Decision Support
with SNOMED CT

Publication date: 2021-03-11

Web version link: http://snomed.org/cds

SNOMED CT document library: http://snomed.org/doc

Table of Contents

The Decision Support with SNOMED CT guide reviews the approaches, tools and techniques used to implement clinical decision support with SNOMED CT, and shares developing practice in this area. It is anticipated that this guide will benefit members, vendors and users of SNOMED CT by promoting a greater awareness of how SNOMED CT has been and can be used to enhance clinical decision support implementations.

Web browsable version: http://snomed.org/cds

SNOMED CT Document Library: http://snomed.org/doc

1. Introduction

Background

SNOMED CT is a standardized and multilingual clinical terminology used by clinicians and other health care providers to record and share health information. As the most comprehensive terminology in the world, SNOMED CT contains over 300,000 active clinical concepts, each representing a unique clinical meaning. These concepts are organized into hierarchies such as 404684003 |Clinical finding| , 71388002 |Procedure| , 123037004 |Body structure| and 373873005 |Pharmaceutical / biologic product|.

SNOMED CT is increasingly being used in clinical decision support (CDS) systems to support healthcare providers in making well informed clinical decisions. SNOMED CT's polyhierarchy, defining relationships and concept model are just some of the terminology's features that help to link patient records to the appropriate guidance, clinical knowledge and decision rules.

Purpose

The guide Data Analytics with SNOMED CT explained how SNOMED CT may be used to support data analytics, and how integrating clinical records with decision support tools can improve the care provided to individual patients by guiding safe, appropriate and effective patient care.

The purpose of this guide is to review the approaches, tools and techniques used to implement clinical decision support with SNOMED CT, and to share developing practice in this area. It is anticipated that this guide will benefit Members, vendors and users of SNOMED CT by promoting a greater awareness of how SNOMED CT has been and can be used to enhance clinical decision support implementations.

Scope

This guide introduces the key components of clinical decision support systems, explores ways in which SNOMED CT can be used to enhance the capabilities within each of these components, and presents some case studies in which SNOMED CT has been used to support clinical decision support. The guide focuses on CDS systems that use a combination of SNOMED CT encoded knowledge artifacts (e.g. CDS rules and guidelines) and SNOMED CT encoded electronic health records. However, using SNOMED CT to enhance non-SNOMED CT enabled CDS and EHR systems is also considered.

Audience

The target audience of this guide includes:

- Members who wish to learn about using SNOMED CT for clinical decision support
- Clinicians, informatics specialists and technical staff involved in the planning, management, design or implementation of clinical record applications or clinical decision support systems
- Software vendors, data analysts, epidemiologists and others designing SNOMED CT based solutions

This guide assumes a basic level of understanding of SNOMED CT. For background information it is recommended that the reader refers to the SNOMED CT Starter Guide.

Guide Overview

The guide presents an introduction to clinical decision support using SNOMED CT and is structured as follows:

- 1. Introduction: Chapter 1 provides an introduction to the guide, and defines clinical decision support (CDS) and clinical decision support systems (CDSS). It then presents an overview of CDS (including its scope, history and the 'five rights'), it explores the functional and clinical areas in which CDS is used, the features of SNOMED CT that support CDS, and a table of abbreviations used in this guide.
- 2. Logical Architecture: Chapter 2 presents an overview of the logical architecture of an electronic health records system that uses CDS, and the internal components of a CDSS system.

- **3. Knowledge Base**: Chapter 3 describes the knowledge base of a CDSS, in which the knowledge artifacts that drive the CDS are stored, and how SNOMED CT may be used within these artifacts.
- **4. Inference Engine**: Chapter 4 explains how the inference engine of a CDSS can use SNOMED CT to execute the knowledge artifacts in the knowledge base.
- **5. Communications**: Chapter 5 explores some of the considerations around implementing the communication mechanisms in a CDSS.

1.1. Overview

What is Clinical Decision Support?

Clinical Decision Support (CDS) is a service that enables healthcare providers to make well-informed decisions by supplying guidance, knowledge, and patient-specific information at relevant points in the patient journey, such as diagnosis, treatment, and follow-up. CDS uses a range of mechanisms to assist users in this process. Examples of these mechanisms include automated alerts or reminders, clinical guidelines, contextually relevant reference information, conditional order sets, diagnostic support, and patient-focused reports, forms, or templates. The beneficiaries of the information derived from CDS may include patients, clinicians, and others involved in the delivery of health care.

It is important to distinguish the general practice of clinical decision support from the application of tools designed to enhance decision support practices. One is performed by humans who make decisions based on knowledge they possess and information they consume. The other is computed by systems and engines using rules and predefined conditions. Although both are important, the technical components of CDS are designed to assist rather than replace the subtle judgment and guidance provided by the clinician.

Applications and tools that provide clinical decision support are known as as Clinical Decision Support Systems[1] (CDSS). A clinical decision support system is defined as a computer system or software application designed to assist clinicians, caregivers, or patients in healthcare and/or treatment decisions.

Notes

- Typically a clinical decision support system responds to triggers, such as specific signs or symptoms, diagnoses, laboratory test results, medication selections, or complex combinations of such triggers. The system then provides information or recommendations relevant to the specific patient.

History

It has been suggested that the origins of clinical decision support (CDS) can be traced back to the 1950s and 1960s. In an early example from 1961, Dr. Homer Warner, a cardiologist from the University of Utah developed a mathematical model which was used to diagnose heart disease.[2] Since then, there have been countless developments and advancements in the area of decision support. Many theories have been proposed as to how CDS should be approached and applied in clinical practice.

The Five Rights

When implemented properly, CDS has the potential to enhance patient care, reduce errors and duplication of effort, and introduce efficiencies to the clinical workflow. Conversely, CDS tools can also be distracting and disruptive, even producing unwanted consequences. It is therefore important to consider the lessons learned from previous implementations of CDS and conduct thorough requirements analysis prior to designing or procuring a CDSS. One of the best practice frameworks that has been developed to guide those considering a CDS implementation is the "CDS Five Rights".[3] "The Five Rights" suggests that to realize the full potential of CDS, solutions should:

- Supply the *right information* (evidence-based guidance, address the clinical need)

- To the *right people* (entire care team, including the patient)

- Using the *right channels* (e.g., EHR, mobile devices, patient portals)

- In the *right intervention formats* (e.g., order sets, flow-sheets, dashboards, patient lists)

- At the *right points in the workflow* (for decision making or action)

Example

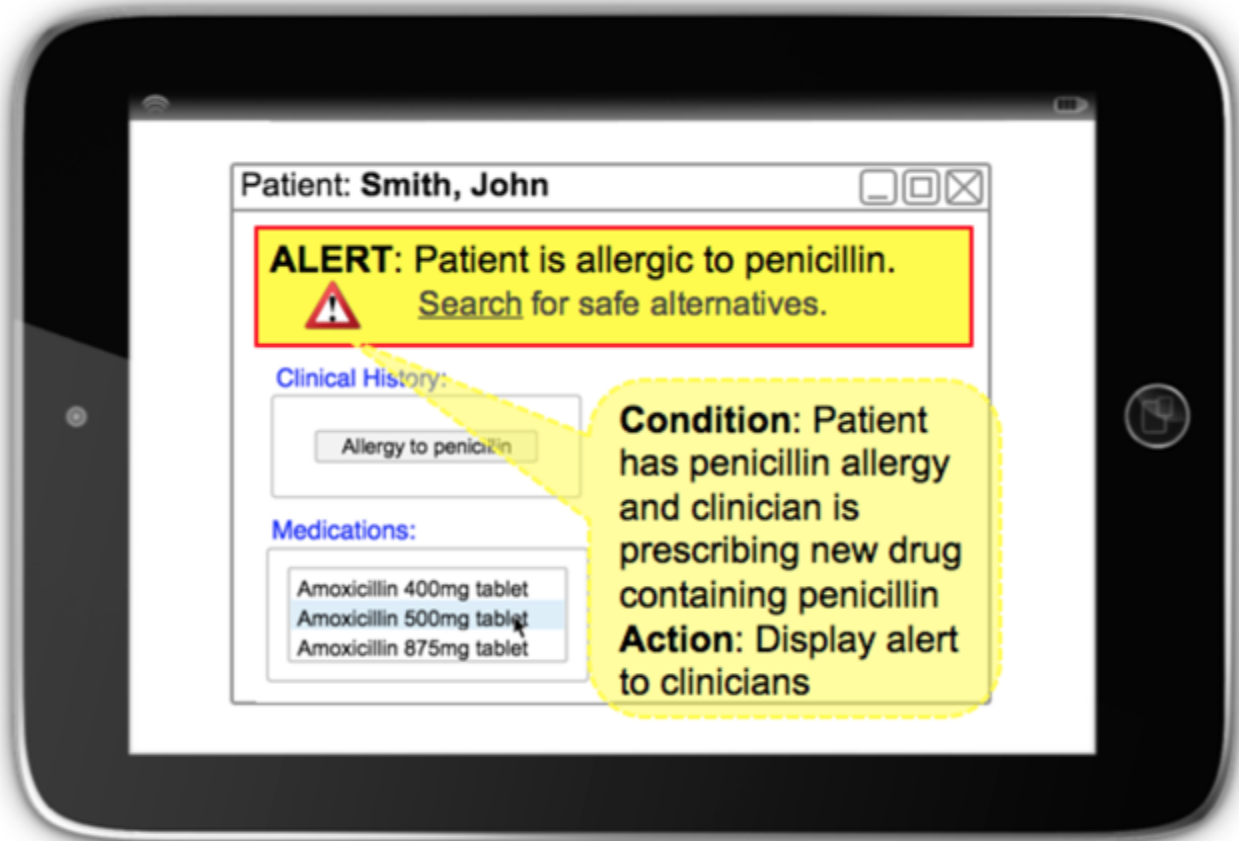A typical application of CDS is shown in the diagram below:

Figure 1.1-1: Example of simple application of CDS

The clinical setting in which this hypothetical tool has been applied is the prescribing of a medication. In this example, the patient has previously had an 91936005 |Allergy to penicillin| recorded. When prescribing a new drug, such as 27658006 |Amoxicillin|, an alert is displayed to remind the clinician of the previously diagnosed allergy. The application may also provide a mechanism to search for alternative medications. Note that the mechanics of this workflow uses a predefined rule which specifies a condition to be evaluated and an action to be taken if the condition evaluates to true.

---

[1] Definition based on content from U.S. Department of Health and Human Services, Agency for Healthcare Research and Quality

[2] Timeline of the Development of Clinical Decision Support (OHSU)

[3] Osheroff, Teich, Levick et al., 2012. Improving outcomes with CDS: an implementer's guide, Second Edition

1.2. Functional Areas

This section addresses the functional scope of clinical decision support. CDS may be represented in a variety of formats or tools which depend on the clinical situation or environment. These tools are often referred to as CDS formats, types, or interventions and can be deployed to a wide variety of systems and platforms, such as mobile devices.

Within these functional areas, CDS can be further subdivided into tools which are prompted by the tasks a clinician performs such as patient charting or diagnosis, and functions that are triggered by external events such as the expiration of a period of time.[1] Some of the more common CDS functions are described briefly in the table below. Use of these functions may be appropriate in a variety of clinical domains or use cases, some of which are discussed in the Clinical Areas section.

Table 1.2-1: CDS Functions

CDS Function	Description
Alerts or Reminders	One of the more common types of decision support is computerized alerts (or reminders). These are triggered by rules and designed to interrupt clinicians or patients at the appropriate time. These alerts are also referred to as "best practice advisories" and can be implemented as pop-ups on a users screen or in monitoring tools such as a dashboard. Alerts can also be used to trigger other communication mechanisms such as paging or faxing. Examples of alerts include drug to drug interactions, or drug allergy warnings triggered when medications are prescribed.
Clinical Guidelines and Reference Information	These CDS functions are often implemented as links to external references which are published by third party, knowledge experts. Guidelines may be represented in a standardized format to facilitate interoperability - for example, the HL7 Infobutton[2] . References can be based on relevant, context-dependent data captured in a patient health record or another electronic artifact such as an order or clinical document.
Diagnostic Support Tools	These tools use a combination of patient data, context-based suggestions and clinical knowledge links to aid the clinician in making a diagnosis. An example would be a tool that prompts a physician for additional findings and suggests additional tests or procedures to help differentiate the diagnosis.
Automatically Triggered Smart Forms	These documentation tools, which include reports and summaries, are aimed at high quality records, the reduction of errors, and more complete information. These tools can be triggered when a specific patient condition is detected or when a finding is deemed reportable to a jurisdictional health body. These can be represented as focused patient data reports or summaries and are often utilized at the point of care (POC) in real time.
Conditional Order Sets and Pathway Support	These are typically designed for complex ordering scenarios. They may be comprised of a proposed set of orders or a treatment regimen which is based on an explicit situation or medical condition. These interventions can ensure compliance with established protocols. They can also be utilized to guide clinicians though complex care pathways.

[1] http://www.himss.org/library/clinical-decision-support/issues
[2] http://www.hl7.org/implement/standards/product_brief.cfm?product_id=208

1.3. Clinical Areas

The focus of this section is the clinical application of CDS tools or how the functional components described earlier can be used in practice. Stakeholders from various clinical domains interact with clinical systems, such as EHRs with CDSS and CPOE (computerized physician order entry). The table below lists some of the clinical areas in which SNOMED CT enabled CDSSs can assist clinicians in making well informed decisions.

Table 1.3-1: Clinical areas

Clinical Area	Description
Medication Management	A clinician uses an EHR with CDS to prescribe 375374009 |Warfarin sodium 4mg tablet|. The CDSS queries the EHR and discovers that the patient is 77386006 |Pregnant|. The CDSS determines that the proposed drug has 372756006 |Warfarin| as an ingredient . As warfarin in contraindicated during pregnancy, the system triggers an alert to be displayed to the clinician. Relevant clinical guidelines are also displayed to the user. These guidelines suggest a safe alternate, such as 714788005 |Dabigatran|, which the clinician then safely prescribes to the patient.
Diagnosis (e.g. Diabetes)[1]	A clinician uses an EHR with CDS in a case analysis scenario to aid in diagnosis. The clinician records the patient's age and gender, then prepares to enter specific clinical findings, history, symptoms, etc. As the physician records symptoms of 55350005 |Hunger|, 84229001 |Fatigue|, and 87715008 |Dry mouth|, a ranked list of common diseases, associated with these clinical findings, is dynamically presented to the clinician. At the top of this list is 73211009 |Diabetes mellitus|. A scale is used to indicate the level of support for each disease. The CDSS then prompts the clinician for additional findings to help differentiate between diseases. Once a confirmed diagnosis is made, the differential diagnoses can be marked as 2667000 |Absent|, 52101004 |Present|, or 261665006 |Unknown|. An additional finding of 17173007 |Always thirsty| is recorded and the level of support for each disease in the list is adjusted accordingly. Support for 73211009 |Diabetes mellitus| has now increased from minimal evidence to sufficient evidence. The clinician then selects 44054006 |Type 2 diabetes mellitus| which opens an evidence screen displaying the recorded findings which either strongly support, support, or do not support the chosen disease. The clinician is then presented with a link that displays all the PubMed articles associated with 44054006 |Type 2 diabetes mellitus|.
Laboratory (e.g. Critical Results)[2]	A patient presented at Emergency complaining of 29857009 |Chest pain| and was subsequently admitted to the hospital. The attending physician ordered a series of lab tests including a 271236005 |Serum potassium measurement|. Laboratory tests are completed and published to the laboratory information system (LIS). The CDSS then queries the LIS and learns that the 365760004 |Potassium level| is 166690008 |Low serum potassium level| and considered critical. The CDSS then queries the EHR to confirm the patient has been prescribed 350608001 |Oral form digoxin|, which has 387461009 |Digoxin| as an active ingredient. A knowledge base rule has been defined which stipulates, if the drug prescribed contains 387461009 |Digoxin| and the laboratory test indicates a 166690008 |Low serum potassium level|, then inform the user. An alert, in the form of an urgent pager message, is generated and sent to the attending physician.
Radiology (e.g. Contraindication)	An ordering physician has requested an upper 75679007 |Gastrointestinal tract x-ray|, which uses 25419009 |Barium sulfate| materials. The patient presents at the imaging clinic on the day of their exam. During study protocoling, the imaging department uses the CDSS to query the patient record and determine the patient has a 161524000 |History of hay fever|. An alert is triggered to advise the imaging technician about the risk of an allergic reaction. The imaging department, in consultation with the GI radiologist, calls the ordering doctor to discuss the associated risks. Additional guidelines related to preparing for reactions and symptom management (247472004 |Hives|, 418290006 |Itching|, 65124004 |Swelling|, etc.) are provided via the CDSS. An additional medication is administered prior to the contrast material to reduce the risk of an allergic reaction. The imaging department proceeds with the planned procedure.
Radiology (e.g. Appropriate Imaging)	A clinician records notes into the appropriate fields of an EHR. For example, Clinical notes: "Pt is 75 yo. LBP (lower back pain) for the past 2 weeks. On exam normal SLR (straight leg raise)…" Using NLP, these notes are encoded as part of the record storage process. (For example, as 279039007 |Low back pain| and 164569007 |On examination - straight leg raising normal - left right|.) The clinician orders a series of imaging tests. The CDSS, based on specific quality metrics (e.g., appropriate use criteria or AUC) , evaluates whether or not imaging guidelines are being followed by analyzing the patient's health record together with the proposed tests. If the guidelines were not followed, the CDSS will display an alert informing the clinician that they may want to consider alternative imaging or additional tests. For example, an alert may indicate: "The patient has 279039007 |Low back pain| and 309537005 |Numbness of lower limb|. A 394451000119106 |MRI of lumbar spine without contrast| for this case has an appropriateness rating of 8 (scale of 10) and is recommended."

