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On the Logical Foundation of a Personalized Medical Prescription System

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ABSTRACT This paper, lays down the logical foundations for a personalized medical prescription system. The proposed system employs detailed pharmaceutical and medical knowledge about a medication and its effects or side effects on the patient, which may go beyond what is available in medication leaflets. The ontology was initially built for the proposed system and employs the description logic system, ALC, for knowledge representation. However, the uncertain nature of medical and medicinal knowledge poses some problems such as drug-drug interactions and drug-disease interactions, which render ALC inadequate to represent and reason within a system such as a personalized medical prescription system. Indeed, there is a need for a more flexible representation that allows reasoning with incomplete knowledge and possibly inconsistent cases. ALC is extended with defeasible rules to obtain defeasible ALC. Defeasible ALC allows the prevention of adverse drug interactions, detection drug-drug interactions and detection of drug-disease interactions. The ultimate purpose of this paper is providing to provide a standard knowledge base system toward a medical prescription capable of dealing with incomplete knowledge, conflicting information (inconsistencies) and exceptions cases, which will enhance individual healthcare and provide an appropriate prescription. This is accomplished by expanding the capabilities of description logic with defeasible rules, to achieve an accurate prescription decision for any patient's condition(s). Once implemented, a personalized medical prescription system intends to assist, not to replace, the clinician during medical prescription(s) or the pharmacist(s).

INDEX TERMS Knowledge base system, medical services, medical treatment, health information management, medicine prescription.

I. INTRODUCTION

Identifying signs and symptoms is essential in performing a diagnosis of the disease(s) a patient is suffering from. Once a diagnosis is made, the process of prescribing the proper drug(s) can be started. The prescription includes the name of the drug(s), the drug(s) form, the calculated dose, instruction for administration and relevant information.

For example, let's consider that NSAIDs denotes a Non-steroidal Anti-inflammatory Drugs, Ibuprofen denotes to drug and TreatPP stands for treats patients who suffer from pain. Consider the following ALC-based knowledge, Knowledge Base (KB) = {Ibuprofen $\sqsubseteq$ NSAIDs, NSAIDs $\sqsubseteq$ TreatPP}. From KB we can conclude classically that Ibuprofen is a treatment for patients who suffer from pain (Ibuprofen $\sqsubseteq$ TreatPP). However, this conclusion may not be appropriate for all patients, as Ibuprofen may not necessarily be the proper treatment for patients who suffer from pain, due to medication or medical condition contraindications. Nonetheless, it may be better to be more flexible. For instance, it can be designated that in the most normal cases, Ibuprofen can treat patients who suffer from pain but that there may be some exceptional cases in which they are not treated by Ibuprofen (defeasible logic).

In fact, the prescription process is more difficult than it seems as it mainly depends on a physician's experience and up-to-date knowledge of treatments. There are many conditions that may affect treatment choices and increase prescription complexity. The medical history and condition of the patient are the most important factors to be considered when describing a safe and effective prescription.

Therefore, the following is needed: (1) A dependable, systematic guideline as a way of checking compatibility and prescribing of the proper drug. (2) A formalism that is explicitly used to represent knowledge related to treatment options that

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consist of drug administration, diseases, patient complaint, patient conditions, and drug interactions.

Ontology is a shared conceptualization of a domain, and it supports automatic reasoning about the domain. It affords a means to conventionally exhibit domain knowledge by the designation of pertinent concepts and the semantic association amidst those concepts [1], [2]. It is a basis for modeling high-quality, linked and coherent data, with possession of the crucial bonds amid concepts already existent that facilitates automated reasoning about the information. It yields nearly effortless navigation, as we can move from one concept to another.

Description Logics (DLs), are employed as the logical formalisms for ontologies. DLs are a group of logics for depicting knowledge that have sound clear semantics. They offer the ability to describe concepts concerning the domain as formulas in a 'First Order Predict Calculus' (FOPC). The main reasoning problems for DLs are typically able to be decided and offer a capable decision strategy [2], [3].

Approaches that are facilitated by FOPC assume complete knowledge and endure the failure to manage inconsistencies. In cases of inconsistencies in a KB, every outcome can be obtained and the system becomes unsuccessful. Nevertheless, typically, in the instance of actual domains, the information knowledge that is accessible is incomplete and uncertain. Defeasible/ Default logic [4]–[15] is pertinent in such circumstances as these when there is partial knowledge. Defeasible/Non-monotonic rule systems grant greater expressive capabilities and come nearer to pragmatic reasoning. Contradictory rules can emerge in several circumstances [8], [13], and [15]. Examples are:

- ❖ Reasoning with incomplete information.
- ❖ Rules with exceptions.
- ❖ Default inheritance in ontologies.

This paper lays down the logical foundations for a Personalized Medical Prescription System (PMDS). PMDS employs deep pharmaceutical and medical knowledge about a patient that may go beyond what is available in medication leaflets. Personalized Medical Prescription Ontology (PMDO) for PMDS was built and employed the DL system, ALC, for knowledge representation encouraged by the fact that ALC is the proper formalism for representing ontologies as it allows us to benefit from available tools such as Protégé. However, the uncertain nature of medical and medicinal knowledge and some problems such as Drug-Drug Interactions (DDI) and drug-disease interactions, make ALC inadequate to represent and reason within a system such as PMDS (see section VI where a detailed example that shows the inadequacy of ALC). Indeed, there was a need for a more flexible representation that allows the ability to reason with incomplete and possibly inconsistent cases. The ALC was extended with defeasible rules to obtain defeasible ALC. Defeasible ALC allows the prevention of adverse drug reactions and detects DDI and drug-disease interactions. Once implemented, the PMDS system is intended to assist, but not to replace, the clinician or pharmacist during the medical prescription(s) process.

The contributions of this paper involve:

- ❖ Building ontology, PMDO, for PMDS and implementing it on Protégé.
- ❖ Representing PMDO ontology in ALC.
- ❖ Example that shows the inadequacy of ALC.
- ❖ ALC extension with defeasible rules to obtain defeasible ALC.

The remainder of this paper is structured as follows. Section II contains a quick overview of some medical ontology. Section III contains basic concepts. Section IV displays how the ontology, (PMDO, of PMDS) is constructed. Section V provides a comparison with previous approaches. Section VI offers an example that portrays the inadequacy of ALC and the need for defeasible ALC. Section VII presents some conclusions and potential future works.

II. RELATED WORK

Medical domains are active areas of KB systems research. In this section, some important endeavors for these domains are introduced.

Ontologies have become an essential tool to assist researchers in their endeavors. Although an assortment of medical ontologies have been developed, work in this area has not reached a standard, as a result of the heterogeneity in the structure and semantics of the knowledge being modeled.

A. PRESCRIPTION ONTOLOGIES

Grando *et al.* [16] suggested ontology for representing drug-related knowledge and an archive for the complexity of multi-drug treatments. The idea of creating a multi-drug prescription ontology model, for patients with various medical conditions, in safe and effective prescription principles was studied. The ontology would undertake the need to diminish injurious drug episodes and the urgency for reasoning on biomedical problems. Semantic Web Rule Language (SWRL) as decision support for multi-drug prescriptions was used.

