Sharable Appropriateness Criteria in GLIF3 Using Standards and the Knowledge-Data Ontology Mapper

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Abstract. Creating computer-interpretable guidelines (CIGs) requires much effort. This effort would be leveraged by sharing CIGs with more than one implementing institution. Sharing necessitates mapping the CIG's data items to institutional EMRs. Sharing can be enhanced by using standard formats and a Global-as-view approach to data integration, where a common data model is used to generate standard views of proprietary EMRs. In this paper we demonstrate how generic guideline expressions could be encoded in the GELLO standard using HL7-RIM-based views. We also explain how the Knowledge-Data Ontology Mapper (KDOM) can be used to simplify GELLO expressions. We are aiming to use this approach for computerizing radiology appropriateness criteria and linking them with EMR data from Stanford Hospital. We discuss our initial study to assess whether such computerization would be possible and beneficial.

Keywords: appropriateness criteria, clinical guidelines, GLIF, GEL, GELLO, EMR, ontology, knowledge sharing, KDOM.

1 Introduction

The American College of Radiology appropriateness criteria (AC) are evidence-based guidelines to assist referring physicians in making appropriate diagnostic imaging or treatment decisions. 147 AC are found in the National Guideline Clearinghouse (ngc.gov). Each set of AC addresses the diagnosis of one clinical problem (e.g., palpable breast mass) and recommends the radiological procedures that are suitable for different patient characteristics (variants). Each AC set contains 1-20 variants. For example, for diagnosing palpable breast mass, one variant is woman under 30 years of age who have palpable breast masses. For this population X-ray diagnostic mammography bilateral is recommended with a rating of 9 (which is the maximum rate) while two other radiological procedures are recommended with a lower rating of 8 (see Table 1) and Magnetic Resonance Imaging (MRI) of the breast is not indicated (has a rating of 2).

By employing AC, providers enhance quality of care by choosing the most appropriate procedures. However, as the AC are not in electronic form, it is difficult to ensure they are widely used in practice. Our aim is to encode AC and interpret them against patient data from electronic medical records (EMRs) in order to provide decision support on appropriate imaging or treatments.

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Table 1. Appropriateness criteria for palpable breast mass for the variant of women under 30

Radiological procedure	Rating
X-ray diagnostic mammography bilateral	9
X-Ray supplemental mammographic views	8
Ultrasound breast unilateral	8
MRI breast	2

Encoding and validating clinical knowledge, such as AC, is a labor-intensive task. Therefore, it would be useful to use a representation formalism that would support sharing the encoded knowledge among implementing institutions. If the knowledge contained in the AC (i.e., guideline knowledge) is expressed in a way that does not depend on the schema and terminology used in electronic medical records (EMRs) used in particular institutions, then the same encoding could be reused by different institutions. To enable execution of the generic guideline knowledge, patient data from the different EMR needs to be retrieved and abstracted to the same level of abstraction used in the guideline knowledge.

In this paper we present our approach to defining sharable guideline knowledge and to the simplification of the knowledge that is represented. We demonstrate our approach using GLIF3 [1] as the guideline modeling language used to represent the guideline knowledge. The paper is structured as follows. Section 2 provides related work. In Section 3 we discuss the methods used in this study: (a) the GLIF3 guideline modeling language, with its two possible expression languages: GEL and GELLO, (b) the HL7 Reference Information Model (RIM) [2] that can be used as a data model that bridges the knowledge of the guideline to the patient data schema of the EMR, and (c) Knowledge-Data Ontology Mapper, KDOM [3], which is an ontology and tool for mapping knowledge to data. In Section 4 we present an architecture for sharing guideline knowledge with different EMR systems. In Section 5 we show how KDOM can support simplification of the guideline knowledge representation. We provide the evaluation of our approach in Section 6. Section 7 provides a discussion.

