Extending the Ontological Model for Urinary Profiles

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Abstract. *Urinalysis (i.e. laboratory test of urine) provides information about patient's health conditions based on the contents present in a urine sample. A key factor to guarantee the quality of the test, it is arranging urinary findings in a clinical context. Aiming to support the task, it was proposed an ontological model for Urinary Profiles (i.e. recurrent characteristics of urine that help in contextualizing it). Besides providing context, it allows predicting which contents should be observed in a sample based on what was already found in it. Although useful, such model defines Urinary Profiles as strictly related to the contents of the urine, when, in fact, it seems to be based on a broader context, including intrinsic properties of urine (e.g. pH) and things outside it (e.g. the patient from which the sample was collected). Thus, this paper proposes an extension to such model including other aspects of the urinary context. It is defined using the Unified Foundational Ontology (UFO).*

Keywords*: Ontological Analysis, Knowledge Representation, Health Informatics, UFO, Profiles, Urinalysis*

1. Introduction

Urinalysis is the laboratory test of urine, which can give a reliable perspective on patient[1]'s metabolic, urinary and renal condition [CLSI, 2001]. It usually comprises two main phases: physicochemical analysis and microscopy [Strasinger, Di Lorenzo, 2008] [Fogazzi, 2010]. Physicochemical analysis aims to identify substances that are present in the urine specimen[2] (e.g. hemoglobin, albumin, glucose) as well as its pH and specific gravity. Microscopy is carried out over a spot of urine disposed on a microscope slide in order to identify urinary particles (e.g. cells, crystals, casts) in the sample. The same slide is analyzed tens of times, in different microscopic fields (i.e. regions of the slide). Information gathered during physicochemical analysis and observation of previous fields guide the search on the following fields.

Despite its clinical importance, the test faces a problem: microscopy is usually performed without correct methods and suitable professional qualification [Fogazzi, Grignani, 1998]. As a consequence, results rely too much on approximated values of

1 Throughout the text, we use the term *patient* as referring to the person from whom the urine sample was collected.

2 Throughout the text, we use *specimen* and *sample* as interchangeable terms.

physicochemical parameters and significant particles are frequently missed, misidentified or misinterpreted. It means missing valuable information about the patient [Fogazzi, Verdesca, Garigali, 2008] and calls into question the quality of the test. Avoiding this situation requires the capability to identify the main urinary particles and arrange urinary findings (i.e. particles and substances) in a clinical context [Fogazzi, Verdesca, Garigali, 2008].

Since those are majorly knowledge/informational requirements, it seems that a computational support may be able to help. Moreover, considering that a great part of the urinalysis domain could be explained in terms of the concepts of urine and its possible contents, the patient it comes from, the tools and procedures used during the test, and the relationships among such concepts, it seems that ontologies (i.e. explicit specifications of conceptualizations [Gruber, 1993]) are a good choice for the task.

In fact, some aspects of this problem are already dealt with using ontological models. For example, [Rodrigues et al. 2015] brings an ontological model for *urinary profiles*. According to it, a urinary profile is associated with a combination of findings that recurrently appear together in urine samples. Such combination is recognized as a unit with its own meaning and usually relates to some clinical condition of the patient (e.g. the presence of glucose and ketones in urine is typical of a diabetic patient). Urinalysis experts internalize such recurrence as a knowledge chunk that is used to put urinary findings in context as well as to predict which contents should be observed in the sample (i.e. if a sample contains elements that characterize a given profile, an expert would expect to find the remaining components related to the profile in such sample). Thus, the proposed ontological model allows to automatically identify the urinary profiles that characterizes a urine sample based on the contents already observed in it – and then it enables predicting which other contents should be observed in the sample.

Although useful, this model of urinary profile has a weak point: it founds the concept of urinary profile exclusively on the presence of urinary contents, whereas it is in fact related to a broader context, including intrinsic properties of urine (e.g. pH, specific gravity, temperature) as well as things outside it (i.e. patient, conditions surrounding the sample). Not tacking into account this type of additional information prevents the model from capturing certain urinary profiles which refer to problematic situations in the sample (e.g. presence of spermatozoa in urine from feminine patient, urine containing a large amount of crystals due to refrigeration). Moreover, without including this information about factors that are external to urine (specially the patient to which it refers), there is no appropriate way to link a profile with its related clinical condition. Therefore, if we intend to deal with such cases, we have to extend the model for urinary profiles in order to comprehend the influence of intrinsic properties and things external to urine – which is, by the way, a future work path left on [Rodrigues et al, 2015].