Farrish and Grando [17] extended the approach that is worked by Grando *et al.* [16] to develop drug ontology. The feasibility of decreasing the complexity of medications was investigated for the purpose of diminishing the complexity of medications prescribed to a patient. SWRL was used to assist in the decision making process of drug combinations.

Ethier *et al.* [18] created a Prescription of Drugs Ontology (PDRO) that addressed problems regarding the structuring of electronic prescriptions with improved semantics founded by Smith *et al.* [19]. The PDRO aimed to improve the semantics of drug prescriptions, which focused on drug administration specification, drug product specification and dose administration.

B. DRUG ADMINISTRATION ONTOLOGIES

Drug ontologies are interested in the representation of vocabulary related to drug information and that are useful for a

variety of motivations. Nelson *et al.* [20] created RxNorm ontology to make a sole, multipurpose guideline terminology for the representation of prescribed drugs and for dose forms. These terminologies can be used or reused for exchange of information about medication among clinical systems. Hanna *et al.* [21] created a Drug Ontology (DrOn) based on RxNorm to meet requirements of comparative effectiveness with mapping of the RxNorm entities to chemical entities of biomedical interest classes. The researches have increased interest in this field to include additional relevant information such as: Adverse Drug Effect (ADE), and drug interactions with substances. The drug interaction substances can result from diseases, other drugs [22], or food [23]. Jiang *et al.* [24] defined a domain pattern for the ADE knowledge depiction. This pattern is considered as a conceivable foundation for an ontological depiction of ADE domain.

C. DDI ONTOLOGIES

DDIs present considerable possibilities of causing inimical effects affiliated with a patient's treatment. DDIs are prevalent inimical reactions amid a pair of medications that conceivably have a serious consequence on a patient's well-being. Many drugs can work well together to help improve a patient's health. On the other hand, other drugs may not work as well together and can cause unwanted adverse drug reactions.

There are several ontologies that focus on the representation of DDI, such as the following:

- Wu *et al.* [25] that developed ontology called PK for the representation of DDI of pharmacokinetic information.
- Rubrichi *et al.* [26] that represented the DDI ontology, which aimed to support decision-making during the prescription process. The resulted ontology model is performed by extracting drug-related information from texts in textual drug descriptions.
- Herrero Zazo *et al.* [27] that organized the first Drug Interaction Ontology (DINTO) which included two types of pharmacology processing: pharmacodynamics and pharmacokinetic mechanisms.
- Moreover, drug interaction mechanisms were discussed by Tannenbaum and Sheehan [28], as strategies for investigating and decreasing a patient's susceptibility to drug interactions.
- Ontology for the representation of DDI evidence and knowledge claims was created by Brochhausen *et al.* [29]. This ontology boasts new and different facets of the representation of information content entities, that describe some aspects of DDI and that are necessary for the organization and collection of evidence pertaining to DDI.
- A potential DDI (PDDI) was defined by Schneider *et al.* [30] as an information content entity that signifies the possibility of the incidence of a DDI. Pharmacological aspects instead of informational aspects are the focuses of the results.
- An extension of the original version of DINTO was introduced by Herrero Zazo *et al.* [31] as comprehensive ontology that systematically organizes all DDI-related knowledge. A formal representation consisting of an extensive scope of DDI mechanisms was provided by DINTO. Its intention is to be a sturdy, useful resource for different applications, and inference of DDI and their mechanisms. Information from different related ontologies is incorporated with DINTO. Here, SWRL has been utilized to detect DDI.

D. DISEASE DIAGNOSIS AND TREATMENT

The ontologies provided many works in disease diagnosis. Scheuermann *et al.* [32] provided a coherent framework for the representation vocabularies for disease diagnosis, which is combined among diseases, diagnosis, and clinical phenotypes.

A method for building defeasible medical ontologies was developed by Obeid *et al.* [33] for disease-symptom diagnosis ontology. In order to achieve a flexible and decidable reasoning system, this method combines the description logic-based ontologies, with a non-monotonic rule system (defeasible logic).

Diabetes Diagnosis Ontology (DDO), created by El-Sappagh and Ali [34] is the initial advance in the development of diabetes diagnosis, using the following as a foundation:

- Reuse of existing ontologies for diabetes domain.
- Use of framework of the basic formal ontology.
- Use of the design principles of the Open Biomedical Ontology Foundry (OBO).

Initial strides were undertaken by Hijazi *et al.* [35] for cultivating a knowledge-based system for proper dosage control of drug to disease treatment. Physicians and pharmacists can be aided by this system when prescribing suitable drugs and their proper dosages. An identical approach was used by [33].

A comprehensive ontology for Diabetes Mellitus Treatment Ontology (DMTO) was built by El-Sappagh *et al.* [36] as a foundation for shared-semantics, and interoperable knowledge, applicable for the treatment of type 2 diabetes mellitus. An appropriate treatment plan for type 2 diabetes mellitus patients is afforded by the ontology that emerged.

E. DISCUSSIONS

While DL systems cater some inference capabilities, ontology and associated tools are suitable for modeling and reasoning about knowledge. Drugs are defined descriptively in most of the current DL ontologies, so that it can be concluded if one class is subsumed by another, while also checking for consistency. They are not however satisfactory for use with prescriptions. Moreover, the DL systems (monotonic logic) can neither manage inconsistencies nor express issues that occur, i.e., exceptions and priorities.

For modeling and reasoning in relation to knowledge, DL based ontologies are relevant. Ontologies, which are used to organize data according to a theory of the domain, also

TABLE 1. Comparison between pmds and previous researches.

Criteria	PMDS	PDRO [18]	Farrish, et al. [17]	Grando, et al. [16]
Purpose	Prescription	E-Prescription	Poly-pharmacy	Poly-pharmacy
Scope	Universal	Limit	Limit	Limit
Approach	Incomplete knowledge	Complete knowledge	Complete knowledge	Complete knowledge
OWL-based	Yes	Yes	Yes	Yes
Axiom	Yes	No	No	No
Defeasible Rule	Yes	No	No	No
Decision Support	Yes (non-monotonic)	No	Yes (monotonic)	Yes (monotonic)

acknowledge the representation of classes of entities and their interrelationships. Although some inference capabilities are furnished by DL system, they are not sufficient enough for tuning the appropriate prescription combination of drugs, diseases and patient conditions. To improve representation and reasoning abilities, the development of a (rule) logic system, along with an ontology language should be afforded. Actually, defeasible systems (non-monotonic), in this situation, are necessary as they have the ability to manage inconsistencies, as well as express issues like exceptions and priorities.

Table 1 provides a comparison between PMDS and three related researches, based on the following seven criteria:

- Purpose
- Scope
- Approach
- OWL based
- Axiom
- Defeasible rules
- Decision support

Even though research efforts in this area have not yet attained standard prescription ontology that encompasses an adequate coverage of essential features, needed for prescription decisions, there are many different ontologies that have been developed. It is clearly seen that the previous work on ontology development of prescriptions is not yet complete. Moreover, available ontologies offer limited goals that do not cover all the factors needed to provide an appropriate drug prescription. They have not used approaches that support cases of exception and conflicting information. Finally, they do not support decision-making on an appropriate drug prescription.