2 Related Work

Representing medical knowledge such that the knowledge can be executed using existing EMR data and at the same time is sharable involves several challenges. First, the guideline modeling language needs to have a patient information model and an expression language that works with it. Guideline modeling languages that support such features include EON and GLIF [4] as well as the more recent SAGE [5] language. The Arden Syntax [6], although developed for modeling single decision rules, could also be used as a language for formulating guidelines [4]. In EON, GLIF, and SAGE, the patient information model is object-oriented and is based on the HL7 Reference Information Model, which is discussed in Section 3.2. In the Arden Syntax, the patient information model is very simple, and includes lists of time stamped data items.

The expression language is a central part of the guideline representation formalism. Such languages are used to formally represent clinical decision criteria that refer to patient data. For radiology AC, they the expression language is the most important feature of a guideline representation language. Expression languages should be expressive enough to represent different types of clinical expressions, including existence expressions (i.e., expressions that indicate existence of a condition, for example diabetes Mellitus), comparison expressions (e.g., systolic_blood_pressure > 120 mmHg), temporal expressions (e.g., latest cough lasting 4 weeks), and logical combinations of other expressions. In addition, expression languages need to be flexible in their use of different data structures, and be extensible such that more operators/functions could be added. Two expression languages have been standardized by HL7 include:

- The Arden Syntax [6], which is supported by commercial execution tools and used in clinical settings [4]. As mentioned above, the Arden Syntax works with a fixed data model which is not object-oriented. This inflexibility was one of the reasons for the development of the GELLO language [7].
- GELLO [8] is an object-oriented expression language that is an HL7 standard that can work with different data structures, is vendor independent and extensible. It is based on the Object Constraint Language (OCL) [9]. GELLO can easily be integrated with any HL7 RIM-based data model.

Fig. 1 shows examples of GEL and GELLO expressions.

```
(a) age < 30 years and gender = "woman" and palpable_breast_mass

(b) (PointInTime.now() self.player.oclAsType(livingSubject).
    birthTime) < ageThreshold and self.participation.act.
    oclAsType(observation).value ->select(code = '246188002' and
    codeSystemName = 'SNOMED-CT')->notEmpty()
   Where ageThreshold is defined as def: ageThreshold :
   PhysicalQuantity = '30 years'
```

Fig. 1. GEL/Arden Syntax and GELLO expressions. (a) The expression in Arden Syntax and in GEL (identical expression) for "woman under thirty with a palpable mass in her right breast"; (b) GELLO expression for "age < 30y".

Another challenge is the ability to share encoded knowledge by different institutions which use different EMRs. To support sharing, clinical criteria need to be specified using non-proprietary EMR codes. Instead, they should refer to standardized clinical terms taken from controlled vocabularies that are later mapped into concrete EMR fields. Much research has been done on facilitating this mapping of abstract guideline terms to concrete terms and EMR codes used in local implementations. Correndo and Terenziani [10] used the HL7 Common Terminology standard services to establish a link between a domain ontology and a database ontology in order to cope with heterogeneous term descriptions. This enabled them to use the GLARE modeling language in a way that is not committed to any specific ontology and database. The group of Shahar [11] developed the Medical Database Adaptor (MEIDA) tool that aids in linking knowledge-based medical decision-support systems to multiple clinical databases, using standard medical schemata and vocabularies. Their mapping tools use three heuristics: choice of a vocabulary to match the type of data item, choice of a key term, and choice of a measurement unit to narrow down the number of terms retrieved by the key term. An additional set of tools automatically maps standard term queries originating from the guideline to queries formulated using the local EMR's schema, terms and units.

