# Epistemology and medical records: an applied evaluation

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***Abstract.*** *Medical records are crucial resources for every aspect of health-care practice. The amount and complexity of the information they bear require the use of automation. In this paper we propose a method for separating and classifying the information available in medical records, drawing on Karl Popper philosophical theories. We test this method by using descriptions of clinical cases within the scope of a biomedical project that deals with the human T cell lymphotropic virus. Our goal is to come up with a framework that allows for the organization and sharing of information in knowledge representation ontologies according to their epistemological or ontological nature.*

## 1. Introduction

The medical record is a complex document employed for several purposes in the healthcare realm. Proper documentation of medical encounters is one of the physician´s most important activities. Medical records have a myriad of uses in healthcare processes, such as: to support patient care, to fulfill external obligations, to support quality management [Haux, Knaup and Leiner 2007]. As a consequence of those multiple uses, medical information is a mix of facts, impressions, measurements, rules, and knowledge recording. A classification encompassing different kinds of information is required in order to represent them in systems.

There are several approaches to organizing and sharing information in medicine: information models, like HL7 [HL7 2012] and Open EHR [Garde et al. 2007]; terminologies, like MESH [Lowe and Barnett 1994]; and thesaurus, like NCI Thesaurus [NCI 2012]. An alternative that has been widely accepted for knowledge representation is the use of formal principles based on philosophical foundations. Under ideal conditions, the terms in a vocabulary would be defined free of ambiguities and overlaps in a structure called an "ontology" [Smith 2003] [Guarino 1998]. Ontologies have been widely adopted in the medical field in order to deal with the massive information produced in medicine [Rosse and Mejino 2003] [Rector and Rogers 2006].

Within the scope of the research on ontologies, a disseminated approach is the so-called "realism". In Philosophy, the term realism is widely used and controversial [MacLeod and Rubenstein 2005], but taken as a methodology, realism is extensively employed in biomedicine [Baker et al. 1999] [Grenon, Smith and Goldberg 2004], e. g, as a guiding methodology for the Open Biomedical Ontologies (OBO) Foundry [Smith et al. 2007]. Realism advocates that when scientists make claims about the types of entities that exist in reality, they are referring to entities called *universals* or *natural kinds* [Munn and Smith 2008]. Here, we call these claims "ontological information".

Some kinds of information, which are relevant for the medical field, cannot be properly represented following realistic guidelines. Examples are claims about the characteristics of signs and symptoms, which we name "epistemological information" [Bodenreider, Smith and Burgun 2004].

In previous papers [Andrade and Almeida 2011], we proposed a method for separating and classifying information available in medical records. In this paper, we extend this framework delving deeper on the theories of Karl Popper, namely the *three worlds* and *truthlikeness*, in order to create an analysis framework to be employed in the organization of the entities found in medical records. With the latter, we rely on our proposed framework to extract information from real medical records, both ontological, regarding those entities that can be represented as universals; and epistemological, which is relevant for medical practice even though it cannot be represented as universals. In addition, we rank epistemological information according to its degree of truth, with the aim of reaching a better characterization of it in ontologies.

We have been conducting the investigation that is the object of this paper, written within the scope of a biomedical project, specifically focused on human blood. The goal of this biomedical project is the development of a knowledge base for scientific and educational applications related to the human T cell lymphotropic virus (HTLV). The basis of infection by HTLV is not well-established [Verdonck et al. 2007], making the project a suitable scenario for an investigation of what could and couldn't be considered universal and to what degree a theory is close to the truth, which is carried out in the present paper.

The remainder of this paper is organized as follows: section 2 describes the theoretical basis of our investigation, presenting Popper´s theories. Section 3 contains our strategies for analyzing real data and the methodological steps taken. Section 4 presents the results of the application of our framework to real medical records. Finally, in section 5 we present a discussion and future works.

## 2. Background

In this section, we present the theoretical background employed as a basis for our investigation. Section 2.1 describes, briefly, the theory of three worlds of the Karl Popper and the section 2.2 his theory about truthlikeness and fallibilism.

