

LABO: An ontology for laboratory test prescription and reporting

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Abstract. LABO is an ontology formalizing laboratory test prescriptions and reporting documents. It is built according to the OBO Foundry methodology, and is a component of a core ontological model that aims to enable interoperability between various clinical data sources in the context of a Learning Health System. This article presents LABO, distinguishing between directive entities and data items, and using the relations **directs** and **is about** to represent their connections with the relevant laboratory test processes.

Keywords. Laboratory test, Information content entity, Directive information entity

1. Introduction

Learning Health Systems analyze health information generated from patients in order to provide secondary use of clinical data and decision support. They rely on access to a wide range of clinical data, such as drug prescriptions or laboratory test prescriptions and results, usually scattered across numerous heterogeneous information systems.

Applied ontologies can support a common, source-independent representation of these data, thus helping to solve the "Tower of Babel problem" in medical informatics. An ontology has already been developed for drug prescriptions: the Prescription of DRugs Ontology (PDRO, read "Pedro") [1]. This paper presents the creation of an ontology using a compatible methodology for representing laboratory test prescriptions and reporting documents: LABO (for LABoratory Ontology). It is being used in the context of the Canadian PASS architecture ("Plateforme apprenante en soutien aux systèmes de santé et services sociaux"), which is used in several projects including PARS3 ("Plateforme apprenante pour la recherche en santé et services sociaux au Québec"), an ontology-based Learning Health System that builds on the former proof of concept European project TRANSFoRM [2]. Ontologies such as PDRO and LABO are being used to generate a relational database structure [REF Ontorela]. This structure is then mapped to databases from various healthcare institutions, in order to support a system of data mediation on the model of what was done in TRANSFoRM [REF CDIM].

Some terminologies such as portions of LOINC [REF] or SNOMED-CT have been developed to represent laboratory tests. LABO does not aim at represent the variety of

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possible laboratory tests and results, but rather at representing the documents that are generated to prescribe them and report on them. However, codes from LOINC or SNOMED-CT are commonly used in various health databases, and could therefore be used in the general relational database built on the basis of LABO (with a system mapping synonymous codes from various terminologies, as described in [REF LexEVS]).
[insert comparison with FHIR and OpenEHR]

2. Methods

LABO has been developed according to a realist approach based on the Basic Formal Ontology (BFO), as a candidate to the OBO Foundry [3]. Like other OBO Foundry candidates, it re-uses other OBO Foundry classes to keep the ontologies compatible with each other. In the following, classes names will be prefixed by the ontology name when they are imported from another OBO Foundry candidate ontology. LABO introduces 87 new classes (some of which via sub-ontologies we developed of demographic or administrative informational entities), and imports whole or parts of OBO Foundry ontologies such as the Information Artifact Ontology (IAO), the Ontology for Biomedical Investigations (OBI) and the Ontology for General Medical Science (OGMS). The ontology can be found at the following address: <https://github.com/OpenLHS/LABO>.

LABO represents informational entities that direct laboratory tests or report on them, and their parts, as subclasses of IAO:*Information content entity* ("ICE") [4]. In particular, it represents entities directing laboratory tests as subclasses of IAO:*Directive information entity* ("DIE") [5] and laboratory results as instances of IAO:*Data item*. It is based on BFO and provides Aristotelian definitions for the created classes [6].

Following the OBO Foundry methodology, we also reuse object properties from other OBO Foundry ontologies and avoid introducing new ones when possible. Still, we introduced a new relation **directs** (and its inverse relation **directed by**) that has as domain IAO:*Directive information entity* and as range BFO:*Process*. The formalization of this relation is ongoing in other work [7]: in the present article, we will provide an informal characterization to ensure proper comprehension of the core of this work, by stating that **d directs p** means that an agent represents the DIE **d** in his cognitive system, has the intention to follow it, and follows it as a consequence of this intention.