Defining mappings between a guideline's patient data items and EMR fields needs to handle different types of discrepancies between the knowledge and data. The discrepancies include (1) mismatch in data model and terminology combinations [3], (2) use of abstractions by guideline authors, including (a) terms that need to be defined in terms of EMR fields (e.g., "breast mass" abstracts from raw data about particular locations of the mass on the right or left breast), (b) temporal abstractions, and (c) terminology abstractions (e.g., palpable breast mass is-a breast mass), and (3) differences in units of measure and time granularity [11]. Knowledge-Data Ontology Mapper (KDOM) [3] addresses the first two of these discrepancies. KDOM uses declarative query mapping supported by a mapping ontology defined in Protégé [12] and an SQL Generator that translates mapping instances into SQL queries used to retrieve the corresponding patient data. KDOM supports the definition of different kinds of abstractions using different types of mapping classes, including temporal mapping (e.g., first visit of a patient during 2004), hierarchical mapping (e.g., palpable breast mass and hard breast mass are kinds of breast masses), logical combination mapping (e.g., age<30 AND palpable breast mass), prior mapping, which allows nesting to support definition of complex mappings, and direct-one-to-one mappings that allow mapping an abstract term directly into an EMR or its view.

A problem that often arises in practical implementations of guidelines is lack of EMR data for clinical terms used in decision criteria. This problem has been observed and addressed in several studies [13, 14]. In some cases it is possible to add the necessary data items to the EMR [13]. Other times it is necessary to redefine the guideline's decision criteria so that they can suit the available local data [14]. In other cases, the abstractions used in the guideline are performed by the clinician, which either include 'holistic' assessments or abstraction rules that cannot be formalized with reasonable effort [13]. For example, rules for determining the aggressiveness of the tumor, or for deciding whether the patient is physically fit for chemotherapy.

3 Methods

In this work we chose to rely on standards. While there is no standard guideline modeling language, GLIF3 is a language that relies on standards, as explained below.

3.1 GLIF3

GLIF3 [1] is a guideline-modeling language that follows the task-network paradigm [15]. Guideline steps represent clinical actions, decisions, and action steps. These steps formally refer to patient data items, clinical concepts, and clinical knowledge. Branch and synchronization steps are used to enable parallel execution. To support sharing of guideline encoding by different institutions, GLIF3 uses standards, including controlled medical vocabularies and patient information model. Patient data items are specified by a *medical concept*, the code for which is taken from any controlled medical vocabulary (e.g., SNOMED-CT) and by a *data structure*, taken from a

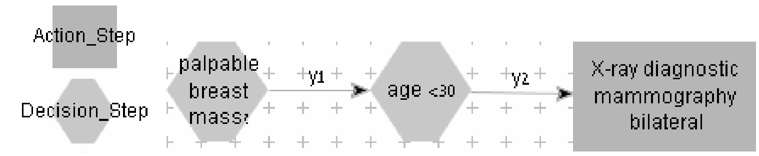


Fig. 2. A GLIF3 guideline corresponding to the appropriateness criteria of Table 1

standard reference information model (RIM), such as the Observation, Medication, and Procedure classes of the Health Level 7 (HL7) RIM [2]. Fig. 2 shows a simple[1] specification of the most recommended radiological procedure for women under 30 with palpable breast masses (Table 1).

GLIF3 has a formal language for expressing decision and eligibility criteria. In GLIF version 3.4, this expression language was the GEL [16] language based on the Arden Syntax [6], which is an HL7 standard. As an example, the GEL/Arden expression for "woman under thirty with a palpable mass in her right breast" is shown in Fig. 1(a). GLIF version 3.5 uses The GELLO expression language. We chose to use GELLO because it is an HL7 standard and can easily be integrated with any HL7 RIM-based data model. Unlike the Arden syntax, GELLO is suited for object-oriented patient information models, which simplifies writing criteria that relate to different properties of a concept. However, GELLO expressions could be quite complex. As an example, the GELLO expression for "age < 30y" is shown in Fig. 1 (b).

GLIF3 is supported by an execution engine [17], which is currently integrated with a GEL interpreter. Version 1 of GELLO is supported by an interpreter developed by the Australian company Medical Objects. That interpreter works with HL7 version 2 and 3 messages. An interpreter for version 2 of GELLO is being developed by InferMed. It will work with the HL7 Care Record model as the RIM-based data model and will align with OCL v2.1, which is about to be released by OMG.