Clinical Area	Description
Emergency Department (e.g. Order sets)	A patient has presented at the Emergency Room (ER) complaining of 267036007 |Shortness of breath|. The attending physician records the appropriate clinical finding codes in the EHR. She then prepares a condition-specific order set in a C omputerized Physician Order Entry (CPOE) system. The selection of the order set triggers the presentation of new clinical guidelines based on an analysis of the patient record with the proposed treatment. The physician then choses alternative treatment. Suggested dosage guidance is provided by relevant contextual links within the order set.
Infectious Disease Reporting	A primary care physician logs on to their EHR with CDS and opens a patient chart to record a condition deemed communicable, such as 36989005 |Mumps|or 14189004 |Measles|. The CDSS then triggers an alert to advise the provider that this condition is considered reportable to the jurisdictional public health office. The CDSS then provides a pre-populated smart form which facilitates quick, consistent, and accurate reporting of the condition to the local officer of medical health. The smart form is completed and submitted to the jurisdictional health office. The clinical findings in the report are terminology-encoded which promotes interoperability and facilitates population based health reporting.
Clinical Treatment Audit	A department head uses an EHR with CDS to conduct a treatment analysis. She uses the system to generate a list of all inpatients with a confirmed diagnosis of 128053003 |Deep venous thrombosis|. She then uses the system to determine which of these patients have received 103746007 |Heparin therapy| for at least 72 hours. The patients which have not met this criteria are flagged for appropriate treatment.
Acute Asthma Management	Staff in an Emergency Department (ED) use their EHR with CDS and clinical management pathways to provide a standardized evidence-based approach to patient assessment of 304527002 |Acute asthma|in adults [3] . The guidelines help document indications and contraindications to determine eligibility. A triage nurse queries the EHR and learns that the patient is over 16 years of age, has a 304527002 |Acute asthma|, and one or more episode of 56018004 |Wheezing|which necessitated 1366004 |Breathing treatment|. The CDSS then triggers an alert to follow the pathway's medical directives, which are carried out by a Respiratory Therapist (RT). The directives, in this case of 370218001 |Mild asthma|, include 47101004 |Heart rate monitoring|, establishing various baseline 251880004 |Respiratory measurements|, and administration of a 372580007 |Bronchodilator|and 374072009 |Prednisone 50mg tablet|. The RT then notifies the attending physician who fills out and signs discharge instructions which a nurse then reviews with the patient. The desired clinical outcomes of this pathway include improved adherence to evidence-based management and improved patient outcomes such as reduced number of hospitalizations and lower ED return rates.
Nursing Interventions	Research has provided evidence to show that patients receiving 40617009 |Mechanical ventilation|are at high risk for |Pneumonia| : |due to| = |Aspiration| . [4] Published guidelines recommend 423171007 |Elevation of head of bed|from 30° to 45°, if not contraindicated, to reduce risk of 233604007 |Pneumonia|. A nursing supervisor uses a dashboard-like tool in an ICU to monitor patients in her ward. Patients who meet the criteria for risk of 422588002 |Aspiration pneumonia|are automatically flagged in the system using CDS logic so that the appropriate action may be initiated by nursing staff in the ward. Once the angle of the patient's bed is adjusted, the system is dynamically updated and the flag is removed.

---

[1] Based on workflow described in DXPlain product literature.
[2] Example uses material from Brigham and Women's Hospital, and was cited in the BC Medical Journal.
[3] Uses material from Educational and decision-support tools for asthma-management guideline implementation and Adult Emergency Department Asthma Care Pathway.
[4] http://ccn.aacnjournals.org/content/32/3/71.full

1.4. SNOMED CT Features

Overview

This section contains a brief summary of key SNOMED CT features and explains how they may be useful in CDSSs.

Concepts

SNOMED CT concepts are used to represent clinical meanings. Every concept in SNOMED CT is uniquely identified by a distinct SNOMED CT Concept Identifier. For example, 195967001 |Asthma|is the concept identifier for the concept 195967001 |Asthma|.

SNOMED CT concepts play an important role in CDS by enabling actions to be triggered based on the meaning of data recorded in the patient records.

Descriptions

SNOMED CT descriptions provide the human-readable terms associated with SNOMED CT concepts. A concept may have one or more descriptions, which act as synonyms for the same clinical meaning. This is also how SNOMED CT supports different dialects and languages.

SNOMED CT descriptions allow common CDS rules to be consistently applied across patient records recorded using different synonyms, dialects and languages.

Relationships

SNOMED CT relationships link concepts together to formally define the meaning of each concept. For example, one type of relationship is the 116680003 |is a|relationship which relates a concept to a parent or supertype. These 116680003 |is a|relationships define the subtype hierarchy of SNOMED CT concepts.

For example, the concepts 53084003 |Bacterial pneumonia|and 75570004 |Viral pneumonia|both have an 116680003 |is a|relationship to 312342009 |Infective pneumonia|which has an 116680003 |is a|relationship to the more general concept 233604007 |Pneumonia|. Subtype relationships can be used by CDS rules to refer to codes in an EHR that are any specific type of a relevant clinical concept.

Additional attribute relationships help to define the meaning of a concept. For example, the concept 75570004 |Viral pneumonia|has a 246075003 |Causative agent|relationship to the concept 49872002 |Virus|and a 363698007 |Finding site|relationship to the concept 39607008 |Lung structure|.

Attribute relationships can be used by CDS rules to refer to codes recorded in an EHR that have a specific meaningful relationship with a concept of interest.

Concept Model

The SNOMED CT concept model is a set of rules that govern the ways in which SNOMED CT concepts are permitted to be modeled using relationships to other concepts. It defines the types of relationships that may be used on each type of concepts, and the permitted values for each relationship type. The Machine Readable Concept Model (MRCM)represents the rules in the SNOMED CT concept model in a form that can be read by a computer and applied to test that concept definitions and expressions comply with these rules.

The SNOMED CT concept model plays an important role in CDS by providing the rules by which the clinical meaning of SNOMED CT encoded health records can be queried. The MRCM makes it possible to process these rules in a machine-processable way.

Expressions

SNOMED CT provides a mechanism which enables clinical phrases to be represented by a computable expression, when a single concept does not capture the necessary level of detail. For example, the following expression represents a right hip:

182201002 |Hip joint| :
   272741003 |Laterality| = 24028007 |Right|

SNOMED CT expressions enable additional clinical meanings to be captured in a health record, without requiring the terminology to include countless combinations and permutations of precoordinated concepts.

SNOMED CT expressions facilitate CDS over an expanded set of clinical meanings that extends beyond individual concepts. For more information about expressions, please refer to the Compositional Grammar - Specification and Guide.

Reference Sets

SNOMED CT reference sets are a flexible and standardized approach used to support a variety of requirements for the customization and enhancement of SNOMED CT. These include the representation of subsets, language preferences for use of particular terms, mapping from or to other code systems, and ordered lists.

Reference sets may be used in the following aspects of CDS:

- Representing subsets of SNOMED CT concepts that may trigger a CDS action
- Representing non-standard aggregations of concepts for specific CDS use cases
- Defining language or dialect specific sets of descriptions over which term searches can be performed

For more information about reference sets, please refer to the Practical Guide to Reference Sets.

Description Logic Features

Description Logic (DL) is a family of formal knowledge representation languages and used as the formal foundation of meaning in SNOMED CT. The way that concepts have been modeled in SNOMED CT permits them to be represented using Description Logic. DL helps computers to make useful inferences about concepts, and to classify SNOMED CT using a DL reasoner. Description Logic also helps by testing expressions for subsumption and equivalence.

The logical inferences supported by DL can be useful when executing CDS rules. For example, when a CDS rule requires an action to be performed when the patient has any type of 195967001 |Asthma|, a DL reasoner may be used to determine that 304527002 |Acute asthma| and 427603009 |Intermittent asthma| are both types of 195967001 |Asthma| and should therefore both trigger the action to be performed.

1.5. Abbreviations

The following table contains the definition of abbreviations used in this document. Please refer to the SNOMED Glossary for additional definitions.