3. Results

Let us consider the following scenario S_1 . Dr. Jones wants to know more about the health status of Mr. Fiennes. He requests to him several lab tests: a complete blood count (CBC), as well as a serum sodium measurement. On a request form (which can be named a "prescription" by analogy with drug prescriptions), he writes 'CBC, serum sodium' (that will be called '**LADIG₀**'). He adds the name of Mr. Fiennes, the date of the day ('May 31st, 2019'), and signs it. Several tests are then realized on Mr. Fiennes as a result of this prescription: a serum sodium test, and a dozen of distinct tests that are directed by the instruction 'CBC': a hematocrit test, a hemoglobin concentration test, etc.

On June 5th, 2019, he receives a paper stating 'serum sodium: in progress; CBC in progress'. On June 8th, 2019, he receives another paper saying 'serum sodium: 138 mmol/L; CBC in progress'. On June 15th, 2019, he receives a final report giving the value

of all the tests that were prescribed by **LADIG₀**. LABO provides categories for all those and related entities, as pictured on figures 1 and 2 below and explained in the following.

3.1. Laboratory test direction

3.1.1. Laboratory test directive item

A central class in LABO is *Laboratory test directive item* (abbreviated hereafter "LADI") which is a subclass of *IAO:Action specification*, and is defined as "An action specification that directs one or several laboratory tests and such that none of its proper parts directs some but not all of those laboratory tests." This definition is motivated by the fact that some instructions, such as 'CBC', direct several distinct tests – more than a dozen for the complete blood count: hematocrit, hemoglobin, etc.; but no part of the ICE 'CBC' does specifically direct a hematocrit test, or a hemoglobin test, etc. Therefore, both 'CBC' and 'serum sodium' are instances of *LADI*. On the other hand, the mereological sum 'CBC; serum sodium' is not a *LADI*, as it has two parts ('CBC' and 'serum sodium') that each direct some test(s).

Several LADIs can be gathered into a *Laboratory test directive item group* ("*LADI group*"), defined as "An action specification that has as parts one or several laboratory test directive items, as well as possibly some statements specifying a starting condition, a stopping condition and a testing condition." In scenario *S₁* above, 'CBC, serum sodium' is a *LADI group*. A LADI can therefore constitute a LADI group, but not all LADIs are a LADI group: if several LADIs have the same starting condition, for example, they are parts of a larger LADI group.

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IAO: Information content entity
  IAO: Document
    PDRO: Health care prescription
    Laboratory test prescription
    Laboratory test report document
  IAO: Directive information entity
    IAO: Action specification
      Laboratory test directive item ("LADI")
      Laboratory test directive item group ("LADI group")
    PDRO: Condition [see taxonomy on figure 2]
  Laboratory test reporting information
    Laboratory test reporting item ("LAR item")
    Laboratory test result item
    Laboratory test reporting group ("LAR group")
    Laboratory test reporting item time specification
    Laboratory test status specification
  IAO: Data item
    OGMS: Clinical finding
    Laboratory result2
  Specimen characteristic specification
BFO: Process
  OGMS: Health care process assay
  OGMS: Laboratory test3
  Directed laboratory test group

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Figure 1: Taxonomy of relevant entities and abbreviations

A *LADI group* is always composed of at least one *LADI*:

LADI group subClassOf *Action specification* and **has part** some *LADI*

A *LADI group* might be composed of only one *LADI*: if Dr. Jones would not have prescribed a CBC to Mr. Fiennes, but only the serum sodium test, then 'serum sodium' would be both a *LADI* and a *LADI group*.

Finally, we define a *Laboratory test prescription* as "A health care prescription specifying the realization of one or several laboratory test(s). A laboratory test prescription encompasses at least one laboratory test directive item group.":

² The class *Laboratory finding* is currently defined by OGMS as 'A representation of a quality of a specimen that is the output of a laboratory test and that can support an inference to an assertion about some quality of the patient.' However, a successful laboratory test can lead to an ICE that is about an entity that is not a quality of the specimen, such as e.g. a disposition or a coagulation time. Therefore, we introduced the class 'Laboratory result', which we define as "A representation of *an entity related* to a specimen that is the output of a laboratory test.".

³ The class *Laboratory test* is currently defined by OGMS as 'A measurement assay that has as input a patient-derived specimen and as output a data item that is about a quality of the specimen.' However, we think that it should rather be defined as 'A measurement assay that has as input a specimen derived from an organism and that *aims at having as output* a data item that is about *an entity related* to the specimen.' As a matter of fact, apart from the problem mentioned in the former footnote, a laboratory test can fail in having as output such a data item if e.g. the sample is spoiled.

