NORMS *such that*

$$\text{ND} \cup \text{FACTS} \cup \{A(n_i) \mid n_i \in \Delta_a\} \cup \{\neg A(n_i) \mid n_i \in \text{NORMS} - \Delta_a\}$$

is consistent. A potential diagnosis Δ *of* NSD *is a subset of some* Δ_a *of* NSD *such that*

$$\text{CONTEXT}_\Delta = \text{ND} \cup \text{FACTS} \cup \{V(n_i) \mid n_i \in \Delta_a\} \cup \{\neg V(n_i) \mid n_i \in \Delta_a - \Delta\}$$

is consistent.

The following example illustrates the adaptation of DIODE.

Example 6 *Consider the normative system of the obligation* $O(c|o)$.

1. NORMS = $\{n_1\}$,
2. ND = $\{(\neg V(n_1) \leftrightarrow (o \rightarrow c)) \wedge (A(n_1) \leftrightarrow o)\}$.

The set of active norms Δ_a *is empty for* FACTS = $\emptyset$, *thus there is no potential diagnosis which contains the norm* n_1. *In particular, the only exigent diagnosis is the empty set. Moreover, consider the following normative system of the two obligations* $O(p_1|q)$ *and* $O(p_2|\neg q)$.

1. NORMS = $\{n_1, n_2\}$,
2. ND = $\{\ (\neg V(n_1) \leftrightarrow (q \rightarrow p_1)) \wedge (A(n_1) \leftrightarrow q), (\neg V(n_2) \leftrightarrow (\neg q \rightarrow p_2)) \wedge (A(n_2) \leftrightarrow \neg q)\}$.

Given the tautology $q \vee \neg q$, *we have for* FACTS = $\emptyset$ *two minimal active sets* $\Delta_a = \{n_1\}$ *and* $\Delta_a = \{n_2\}$. *Finally, consider the following normative system of the two obligations* $O(p|q)$ *and* $O(q|\top)$.

1. NORMS = $\{n_1, n_2\}$,
2. ND = $\{\ (\neg V(n_1) \leftrightarrow (q \rightarrow p)) \wedge (A(n_1) \leftrightarrow q), (\neg V(n_2) \leftrightarrow q) \wedge (A(n_2) \leftrightarrow \top)\}$.

The minimal active set for FACTS = $\{\neg p\}$ *is* $\Delta_a = \{n_2\}$.

4.2 DIO(DE)^2

A theory of diagnosis like DIODE is based on the distinction between violated and non-violated, and a (qualitative) decision theory is based on the distinction between fulfilled and non-fulfilled. DIO(DE)^2 is the DIagnostic and DEcision-theoretic framework for DEontic reasoning. It combines reasoning about violated and fulfilled norms. Hence, it combines reasoning about the past (violated versus non-violated) with reasoning about the future (already fulfilled versus not yet fulfilled). As illustrated in Figure 1, DIO(DE)^2 combines the reasoning of a judge with reasoning of a rational agent. DIO(DE)^2 is the extension of DIODE with (1) goal oriented reasoning, (2) distinction between parameters and decision variables and (3) addition of uncertainty and strategies. Here, we restrict ourselves to the first item. Technically, it has fulfilled-norm constants (F). In the following definition of DIO(DE)^2, for an obligation $O(\alpha|\beta)$ we have besides $\neg V(n) \leftrightarrow (\beta \rightarrow \alpha)$ also $F(n) \leftrightarrow (\beta \wedge \alpha)$. We minimize the applicable norms by minimizing the relation $(\Delta_f, \Delta_v) \leq (\Delta'_f, \Delta'_v)$.

Definition 8 **(DIO(DE)^2)** *A* normative system *is a* DIODE *tuple* NS = (NORMS, ND) *where* ND, *the* norms description, *is a set of* conditional obligations $\neg V(n_i) \leftrightarrow (\beta \rightarrow \alpha) \wedge F(n) \leftrightarrow (\beta \wedge \alpha)$. *Let* NSD = (NORMS, ND, FACTS) *be a normative system to be diagnosed. A* fulfilled-violated set (Δ_f, Δ_v) *of* NSD *is a pair of subsets of* $norms$ *such that*

$$\begin{aligned}\text{CONTEXT}_\Delta = \text{ND} \cup \text{FACTS} \quad & \cup\{V(n_i) \mid n_i \in \Delta_v\} \cup \{\neg V(n_i) \mid n_i \in \text{NORMS} - \Delta_v\} \\ & \cup\{F(n_i) \mid n_i \in \Delta_f\} \cup \{\neg F(n_i) \mid n_i \in \text{NORMS} - \Delta_f\}\end{aligned}$$

is consistent. Let $\leq$ *be the ordering on fulfilled-violated sets defined by* $(\Delta_f, \Delta_v) \leq (\Delta'_f, \Delta'_v)$ *iff* $\Delta_f \subseteq \Delta'_f$ *and* $\Delta_v \subseteq \Delta'_v$. *A* potential diagnosis (Δ_f, Δ_v) *of* NSD *is a pair of subsets of* NORMS *that is minimal in the ordering* $\leq$.