Table 1.5-1: Abbreviations

Abbreviation	Full term linked to the SNOMED Glossary definition

CDS	Clinical decision support, which is defined as a service that assists clinicians, caregivers, or patients in healthcare and/or treatment decisions.
	Notes
	• A clinical decision support system is a computer system or software application designed to assist clinicians, caregivers, or patients in healthcare and/or treatment decisions.
CDSS	Clinical decision support system, which is defined as a computer system or software application designed to assist clinicians, caregivers, or patients in healthcare and/or treatment decisions.
	Notes
	• Typically a clinical decision support system responds to triggers, such as specific signs or symptoms, diagnoses, laboratory test results, medication selections, or complex combinations of such triggers. The system then provides information or recommendations relevant to the specific patient.
EHR	Electronic health record, which is defined as a systematic collection of health information about individual patients or populations that is stored in digital form.
KB	Knowledge base, which is defined as the underlying set of facts, assumptions, and rules which a computer system has available to answer a question or solve a problem.
UI	User interface, which is defined as the way in which a software application presents itself to a user.
NLP	Natural language processing, which is defined as a service in which a computer system converts human-readable text and/or spoken language to formal representations of information.
POC	Point of care, which is defined as the time and location at which healthcare professionals deliver healthcare products and services to patients.

2. Logical Architecture

This section provides an overview of the logical architecture of an electronic health record (EHR) which uses CDS.

In particular, it focuses on the logical architecture of knowledge-based CDSSs,[i] which use pre-loaded CDS artifacts (such as rules and guidelines) that closely match a human's natural reasoning process. Non-knowledge-based CDSSs, which use artificial intelligence (AI) or machine learning to acquire knowledge over time, are outside the scope of this guide.

The logical architecture of knowledge-based CDSSs are explored in the following subsections:

---

[i] https://en.wikipedia.org/wiki/Clinical_decision_support_system#Knowledge-based_CDSS

2.1. EHR System Architecture

To understand how clinical decision support (CDS) works, it is important to understand how CDS fits within the logical architecture of an EHR system. This section describes the major architectural components of an EHR system, and the interactions between these components.

Major Components

Table 2.1-1: Descriptions of the major architectural components of an EHR system

EHR System Component		Description
	User Interface	The user interface (UI) is a fundamental component of almost any clinical application, and is used within an EHR to both enter and display patient health records. The UI also has two main CDS functions. Firstly, the UI is used to provide inputs to the CDSS, such as recording a proposed medication or an observed finding. The second function of the UI is to display alerts, advisories and clinical guidelines to the user in an appropriate format, on behalf of the CDSS.
	Record Services	Record services are a set of services for managing patient health records. Record services provide functions like entering data into health records, searching for and retrieving health records, querying or extracting data from health records, and communicating or exchanging health records with other systems or applications. Record services interact with other components in this model such as the CDSS and the UI.

	Terminology Services	Terminology services are those services that directly manage the terminology resources. They include functions like querying concepts, relationships and reference sets, and installing or updating SNOMED CT from release files. Terminology services interact with the CDSS component in this model.
	Clinical Decision Support System	The primary role of the CDSS is to execute the decision support logic. The CDSS does this using a number of subcomponents and subprocesses, which will be described in the next section - Logical Architecture of a CDSS . The CDSS interacts with each of the other major components in the EHR.

Interactions

The major architectural components of an EHR system that incorporates CDS interact with each other in a variety of ways to support the overall functioning of the EHR. The diagram below uses orange arrows to illustrate the primary interactions between these EHR components.
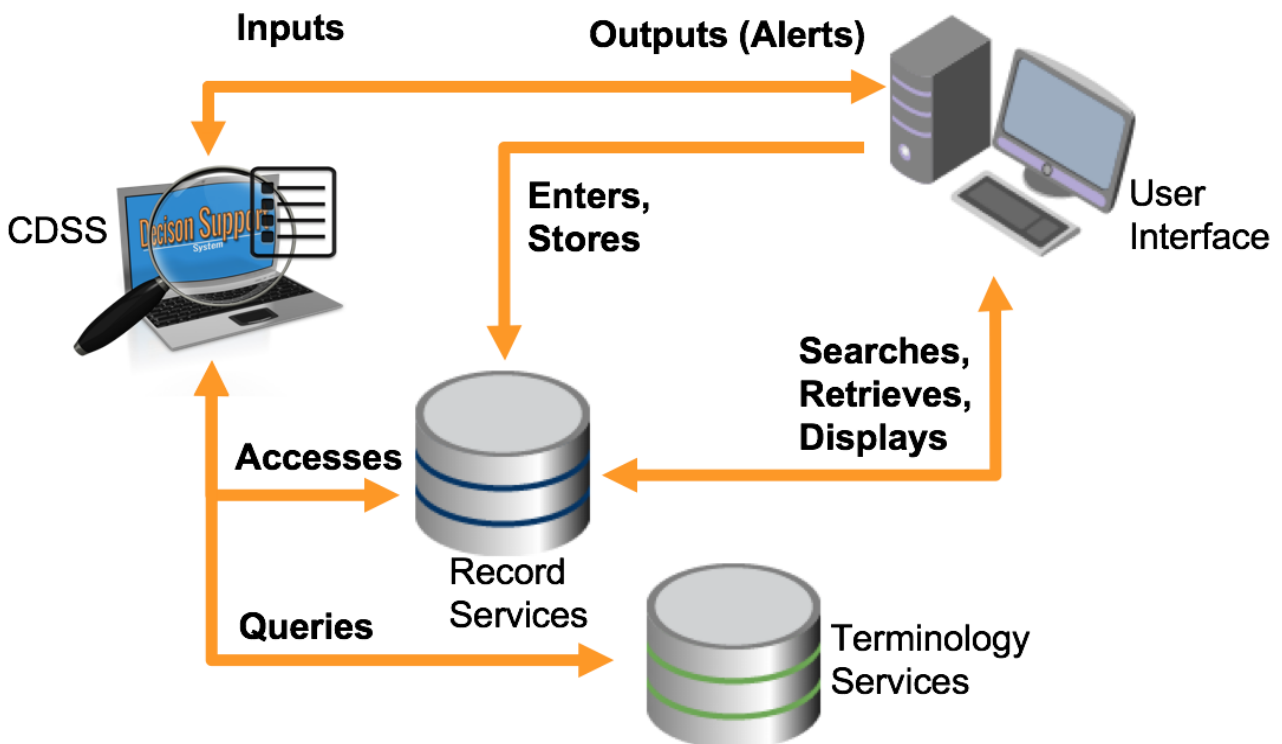
Figure 2.1-1: EHR components and key interactions

As shown above, the UI communicates with the record services to facilitate the storage and subsequent retrieval of health record data. The UI also provides inputs to the CDSS and displays alerts and guidelines on its behalf. The CDSS uses the inputs from the UI and data from the record and terminology services to processes decision support rules. The CDSS uses the inputs from the record and terminology services to determine whether or not the CDS conditions have been met, and if so then CDS interventions, such as alerts or knowledge resources, are delivered back to the UI. The internal components and processes of the CDSS will be described in more detail in the next section - Logical Architecture of a CDSS.

2.2. CDS System Architecture

This section describes the major architectural components of a CDSS and explores how they work together with the components of an EHR, as described in 2.1. EHR System Architecture.

Major Components

Table 2.2-1: Descriptions of the major architectural components of a CDSS

CDSS Component		Description
	Knowledge Base	The knowledge base (KB) stores clinical knowledge developed by domain experts as CDS artifacts. These knowledge artifacts (e.g. rules and guidelines) are stored in a machine processable format and made available to the inference engine to drive the CDS workflow. For additional information on this component please refer to section 3. Knowledge Base.
	Inference Engine	The inference engine processes the CDS knowledge artifacts, using information from the record services, the terminology services and user input to execute the CDS logic. A key part of this process is to determine which actions should be performed, based on the given patient's circumstances. For additional information on this component please refer to section 4. Inference Engine.
	Communications	The communications mechanism is responsible for accepting inputs from the user and delivering the outcomes of the inference engine back to the user. For example, when a clinician prescribes a drug, this information is communicated to the inference engine as an input. If the inference engine discovers that the medication is contraindicated, the communications mechanism will deliver an alert to the user interface. For additional information on this component please refer to section 5. Communications.

Logical Architecture

The diagram below illustrates how the components of the CDSS (shown in the blue box) work together with the components of the EHR system (shown in the red box).