Laboratory test prescription subClassOf *PDRO:Health care prescription*
and **has part** some *LADI group*

A Laboratory test prescription might have several LADI groups though; consider for example a prescription with the instructions:

'CBC on 2019/06/01;

Na, K, creatinine on 2019/08/01'

Here, 'CBC' is a first *LADI group*, and 'Na, K, creatinin ' is a second *LADI group*.

Laboratory test prescription inherits the following axiom from *PDRO:Health care prescription*:

Laboratory test prescription subClassOf
has part some *IAO:Author identification*
and **has part** some *PDRO:Patient identification*
and **has part** some *PDRO:Document creation time identification*

An example of laboratory test prescription is the prescription mentioned above that has **LADIG₀** as part. Many LADIs are parts of a *Laboratory test prescription*, but not all of them - consider e.g. an instruction directing a laboratory test as part of a research study.

3.1.2. Laboratory test conditions

As suggested by the definition of *LADI group* provided above, some LADI groups can have a conditional structure. Consider for example 'PTT q2h start 2h post-op for 24h', where 'PTT' stands for "partial thromboplastin time", 'q2h' for "every 2 hours", and 'post-op' stands for "post operation". It is composed by the *LADI* 'PTT', as well as a *Starting laboratory test protocol condition* '2h post-op', a *Continuing laboratory test protocol condition* 'for 24h' (which is synonymous to an ending condition being satisfied 24h after starting) and a *Laboratory test administration condition* 'q2h'. As it happens, this is a similar structure to a drug prescription structure such as 'Amoxicilin 500 mg q8h for 14 days, start in case of symptoms of bronchitis'. And as it happens, very similar classes are already defined in PDRO, such as *Starting drug administration condition*, *Continuing drug administration condition* and *Dosing condition*. We therefore introduce the parent classes: *Starting condition*, *Continuing condition* and *Action condition*, with the following taxonomy:

PDRO:Condition
_____ *Starting condition*
_____ *Starting laboratory test protocol condition*
_____ *PDRO:Starting drug administration condition*
_____ *Continuing condition*
_____ *Continuing laboratory test protocol condition*
_____ *PDRO:Continuing drug administration condition*
_____ *Action condition*
_____ *Laboratory test administration condition*
_____ *PDRO:Dosing condition*

Figure 2: Extract from the taxonomy of conditions in PDRO/LABO

3.2. Laboratory tests

Although LABO focuses on informational entities pertaining to lab test prescription and reporting, the connection between those informational entities and the laboratory tests they are related to needs to be represented. As a matter of fact, it can be important to represent the connection between several ICEs – e.g., representing that several ICEs were generated by the same laboratory test. A *LADI* does not necessarily direct a *Laboratory test* (think about a *LADI* that is never followed), but any *Laboratory test* is directed by some *LADI* (at least the *LADI* that is concretized in the brain of the person performing the lab test, if we follow IAO's ontology of mental entities [4]); therefore, we add the following axiom:

Laboratory test subClassOf OGMS:*Health care process assay*
and **directed by** some *LADI*

We also need to introduce the entity *Directed laboratory test group* as "A health care process assay constituted by all laboratory test(s) that are directed by a single laboratory test directive item." (where *Health care process assay* is defined in OGMS [8]). In our example, the item 'CBC' above directs an instance of *Directed laboratory test group* composed by an instance of *Hematocrit test*, an instance of *Hemoglobin test*, etc. Thus, all the laboratory tests that are directed by the same *LADI* are parts of one *Directed laboratory test group* (which is also directed by this *LADI*):

Directed laboratory test group subClassOf OGMS:*Health care process assay*
and **directed by** exactly 1 *Laboratory test directive item*
and **has part** some *Laboratory test*

3.3. Laboratory test reporting

3.3.1. Laboratory test reporting item

Once a laboratory test has been performed, one or several documents may report on its progress and result. Consider again scenario S₁. Suppose that on 2019/06/15, Dr. Jones receives a document with the date, the name of his patient, and results about the tests that were prescribed, such as:

- 'RBC 5.2 10¹²/L, 2019/06/15' (where 'RBC' stands for "Red blood cell count")
- 'WBC 12.1 10⁹/L, 2019/06/15' ('WBC' stands for "White blood cell count")
- 'serum sodium 138 mmol/L, 2019/06/08'
- etc.