The following example illustrates the adaptation of DIO(DE)^2 and compares it with DIODE with applicable norms.

Example 7 *Consider the following normative system of the obligation $O(c|o)$.*

1. NORMS = $\{n_1\}$,
2. ND = $\{(\neg V(n_1) \leftrightarrow (o \rightarrow c)) \wedge (F(n_1) \leftrightarrow (c \wedge o))\}$

The unique potential diagnosis for FACTS = $\emptyset$ *is* $(\Delta_f, \Delta_v) = (\emptyset, \emptyset)$. *In* DIODE *with applicable norms, the set of active norms Δ_a is empty for* FACTS = $\emptyset$. *Hence, the two systems behave similarly. Moreover, consider the following normative system of the two obligations $O(p_1|q)$ and $O(p_2|\neg q)$.*

1. NORMS = $\{n_1, n_2\}$,
2. ND = $\{(\neg V(n_1) \leftrightarrow (q \rightarrow p_1)) \wedge (F(n_1) \leftrightarrow (p_1 \wedge q)), (\neg V(n_2) \leftrightarrow (\neg q \rightarrow p_2)) \wedge (F(n_2) \leftrightarrow (p_2 \wedge \neg q))\}$

The potential diagnoses (Δ_f, Δ_v) for FACTS = $\emptyset$ *are* $(\{n_1\}, \emptyset)$, $(\{n_2\}, \emptyset)$, $(\emptyset, \{n_1\})$ *and* $(\emptyset, \{n_2\})$. *In* DIODE *with applicable norms, we have for* FACTS = $\emptyset$ *two minimal active sets* $\Delta_a = \{n_1\}$ *and* $\Delta_a = \{n_2\}$. *Hence, the two systems behave again similarly. Finally, consider the following normative system of the two obligations $O(p\,|\,q)$ and $O(q|\top)$.*

1. NORMS = $\{n_1, n_2\}$,
2. ND = $\{\ (\neg V(n_1) \leftrightarrow (q \rightarrow p)) \wedge (F(n_1) \leftrightarrow (p \wedge q)), (\neg V(n_2) \leftrightarrow q) \wedge (F(n_2) \leftrightarrow q)\}$.

The potential diagnoses for FACTS = $\{\neg p\}$ *are* $(\Delta_f, \Delta_v) = (\emptyset, \{n_2\})$ *and* $(\Delta_f, \Delta_v) = (\{n_2\}, \{n_1\})$. *In* DIODE *with applicable norms, the minimal active set for* FACTS = $\{\neg p\}$ *is* $\Delta_a = \{n_2\}$. *The two systems do not behave similarly, because in* DIO(DE)^2 *it is possible that the first obligation is violated.*

There is an interesting connection between the latter set of obligations of Example 7 and deontic detachment (or transitivity) $O(\alpha\,|\,\beta) \wedge O(\beta\,|\,\gamma) \rightarrow O(\alpha\,|\,\gamma)$. With deontic detachment we can derive the obligation $O(p\,|\,\top)$ from the two premises $O(p\,|\,q)$ and $O(q\,|\,\top)$. Thus, if deontic detachment is valid, then the fact $\neg p$ is a violation. In DIODE, there is only one active set, that contains the second obligation. It is possible that this obligation is fulfilled, and there are therefore no violations. On the other hand, in DIO(DE)^2 every potential diagnosis contains violations.

4.3 The two-phase deontic logic 2DL

The two-phase preference-based deontic logic 2DL [TvdT96, vdTT97b] can be used to make the comparison between DIO(DE)^2 and classical deontic logics. In the modal preference semantics of 2DL, the accessibility relation is interpreted as a preference relation. For example, $w_1 \leq w_2$ has to be read as 'world w_1 is at least as preferable as world w_2.' It is a well-known problem from preference logics that we cannot define an obligation Op as a strict preference of p over $\neg p$, because two obligations Op_1 and Op_2 would conflict for $p_1 \wedge \neg p_2$ and $\neg p_1 \wedge p_2$. This motivates the following weaker definition: an obligation p is the absence of a preference of $\neg p$ over p, see [TvdT96, vdTT97b].