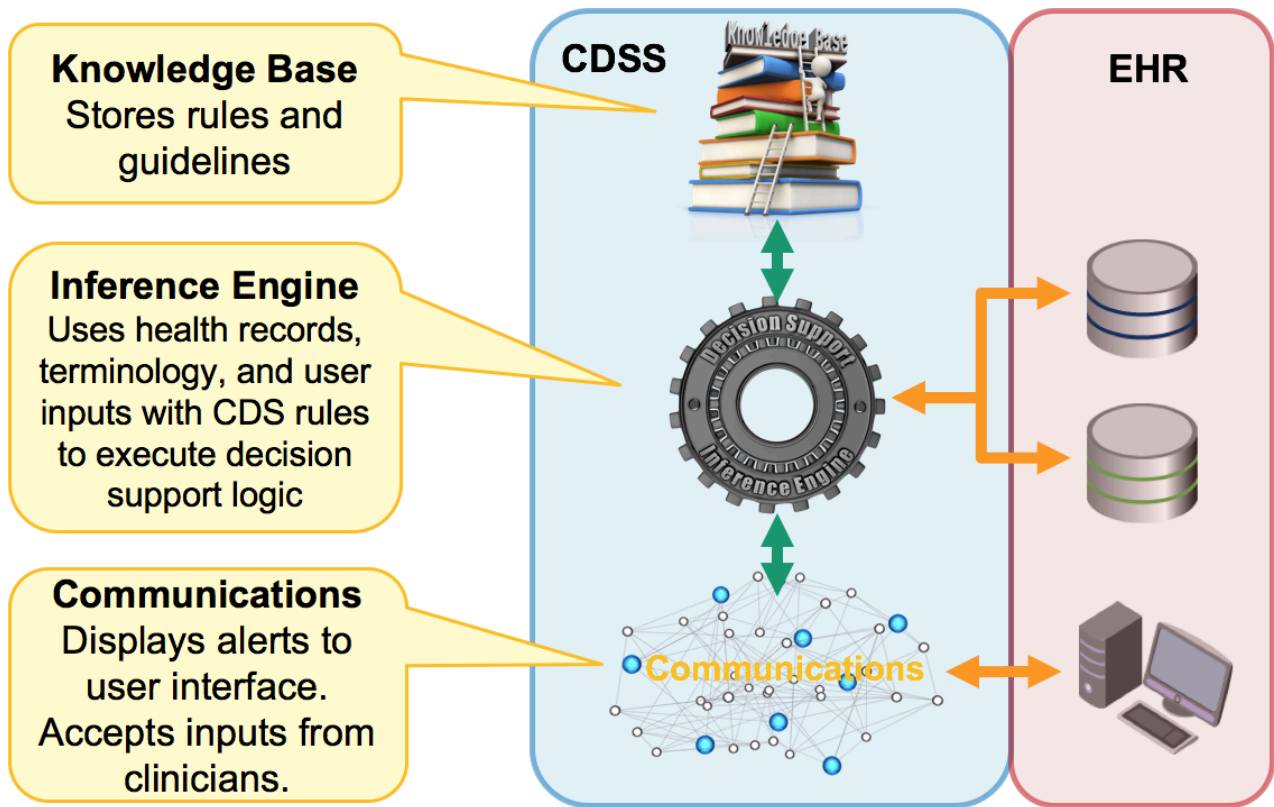**Figure 2.2-1: CDSS components and key interactions**

Internal CDSS interfaces are represented by the green directional arrows, while external CDSS interfaces are represented by the orange arrows. Note that the inference engine interfaces directly with record and terminology services while communications, which is focused on the delivery of CDSS inputs and outputs, interfaces directly with the user interface.

3. Knowledge Base

The knowledge base can be thought of as the brains of a clinical decision support system. Clinical knowledge is what fuels the knowledge base. This knowledge is documented by the clinical experts in their respective domains. The knowledge is then loaded into the KB as knowledge artifacts and stored in a machine processable format. These artifacts are then made available to the inference engine to execute the decision support logic. Knowledge artifacts may be updated when new clinical knowledge becomes available. In some CDSSs this is done using a specialized knowledge artifact management interface, which may support tasks such as rule creation, customization, and updating. In other cases, clinical knowledge artifacts are used from third party providers, who specialize in supporting CDSSs.

Types of CDS knowledge artifacts include:

- Decision support rules
- Clinical guidelines and care pathways
- Documentation templates
- Order sets

The characteristics of these knowledge artifacts are described in the section 1.2. Functional Areas.

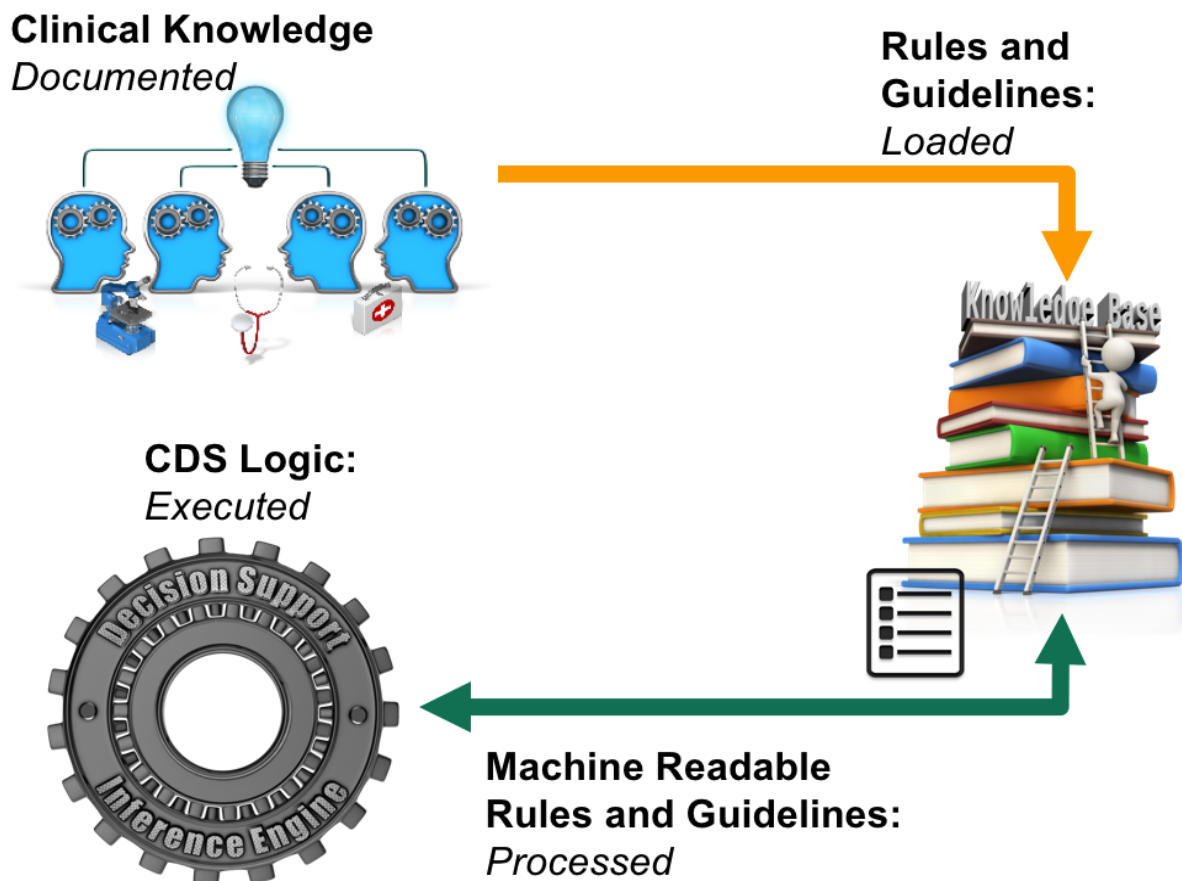The diagram below illustrates the key interactions with the knowledge base, as described above.

Figure 3-1: Knowledge base interactions

The topics below are presented in more detail in the following sections:

3.1. Rules

Clinical decision support rules play a key role in the overall delivery of CDS. CDS rules typically follow a common pattern, which has been modeled in several healthcare standards formalisms. The Event-Condition-Action[1] model, as used in the HL7 community, is described below.

Event

A CDS event is the *clinical situation* in which a decision support rule will be applied. First something must happen before the rule can be utilized. Examples of CDS events include:

- A clinician is prescribing a drug to a patient
- A nursing supervisor is reviewing a list of patients previously diagnosed with cancer
- A clinician is assessing a patient enrolled in a jurisdictional diabetes monitoring program

Condition

A CDS condition defines the *question(s) that must be answered* to determine the outcome of the rule. Examples of conditions include:

- Does the usual drug of choice for this patient's condition contain a substance to which the patient is allergic?
- Have any patients with a suspected cancer diagnosis NOT been referred to a specialist within 14 days of diagnosis?
- Has the patient with a previous diagnosis of diabetes type II NOT had HBA1C tested within the last 12 months?