III. BASIC CONCEPTS

DL provides a set of logical features which together determines the expressive power of DL.

A. DESCRIPTION LANGUAGE

Essentially, DL is comprised of concepts and roles. The concepts can be represented as unary predicates. Concepts are related to particular entities within the KB. For example, the 'Drug' is a concept, and 'Ibfen' is the instance of the concept. The set of role names are represented as binary relations between individuals. That is, wherever there may be an instance of 'Ibuprofen' as treatment of a 'Fever', it can be concluded that 'Ibfen' can be associated with the role 'is-treat-of'. For example, (is-treat-of (Ibfen, Fever)), where 'is-treat-of' is the role that binds the drug, 'Ibfen', to the disease, 'Fever'.

DL is characterized by a set of constructors that facilitate building complex concepts and roles. Concepts are interpreted as sets of objects and roles are seen as (binary) relations between objects in the domain. DL provides the following constructors:

Negation ($\neg$), Conjunction ($\sqcap$), Disjunction ($\sqcup$), Existential ($\exists$), and Universal Restriction ($\forall$).

The construct that enables complex concepts to be defined with the negation of another concept are known as *concept negation*. It is useful in situations that require defining disjoint concepts.

The ability to join one or more concepts to define a complex concept or at least its properties or characteristics, is related to *concept conjunction*.

The ability to restrict the definition of a complex concept or at least its properties or characteristics, to appearing in the set of one concept or the other, is related to *concept disjunction*.

DL also allows value or role restriction constructs. Role restriction ($\forall$ R.C) is the construct that requires that all the individuals that are in a specified relationship R with the concept being described belong to the concept C.

B. ALC DESCRIPTION LOGIC

ALC is a powerful expressive DL, which is considered to be of moderate to high expressivity is composed from three parts:

- Description language
- Knowledge base
- Reasoning component

Figure 1 illustrates the DL system (ALC system).

There are many researches, like [33], [35], that used ALC in their work approach.

ALC has theoretical semantics. Let Int denote interpretation and D represent the domain of Int. Int is a function that assigns to every atomic concept (refers to the concept) P a set $P^{Int} \subseteq D^{Int}$ and to every atomic role R a binary relationship $R^{Int} \subseteq D^{Int}$ x D^{Int}. Int can be extended to more complex concepts using the following definitions:

Let T (resp. $\perp$) denotes to universal (resp. Bottom) concept.

$$T^{Int} = \Delta^{Int}, \perp^{Int} = \emptyset, (\neg P)^{Int} = D^{Int} \setminus P^{Int},$$
$$(P_1 \sqcap P_2) = P_1^{Int} \bigcap P_2^{Int}$$
$$(\forall R.P)^{Int} = \{\alpha \in D^{Int} \mid \forall \beta.(\alpha, \beta) \in R^{Int} \rightarrow \beta \in P^{Int}\}$$
$$(\exists R.T)^{Int} = \{\alpha \in D^{Int} \mid \exists \beta.(\alpha, \beta) \in R^{Int}\}$$

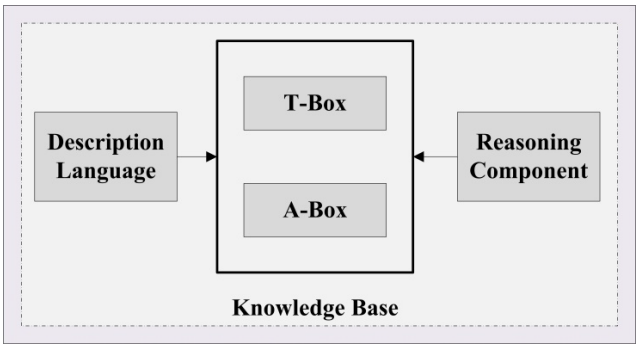

FIGURE 1. Description logic system.

An ALC-KB consists of two parts: Terminological component (T-Box) and Assertion component (A-Box). T-Box contains general knowledge about a domain. Such knowledge is expressed as axioms about the relationships between concepts and / or roles necessary to define complex concepts from existing concepts. T-Box axiom may take one of the following forms:

- Strict subsumption ($\sqsubseteq$) relation between concepts ($P_1 \sqsubseteq P_2$) and/or roles ($R_1 \sqsubseteq R_2$).
- Equality ($\equiv$) relation between concepts ($P_1 \equiv P_2$) and/or roles ($R_1 \equiv R_2$). It can define as follows: ($P_1 \equiv P_2$) is equivalent to ($P_2 \equiv P_1$).

A-Box, which denotes assertion box, is used to describe a specific state of affairs related to a domain.

C. ONTOLOGY WEB LANGUAGE

Ontology Web Language (OWL) is logically supported by DL and provides additional non-logical features such as annotations. OWL is achieved by exploiting the common reasoning tasks for basic DL, used to express the ontology. The OWL-DL is a defined OWL syntax language.

OWL-DL uses DL to represent the relations between concepts and/or roles. It provides maximum expressiveness, while preserving the integrity of computational properties. Thus, it can make correlation between DL syntax and OWL syntax. Table 2 illustrates of these correlations.

D. DEFEASIBLE LOGIC

Defeasible Logic is non-monotonic reasoning. The defeasible-KB consists of five types of components as follows:

- Set of Facts
- Strict rules
- Defeasible rules
- Defeater rules
- Superiority relation

The *facts* are indisputable data, for example, (Ibfen is-a drug). In logic, this may be expressed as:

$$\text{Drug (Ibfen)}$$

Strict rules are rules in the classical sense, whenever the premises are indisputable, then the conclusion is so.

TABLE 2. Correlation between dl and owl syntax.

OWL Constructor	DL Syntax	OWL Syntax
Intersection-Of	C ⊓ D	C AND D
Union-Of	C ⊔ D	C OR D
Complement-Of	¬ C	NOT C
Some-Values-Form	∃ R C	R SOME C
All-Values-Form	∀ R C	R ONLY C
Cardinality	= N R	R EXACTLY N
Has-Value	∃ R {a}	R VALUE a

This strict rule uses typical logical expression as follows:

$$\text{Antecedent} \rightarrow \text{consequent}$$

where $\rightarrow$ means implies. The antecedent and consequent are conjunction of atoms, written as:

$$X_1, X_2, \ldots., X_n \rightarrow Y$$

where X_n and Y are atomic formulas, and ',' a conjunction

Defeasible rules are rules that can be defeated by contrary evidence. Implicit meaning cannot be the implicit meaning of classical logic, but it must be the implicit meaning that corresponds to the defeasible subsumption ($\Rightarrow$).

Defeater rules are rules that cannot be used to draw any conclusions. They are used only to prevent certain conclusions. In other words, they are used to defeat some defeasible rules by producing evidence to the contrary.

Superiority relation ($\geq$) is used between rules to prioritize them. That is, where one rule can go beyond the conclusion of another rule. Rules are named to allow reference. This requires defining $\geq$ as a binary superiority relation between the defeasible rules.