3.2 HL7's Reference Information Model (RIM) and Virtual Medical Record

HL7's Reference Information Model (RIM) [2] is the primary interchange standard for clinical data both in the U.S. and internationally. The RIM, previously known as Unified Service Action Model (USAM) [18], provides a declarative way of specifying medical concepts and data items that are used in a guideline. The subset of the RIM used in GLIF3 contains the Act class and three of its subclasses: Observation, Medication, and Procedure, providing an information model for observations made about the patient, his prescribed medications, and medical procedures he underwent.

HL7 is currently developing a Virtual Medical Record (vMR). A vMR [19] provides a simplified RIM-based information model for patient data, enabling a guideline-based decision-support system to query a patient's state. HL7's vMR is being developed on the basis of the HL7 CareRecord refinement of the HL7 RIM.

[1] A more complex representation can use utility choices to represent all four possible radiological procedures using their ratings as utilities.

3.3 Knowledge-Data Ontology Mapper (KDOM)

We chose to use the KDOM mapping ontology and tool, discussed in Section 2 in order to map abstractions used in the guideline to EMR terms. KDOM is appropriate for this task and was evaluated to support mappings of a wide variety of guidelines; we previously used it to define all mappings necessary for linking the abstract terms defined in a GLIF3-encoded guideline for diabetic foot to patient data found in two different EMR schemas [3]. In addition, we found it sufficient for defining mappings from abstract terms contained in 15 GLIF3 encoded guidelines and one SAGE-encoded guideline into RIM views of these data items [3].

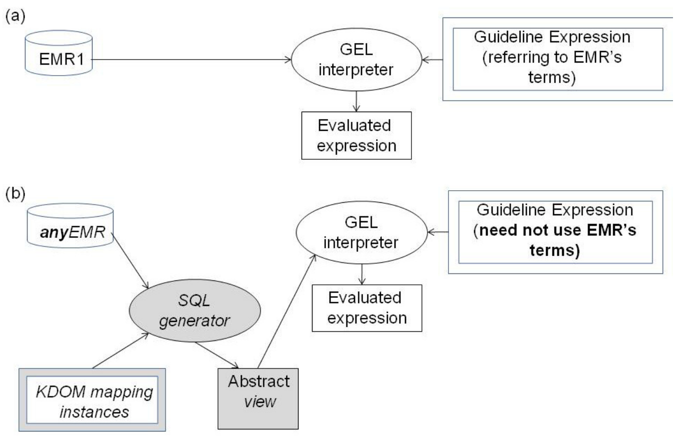
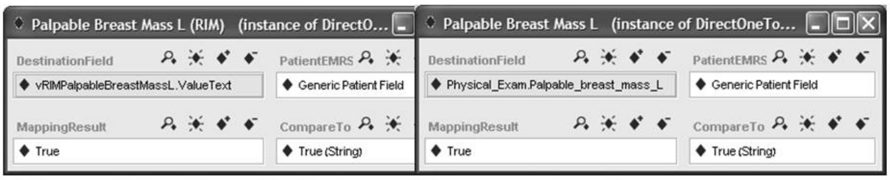


Fig. 3. Architectures for linking guideline knowledge to EMR data. (a) Direct linking of guideline terms to EMR data. When the guideline refers to EMR terms the expression interpreter (GEL interpreter) can evaluate the guideline expression; (b) Mapping guideline knowledge to EMR data using abstract view of the EMR data using KDOM and its SQL generator. The SQL generator translates KDOM mapping instances into SQL queries. Running the queries in the EMR database management system produces abstract views of the EMR data. These views are stated using the terms that the guideline expression uses, which may be different than the EMR's terms. This enables writing the guideline expression using terms that abstract away from particular EMR implementations. The abstract view may (but does not have to) correspond to HL7's RIM model.