### 2.1. Three worlds and medical reality

A useful approach combining reality, cognition and representations was proposed by Popper in his theory of three worlds. Popper proposes a pluralist view of the universe that recognizes at least three different but interactive worlds [Popper 1978].

According to Popper, there is a world that consists of physical bodies, such as stones, plants and animals, which is called *world 1*. World 1 can be divided into the world of *non-living physical objects* and the world of *living things* or *biological objects*. There is the mental and psychological world, called *world 2*, which includes thoughts, perceptions and observations, that is, the mental and psychological processes and subjective experiences. In world 2 we can distinguish conscious experiences from dreams, or distinguish human consciousness from animal consciousness. There is also another world, called *world 3*, which includes all content of world 2 mental processes, such as languages, scientific theories, mathematical constructions, symphonies and

sculptures. While a block of marble pertains to world 1, the creation by an artist of a sculpture using this block is a manifestation in world 3. From an ontological perspective, one can claim that world 2 and world 3 are evolutionary products of world 1.

Popper´s three worlds theory has been applied to investigations in health information science [Bawden 2002]. In the healthcare realm, world 1 consists of entities such as pains, wounds and bacteria, to mention but a few, all of them defined on the side of the patient [Ceusters and Smith 2010] [Smith et al 2006]. In world 2 one can find the cognitive representations of world 1, such as observations, interpretations and beliefs, defined both on the side of patients and physicians. World 3 is composed of concretizations of world 2 cognitive representations in diverse information artifacts, for example, terminologies, categorical systems and medical records. Moreover, diagnoses in physicians´ minds (world 2) and electronic health record entries (world 3) are related to disorders and diseases (world 1) through the relation of aboutness [Schulz and Karlsson 2011].

While Popper´s ontological view allows one to better understand the relation between entities pertaining to the world, his epistemological view proposes that every conceptualization reveals mismatches between reality and theories about reality. Though Popper's theories have been criticized [Bawden 2002], there are favorable views in which they are considered a useful model for understanding epistemological information [Abbott 2004]. Accordingly, one can find additions and improvements to Popper´s views, which propose additional sub-divisions of the original layers [Niiniluoto 1999] [Bhaskar 1978] or further subdivision of levels of reality into a material stratum, psychological stratum and social stratum [Poli 2010].

### 2.2. Fallibilism and truthlikeness

In addition to the three world's theory, Popper is also known for his *falsifiability criterion* and for his advocacy of *fallibilism*. According to the falsifiability criterion, scientific hypotheses are falsifiable and, therefore, scientists are able to state what empirical findings make such hypotheses false. Fallibilism is the view that no presumed knowledge, not even scientific knowledge, is absolute certain.

In this line of thought, epistemological searches are fallible. As human knowledge is incomplete, probable, and conjectural, one should seek truth but expect truthlikeness. Truthlikeness is a qualitative measure of how a theory can be more or less close to truth [Bhaskar 1978]. For example, consider these three statements in a healthcare situation: i) there are four blood groups plus a Rh factor; ii) there are four blood groups; iii) all blood has the same chemical composition. If the first assertion is true, then intuitively the second assertion has higher degree truthlikeness and approximates truth better than the third.

The medical practice is still heavily grounded in the study of signs and symptoms, which are interpreted by a physician. Medical reasoning is a sum of different cognitive practices including induction, abduction and deduction [Pottier and Planchon 2011]. In such context, in which no definitive account of truth can be reached in some cases, the notion of fallible theories being constructed from medical records is aligned with the need to search for universals.

## 3. Methodology

In order to develop better possibilities for medical record representation, we need to organize the kinds of information they contain. The method we propose here is composed of the following four steps.

First, we develop an analysis framework, which draws on inputs from Popper´s three worlds and we also researched by recent medical ontologies, namely, the Basic Formal Ontology (BFO) [Grenon, Smith and Goldberg 2004] as upper-level ontology to organize universals, the Ontology of General Medical Science (OGMS) [Scheuermann, Ceusters and Smith 2009] and the Information Artifact Ontology (IAO) [IAO 2012]. These ontologies were chosen because the project in which the present investigation is inserted is based on the top-level ontology BFO. It is also the ontology that provides grounds for IAO and OGMS.