Thus, this work presents an extended version of the current ontological model for urinary profiles presented in [Rodrigues et al. 2015], based on the Unified Foundational Ontology (UFO) [Guizzardi, 2005]. This extended model is conceived to represent urinary profiles that are based on aspects beyond the contents of urine, while keeping compatibility with its previous version (i.e. being able to represent the content-based urinary profiles). Moreover, it is also intended to allow answering the same types

of questions posed in that work (i.e. those concerning the recognition of a urinary profile in some urine sample, the identification of the aspects of urine that allowed recognizing such profile, and the prediction of contents that should be found in that sample), including support to prediction of other aspects of urinary context.

The remaining sections of this article are organized as follows: section 2 recollects the current model for urinary profiles, section 3 discusses the limitations of such model and proposes an extension, and section 4 brings our concluding remarks and points out some opportunities for future work.

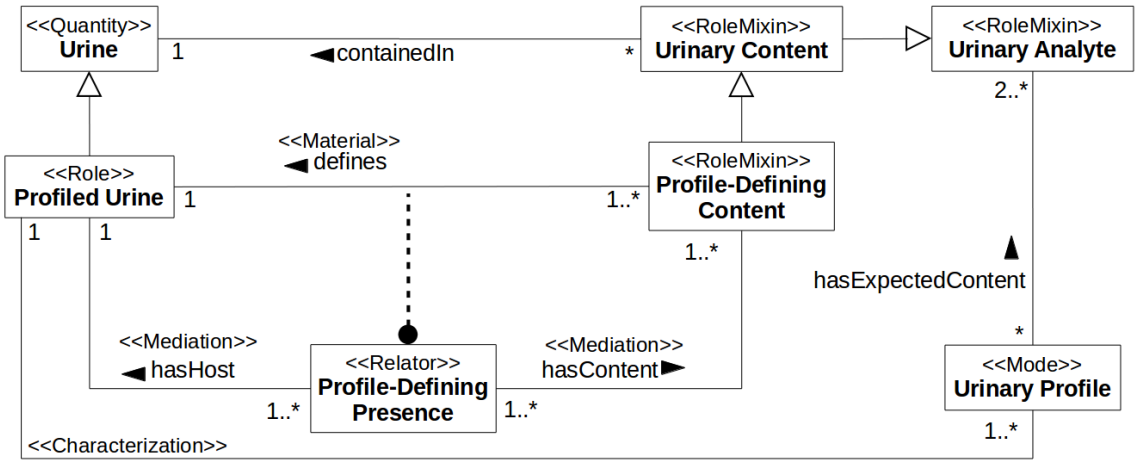

Figure 1. Current model for urinary profiles (adapted from [Rodrigues et al, 2015])

2. Ontological Model for Urinary Profiles

This section briefly recollects the current ontological model for urinary profiles (Figure 1). A short description of each of its concepts is following presented. For a further analysis, please refer to [Rodrigues et al, 2015].

Urine. A body fluid, produced inside kidneys, with a specific composition. It is classified as a UFO's Quantity universal[3] (i.e. a rigid universal that supplies its instances with a principle of identity and whose individuation principle is based on the idea of piece – i.e. a maximally self-connected portion of matter).

Urinary Analyte. Things of interest in urinalysis (both particles and substances that are not part of the urine composition). Assuming that what is of interest in urinalysis would be so in any possible world, this concept is classified as a UFO's Category universal (i.e. a dispersive, rigid and relationally independent universal that aggregate properties that are common to different sortals).

Urinary Content. Any Urinary Analyte that is present in urine. It is a role played in relation to some Urine by a variety of types of particles and chemical substances. Thus, it is classified as a UFO's RoleMixin universal (i.e. a dispersive, anti-rigid universal that aggregates properties which are common to different roles, that does not carry any identity principle and whose instances are relationally dependent on other particulars).

3 Except for explicitly stating otherwise, the definitions of UFO concepts hereafter mentioned are based on [Guizzardi, 2005]

Profiled Urine. A Urine that, given the presence of instances of specific Urinary Contents, is recognized as presenting some Urinary Profile. Thus, it is a role played by some urine in relation to a set of specific urinary contents present in it. Thereby, Profiled Urine is a UFO's Role universal (i.e. an anti-rigid universal that carries an identity principle – in this case, that of Urine – and whose instances are relationally dependent on other particulars – in this case, specific urinary contents).