For example, these are given rules:

R1: Drug(x), Disease(y), Patient(p), complaints(p,y), is-treat-of(x,y) $\Rightarrow$ Prescribe(x,p)
R2: Drug(x), Disease(y), Patient(p), complaints(p,y), is-treat-of(x,y), has-allergy(p,x) $\Rightarrow \neg$ Prescribe(x,p)

If we have the facts that patient y is suffering from a pain and x is a treatment for that pain but the patient has allergy to the drug x, then both R1 and R2 can be applied. If R1 is applied then it derived Prescribe(x,p) is derived, while applying R2 gives that the contrary conclusion $\neg$ Prescribe(x,p). It makes sense to prefer applying R2 over R1 since R2 is applied to more specified information. We can specify this preference using R2 > R1.

A defeasible theory is comprised of three parts as follows:

- A finite set of facts (F)
- A finite set of rules (R)
- A superiority relation (>)

A conclusion of defeasible is a tagged literal and has one of the four forms, as follows:

- $+\Delta$b: b is definitely provable in defeasible (it using only facts and strict rules).
- $-\Delta$b: b is not definitely provable in defeasible.
- $+\partial$b: b is defeasible provable in defeasible.
- $-\partial$b: b is not defeasible provable in defeasible.

Provability is based on the concept of derivation (or proof) in defeasible. A proof is a finite sequence of tagged literals satisfying four conditions, which correspond to inference rules for each of the types of conclusion. Let P(1…i) denote the first i steps of a proof of length n where i<n. [37]

$+\Delta$:If $P(i+1) = +\Delta b$ then
(1) $b \in F$ or
(2) $\exists r \in R_s[b]\ \forall a \in A(r)$: $+\Delta a \in P(1\ldots i)$
$-\Delta$:If $P(i+1) = -\Delta b$ then
(1) $b \notin F$ and
(2) $\forall r \in R_s[b]\ \exists a \in A(r)$: $-\Delta a \in P(1\ldots i)$

The definition of Δ is the standard definition of forward sequence of strict rules. In order for a literal 'b' to be definitely provable, we need to find a strict rule with the consequence 'b', which has already been proven by all antecedents previously. And to prove that 'b' cannot be proven definitely, it must be proved that for every strict rule with head 'b' there is at least one antecedent that has proved to be non-provable. [37]

$+\partial$: If $P(i+1) = +\partial b$ then either
(1) $+\Delta b \in P(1\ldots i)$ or
(2) (2.1) $\exists r \in R_{sd}[b]\ \forall a \in A(r)$: $+\partial a \in P(1\ldots i)$ and
(2.2) $-\Delta \neg b \in P(1\ldots i)$ and
(2.3)$\forall s \in R[\neg b]$ either
(2.3.1) $\exists a \in A(s)$: $-\partial a \in P(1\ldots i)$ or
(2.3.2) $\exists t \in R_{sd}[b]$ such that $t > s$ and
$\forall a \in A(t)$: $+\partial a \in P(1\ldots i)$

The idea is as follows: to show that 'b' is defeasibly provable, there are two choices: either

- (1) Show that 'b' is already definitely provable; or
- (2) Argue using the defeasible part as well.

This requires performing one of the following steps:

- (2.1) require that there must be a strict or defeasible rule with head 'b' which can be applied.
- (2.2) to prove 'b' defeasible it must be shown that $\neg b$ is not definitely provable.
- (2.3) the set of all rules must be considered, which are not known to be inapplicable and which have head '$\neg$b' (note that here we consider defeaters, too, whereas they could not be used to support the conclusion 'b'; this is in line with the motivation of defeaters given earlier).

Essentially each such rule's' attacks the conclusion 'b'. for 'b' to be provable, each such rule 's' must be counterattacked by a rule 't' with head 'b' with the following properties:

- 't' must be applicable at this point, and
- 't' must be stronger than 's'. Thus, each attack on the conclusion 'b' must be counterattacked by a stronger rule.

In other words, 'r' and the rules 't' form a team for 'b' that defeats the rules 's'. In an analogous manner one can define -∂b as: [37]

TABLE 3. Comparison between dl and defeasible logic.

Criteria	DL	Defeasible
Scope	Limit	Universal
Property Approach	Monotonic	Non-monotonic
Handle Exception	No	Yes
Handle Inconsistency	No	Yes
Axiom	Classical	Defeasible
Rules	Strict implication	Defeasible implication
Decision-Based	Complete Knowledge	Incomplete Knowledge

$-\partial$: If $P(i+1) = -\partial b$ then
(1) $-\Delta b \in P(1\ldots i)$ and
(2) (2.1) $\forall r \in R_{sd}[b]\ \exists a \in A(r)$: $-\partial a \in P(1\ldots i)$ or
(2.2) $+\Delta \neg b \in P(1\ldots i)$ or
(2.3)$\exists s \in R[\neg b]$ such that
(2.3.1) $\forall a \in A(s)$: $+\partial a \in P(1\ldots i)$ and
(2.3.2) $\forall t \in R_{sd}[b]$ either $t \not> s$ or
$\exists a \in A(t)$: $-\partial a \in P(1\ldots i)$

The purpose of the -∂ inference rule is to establish that it is not possible to prove $+\partial$. This rule is defined in such a way that all the possibilities for proving $+\partial b$ are explored and shown to fail before -∂b can be concluded. Thus, conclusions tagged with -∂ are the outcome of a constructive proof that has a corresponding positive conclusion.

E. DESCRIPTION LOGIC VS. DEFEASIBLE LOGIC

DL is useful with applications of complete knowledge, but it has limited scope. It is not used with applications that require exceptions and inconsistencies.

Defeasible logic is useful with applications of incomplete knowledge, and it has universal scope. It deals with exceptions and inconsistency cases.

Table 3 provides a comparison between DL and defeasible logic, based on seven criteria:

- Scope
- Property Approach
- Handle Exception
- Handle Inconsistency
- Axiom
- Rules
- Decision-Based

DL can be misleading if it is used alone to describe the PMDS that is of interest to this paper. This contribution requires the integration of ALC-DL with defeasible Rules.

F. DEFEASIBLE ALC SYSTEM

This section introduces the extension of the ALC with defeasible rules. The defeasible ALC considers the relationships between a KB in ALC and a defeasible theory. The A-Box corresponds to the set of facts, while the T-Box corresponds to the monotonic part of rules in a defeasible theory.

The two components that are used to comprise the defeasible ALC integration, as follows:

- Monotonic part: subsumption of ALC or strict derivability of defeasible logic.

❖ Non-Monotonic part: defeasible rules and superiority relation.

Following are the three steps that accomplished the PMDS:

Step 1: The domain of the theory corresponds to the A-Box and/ or T-Box, that is, the set of all individuals and facts occurring in the assertions (A).

Step 2: To derive role restriction in a defeasible theory way used in [37]:

$+\partial\forall$R.C: If P(i+1) $= +\partial\forall$R.C(a) then
$\forall b \in A$ either
(1) $-\partial$R(a,b) or
(2) $+\partial$c(b)

This means, to prove $+\partial\forall$R.C, for all the elements 'b' in the KB domain, either it cannot prove that 'b' is not related via R with 'a', or we can show that 'b' is an instance of the concept C.