As a second step, we are testing such framework on real medical records under evaluation in a biomedical project about blood diseases [Almeida, Proietti and Smith 2011]. In this paper, we will present as an example a clinical case description, which is considerably clearer than real medical records, while still requiring proper representation of the full range of medical entities. We use a generic clinical case available at Connors and Britton (2009) as a test-bed for our methodology.

In order to identify propositions within the clinical case, a domain expert transcribed the records into sentential fragments that make sense to him. The domain expert was asked to identify the reason for recording those entities and the information that is being conveyed by the representation. The transcription draws upon principles of logic and controlled languages [Fuchs et al. 2005], which allowed the identification of entities recorded in natural language, outside of the particular context in which the event took place. In addition, on the classification side, we use the rationale underpinning OGMS. This rationale is adopted to model the domain. It describes a disease as a disposition [Scheuermann, Ceusters and Smith, 2009], in which the three major stages are: etiological process, course of disease and therapeutic response. On the logical side, we took into account the fact that some parts of speech in natural language have no clear representation in logical statements.

As a third step, we consider an alternative for measuring truthlikeness, in order to classify epistemological information that came from the selected records. We took the position that epistemological information relevant in the context of medical practice cannot be registered in an ontology as a universal, following the tenets of the adopted realistic methodology [Grenon, Smith and Goldberg 2004]. It should then be registered in the form of annotations and classified according to a degree of truthlikeness. As truthlikeness is a comparative notion, we define situations which are considered true according to the current knowledge of the virus. Indeed, knowledge about the pathogenesis of infection by HTLV is fairly recent, even though this virus is endemic in several regions of the world. Genetic and immunological factors are in general the cause of the associated clinical manifestations, which may be divided into three categories: neoplastic, inflammatory and infectious [Romanelli, Caramelli and Proietti 2010]. In this step, we focus on extracting the epistemological information required to make correlations between the virus and the etiological suspects in their diverse clinical manifestations.

Finally, as fourth step, we organize the information from the medical records into four types, which are then employed in order to recommend both a data arrangement and a scenario for collaboration among different representations.

## 4. Results

In this section, we present the analysis framework created to organize information present in a medical record (section 4.1) and, in the section 4.2, we conduct a preliminary test of the framework by analyzing individual information entities contained in examples of the medical records.

### 4.1. Analysis Framework

We propose the analysis framework depicted in Fig. 1, which was created to organize information present in a medical record according to the best possibility for representation. This framework is divided into two sub-frameworks, the first one organizing the kinds of general information present in a medical record based on the three world's theory (slightly modified from Andrade and Almeida (2011) and Almeida and Andrade (2011) – a brief explanation is given for clarity); the second organizing epistemological information based on truthlikeness.

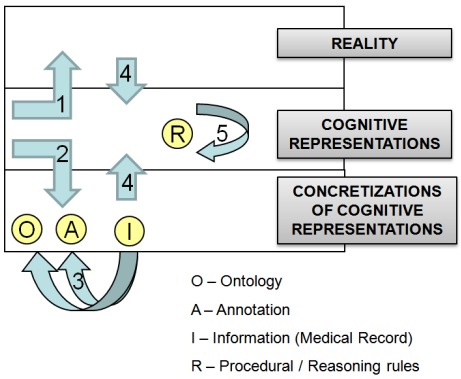


**Figure 1. Framework used for analysis.**

In this framework, everything begins at the level of cognitive representations when a physician observes the reality at the patient side (arrow 1). Each of these entities are filtered by cognition and represented by artifacts (arrow 2). Ontological entities (entities O) are analyzed according to strict philosophical tenets, and are based on reality itself rather than on physician´s mental representations. Examples of ontological entities are cells, anatomical features and chemical substances. These entities are directly considered in world 1 because in the realistic methodology adopted here [Grenon, Smith and Goldberg 2004] things exist in reality independently of any human beliefs. World 1 is the world of every thing that exists, observable or not. Epistemological entities are recorded in annotations (entities A). They stand for cognitive representations of reality, and may include entities without a referent in reality. Examples of these include "severity" of a pain and a sensation of "feeling well". Then, the physician creates a record (entity I) to register those representations according to their practical and theoretical knowledge (arrow 3).