Action

The CDS action describes *what should be done* if the condition evaluates to true. Examples of actions include:

> - Alert the clinician and suggest a safe alternative medication
> - Refer patients to an oncology specialist
> - Order HBA1C test

Event-Condition-Action Model

An informal representation or rule template which captures the Event-Condition-Action pattern is shown below. This pattern can be read as "ON event IF condition THEN action".

Figure 3.1-1: Event-Condition-Action rule template

Rules may reference both EHR data and reference data such as terminology to determine whether or not a specific condition is true. This topic will be explored in more detail in section 4. Inference Engine.

⬚ http://hl7.org/fhir/2016Sep/cqif/cqif-knowledge-artifact-representation.html#event-condition-action-rule

3.1.1. Context in CDS Rules

Context has been defined as the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood. ⬚ Contexts that modify the meaning of a diagnosis or procedure may include family history, past history, suspected diagnoses, planned procedures and procedures not done. It is important to understand the context of each statement in a health record, to determine whether or not it is appropriate to for a CDS rule to be applied.

> When evaluating the condition within a CDS rule it is important to take account of context.
>
> - For example, a rule that requires a *current diagnosis* of diabetes should not trigger an action in response to a record that states that a patient has a *family history* of diabetes.

Representing Context in a Health Record

Context can be expressed in a health record in a number of ways. Firstly, a precoordinated expression can be used in which the context is captured in the meaning of the concept. For example, 160303001 |Family history: Diabetes mellitus|. Alternatively, a postcoordinated expression can be used. This is where the meaning is expressed by combining codes in a structured way using SNOMED CT Compositional Grammar. For example: 281666001 |Family history of disorder| :

246090004 |Associated finding| = 73211009 |Diabetes mellitus| A third way to express context is to use a context-specific section or field, such as a "Family history section", which captures the context in the meaning of the section or field name. Lastly, it is also possible to use two separate fields - one which captures the finding |Diabetes mellitus|, and the other which captures the context |Family history of disorder|.

Table 3.1.1-1: Techniques for recording context in an EHR

Technique for Representing Context	Example	
Precoordinated as a single SNOMED CT concept identifier explicitly representing family history of diabetes mellitus.	160303001 |Family history: Diabetes mellitus|	
Postcoordinated as a SNOMED CT expression that includes a concept representing a family history of disorder and specifies the diabetes mellitus as the disorder.	281666001 |Family history of disorder| : 246090004 |Associated finding| = 73211009 |Diabetes mellitus|	
A context specific family history section in the record structure	Family History Record Section	73211009 |Diabetes mellitus|
A separate field in the record structure to indicate the context of the disorder recorded	Disorder 73211009 |Diabetes mellitus|	Context 281666001 |Family history of disorder|

False Positives and False Negatives

Considering context that is captured in either the terminology or the information structure is important when executing CDS rules.

- Logic based purely on the presence or absence of codes, without considering the context implied by the information structure, may lead to CDS alerts being triggered unnecessarily (i.e. false positives).
- Conversely, logic based purely on the presence or absence of codes, without considering context implied by the information structure, may lead to CDS alerts not being triggered when required (ie. false negatives).

False Positive Example

In the following example, a CDS rule is triggered inappropriately (i.e. false positive):

- A CDS rule is designed to display clinical practice guidelines for stage 1 chronic kidney disease when the code 431855005 |Chronic kidney disease stage 1| is found in the EHR. A retrospective analysis of a false

positive trigger reveals that the code was recorded in the *past history* section of the health record. As this record indicates that the |Chronic kidney disease stage 1| was part of the patient's |Past medical history|, the display of stage 1 chronic kidney disease guidelines was inappropriate.

False Negative Example

In the following example, a CDS rule is not triggered when required (i.e. false negative):

- A CDS rule is designed to display patient-focused, preventative educational material when the code 160303001 |Family history: Diabetes mellitus| is found in the EHR. This rule is implemented in an EHR system, which uses a *family history* section to record the family history of disorders. Even though the SNOMED CT concept 73211009 |Diabetes mellitus| is recorded in the patient's family history, the CDS rule is not triggered as required.

Default Context

When neither the SNOMED CT concept nor the surrounding health record explicitly states the context, a default context applies.

Table 3.1.1-2: Default context values alongside their corresponding attributes

	Attribute	Value
Clinical Findings	408729009 |Finding context|	410515003 |Known present|
	408732007 |Subject relationship context|	410604004 |Subject of record|
	408731000 |Temporal context|	410512000 |Current or specified time|
Procedures	408730004 |Procedure context|	385658003 |Done|
	408732007 |Subject relationship context|	410604004 |Subject of record|
	408731000 |Temporal context|	410512000 |Current or specified time|

For clinical findings, it is assumed that the finding is known to be present (as opposed to known to be absent), we assume that the finding is about the patient (as opposed to someone else), and we assume that the finding occurred at either the present time or a time specified in the record structure (as opposed to a general time in the past).

Data Entry with Context

The following diagram illustrates how additional context can be captured during the data entry process. The diagnosis (disorder) of 372064008 |Female breast cancer|is selected using the pick-list in the top left corner of the screen and then the context values are selected using the other radio button and pick-list. These context values for *relation to subject* and *finding context* must be considered when the conditions in this CDS rule are evaluated.
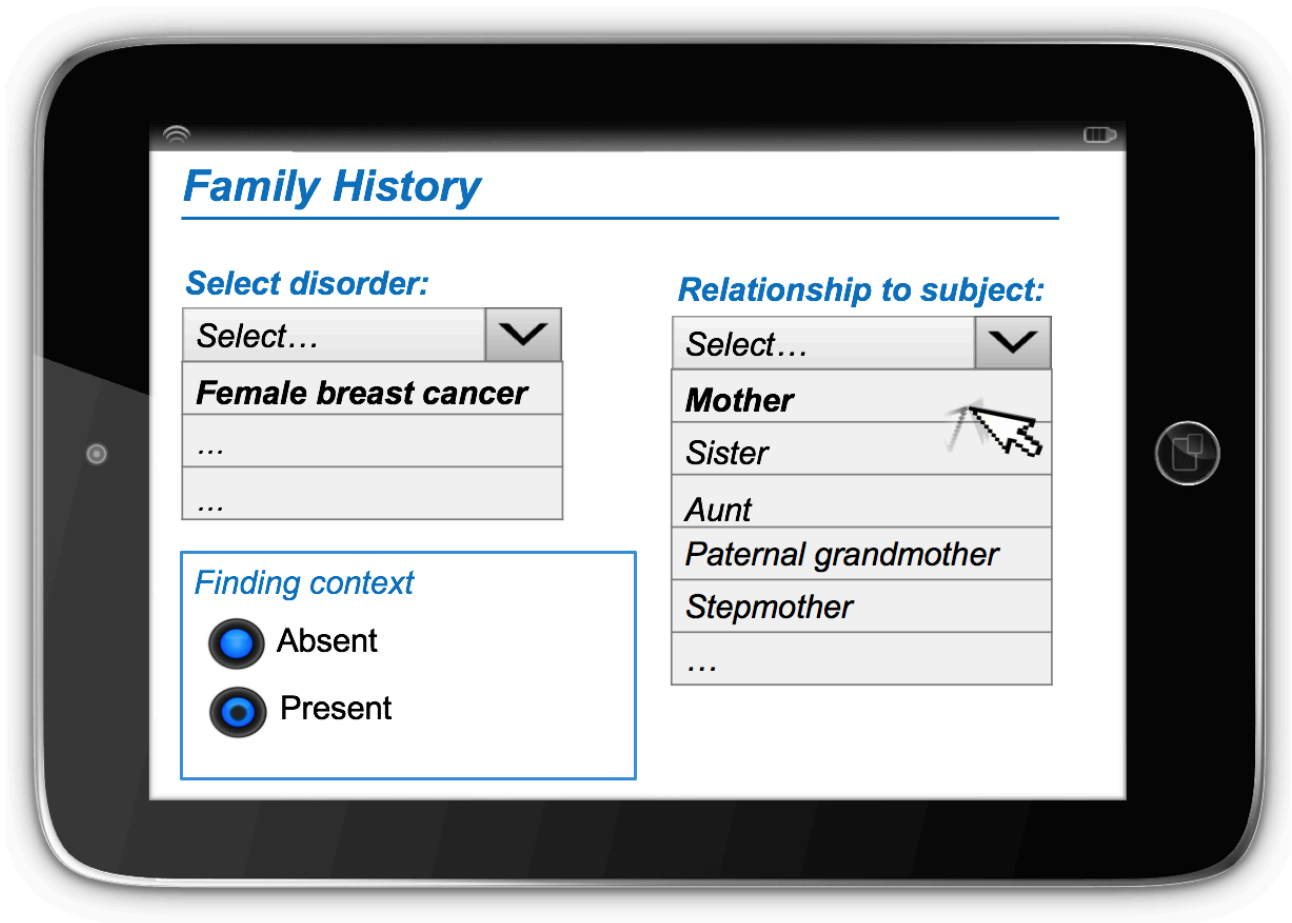
Figure 3.1.1-1: Capturing context during data entry

Defining Context in Rules

It is important to always consider context when defining (and executing) the conditions in a CDS rule. If the default context applies to the condition, then it does not need to be explicitly stated in the CDS rule. However, care should be taken when testing the CDS condition against health records, to ensure that the recorded values share the same context as is required by the CDS rule. If a non-default context is required in a CDS rule, then the rule must explicitly state the context that is required. This context must also be appropriately checked when testing the CDS condition against health records.