$-\partial\forall$R.C: If P(i+1) $= -\partial\forall$R.C(a) then
$\exists b \in A$ such that
(1) $+\partial$R(a,b) and
(2) $-\partial$c(b)

This means, to prove $-\partial\forall$R.C(a), there must exist an element 'b' in the KB domain, such that it is defeasibly provable that 'b' is in the role R with the concept instance 'a' from the role restriction statement, and it must be defeasibly, not provable that 'b' is an instance of the concepts C.

Step 3: Superiority relation, is used to improve the accuracy of decisions by using it among rules.

IV. PMDS SYSTEM DEVELOPMENT

The methodology of this paper is divided into four steps:

Step 1: Extract all relevant knowledge necessary from previous researches, patient information leaflet and domain expert. The information extracted is natural language form.

Step 2: Develop and formalize the PMDO ontology conceptual model, which formulates the ontology classes and their relationship.

Step 3: Implement the monotonic part of PMDO ontology using Protégé tool, and evaluate with pellet reasoning, to ensure consistency and coherency.

Step 4: Extend the PMDO ontology with defeasible rules.

Presently, matching proper prescription to patient information is manual. This paper investigates the possibility of a feasible solution for PMDS process, i.e. finding a proper prescription that matches the patient information criteria. This paper builds PMDO ontology as KB for PMDS system.

A. PMDO ONTOLOGY CONSTRUCTION

The development of ontology typically begins with a specification. This is especially true when determining boundaries of the model, and the detail levels. It is possible to reuse the ontology again in a similar domain, when it has been finished. All relevant data must be represented in a hierarchy of concepts and relations, in order to develop a superior level of PMDO ontology. PMDO development can be seen in figure 2.

The PMDO ontology mapped the defined terms into classes, properties, and axioms. All classes were characterized consistency and in an identical manner. These classes cooperate to implement the logic of a proper drug. The PMDO ontology is composed of five classes which are: drugs, patient, diseases, dosage form and situation. Furthermore, it is composed of eight relationships among classes which are: contraindication-with, caution-use-with, is-treat-of, has-dose-form, takes-medication, suffer-from, has-situations and has-allergy.

As many characteristics as possible were collected by the PMDO ontology, in order to make the resulting decisions as competent as possible. Most classes in the PMDO ontology are managed by a set of axioms, with the most important ones being the drug class, and the patient class. Logical definitions of types, which support the computational search, are formulated by axioms. The definition of the drug class is defined as follows:

Drugs $\sqsubseteq$ PMDO
Drugs $\sqsubseteq \exists$(is-treat-of. Diseases $\sqcap$
$\exists$has-dose-form. Dosage_form $\sqcap$
$\exists$ caution-use-with. Diseases $\sqcap$
$\exists$ caution-use-with. Drugs $\sqcap$
$\exists$ caution-use-with. Situations $\sqcap$
$\exists$ contraindication-with. Diseases $\sqcap$
$\exists$ contraindication-with. Drugs $\sqcap$
$\exists$ contraindication-with. Situations)

From the class of drug, special manipulations are given to the subclass of drug, as it will be used in defining specific characteristics. A few properties were collected that can describe this Ibuprofen class and is implemented as follows:

Ibuprofen $\sqsubseteq$ Drugs
Ibuprofen $\sqsubseteq \exists$(is-treat-of. (Osteoarthritis $\sqcup$ Rheumatoid-Arthritis $\sqcup$ Dysmenorrhea $\sqcup$ Fever $\sqcup$ Pain $\sqcup$ Inflammatory-Disease) $\sqcap \exists$ has-dose-form. (Intravenous-IV $\sqcap$ (has-dose-strength value "200mg/ml") $\sqcup$ (Tablet-Chewable $\sqcap$ (has-dose-strength
value "50mg, 100mg")) $\sqcup$ (Tablet $\sqcap$ (has-dose-strength
value "100mg, 200mg, 400mg, 600mg, 800mg"))$\sqcap \exists$ has-caution-use. (Asthma $\sqcup$ Fluid-Retention) $\sqcap \exists$ has-contraindication. (Advance-liver-damage $\sqcup$ Renal-Damage))

Each patient has characteristics. The patient class is designated as follows:

Patient $\sqsubseteq$ PMDO
Patient $\sqsubseteq \exists$(has-situation. Situations $\sqcap$
$\exists$ has-allergy. Drugs $\sqcap$
$\exists$ takes-medication. Drugs $\sqcap$
$\exists$ suffer-from. Diseases)

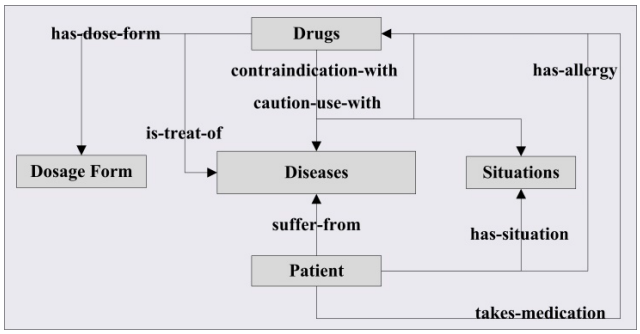

FIGURE 2. Personal medical prescription ontology (PMDO).

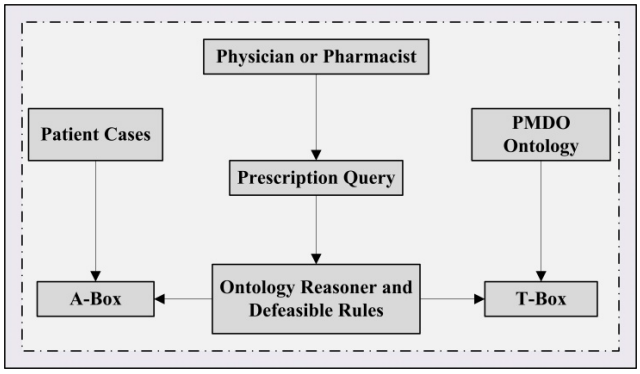

FIGURE 3. Architecture for the PMDS system.

Protégé is one of the most widely used development platforms for ontology-based systems. Protégé interface is suitable for small scale ontology development, due to its capabilities of reasoning and language features.

Protégé provides support for working with ontologies. OWL is used to represent and express DL-based ontology by using Protégé. Currently, the PMDO ontology contains 95 concepts and 19 properties.

B. PMDS SYSTEM CONSTRUCTION

This paper presented a PMDS system based on defeasible rules as an extension of KB, resulting from the representation of PMDO ontology (see example in section VI, which automatically integrates drug information with patient into information a unified KB). The architecture for the PMDS system is shown in figure 3. This architecture for inferring a proper prescription matches the patient case.