Other physicians can constantly interpret records and reality (arrows 4), resulting in new cognitive representations. Finally, the physicians involved in healthcare

make judgments and process past and current information. Some of this processing of information (arrow 5) follows medical training rules, which determine the likelihood of a diagnosis and the correct interpretation of an exam result, to mention but a few. The representation of this reasoning process is also required for care continuation, which is a complementary part of the record (entity R). Examples of this include rules for interpreting lab data, as hemoglobin level < 12 g/dl means "low hemoglobin level"; and relevant negative information such as "lack of bowel alteration during episodes".

When performing this sort of analysis, we distinguish ontological information from epistemological information, the latter represented as entities in Popper´s world 3, which is equivalent in Fig. 1 to the concretizations of cognitive representations level. Within this sub-framework we recognize at least four kinds of information to be separated according to their suitability for information systems: i) information that represents aspects of reality; ii) information that represents useful constructs for the medical practice that are not empirically verifiable; iii) information that represents observations about the reality, not the reality itself; iv) information that represents observations about the physician´s understanding of the clinical situation, not about the reality.

According to the aforementioned approach, only information that represents aspects of reality can be properly represented by universals. The other three sorts identified are epistemological information. It´s worth mentioning the link between belonging to one of the three worlds and the degree of truthlikeness. The information that pertains to worlds 2 and 3 is epistemological information and it will be classified according to a degree of truthlikeness. We don´t use the notion of truthlikeness to deal with ontological information pertaining to world 1.

It is clear that (ii) and (iii) are closely related to reality, with (ii) being a surrogate for a defined state of things on the side of the patient, and (iii) an objective account of its measures. Relations that allow for proper interpretation of those statements are particular to each domain. For instance, the examination of the color of the sclera may indicate jaundice (yellow color, surrogate for liver problems) or anemia (blue color, surrogate for iron deficiency anemia). The interpretation of what such signs mean depends on training, cultural practices and subjective characteristics. There are also specific relationships with regard to lab tests, since statements like "the total bilirubin level in the blood of patient X is high" requires knowledge of the method of sampling and analysis, knowledge of the probabilistic distribution of bilirubin concentration in the normal population, consideration of measurement errors and confusion factors and understanding of the meaning of measurement units. The last category (iv) requires more attention, since medical reasoning practices include both ontological relations and ad hoc heuristic rules that are not guaranteed to hold true in the world. We consider that the information in (iv) will eventually be registered in medical records as part of a learning process.

Our proposal also includes a way of characterizing epistemological information based on its likeness to the truth. Following semantic approaches distinct from Popper´s account, such as Volpe (1995), Tichý (1978), Hilpinen (1976), we consider sentences extracted from the medical records. The semantic contents of such sentences are propositions that can be true or false.

In this sense, a simple propositional framework with three primitives (h, r, w) and the correspondent logical spaces are depicted in Fig. 2 as an example. The sentences from the associated propositional language are taken to express propositions within these logical spaces. This framework can be useful for characterizing information and scientific findings around a virus that has been studied only in the last few years, such as HTLV.

| | |
|---|---|
| w1 | h & r & w |
| w2 | h & r & ~w |
| w3 | h & ~r & w |
| w4 | h & ~ r & ~w |
| w5 | ~h & r & w |
| w6 | ~h & r & ~w |
| w7 | ~h & ~r & w |
| w8 | ~h & ~r & ~w |

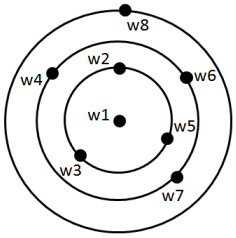


**Figure 2. Three propositions generate eight levels numbered w1 to w8.**

## 4.2. Testing the Framework

Here we conduct a preliminary test of the framework by analyzing individual information entities contained in medical records. As an example, we present a small extract of the clinical case available at Connors and Britton (2009), due to clarity and completeness of this case, and due to explicit description of reasoning processes.