4 An Architecture for Sharing Guideline Knowledge with EMR Systems

Fig. 3 (a) shows an architecture for linking guideline knowledge directly to an EMR system. In this architecture, guideline expressions refer directly to EMR terms, making it possible for the expression language interpreter (e.g., GEL interpreter) to evaluate the expression against EMR data. Fig. 3 (b) shows how KDOM and its SQL generator can be used to enable separation between the guideline terms and the EMR terms. This enables encoding the guideline expression using terms that abstract away from particular EMR implementations.

(a)



(b) Physical_Exam | Visit

ID	PatientID	Palpable_breast_mass_R	Palpable_breast_mass_L	Hard_bre	Hard_bre	Time
1	1234	yes	no	no	no	22/04/2009
2	1234	no	yes	no	no	01/04/2009
3	1234	no	no	no	no	25/04/2009
4	41395922	no	no	no	no	01/07/2009
5	67767624	yes	yes	yes	yes	01/07/2009

(c)

```
SELECT "Observation" AS PatientDataItem, Physical_Exam.PatientID AS ID,
"PalpableBreastMass" AS ServiceCdConceptName, "Time_Interval" AS CriticalTimeType,
Physical_Exam.Time AS CriticalTimeDisplayName, "Text" AS ValueType,
Physical_Exam.Palpable_breast_mass_L  AS ValueText
FROM Physical_Exam
WHERE (Physical_Exam.Palpable_breast_mass_L = 'Yes');
```

(d) vRIMPalpableBreastMassL

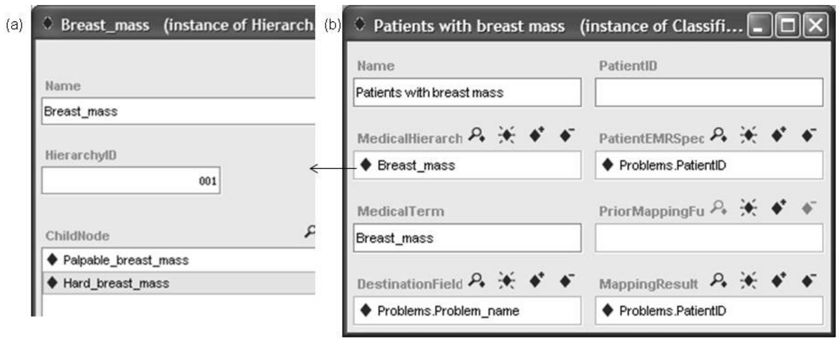
PatientData	ID	ServiceCdConceptName	CriticalTime	CriticalTime	ValueType	ValueText
Observation	1234	PalpableBreastMass	Time_Interval	01/04/2009	Text	yes
Observation	67767624	PalpableBreastMass	Time_Interval	01/07/2009	Text	yes

Fig. 4. Generation of RIM views by KDOM. (a) Direct-one-to-one mapping instances that indicate the tables and field in the RIM view (left) and in the source EMR (right), defined using the Protégé tool [12]. These mapping return a Boolean value if the field corresponding to palpable breast mass (in the RIM view or in the original EMR) holds the value "true" (represented as a String); (b) The EMR table "Physical Exam" and field "Palpable_breast_ mass_L (mass on the left breast) from which the RIM view is generated; (c) the SQL query used to generate the RIM views; (d) the RIM view produced by executing the SQL queries.

Using the architecture shown in Fig. 3 (b), KDOM can be used to implement the Global-as-View approach of data integration, where guideline expressions are mapped to EMR views in a common data model. To implement this approach, KDOM mapping instances of type Direct-one-to-one mappings (Fig. 4a) are used to access views of the EMR as an alternative of accessing a proprietary EMR. Fig. 4 shows how SQL queries (Fig. 4c) could be used to create RIM views (Fig. 4d) of a proprietary EMR (Fig. 4b). These queries are manually generated while the queries for defining abstractions over RIM views of the raw EMR data are automatically generated by the SQL Generator based on mapping instances.