The patient case inputs are given as input to the PMDS system. The prescription query is given to the ontology reasoners and defeasible rules, with superiority relations, in-order to execute the query against both the patient information and PMDO. This system must implement defeasible rules with PMDO to connect different criteria under exceptions and inconsistent cases, in order to achieve a proper prescription query for each patient.

The major obstruction in the PMDS implementing process by using Protégé tool is that it does not support the application of exceptional and inconsistent cases. Because OWL language does not provide a mechanism for defeasible reasoning, there are no standardized OWL language elements for expressing cases of exception and inconsistency. It has no inbuilt support for reasoning about what is typically or generally true. In some researches, this is handled by adding a separate plugin tool connected with Protégé interface without integrates, and with inference engine automation as a single system.

V. COMPARISON WITH PREVIOUS APPROACHES

This paper explored the approaches used in the field of its interest to find a solid approach commensurate with the construction of a new PMDS system in the field of prescriptions, which supports the decision for a suitable prescription according to the conditions of the patient.

The results were as follows:

- ❖ Complete knowledge approach
- ❖ Incomplete knowledge approach

A. COMPLETE KNOWLEDGE APPROACH

The ontology technique, based on the representation of knowledge, generally supports a complete knowledge of the domain with strict rules (monotonic properties) by defining the classes, relationships and characteristics that make up any domain. Representation requires complete knowledge of a specific target with limited scope to obtain accurate conclusions.

Most of the previous researches have focused on the development of their ontology within a very limited scope with complete knowledge. In addition, they relied on techniques offered by ontology such as knowledge sharing, reuse and interoperability. They used the Protégé tool, which is the most powerful tool for the representation of medical knowledge. It supports the monotonous logic in the representation of knowledge and the monotonic rules (SWRL) used to implement their new ontologies to improve the health care of patients with multiple goals. This is presented in the second section of this research.

These researches have also focused on reusing classes, relationships and characteristics spread across several different ontologies, in order to build a new ontology with limited purpose. In spite of these research contributions, it has made the reuse ontology technique of previous researches to be uniformly committed to build a new ontology.

A few of the previous works presented comprehensive works as in [31], [36], but they did not fall outside the scope of the limited and complete knowledge.

This paper examined this approach, which focused on the use of a monotonous component, based on complete knowledge. However, this is not commensurate with the PMDS system that this research is focused on developing. There would be many inconsistency cases and exceptions, which would make this approach futile in finding accurate conclusions for an appropriate prescription for each patient's conditions.

The medical prescription is a non-monotonic process that depends on the patient's condition, which is unpredictable with strict rules, in order to make a suitable prescription for a patient's condition, which varies from patient to patient. Thus, it needs to choose another approach that deals with

TABLE 4. Comparison between pmds and previous researches based on complete knowledge.

Criteria	PMDS	Zazo, et al. [31]	El-Sappagh et al.[36]
Domain	Prescription	DDI	Diabetes Mellitus2
Scope	Universal	Limit	Limit
CM	Yes	Yes	Yes
P-Tool	Yes	Yes	Yes
OWL	Yes	Yes	Yes
AR	Yes	Yes	Yes
SA	Yes	No	No
TA	Yes	No	No
DR	Yes	No	No
DS	Yes	Yes	Yes
Results	Infer a proper prescription	Infer detect DDI	Infer treatment

TABLE 5. Comparison between pmds and previous researches based on incomplete knowledge.

Criteria	PMDS	Obeid, et al. [33]	Hijazi et al.[35]
Domain	Prescription	Disease Diagnosis	Dosage Control
Scope	Universal	Universal	Limit
CM	Yes	No	Yes
P-Tool	Yes	No	No
OWL	Yes	No	No
AR	Yes	No	No
SA	Yes	No	No
TA	Yes	No	No
DR	Yes	Yes	Yes
DS	Yes	Yes	Yes
Results	Infer a proper prescription	Infer disease diagnosis	Infer a proper dose

inconsistent and exceptional cases. It is impossible to rely on the representation of drug information alone, which appears in the patient information leaflet, as it only provides general treatment recommendations, without providing alternatives to the prescription decision in cases of drug interactions, contraindications, and caution of use, that vary from patient to patient.

B. INCOMPLETE KNOWLEDGE APPROACH

A few extensions of previous medical ontology with defeasible logic can be used to handle incomplete knowledge approach in either limited or universal scope, as in [33] and [35].

Table 4 provides a comparison between the PMDS system and previous researches, which used a complete knowledge approach. Table 5 provides a comparison between the PMDS system and a previous research that used an incomplete knowledge approach and is based on the following eleven criteria:

- Domain
- Scope
- Conceptual Model (CM)
- Implement by Protégé (P-Tool)
- OWL-based
- Evaluate by Automatic Reasoner (AR)
- System Architecture (SA)
- Theorem Approve (TA)
- Defeasible Rules (DR)
- Decision Support (DS)
- Results

VI. DISCUSSION AND EXAMPLE

This section first begins with a brief presentation of PMDO ontology.

Figure 4 shows the top level of PMDO ontology. Figure 5 shows subclasses of drug class. Figure 6 shows subclasses of administration.

All the PMDO ontology classes hierarchy was defined in the same way. The type of information needed for this

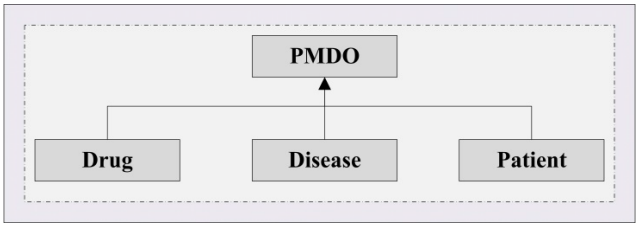

FIGURE 4. Top level class of PMDO ONTOLOGy.

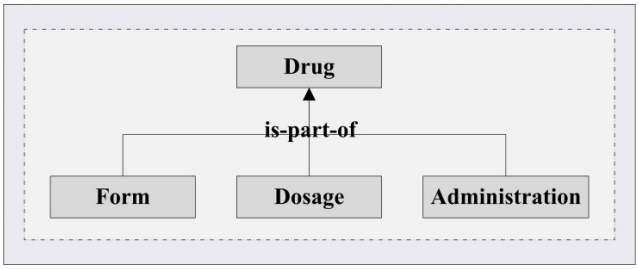

FIGURE 5. Subclasses of drug class.

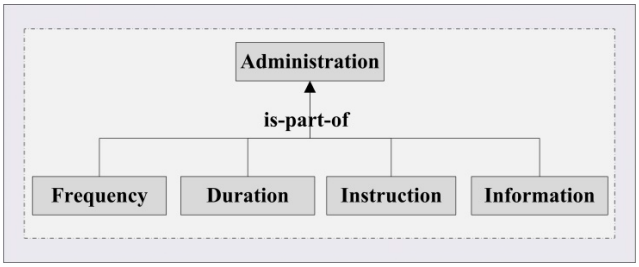

FIGURE 6. Subclasses of administration class.

ontology was extracted from previous studies, patient information leaflets and domain experts. This made the task of developing uniform terminology extremely difficult. PMDO classes are mainly named based on knowledge derived from various knowledge sources.