After we obtain a sentential fragment from an evaluation by a domain expert, we then isolate what could be represented in realism-based ontologies following the rationale of the BFO, OGMS and IAO. After that, we arrange the information according to the sub-frameworks mentioned in section 4.1. The final results systematize the information contained in a medical record based on either their ontological or epistemological nature. To the second kind, that of an epistemological nature, we add a classification based on the level of truth.

> "A 62-year-old woman presented to the urgent care clinic with gingival bleeding after periodontal scaling of her lower-right second molar. She had undergone the procedure 5 hours before presentation, and the bleeding has persisted despite the application of pressure and ice. [...]
> The patient recalled a similar episode that had occurred 6 months earlier, also after a periodontal procedure, in which bleeding had stopped only after firm pressure had been applied and held for 6 hours. [...]
> She was otherwise in her usual state of good health. She reported no easy bruising, epistaxis, rectal bleeding, hematuria, weakness, fatigue, arthralgia, dyspnea, jaundice, abdominal pain, back pain, rash, confusion..." [Connors and Britton 2009]

In the Fig. 3, hereafter, we present samples of data obtained from the medical record in Fig. 4 and classified it according to the kinds proposed in section 3.

| Data representing aspects of the reality | Data that represent useful constructs for the medical practice | Data that represents observations about the reality | Data that represents observations about the physicians understanding |
|---|---|---|---|
| Physician Woman | State of good health | Heart rate: 80 bpm | Patient class: "Emergency patient" |
| 62 years-old | Former smoker | Blood pressure: 128/76 mmHg | Bleeding had persisted despite the application of pressure and ice |
| Patient report | No prior episodes of | White-cell count = 6,200 | Bleeding had stopped only |

| | | | |
|---|---|---|---|
| | unpredictable bleeding | | after firm pressure had been applied and held for 6 hours |
| Time of bleeding | No allergies | Lymphocytes = 37 | … |
| Time between episodes | … | Platelet-count = 352,000 | The timing of bleeding after vascular trauma is different |
| Aspirin | … | Creatinine = 1.4 | The patients presentation suggests platelet disorder |
| Aspirin taken daily (rule) | … | Albumin = 3.9 | **…** |
| Thiazide diuretic | … | Prothrombin time = 13 sec | Patient class: "Emergency patient" |
| Physical exam finding of that encounter | … | … | Bleeding had persisted despite the application of pressure and ice |

**Figure 3: Four kinds of information extracted of an example of a medical history.**

This data classification was based on both the levels of representation provided in section 4.1. From the empirical assessment by physicians, the categories suggested in figure 3 were created. The relation between the proposed framework and the organization of data from medical records can be summarized as follows:

a) "Data representing aspects of reality" (column 1) were mapped from processes (1) and (2) to entities (O) (Fig. 1) - only this information that can be directly used to populate realist ontologies, since terms in ontologies refer to universals;
b) "Data that represent useful constructs for the medical practice" (column 2) were mapped from the process (1) and (2) to entities (A) (Fig. 1);
c) "Data that represents observations about the reality" (column 3) were mapped from process (3) to entities (I) (Fig. 1);
d) "Data that represents observations about the physicians understanding" (column 4) were from processes (4) mapped to entities (R) (Fig. 1).

Already the information classified in (b), (c) and (d) can to be use to support the building sets of sentence. For both, we define a set of true sentences about a blood disease following the orientation of experts. In context of the existence of the HTLV virus in a patient, a set of related sentences would be: i) HTLV cause neoplastic manifestation on human being infected by it, which we call proposition n; ii) HTLV cause inflammatory manifestation on human being infected by it, which we call proposition f; iii) HTLV cause infectious manifestation on human being infected by it, which we call proposition i. We can then consider that, in context of HTLV prevention and treatment, in a patient infected with the virus that presents both a neoplastic, an inflammatory and an infectious manifestation, those manifestations were cause by the HTLV virus. This complex situation is considered a true equivalent to the actual world we name w1. Table 1 depicts combinations of propositions ranging from w2 to w8, according to the relative closeness to the truth.