Definition 9 (2DL) *A Kripke model $M = \langle W, \leq, V\rangle$ consists of W, a set of worlds, $\leq$ a binary transitive and reflexive accessibility relation interpreted as a preference relation, and V, a valuation of the propositions at the worlds. We have $M \models O(\alpha|\beta)$ iff*

1. *for all w and w' such that $M, w \models \alpha \wedge \beta$ and $M, w' \models \neg\alpha \wedge \beta$, we have $w' \not\leq w$, and*
2. *there are such worlds w and w'.*

DIO(DE)^2 corresponds to deontics-based diagnosis based on the modal logic 2DL. That is, DIO(DE)^2 corresponds to deontics-based diagnosis in Definition 6 in the previous section, where the logic LDD is replaced by 2DL. The correspondence follows directly from the preference-based semantics. An obligation $O(\alpha|\beta)$ in DIO(DE)^2 is a preference of $\alpha \wedge \beta$ (fulfilled norm) over $\neg\alpha \wedge \beta$ (violated norm). This preference is defined in two steps: in the base language the fulfilled and violated norm constants are defined, and in the definition of potential diagnosis the set of applicable norms is minimized. In 2DL, the preference is not represented by fulfilled and violated norm constants, but defined directly in the preferential semantics. With other words, DIO(DE)^2 is the deontic logic 2DL in which certain aspects (fulfillments and violations) are made explicit with the use of a naming convention, i.e. to use names n_i to denote norms.

5 Comparison

The similarity between the two approaches DDD and DIO(DE)^2 presented in this paper is that exigent diagnosis is like reasoning about goals. Moreover, there are several technical similarities between the logics LDD and 2DL like the use of a contingency clause (consistency checks) and lack of weakening of the consequent.

5.1 Exigent diagnosis and goal oriented reasoning

The main similarity between DDD and DIO(DE)^2 is that both are extensions of DIODE with concepts of qualitative decision theory. The extended diagnostic framework DDD can be considered as a kind of qualitative decision framework for the following reason. The exigent diagnosis of DDD reports norms not yet fulfilled. Hence, it reports norms that should be fulfilled in the future. These norms are the goals in decision theory, which are represented by F predicates in DIO(DE)^2.

We can discriminate two phases in DDD and DIO(DE)^2. The first phase reasons about all potential diagnosis and the second phase only about benevolent or exigent diagnoses. This is in accordance with the argumentation in [TvdT96] about the two-phase treatment of violated obligations. Moreover, Lang [Lan96] observes that his methodology in an alternative approach to qualitative decision theory contains two phases. First generate the preference relation from a set of desires, and then find the optimal feasible worlds, and thus the optimal decision.

5.2 Properties of the logics LDD and 2DL

There are two important similarities between the logics LDD and 2DL, contingency clause (consistency checks in the definition of obligation) and most importantly the lack of weakening of the consequent. In this paper, we argued that these properties are essential for diagnosis. In [TvdT96] it is shown that these properties are essential to solve the notorious contrary-to-duty paradoxes of deontic logic.

5.2.1 Contingency clause

Von Wright introduced the contingency clause, because he wanted to formalize a deontic logic based on a theory of conditions: ‘to say that something ought to be, or ought to be done, is to state that the being or doing of this thing is a necessary condition (requirement) of something else’ [vW71]. In DDD the contingency clause is introduced, because the consequent is restricted to design actions. In 2DL we have $O(\alpha|\beta) \to \Diamond(\alpha \wedge \beta)$ and $O(\alpha|\beta) \to \Diamond(\neg\alpha \wedge \beta)$. These consistency checks were introduced, because they are necessary to solve the notorious contrary-to-duty paradoxes like the Forrester and Chisholm paradoxes.

A distinction is that in 2DL we have $O(\alpha|\beta) \to \Diamond(\alpha\wedge\beta)$ whereas in LDD we only have $O(\alpha|\beta) \to \Diamond\alpha$. Notice that in LDD obligations of type $O(p|\bot)$ can be valid. Even if an obligation can never be violated in a model (the condition never holds), there are situations where the obligation should hold. Consider the following example: *all salesman responsible for at least one region must participate in the preparation of the annual budget.* It could be the case that, in a particular moment (i.e., in a model, if we consider that been responsible for a region is a structural concept), there are no salesmen responsible for regions (due, for example, to a ungoing reorganisation), i.e., the obligation is always fulfilled. However, since this is a temporary situation, the organization could be interested in keeping the rule (in order to avoid the necessity to change the normative systems when the structure changes).