Profile-Defining Content. Any Urinary Content that, lonely or together with other contents, allows the Urine that contains it to be recognized as a Profiled Urine. Therefore, it is a role played in relation to a single Profiled Urine and to its other Profile-Defining Contents that allows such recognition. Since different types of particles and substances may assume this role, it cannot carry any identity principle – and so it is also classified as a UFO's RoleMixin universal.

Urinary Profile. A set of "expectation[4]-maker" particulars that inhere in a Profiled Urine and can lead a trained observer to expect that certain contents are present in the urine. It acts as a disposition – like that of a magnetic material to attract metallic objects [Guizzardi, 2005]. Such set is an externally dependent mode[5] dependent on the Profile-Defining Contents that allow the recognition of a Profiled Urine and that justify the expectations raised by the profile. Thus, this concept can be classified as a UFO's Mode universal (i.e. intrinsic moment[6] that is not directly related to quality structures and can be conceptualized in terms of multiple separable quality dimensions).

Profile-Defining Presence. the presence of a special combination of Urinary Contents in a Profiled Urine that allows it to be recognized as a Profiled Urine (the foundation for the existence of an Urinary Profile). It represents the conditions in which the instances of Urine and Urine Contents must connect to one another (including content combination and quantities) in order to receive the roles of Profiled Urine and Profile-Defining Content. Thus it is classified as a UFO's Relator (i.e. relational moment, which depends on a plurality of individuals and mediates them, that is base for the existence of a material relation). A single instance of Profiled Urine may host different Profile-Defining Presences. As each of such presences may represent a different combination of Profile-Defining Contents, corresponding to different specific Urinary Profiles, an instance of Urine may play different Profiled Urine roles, characterized by different Urinary Profiles. The same way, an instance of Profile-Defining Content may be combined with other contents to form different Profile-Defining Presences. In this case, it would share more than one instance of the "defines" relationship with its containing Urine – thus assigning different roles to it.

Figure 2 presents the application of this model to a simplified version of Nephritic Profile (i.e. a urinary profile generally presented by urine specimens of patients suffering from nephritic syndrome). Gray boxes hold concepts from the general model; white boxes hold concepts from the specific case. According to it, a professional observing an urine which presents such profile (i.e. a Nephritic Urine) would expect to

4 A belief that something will happen or is likely to happen (http://www.merriam-webster.com/)

5 An individual mode that inheres in a single individual but that existentially depends on other individuals that are independent of its bearer [Guizzardi, Wagner, 2010]

6 An abstract property [Guizzardi, Wagner, 2010]

find some analytes (i.e. RBC Cast, Dismorphic RBC, hemoglobin, and albumin). To be recognized as a Nephritic Urine, an instance of Urine must host a Nephritic-Defining Presence, which mediates Nephritic-Defining Contents. The model presents two variations of Nephritic-Defining Presence: Nephritic-Defining Presence of RBC Cast and Nephritic-Defining Presence of Substances (i.e. hemoglobin and albumin).

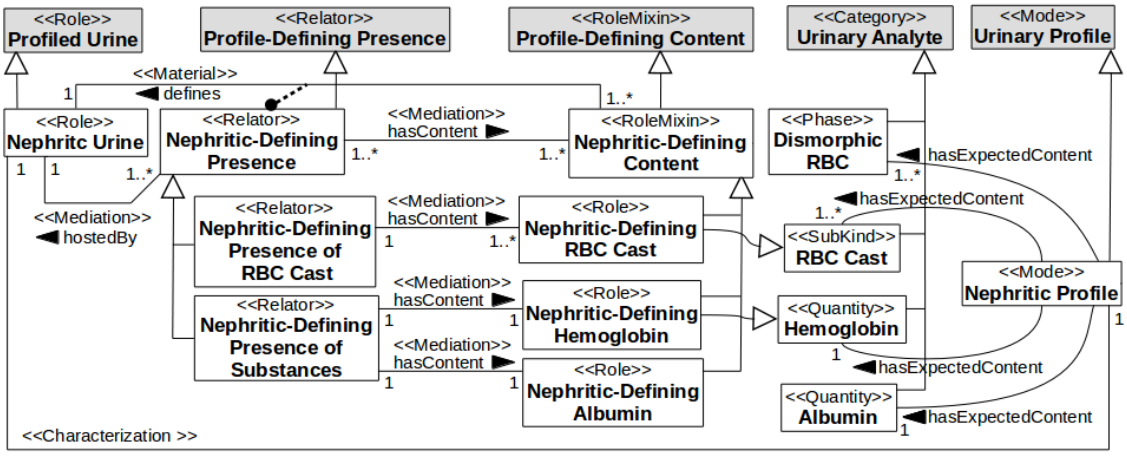

Figure 2. Ontological Model for Nephritic Profile (adapted from [Rodrigues et al, 2015])