5 Using KDOM to Simplify Guideline Expressions

KDOM's mapping ontology can be used to define abstractions relating to simpler clinical concepts. By defining abstractions using KDOM, the guideline expressions that are defined in a guideline expression language such as GEL and GELLO can be simplified. For example, if the EMR includes two fields for specifying palpable breast mass –one for the right breast and one for the left– then KDOM can be used to generate a RIM view of palpable breast mass that combines the two separate fields using logical OR. In this way, the GELLO expression could be written in a generic way, as shown in Section 2.1, without the need to refer to the two fields separately. Moreover, KDOM can be used to integrate the EMR fields relating to palpable breast mass and to the patient's age into a single field: woman_under_30_with_palpable_ breast_mass, simplifying the guideline expression even further. The GELLO (or GEL) expressions refer to RIM views and not to actual EMR tables, allowing reuse of the mappings defined from guideline abstractions to RIM views. Changing of EMR data structure will not affect the original linkage of the guideline to the RIM view.



(c)
```
SELECT Problems.PatientID
FROM Problems
WHERE Problems.Problem_name IN ('Breast_Mass', 'Palpable_Breast_Mass', 'Hard_Breast_Mass');
```

Fig. 5. Hierarchical mapping of breast mass using KDOM. (a) The hierarchy of breast masses defined in KDOM; (b) a classification hierarchy mapping instance that defines the abstract term corresponding to patients with breast mass. This mapping refers to the destination field Problems.Problem_name in an EMR. Through the MedicalHierarchy slot, this mapping instance defines the "Breast_mass" medical hierarchy (shown in part a) to be the hierarchy that specifies terms to be compared to the destination field. The MedicalTerm slot specifies that the search of the Breast-mass hierarchy should start with the root concept Breast_mass and visit its child nodes recursively. The result returned from the mapping would be the ID of patients with breast mass; (c) the SQL query generated by the SQL Generator using the knowledge defined in parts a-b.

The abstraction mappings supplied by KDOM include logical mappings (as in the example above), hierarchical mappings, and temporal mappings, which can be nested using the prior mapping class. All of these mapping classes could be used to simplify guideline expressions. For example, we can write a guideline expression that refers to breast masses and define in KDOM a hierarchical mapping that defines palpable breast mass and hard breast mass to be subclasses of breast mass. The SQL Generator would then be able to generate an SQL query that queries all these types of breast masses, as shown in Fig. 5.

Fig. 6 shows an example of a temporal abstraction mapping instance defined using KDOM and the SQL query generated by the SQL Generator, based on the mapping instance. While GEL includes temporal operators such as first and last, GEL's mapping interpreter does not support these operators. Therefore, KDOM can be used to define temporal abstractions, simplifying GEL expressions. For example, Fig. 5 shows a mapping instance defining the first visit during a certain year (2004). The results returned by this query could be bound to a variable called "first_visit_date" and a GEL criterion such as "first_visit_date > 2004-09-01" could thus be interpreted by the GEL interpreter. GELLO expression could also be simplified by referring to temporal abstractions defined in KDOM.


```
SELECT Min(Visit.Time) AS TemporalResult
FROM Patient, Visit
WHERE Patient.PatientID=304553341 AND Visit.Time>='01/01/2004' And Visit.Time
<='31/12/2004';
```

Fig. 6. TemporalAbstractionMapping instance defining the first visit during a certain year (2004) for a patient. Using this information the SQL query generator generated the SQL query.

6 Evaluation

We examined 44 of the 147 ACs (30%) to see whether they could be potentially represented in GELLO and whether data existed for these AC in the medical records used at Stanford Hospital. We first categorized the 44 AC according to the complexity of the criteria. We found that of the 44 AC, 9 were simple existence expressions (e.g., palpabale breast mass), 3 were expressions involving temporal operators (e.g., second trimester bleeding, recurrent UTI, chronic renal failure), 6 involved comparison (e.g., age < 65y), and 34 were complex expressions involving any of the other expression types. Note that some criteria that were complex also contained temporal or comparison criteria hence the number of criteria falling into the different categories do not add up to the total number of criteria in each category. The interesting result was that GELLO supported the expression of all of these criteria types.