All those ICEs and some of their parts – such as the result 'WBC 12.1 10⁹/L', the date '2019/06/08', or the status report 'in progress', are instances of *Laboratory test report information* ("LAR information"), which is defined as an 'An information content entity which reports on some aspect(s) of a particular laboratory test.'

More specifically, we define a *Laboratory test reporting item* ("LAR item") as "A laboratory test reporting information that is part of a laboratory test reporting group, that is about a laboratory test, and that mentions which characteristic of a specimen this test was supposed to assess, and a time at which this information was valid". For example, 'WBC 12.1 10⁹/L, 2019/06/15' and 'RBC 5.2 10¹²/L, 2019/06/15' are LAR items.

Note that a *LAR item* does not necessarily report a result of a test: for example, 'serum sodium in progress, 2019/06/05' is a *LAR item*. To account for such items, we define a *Laboratory test status specification* as "A laboratory test reporting information that specifies the status of a group of laboratory tests." (where "a group of laboratory tests" can refer to only one laboratory test) Examples of laboratory test status specifications include 'in progress' (before a test result was obtained), 'resulted' (when a test result was obtained), 'validated' (when the test result was [...]) or 'canceled'.

A reporting information must contain a time specification and an information specifying the specimen characteristic to be of enough relevance. Therefore, we define a *Laboratory test reporting item time specification* ("*LAR item time specification*") as "A laboratory test reporting information that specifies a time at which a laboratory test reporting item was valid." This time specification does not refer to the time when a given lab document was generated, but rather the moment at which information from the laboratory test process was created as it unfolded. Examples of *LAR item time specifications* would be '2019/06/08' or '2018/07/12' mentioned above.

Finally, we define a *Specimen characteristic specification* as "An information content entity that specifies a particular characteristic of a specimen or a class of characteristics of specimens." For example, 'blood group' in a prescription of blood group test or 'serum sodium concentration' in a *LAR item* 'serum sodium concentration 140 mmol/L, validated, 2018/07/28' are instances of *Specimen characteristic specification*.

Once those classes are defined, we propose the following necessary conditions for a *LAR item*: it is about a *Laboratory test*, and it contains ICEs specifying the time and specimen characteristic (and we will see later one additional axiom):

Laboratory test reporting item subClassOf
Laboratory test reporting information
 and **has part** exactly 1 *LAR item time specification*
 and **has part** exactly 1 *Specimen characteristic specification*
 and **is about** some 1 *Laboratory test*

3.3.2. *Laboratory test result item*

As we mentioned above, not all *LAR items* include a laboratory result. To characterize the *LAR items* that do include a result, we define *Laboratory test result item* as "A laboratory test reporting item that includes the result of the laboratory test" and *Laboratory result* as "A clinical finding representing an entity related to a specimen that is the output of a laboratory test":

Laboratory test result item subClassOf *Laboratory test reporting item*
 and **has part** some *Laboratory result*

Laboratory result subClassOf OGMS:*Clinical finding*
 and **is specified output of** some OGMS:*Laboratory test*

For example, in scenario S_1 above, 'serum sodium 138 mmol/L' is an instance of *Laboratory test result item*, and '138 mmol/L' is an instance of *Laboratory result*⁴.