**Table 1. Logical spaces for the presence of HTLV virus.**

| **actual world = w1** | **neoplasic manifestation** | **inflammatory manifestation** | **infectious manifestation** |
|---|---|---|---|
| w1 | n | f | i |
| w2 | n | f | ~i |
| w3 | n | ~f | i |

| | | | |
|---|---|---|---|
| w4 | ~n | ~f | ~i |
| w5 | ~n | f | i |
| w6 | ~n | f | ~i |
| w7 | ~n | ~f | i |
| w8 | ~n | ~f | ~i |

The truthlikeness gives us an objective criteria to evaluate the consequences of inclusion of such rules of thumb (weakness in HTLV infection is a neurologic complication) will behave in ontologies. Using this general rationale we can create "n" systems of spheres representing the situation considered real and other situations standing a logical distance from the actual world that is the truth (Fig. 4).

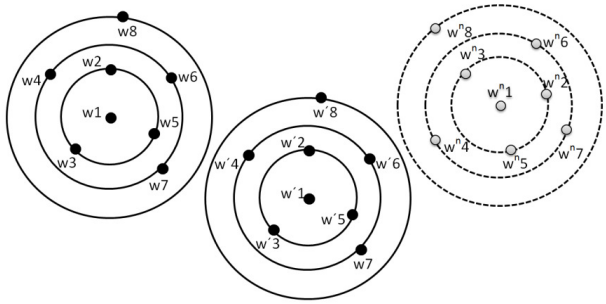


**Figure 4. Logical spaces corresponding to different sets of conjunctions.**

## 5. Discussion and future works

In this paper we presented a framework that aims to clarify the distinctions between reality, medical understanding and the recording of it, while maintaining the medical record as the main information source. Besides, we propose a way of dealing with epistemological information based on the notion of truthlikeness.

It is now well established that ontologies are an important resource to explicitly define the meaning of terms, especially when coupled with advances in description logics. Description logic is a powerful logic for describing the world, but is susceptible to inconsistencies, particularly when dealing with instance data. We advocate that realist ontologies provide a robust way of representing entities in reality, ensuring interoperability and safe inferences. This is possible because epistemological information, which can cause inconsistencies in inference processes, is not used in the ontology. Interoperabiliy is favored by the use of the top-level ontology which is the basis of the methodology adopted in this paper [Grenon, Smith and Goldberg 2004].

However, as we have shown, many entities in medical records do not have a referent in the world, being representations of epistemological evaluations by physicians and patient or measurements about real world entities. Ontologies, as pointed by Schulz in Brochhausen et al. (2011) are not "Swiss army knives for knowledge representation" and are unable to represent every single bit of knowledge required for correct interpretation of assertions. Our framework intends to make clearer which kinds of instance shouldn't be used in logical inferences, as robustness is not guaranteed. For instance, "unpredictable bleeding" is an important construct for hematologist evaluation, but a bleeding process doesn't change its way of being if someone claims it could be predicted.

Popper's theories provide a useful perspective on the different levels of reality and the relationship between theories (the ontology artifact being one of these theories) and reality *per se*. Our treatment of epistemological information seems to be an alternative to dealing with uncertainty common in the medical practice, from a logical point of view. Popper´s initiative in this regard, while essentially syntactic, entails the idea that no false theory is closer to the truth than any other. Other authors [Hilpinen 1976] [Volpe 1995] follow a semantic-oriented approach in looking for a plausible theory of distance between the semantic content of sentences. We believe that this latter approach fits well to the needs of a still-evolving subject that has to be captured in ontologies.

The proposed method has been tested in sentences obtained from real medical records, but the partial results have suggested the need for refinement. The test presented in this paper deals with a very small number of sentences and the feasibility of the approach has to be tested in more complex situations. The possibility of dealing with more complex cases is presented, for example, in Hintikka (1963). However, as a qualitative measure, truthlikeness can work as a kind of secondary metric which helps to make sense of the large amount of information in medical records.

In future works, we intend to create clear rules for dividing kinds of information in a semi-automatic fashion. It will then be possible to test our approach against a greater sample. In doing so, we aim to explore the best characteristics of different systems and which representations suitable for each sort of system.

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