3. Extending the Model

The current model for urinary profiles is well suited to model profiles that are solely based on the contents present in a urine sample (such as the nephritic profile presented in the previous section). Nevertheless, restricting the foundation of urinary profiles to urinary contents, the model is not able to represent profiles based on other aspects of the context of the sample, such as its intrinsic properties (e.g. pH, temperature) or things external to urine (e.g. the patient from whom the urine was collected, conditions to which the sample is exposed). Due to this limitation, we cannot use the referred model to depict certain types of profile whose definition relies on such aspects. Among them, we have some profiles used to pinpoint situations that hamper the analysis (e.g. menstrual contamination, precipitation of a large number of crystals due to sample refrigeration) or indicating incoherences in the sample (e.g. presence of spermatozoa in urine from feminine patient, presence of acid crystals in urine with alkaline pH).

Another drawback of the current model for urinary profiles is that, as it does not accept external contextual aspects as able to define a profile, it does not provide a clear link from the urine that presents a profile to the patient's clinical condition that originated the profile. Taking the example of nephritic profile again: although it is well known among experts that such profile is related to nephritis (i.e. an inflammation of the kidneys), there is nothing on the ontological definition of the profile that links it to such clinical condition – the only tip is the name of the profile, which we cannot rely on if intending to formally represent the knowledge. As a result, if we are to apply the idea of urinary profiles to such situations, we must give up that restriction.

In the current model, urinary profile description is centered on the relation of containment that holds between urine and its contents. In spite of that, things outside

urine as well as intrinsic properties of urine itself may also contribute to the definition of a profile. Then, it becomes clear that the relation of containment is not enough to represent the connection between some urine and the aspects that may define a profile for it. But what could be a good replacement for such relation?

Given the variety of external aspects that can influence a urine (e.g. the patient it is collected from, the container where it is stored, exposure to conditions such as heat, direct light, or refrigeration), it is probably not feasible to point out a single relation to account for all situations. The picture gets even more complicated when we consider that it would also have to comprise the relation of *characterization* between urine and some intrinsic property that would possibly help to define a profile. Bearing in mind this diversity of possible relations, we define the concept of ***Urinary Relatum***. It is a role played with respect to a Urine by something related to it in any possible way – which we represent by a rather general *relatesTo* relation. As virtually anything could play such a role – including both objects and intrinsic properties –, this concept is classified as a UFO's RoleMixin universal[7]. It is also noteworthy the fact that, due to the variety of different relations that can establish such a role, it is possible that the same particular Urinary Relatum may relate to different instances of Urine (e.g. the same patient may be the origin of multiple urinary samples, a set urinary samples may be exposed to the same heat source).

Following that, we specialize Urinary Relatum with the concept of ***Profile-Defining Relatum***. This concept encompasses those instances of Urinary Relatum that, alone or together with other relata, allow to recognize the urine they relate to as a Profiled Urine. Being a role played in relation to some Profiled Urine (and possibly to other instances of Profile-Defining Relata too) by things with diverse identity criteria, this concept is also classified as a UFO's RoleMixin. As a result, Profiled Urine now refers to a role that some Urine plays in relation to a set of specific Urinary Relata (i.e. it is the existence of such relata that allow a Urine to be recognized as a Profiled Urine). Likewise, the external dependence of Urinary Profile migrates from Profile-Defing Contents to Profile-Defining Relata.

Finally, as the foundation of a Urinary Profile is no longer exclusively based on the presence of a combination of Urinary Contents, but on a rather broader context, we define the concept of ***Profile-Defining Context***. This concept is a UFO's Relator that represents the conditions in which instances of Urine and Urine Relatum must be associated to receive the roles of Profiled Urine and Profile-Defining Relatum, respectively.