The process of choosing a suitable prescription depends on the patient's condition(s). In this regard, patients differ in their conditions. This makes it necessary to derive rational inferences from knowledge in the presence of inconsistent

TABLE 6. The options summary of prescription.

Patient	Option	Drug
P0	Normal Case	Default List
P1	Allergy Condition	Filter List
P2	DDI	Filter List
P3	Drug-Disease Interaction	Filter List
P4	Drug-Situation Interaction	Filter List

knowledge. However, the knowledge representation allows the expression of knowledge in the ontology, but does not provide ways of extracting new knowledge from the previously asserted knowledge. Rules are the standard off-the-shelf logical mechanisms used to achieve this. However, defeasible rule can deal with inconsistencies and priorities.

The PMDS is a non-monotonic process. Moreover, ontologies, which are equipped with monotonic logical inference machinery, are represented as fragments of FOPC. Though PMDO ontology may be of possible use and help in the process of prescribing drugs, they are not capable of supporting a conclusive drug decision, as they are incapable of managing the ambiguity and deficiency of the assessable drug knowledge. Accordingly, the PMDO ontology was expanded with defeasible rules. This expansion grants increased expressive capabilities and resembles commonsense reasoning.

Rules were organized according to the stage at which they were applied in the PMDS-based ontology. The rules were generated from different classes of the PMDO ontology. These rules provide suggestions for a proper drug, are defined as follows:

- *Normal Rule:* Evaluates a patient's complaints. For instance, if the disease Dis_k is present in a patient, we have the rule: 'Dis_k implies Drug_1'. More formally:

$$\text{Dis}_k \Rightarrow \text{Drug}_1$$

- *Filter Rule:* Evaluates the patient's condition(s) regarding allergy and drug interactions with: drug usage, current disease and current situation. For instance, if the disease Dis_k and conditions Con_k are both present in a patient, we have the rule: 'Dis_k and Con_kimplies Drug_2'. More formally:

$$\text{Dis}_k, \text{Con}_k \Rightarrow \text{Drug}_2$$

- *Prescription Decision:* The defeasible derivation has to decide whether the proper prescription is either Drug_1 or Drug_2, depending on the patient conditions.

Table 6 presents a summary of the prescription options: In PMDS, the drug is selected based on the patient's complaint. However, this may change as there are a number of conditions to consider, as well when choosing the right drug, such as: the contraindications of the drug when used concurrently with drugs the patient is already taking, diseases, allergies and the patient's situation.

A. AN EXAMPLE

This example shows three parts of the knowledge base system as follows:

- A-Box
- Rules
- Superiority relation

The following, *A-Box*, describes entries in a medical prescription domain. It represents four drugs, four diseases and six patients. It also represents the relationships between the drug and the disease that describes treatment, contraindications and caution against the use of the drug. The example also represents the complaint and condition of each patient. In this example, let's consider that: (Fever, Pain, Asthma, and High-pressure) an instances of (Fever, Pain, Asthma, and High-pressure) concepts respectively. And (Ibfen, Aspirin, Paracetamol and Warfarin) an instances of (Ibuprofen, Aspirin, Paracetamol and Warfarin) concepts respectively.

Drug(Ibfen) Drug(Aspirin)
Drug(Paracetamol) Drug(Warfarin)
Disease(Fever) Disease(Pain)
Disease(Asthma) Disease(High-Pressure)
Patient(P1) Patient(P2)
Patient(P3) Patient(P4)
Patient(P5) Patient(P6)
complaints(P1,Fever) complaints(P2,Fever)
complaints(P3,Fever) complaints(P4,Fever)
complaints(P5,Fever) complaints(P6,Pain)
allergy(P4, Ibfen) suffers(P3,Asthma)
is-treat-of(Ibfen,Pain) is-treat-of(Ibfen,Fever)
is-treat-of(Aspirin,Fever) is-treat-of(Aspirin,Pain)
is-treat-of(Paracetamol, Fever)
suffers(P2,High-Pressure)
takes-medication(P5,Warfarin)
contraindication(Ibfen,High-Pressure)
contraindication(Ibfen,Warfarin)
contraindication(Aspirin,Warfarin)
caution-use(Ibfen,Asthma)
caution-use(Aspirin,Asthma)

The following *Rules* represent integrity restriction on the prescription process. For example, the first rule (R1), says to prescribe the drug for a patient that only has complaints of a disease treated by that specific drug. Other rules (R2-R5), say not to prescribe the drug for a patient that has a condition(s) that negatively interact with prescribed drug. Rule (R6) states not to prescribe the drug for a patient who has an allergy to the prescribed drug. Implementation of these rules results in improving the accuracy of providing the appropriate prescription. This is accomplished by choosing a drug that does not conflict with the patient's condition(s), by using *superiority relations* among the rules.

R1:
Patient(y), ∀ complaints.Disease(y), Drug(x),
∀ is-treat-of.Disease(x) ⇒
Prescribe(x,y)

R2:
Patient(y), ∀ suffers.Disease(y), Drug(x), ∀ caution-use.Disease(x) ⇒ ¬ Prescribe(x,y)

R3:
Patient(y), ∀ takes-mediaction.Drug(y), Drug(x), ∀ caution-use.Drug(x) ⇒ ¬ Prescribe(x,y)

R4:
Patient(y), ∀ suffers.Disease(y), Drug(x), ∀ contraindication.Disease(x) ⇒ ¬ Prescribe(x,y)

R5:
Patient(y), ∀ takes-medication.Drug(y), Drug(x), ∀ contraindication.Drug(x) ⇒ ¬ Prescribe(x,y)

R6:
Patient(y), ∀ allergy.Drug(y), Drug(x) ⇒ ¬ Prescribe(x,y)

Superiority relation:
R2>R1
R3>R1
$R4>R_k$ where 3> k >1
$R5>R_k$ where 4> k >1
$R6>R_k$ where 5> k >1

From the above defeasible ALC-KB, Patient (P1) can take the following drugs: Ibfen, Aspirin, and Paracetamol ($+\partial$ derivation), due to the fact that P1 is a patient that is complaining of fever treated with these drugs according to:

- $+\partial\forall$ complaints.Disease(P1)
- $+\partial\forall$ is-treat-of.Disease(Ibfen)
- $+\partial\forall$ is-treat-of.Disease(Aspirin)
- $+\partial\forall$ is-treat-of.Disease(Paracetamol)

To prove this, it must be noticed that there are no rules with a heading for:

- complaints(a,P1)
- is-treat-of(a,Ibfen)
- is-treat-of(a,Aspirin)
- is-treat-of(a,Paracetamol)

Thus for every element b in the domain such that {complaints(a,P1), is-treat-of(a,Ibfen), is-treat-of(a,Aspirin), and is-treat-of(a,Paracetamol)} are not given in the A-Box we can prove the following:

- $-\partial$ complaints(a,P1)
- $-\partial$ is-treat-of(a,Ibfen)
- $-\partial$ is-treat-of(a,Aspirin)
- $-\partial$ is-treat-of(a,Paracetamol)

For the remaining elements of the domain, namely 'Fever', it must be proven that:

$$+\partial\text{Disease(Fever)} \tag{1}$$

Both follow immediately since they are in the A-Box, and hence are facts of the given theory.