The following diagram illustrates a CDS rule, which explicitly states the context of a 372064008 |Female breast cancer|diagnosis that must be matched in order for the action to be triggered. In this example, the CDS condition requires that for patients over the age of 30 258707000 |years|, a diagnosis of 372064008 |Female breast cancer|must be present, in a female family member of the subject, with genetic ties.
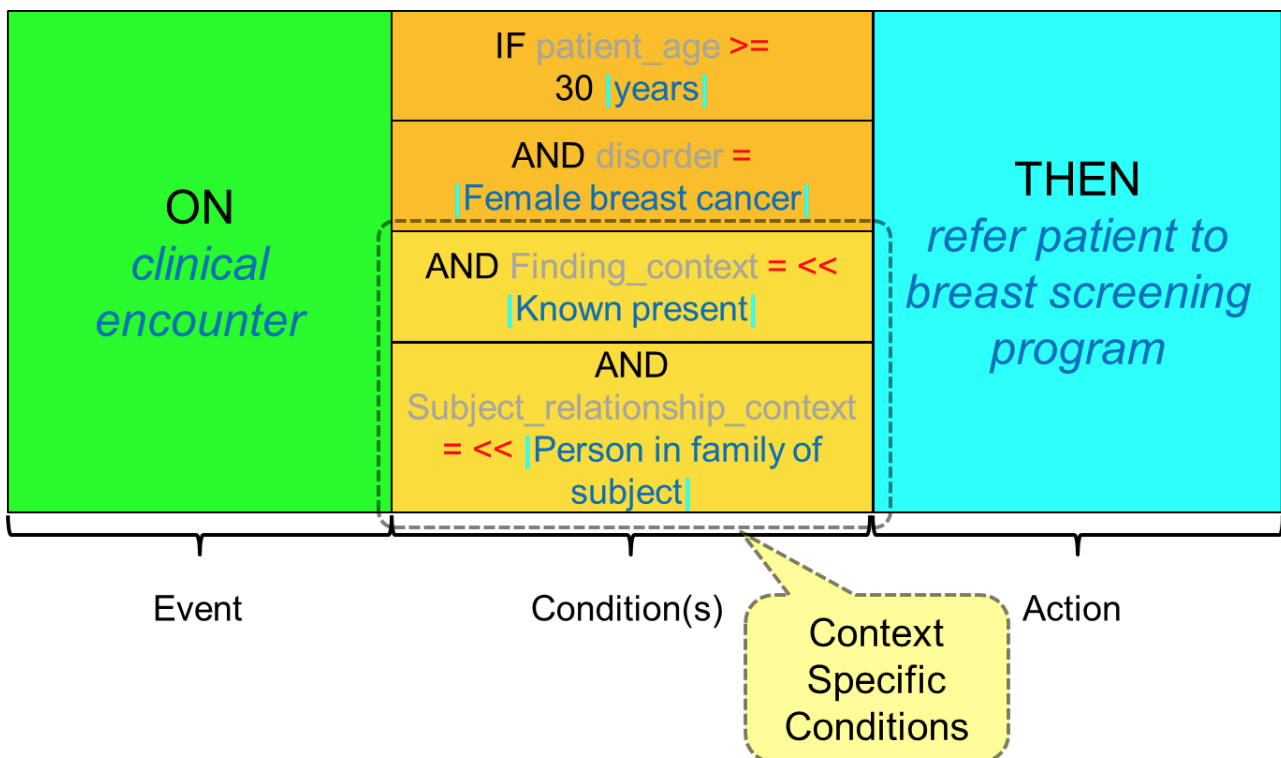
Figure 3.1.1-2: CDS rule with the context explicitly stated

The contextual selections in the data entry screen above would satisfy the conditions in this rule because the user has specified that the diagnosis of female breast cancer occurred in the mother of the subject. This can be seen in the postcoordinated expression below, which corresponds to the user's selections in the data entry screen:

372064008 |Female breast cancer| :
   408729009 |Finding context| = 410515003 |Known present| ,
   408732007 |Subject relationship context| = 444301002 |Mother of subject|

Note that a selection of 65412001 |Stepmother|would not trigger the rule as this concept is not a descendant of 444148008 |Person in family of subject|. (Stepmother has no genetic relationship to the patient.)

📄 https: //en.oxforddictionaries.com/definition/context.

3.1.2. Rule Components and Criteria

The components and criteria within a CDS rule should also be considered when designing or implementing the rules. Some of the additional aspects of these considerations have been described below.

Multi-Component CDS Rules

Multiple events, conditions, or actions may be associated with each CDS rule . For example, two separate actions defined in a medication allergy rule might be:

1. *Firstly* to alert the user and;
2. *Secondly* to suggest an alternative drug

Additional examples of complex rules, with multiple conditions and actions, are provided in the section 3.1.3. Rule Examples.

Criteria in CDS Conditions

Each CDS condition can be further subdivided into one or more criterion, each consisting of a "name-value" pair. The criterion name will typically map to a data element in the electronic health record, while the criterion value is compared with the data that populates this element in the patient's health record.

Table 3.1.2-1: Examples of criterion name-value pairs

Criterion Name	Criterion Value
Pregnancy status	77386006 |Pregnant|
Drug prescribed	85990009 |Codeine|
Hematocrit result	41 118582008 |%|

Criteria Values

Some criteria may refer to the value of coded data elements, while others may refer to the value of non-coded data elements. When a criterion refers to a SNOMED CT encoded data element, the value may be a SNOMED CT Expression Constraint that defines the permitted subset of concepts that will satisfy this criteria.

Table 3.1.2-2: Examples of criteria which refer to coded data elements

Criterion Name	Criterion Value
Condition	<< 195967001 |Asthma|
Diagnosis	<< 29857009 |Chest pain|
Procedure	< 71388002 |Procedure| : << 363704007 |Procedure site| = << 20139000 |Structure of respiratory system|

Criteria that refer to non-coded data elements may use operators that are valid for the given element's data type. For example, criterion that refer to numeric data elements may use standard mathematical operators to restrict the required value.

Table 3.1.2-3: Examples of non-coded data elements

Criterion Name	Data Type	Operator	Value	Units
Wait time	Quantity	>	90	258703001 |days|
Lab result	Quantity	<=	7.5	258813002 |mmol/L|
Birth date	Date	>=	1990/01/01	n/a

3.1.3. Rule Examples

In this section we present a number of examples of CDS rules, using the 'ON event IF condition THEN action' pattern described in section 3.1. Rules.

Asthma Diagnosis

This simple CDS rule was designed to be used during a clinical encounter. If the patient is diagnosed with asthma, the appropriate management guidelines are automatically displayed on the clinician's workstation.
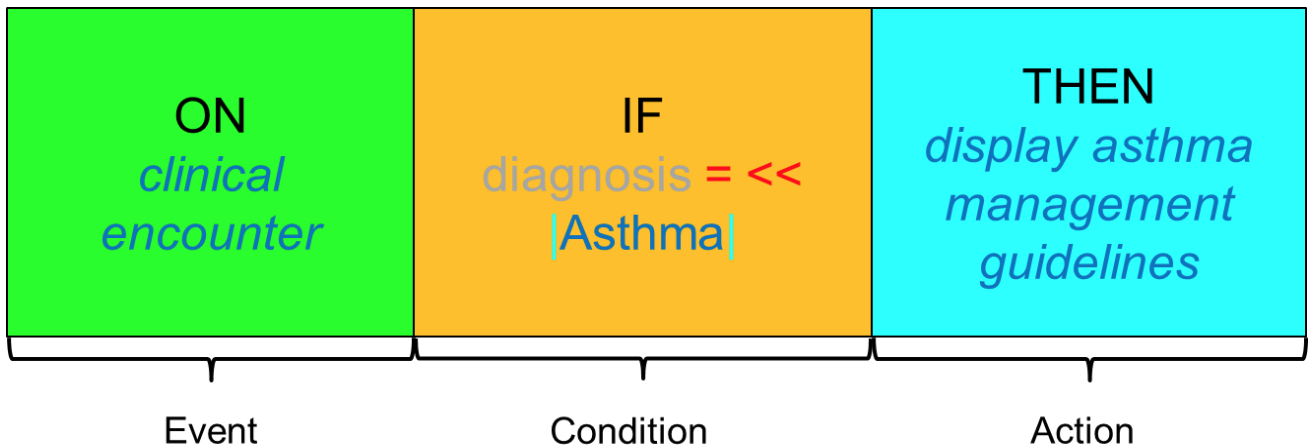

Figure 3.1.3-1: This rule demonstrates the use of a single event, criterion, and action, an expression constraint in the criterion value, and use of the default context.