After these considerations, figure 3 presents the extended ontological model for urinary profiles. Since *relatesTo* arguably subsume the relation of *containment,* Urinary Content, Profile-Defining Content and Profile-Defining Presence become special cases of Urinary Relatum, Profile-Defining Relatum and Profile-Defining Context respectively (e.g. as Urinary Content is something related to some Urine by a relation of

7 Although the original work concerning UFO and OntoUML [Guizzardi, 2005] prescribes that anti-rigid types (such as RoleMixin types) could be instantiated exclusively by objects, more recent works [Guizzardi, Guarino, Almeida, 2016] acknowledged the idea that all endurants (including intrinsic properties, such as Modes or Qualities) can instantiate anti-rigid types.

containment, it is also a Urinary Relatum). This way, the compatibility with the previous version of the model is guaranteed.

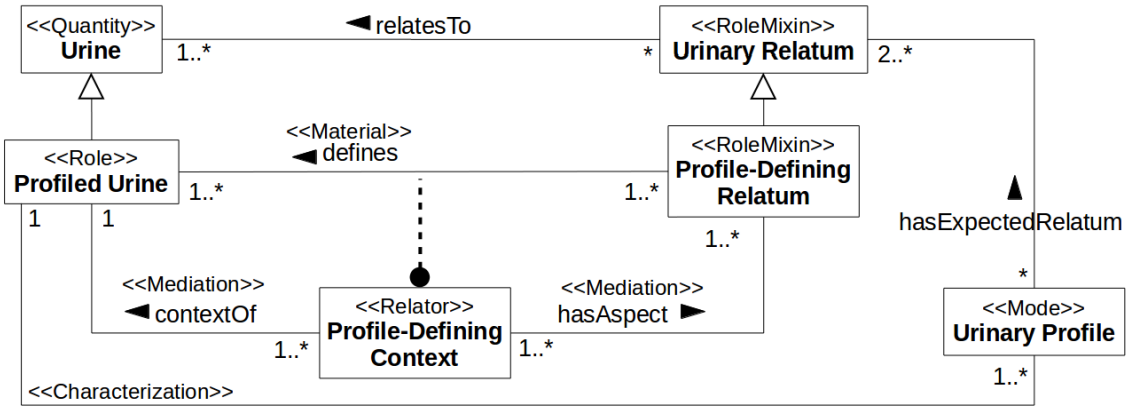

Figure 3. Extended ontological model for urinary profiles

Another important change concerns the *defines* relation between Profile-Defining Relatum and Profiled Urine. Since the previous model is centered on the idea of presence, in such model the *defines* relation is a particular case of *containedIn*. Then, its cardinality on the Profiled Urine end is 1 – since the Profile-Defining Content would be contained in exactly one instance of Urine. However, in the extended model, *defines* relation becomes a specialization of *relatesTo*, so that the cardinality on the Profiled Urine end becomes 1..*. This reflects the possible existence of instances of Profile-Defining Relatum which are external to urine and simultaneously related to more than one specimen (e.g. a patient that provides more than one sample).

A last noteworthy detail is a change in Urinary Profile definition. Since the idea of urinary profile is now based on a context that goes beyond urinary contents, what a profile would lead to expect is no longer restricted to some Urinary Analytes present in urine, but includes any type of Urinary Relatum. By indicating a Urinary Relatum as the object of expectation of a profile, we are simultaneously indicating the type of thing which is expected and the type of relation it is expected to have with urine – allowing the prediction of other aspects of the sample besides its content.

Figure 4 presents the application of the extended model to represent the Spermatozoa Contamination profile (i.e. situation in which a urine specimen that was collected from a feminine patient contains spermatozoa – and, since this kind of cell is not part of women's physiology, it is a sign that the specimen under analysis is contaminated by somebody else's material). Again, gray boxes represent concepts from the general model and white boxes depicts concepts specific to the case.

In this example, there is only a single combination of Urinary Relata that form a Profile-Defining Context – i.e. a feminine patient as the origin of the urine sample and some spermatozoon present in it. Thus, according to the model, given the existence of such relata, one can recognize a sample as contaminated by the spermatozoa it contains (i.e. presenting the Spermatozoa Contamination Profile). Although this profile is not

used to make predictions, but rather to recognize a situation in which the sample must be discarded, it still allows to predict contents – more precisely, the existence of other spermatozoa, what could be searched for in order to confirm the occurrence of contamination.