⁴ Note that this does not mean that all ICEs that are composed by the chain of characters "138 mmol/L" are instances of *Laboratory result*: such informational entities can be created outside the context of a laboratory test. However, we endorse here the conception presented in [REF IAO], according to which the identity of an

3.3.3. *Laboratory test reporting group and report document*

As we defined it earlier, a *LAR item* is about only one test. Therefore, a *LAR information* such as 'CBC in progress' is not a *LAR item*, because it reports on several tests, not just one. To provide a more specific class for such instructions than *LAR information*, we define *Laboratory test reporting group* ("*LAR group*") as "A laboratory test reporting information which reports on the test(s) directed by one laboratory test directive item." – that is, it reports on the *Directed laboratory test group* directed by this *LADI*. For example, reporting information such as 'serum sodium: 138 mmol/L', 'CBC in progress' or the whole list of results for a unique CBC ('RBC 5.2 10¹²/L, 2019/06/15'; 'WBC 12.1 10⁹/L, 2019/06/15 [etc.]') are each instances of *LAR group*.

On the other hand, a *LAR item* is always part of a *LAR group* (even if this group is only composed by this *LAR item*):

Laboratory test reporting item subClassOf
 Laboratory test reporting information
 and **part of** some *Laboratory test reporting group*

Since a *LAR group* reports on the *Directed laboratory test group*, it is about it. Also, a *LAR group* has as part the *LADI* that directed the *Directed laboratory test group* that this *LAR group* is about (for example, 'CBC in progress' contains the *LADI* 'CBC'):

Laboratory test reporting group subClassOf
 Laboratory test reporting information
 and **is about** some *Directed laboratory test group*
 and **has part** some *Laboratory test directive item*

Finally, we define a *Laboratory test report document* as 'A document reporting on one or several laboratory tests'. It has as part (at least) one *LAR Group*:

Laboratory test report document subClassOf *IAO:Document*
 and **has part** some *Laboratory test reporting group*

Note that the reciprocal relation does not hold: not all laboratory tests lead to a laboratory result (think about a test that does not conclude to any result because, for example, the sample was spoiled).

ICE depends on the intention of the creator of this ICE. Therefore, the ICE '138 mmol/L' created in scenario *S*₁ is indeed an instance of *Laboratory result*.

SPECIMEN INFORMATION SPECIMEN: 123123456	PATIENT INFORMATION Mr FIENNES DOB: 1969/11/05 AGE: 49 yrs GENDER: M	<div>REPORT STATUS: FINAL</div> ORDERING PHYSICIAN: Dr JONES DATE: 2019/06/05
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Test Name	Result	Flag	Reference Range
CBC (INCLUDES DIFF/PLT)			
WHITE BLOOD CELL COUNT	3.9		3.8-10.8 Thousand/uL
RED BLOOD CELL COUNT	5.24		4.20-5.80 Million/uL
HEMOGLOBIN	16.6		13.2-17.1 g/dL
HEMATOCRIT	49.7		38.5-50.0 %
MCV	94.9		80.0-100.0 fL
MCH	31.8		27.0-33.0 pg
MCHC	33.5		32.0-36.0 g/dL
RDW	12.3		11.0-15.0 %
PLATELET COUNT	176		140-400 Thousand/uL
MPV	11.0		7.5-11.5 fL

Figure 3: Example of a laboratory test report document with a laboratory test reporting group about a CBC⁵

4. Discussion and conclusion

The LABO ontology formalizes laboratory test prescriptions, results and reporting, as well as their parts. Along with PDRO, it is a part of a core ontological model to enable interoperability between various clinical data sources in a LHS context: data at different levels of taxonomical generality or mereological extent can be annotated using the various classes of those two ontologies.

Future work will investigate more in detail the structure of laboratory test results, which can be given in a variety of formats (scalar, ratio, intervals with inclusive or exclusive boundaries, etc.). An important point (already noticed in [REF PDRO], p. 285, fn 6) is that several classes introduced in LABO imply a role character. For example, instances of *Laboratory result*, *Starting condition* or *Specimen* are such because they bear some roles: '140 mmol/L' is a laboratory result because it has been generated by a process that led this ICE being generated – that is, because it stands in some relation with other entities (in particular, processual entities); similarly, 'at t, symptoms of bronchitis are present' would be a *Starting condition* only because it is part of a laboratory test protocol that tests for a possible bronchitis. Therefore, more detailed investigations in how ICEs can bear roles will be required.

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⁵ In addition to the laboratory test report items mentioned above, we usually find information such as the range of normal values for a given test and a flag indicating if a test is abnormal. These items have also been represented in our ontology.

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