Furthermore, given the challenge of discovering if P2 can be taken; Ibfen, Aspirin, or Paracetamol, there are some decisions left to make. Here it can be seen that P2 is a patient and she/he have 'Fever' and 'High-pressure', which are both diseases. 'Fever' is the first disease, and it has already been concluded that 'Fever' is treated by Ibfen, Aspirin, or Paracetamol since they are classified as drugs to treat of 'Fever'. The other disease that P2 suffers from is 'High-pressure'. In the KB, 'High-pressure' is identified as a disease that has a contraindication for use with 'Ibfen'. When attempting to demonstrate the 'High-pressure' is treated by Ibfen via R1, it displays -∂ Disease(High-pressure). This is because it cannot be shown that the role restriction in this rule is defeasibly provable; actually, the opposite can be exhibited -∂ complaints. Disease (High-pressure), as a result of the presence of the fact of Disease (High-pressure) and the role contraindication (Ibfen, High-pressure). This concept and role are favorable for conditions exhibited by the behavior of negative role restriction.

Furthermore, as 'High-pressure' is a disease that cannot be defeasibly treated by Ibfen, then it can be concluded that P2 is a patient that cannot take Ibfen for 'Fever'. Given the **R4:**

Patient(P2), ∀ suffers.Disease(P2), Drug(Ibfen), ∀ contraindication.Disease(Ibfen) ⇒ ¬ Prescribe(Ibfen,P2)

There is demonstration that the role restriction for rule (R4) has superiority relation through (R4>R1) and is defeasibly provable, because the information that P2 suffers 'High-pressure', is given and it can be derived that 'High-pressure' is defeasibly not treated by Ibfen. As the role restriction in R4 is defeasibly provable, it can be defeasibly implied that P2 is a patient that cannot be treated with Ibfen. While it is concluded that Aspirin and Paracetamol can be taken by the P2 according to R1.

Following the same reasoning, it can be concluded that patient P3 can be given Paracetamol according to rule R1. However here it can be noted that P3 is a patient that has a 'Fever' and 'Asthma', which are both diseases. It can be observed in the KB that 'Asthma' has cautionary use with Ibfen and 'Aspirin'. While trying to show that 'Asthma' is treated by Ibfen or Aspirin via rule R1, it shows -∂ Disease(Asthma), due to the presence of the fact Disease(Asthma) and the role caution-use(Ibfen,Asthma) and caution-use(Aspirin,Asthma). This concept and role are conductive to the conditions demonstrated by the behavior of negative role restriction. Furthermore, according to the rule R2, we conclude that 'Asthma' is defeasible as a disease not treated by Ibfen or Aspirin, we cannot defeasibly conclude that P3 is a patient that can take Ibfen or Aspirin, through the superiority relation between (R2 > R1). However, it is concluded that Paracetamol can be taken by the P3 according to the R1.

Likewise, it can be concluded that patient P4 can be given Aspirin or Paracetamol according the superiority relation between (R6 > R1). Here we can see that P4 has a 'Fever'

and allergy from Ibfen. Therefore, P4 will not be given Ibfen due to a known allergy to the drug.

Additionally, it can be concluded that patient P5 can be given Paracetamol according to the superiority relation between (R5 > R1). Here we can see that P5 presents with 'Fever' and 'has taken Warfarin'. Consequently, P5 will not be given Ibfen or Aspirin, as it is contraindicated to prescribe them in the presence of Warfarin therapy.

Finally, it can be concluded that patient P6 can be given Ibfen, Aspirin, or Paracetamol. This is decided because P6 presents with 'Pain', and since 'Pain' is a disease that can be treated with Ibfen, Aspirin, or Paracetamol, according to the rule R1, it can be prescribed for the patient's condition.

In the result, the prescription requires personalization in line the patient's unique conditions. Concurrently, numerous factors are implicated in the prescription decision. The integration with rule-based facilitates the decision of a proper drug. For instance, if there are two patients that present with the same complaints (has 'Pain' in the thigh), and it is known that the first patient has no specific conditions, while the second patients have specific conditions, several different decisions can be proposed, based on the PMDS system.

This work comes with the help of five pharmacists and five medical doctors who were impressed by the PMDS system. This paper provides the initial version of the PMDS system. In terms of coverage of such a complex domain, PMDO is still expected to grow over time. Indeed, little medical ontology can be regarded as totally complete, i.e. the ontology that provided treatment ontology about diabetes mellitus [36] and the ontology which provided a comprehensive detect ontology about DDI [31]. However, these ontologies capture only descriptive information of the content regarding observations, discovered findings and identified drugs. Even their use of the rules did not go beyond the monotonic rules. This meant that they did not address new knowledge problems including inconsistencies.

The main thrust in this paper is to show that the use of the DL reasoning alone is insufficient to achieve the accuracy of medical prescription decisions and handle cases with inconsistencies. Thus, it is expanded with defeasible rules, in order to achieve a flexible and decidable reasoning system. It can be useful to both physicians and pharmacists during the drug prescribing process.

VII. CONCLUSION AND FUTURE WORK

The ultimate aim of this research is to develop a Personalized Medical Prescription System (PMDS). This paper lays down the logical foundations. The system employs deep pharmaceutical and medical knowledge about a patient that may go beyond what is available in medication leaflets. Personalized Medical Prescription Ontology (PMDO) for PMDS was built, and employed the description logic system, ALC, for knowledge representation encouraged by the fact that ALC is the proper formalism for representing ontologies as it allows the benefit from available tools such as Protégé. However, the uncertain nature of medical and medicinal knowledge, some problems such as DDIs and drug-disease interactions make ALC inadequate to represent and reason within a system such as PMDS.

A detailed example has been provided that shows the inadequacy of ALC and the need for a more flexible representation that allows the ability to reason with incomplete and possibly inconsistent cases. The ALC was extended with defeasible rules to obtain defeasible ALC. Defeasible ALC allows the prevention of adverse drug reactions and detect DDIs and drug-disease interactions. Once implemented, PMDS system is intended to assist, not to replace, the clinician or the pharmacist during the medical prescription(s) process.

Some of the features of PMDS/PMDO are that they take into consideration aspects that interfere with the appropriate safety issues of prescribing drugs, not covered by many of the available approaches/ontologies. The monotonic part (PMDO) of the system (PMDS) was implemented using the Protégé tool.

The system, once completed, will encompass in one single framework, many aspects that are scattered in many existing available ontologies. These aspects include considering caution in use, preventing contraindications, preventing drug interactions, minimizing side effects and deciding an appropriate prescription, which will enhance individual health and reduce medical errors.

Future enhancements to the PMDS system will make it easier to choose the most appropriate drug, from a generated list of drugs, which offer the best proper prescription, with maximum effect percentage and minimum serious side effects. Lastly and most importantly, in the future, we will build a comprehensive framework-based ontology to support medical prescription in terms of coverage of such a complex domain, sharable with available ontologies, which will facilitate the development process.

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