5.2.2 Lack of weakening of the consequent

Lack of weakening of LDD is a desirable property in DDD^2, because it avoids too many violations as discussed in Section 3.2. Lack of weakening is used in 2DL because of the ctd paradoxes. Lack of weakening of the consequent is a well-known theme in deontic logic. Ross, who gave the following counterintuitive example of weakening of the consequent, called the Ross paradox: ‘if you should mail the letter, then you should mail or burn the letter’ [Ros41]. A similar SDL theorem has been questioned by Von Wright. He observed that ‘in a deontic logic which rejects the implication from left to right in the equivalence $O(p \wedge q) \leftrightarrow (Op \wedge Oq)$ while retaining the implication from right to left, the paradoxes would not appear’ [vW81, p.7]. Beatty [Bea73] suggests that ‘descriptive sentences’ do not have closure under logical implication. Jennings [Jen85] observes that ‘It has been suggested that a unary operator O capable of bearing a deontic interpretation might be defined in a logic of preference by $O\alpha =_{def} \alpha P \neg\alpha$’, and that ‘if the preference logic has the natural distributive properties as von Wright advocates, the defined deontic necessity will be nonmonotonic’ (i.e. does not have weakening).

5.2.3 Fulfilled goals and violations in LDD

Reconsider the definition of LDD $O(\alpha \mid \beta) =_{def} I(\beta \leftrightarrow \alpha) \wedge \neg I(\neg\alpha \wedge \beta) \wedge \neg struct(\alpha)$. The following definition discriminates between violations and fulfillments of this definition of obligations in the deontic logic LDD.

Definition 10 **(**LDD**)** *The logic* LDD *is a minimal deontic logic as defined in Definition 5, extended with the following definitions.*

$$
\begin{array}{lll}
struct(\alpha) & =_{def} & \Box\alpha \vee \Box\neg\alpha \\
F(\alpha|\beta) & =_{def} & I(\alpha \leftrightarrow \beta) \\
V(\alpha|\beta) & =_{def} & \neg I \neg(\beta \rightarrow \alpha) \\
O(\alpha|\beta) & =_{def} & F(\alpha|\beta) \wedge V(\alpha|\beta) \wedge \neg struct(\alpha)
\end{array}
$$

Observe that $(\alpha \leftrightarrow \beta) \leftrightarrow ((\alpha \wedge \beta) \vee (\neg\alpha \wedge \neg\beta))$. In DIO(DE)^2 only $\alpha \wedge \beta$ corresponds to a fulfilled goal, in LDD also $\neg\alpha \wedge \neg\beta$. The intuition of the bi-implication in LDD is as follows. In conditional obligations, ideally, if the condition is true, the action must be performed (and the condition cannot be true if the action is not performed). A situation where the condition is true and the action is not performed, is not an ideal one. Situations where the condition is false, and the action is performed, are not in the scope of truth in conditional obligations. We can analyze properties of the logic LDD by analyzing the properties of the definitions F and V. For example:

$$
\begin{array}{ll}
F(\alpha|\beta) \leftrightarrow F(\neg\beta|\neg\alpha) & V(\alpha|\beta) \leftrightarrow V(\neg\beta|\neg\alpha) \\
F(\alpha|\beta) \leftrightarrow F(\beta|\alpha) & V(\alpha|\beta) \leftrightarrow V(\beta \rightarrow \alpha|\top) \\
F(\alpha|\beta) \leftrightarrow F(\neg\alpha|\beta) & \\
F(\alpha|\beta) \leftrightarrow F(\beta \leftrightarrow \alpha|\top) &
\end{array}
$$

6 Conclusions

Classical approaches to a theory of diagnosis are based only on minimal diagnoses, and as a consequence they are not suitable to support decision-making processes. That limitation of classical approaches becomes more relevant when diagnosis is used in the context of a design support framework. In this paper two distinct non-classical diagnosis approaches have been presented, DDD and DIO(DE)^2, both supporting the design of procedures/ process in organizations. Both are extensions of DIODE, a deontic version of classical diagnoses.

LDD and 2DL are two deontic logics that have been introduced in a theory of diagnosis. Both languages presented are based on propositional logic. We are aware that this is a simplification of the real process/ procedures diagnosis. Usually the rules that guide designs are generic ones, which have to be expressed in first-order logic. It is necessary to extend the languages in order to capture those generic rules (see also [CL92]). Conflicting obligations is also a subject that it is important to consider in a framework that aims to help a designer. Not only because conflicting sometimes occur in organizations, but also due to alternative diagnoses. It is important to find a useful way to help the designer to deal with alternative choices. Conflict resolution strategies from defeasible deontic logic could be a possible answer, see [vdTT95, vdTT97a]. Castañeda's proposal [Cas81] for handling conflicting obligations is another possible approach.

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