However, the hard part was availability of data that the AC's noun phrases described. We examined the availability of data at Stanford Hospital. We differentiated between data that was found in structured form (e.g., pulsatile abdominal mass) and data that could be retrieved from radiology reports using natural language processing (NLP) techniques. For example, radiology reports of wrist exams include phrases that correspond directly to terms found in AC (e.g., distal radius fracture, scaphoid fracture, trauma) and phrases that would require inference (e.g., "fell off bike" or "motorcycle accident" that suggests trauma). As shown in Table 2, of the 44 AC, structured data was available for 5 criteria and data could be retrieved by NLP for 6 criteria, totaling in data availability for 25% of the AC. Data was not available for 33 of the 44 AC, for the following reasons. 14 noun phrases were too vague (see Table 2 for examples) and therefore naturally data for them did not exist in the medical records in structured form nor was there enough direction to suggest how NLP could be used to extract them from radiology reports. 4 noun phrases involved negative results that were not structured and could not be inferred with certainty from radiology reports. Finally, 20 AC contained phrases that were too detailed and often were not recorded in radiology reports or were recorded in such a varied way such that a fixed set of terms could not be defined to identify terms using NLP.

Table 2. Data availability and unavailability for ACs with different noun phrase types

Noun type	#AC	Example
Available data		
Structured	5 (11%)	Pulsative abdominal mass
Via NLP	6 (14%)	Wrist trauma
Total	11 (25%)	
Unavailable data		
Too detailed	20 (45%)	Suspect referred pain but wish to exclude hip
Vague	14 (32%)	Neurologic signs or symptoms present
Negative results	4 (9%)	Internal cervical os not visible by ultrasound
Total	33 (75%)	

7 Discussion

In this paper we demonstrated how the Global-as-View approach of data integration could be used to support guideline models that are encoded using abstract terms, which are mapped into a common global view of data arriving from various EMR formats. We further showed how KDOM could simplify authoring guideline expressions by defining clinical abstractions. The mapping of clinical abstractions to RIM views using KDOM could be reused when the same abstractions or data items are used in different criteria. When examining the ACs, we saw that many of the variants in a AC set refer to the same abstractions. Such reuse makes the work required to represent mapping instances more beneficial. While we demonstrated our approach using the GLIF3 language and its expression languages GEL and GELLO, this approach could potentially be used with other formalisms as well.

Our goal is to represent and share radiology appropriateness criteria. As we are interested in sharing knowledge, we prefer using a standard guideline expression language. Currently, the only standard guideline expression language that could be integrated with a standard object-oriented patient information model is GELLO, developed by HL7. Therefore, our intent is to use GELLO as the language for specifying appropriateness criteria and HL7's vMR as the common RIM model (data model) against which the GELLO criteria would be evaluated.

The characterization of criteria types as simple, complex, temporal, or comparison expressions makes it easier to find reusable patterns of representation in GELLO and in KDOM. Thus, after representing one type of criterion in GELLO or KDOM, similar criteria are represented similarly. The temporal operators recurrent and chronic could be expressed directly in GELLO, once their meaning is clarified (e.g., chronic meaning lasting over 3 weeks). Alternatively, KDOM could be extended to support these operators and simplify the encoding of GELLO criteria.

Lessons learned

We examined in detail 30% of the 147 ACs (44 AC) and saw that they could be potentially represented in GELLO; all the types of expressions, whether complex or simple, involving temporal operators or comparison operators could be represented. However, while technically it is possible to computerize radiology AC using the architecture and tools explained in this paper, what is needed is available EMR data. Unfortunately, data was available in structured form only for 11% of the criteria examined. Data for an additional 14% of the AC could potentially be retrieved from radiology reports using NLP techniques. Considering that a large effort is required to manually encode AC and map RIM views (corresponding to the vMR model) to EMR data and even more effort is required to integrate natural language processing, we are now assessing whether the effort required for AC automation, which could be done for just a small subset of the AC would be productive.

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