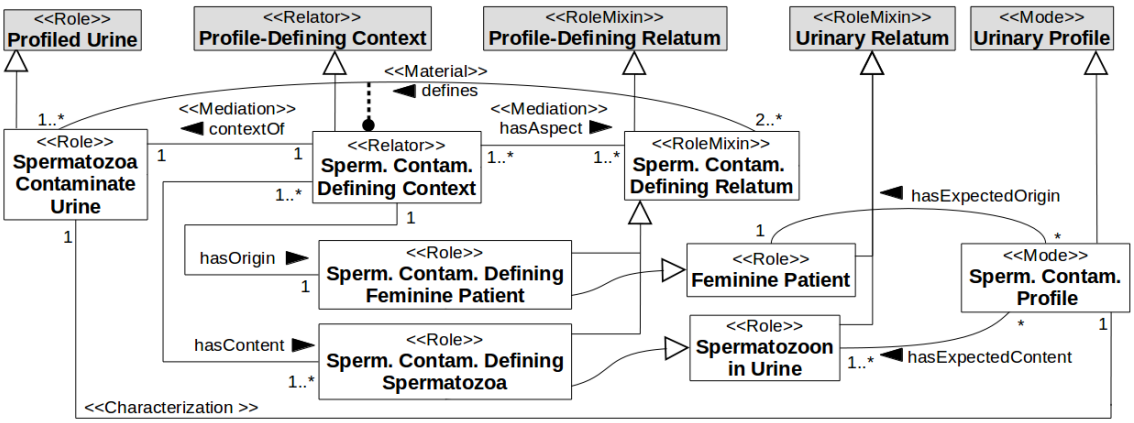

Figure 4. Ontological Model for Spermatozoa Contamination Profile

It is also possible to observe that we can specialize the *hasAspect* relation (in this case, with the relations of *hasOrigin* and *hasContent*) in order to better identify the role of the relatum that is defining the profile. The same apply to *hasExpectedRelatum* relation (specialized in *hasExpectedOrigin* and *hasExpectedContent*) in order to better identify the role of the relatum that should be expected given the profile. Anyway, given the definition of patient used in this work (i.e. the person from whom the sample was collected), the Feminine Patient role alone implies the relation *refersTo* from Urine towards Patient. Analogously, the Spermatozoon in Urine role would implies the relation of containment.

4. Discussion and Concluding Remarks

This work extended a previously proposed model for urinary profiles. This extension comes from realizing that the context which allows the recognition of some urine as presenting a urinary profile is not restricted to what such urine contains, but also comprehends its intrinsic properties and external things that somehow characterize the urine. Analyzing the existent model we identified that its limiting factor is its focus on the relation of *containment* – keeping it centered on the idea that the *presence* of urinary *contents* is the only foundation of a urinary profile. Becoming aware of the fact that different types of relation in which a urine can take part may cause the emergence of a urinary profile, we departed from that view and adopted the idea of a broad context as the base for identify profiles – deeming the notion of *presence* to a particular (though very important) case of context.

Such change in perspective has important implications. The leading one is increasing the range of profiles that are possible to represent. Coupled with that, the extension also offers new ways to recognize a profile – namely, by identifying external things related to urine. For example, knowing that a sample comes from a Nephritic Patient, according to the model it would immediately acquires the Nephritic Profile.

This capability increases the prediction power of the model. Conversely, it also allows, given some observed contents in urine, the prediction of things external to the sample. As a result, the model offers clear means to link a profile to its originating clinical conditions (namely, by relating it to the patient from whom the urine was collected and then to the clinical condition that inheres in her/him), really giving a clinical context to the urinary findings.

Another rather subtle result is that, by detaching the idea of Urinary Profile from the idea of containment and allowing it to be described things related to urine in various ways, we take a step toward the notion of a general profile – i.e. one that could be applied to any domain (e.g. a similar structure could be used to describe the social profile of a person given her/his relations with other people).

As a last word, it is clear that the idea of identifying the profile of something is not new and there are plenty of profiling mechanisms out there. Nevertheless, what we intend to leave as a contribution is the ontological analysis concerning the nature of profiles and the dynamics of profiling (which would include, according to [Rodrigues et al, 2015], the ability to deal with the uncertain aspect of expectations by disentangling the notion of expectation/possibility that the urine contains/is related to something from the idea of actual containment/relation).

This work integrates the efforts to develop a knowledge-based system for urinalysis, aiming to be used both for decision support during the test and for professional training. The presented ontological model integrates a larger ontology for urinalysis domain and is being used to model the different possible types of urinary profiles and so explain and reproduce the predictions urinalysis experts make during examination of the specimen. Thus, as already mentioned, future work will be directed towards the inclusion of intrinsic properties on the proposed model, in order to fully depict the whole variety of existing profiles – and possibly generalize it to other domains (e.g. the analysis of other body fluids, such as blood).

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