Medication Order

This rule has been designed to be used when ordering a medication. If the patient is 77386006 |Pregnant| and the drug has an active ingredient of 372756006 |Warfarin|, the clinician will be alerted and the CDSS will suggest an alternative blood thinner which does not pose a risk for expectant mothers.
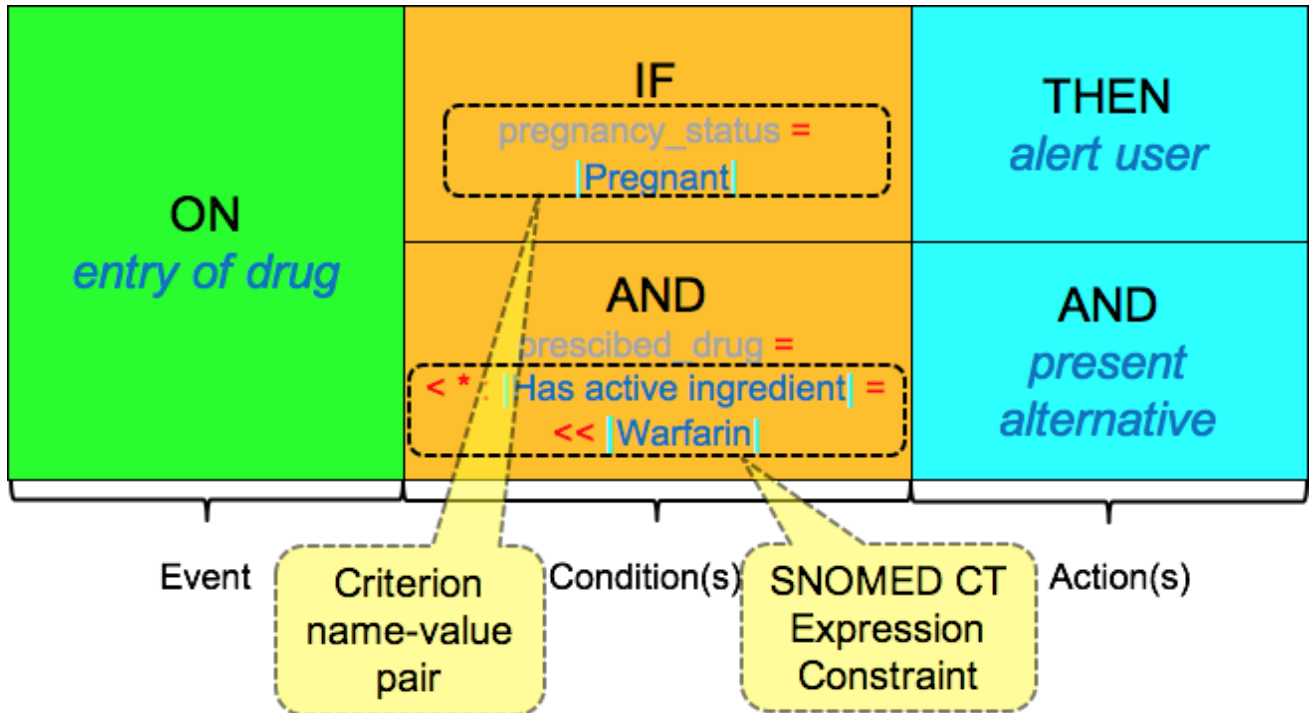

Figure 3.1.3-2: This rule demonstrates the use of multiple criteria, multiple actions, expression constraints in the criterion value, and use of the default context.

Emergency Department

The following example is a CDS rule designed to be used in an Emergency Department setting, when a patient has presented in the ER with chest pain. In this scenario, the attending physician may order a 312468003 |Blood potassium measurement|. If the patient is currently taking a medication with an active ingredient of 387461009 |Digoxin|, and the lab result is published indicating that the patient's potassium level is less than 3.0 mmol/L, the attending physician will be paged.
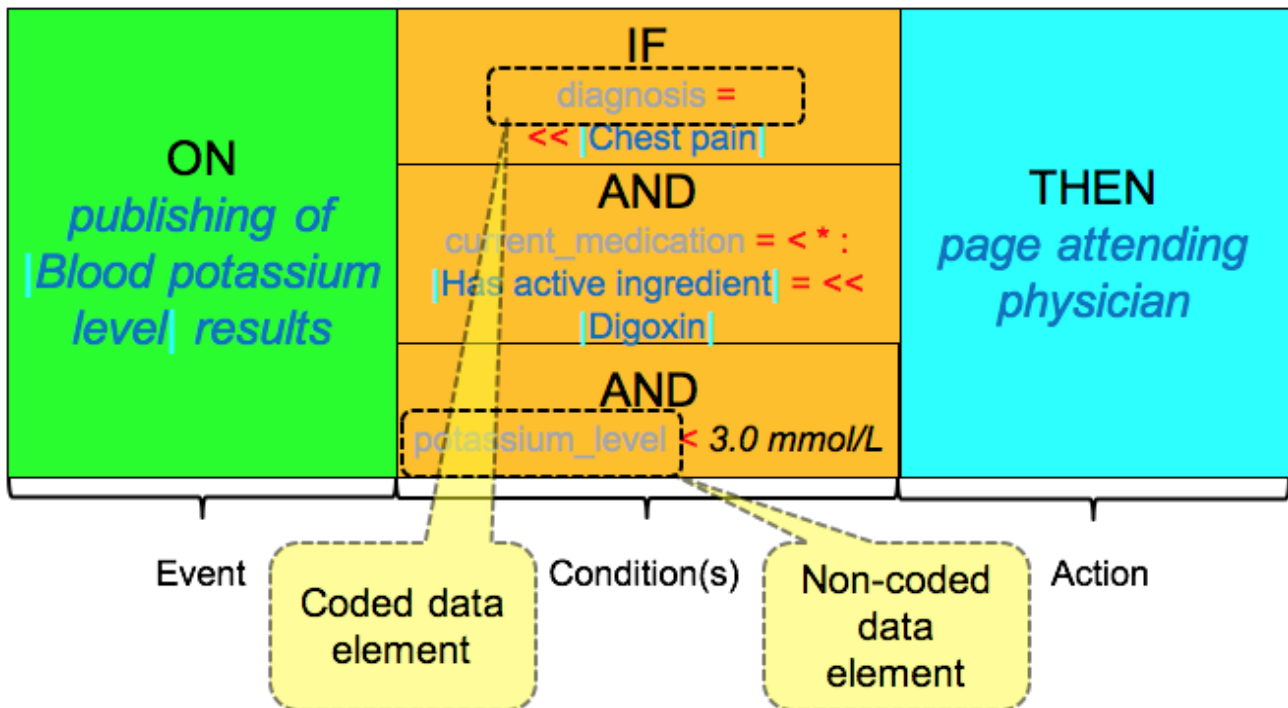

Table 3.1.3-1: This rule demonstrates the use of multiple criteria, expression constraints in the criterion value, a non-coded criterion with a mathematical operator, and use of the default context.

3.1.4. Standards for CDS Rules

This section presents some examples of standards used to represent CDS rules. Please note that this list is not exhaustive, and other established and emerging standards for rule representation do exist.

Expression Constraint Language

The SNOMED CT expression constraint language (ECL) provides a computable way of intensionally defining a set of clinical meanings represented in SNOMED CT. For example, the expression constraint below represents the set of lung disorders that have an associated morphology that is a type of edema.

```
< 19829001 |Disorder of lung| :
    116676008 |Associated morphology| = << 79654002 |Edema|
```

When executed against a specific SNOMED CT edition, an expression constraint will return the set of concepts that match the given constraint. Expression constraints can also be used to query over precoordinated and postcoordinated expressions recorded in EHRs.

SNOMED CT expression constraints provide a standard way of referring to intensionally defined sets of SNOMED CT concepts (or expressions) that are required to test CDS rule criterion. Examples of CDS rules that use SNOMED CT expression constraints can be found in 3.1.3. Rule Examples.

For more information about expression constraints, please refer to Expression Constraint Language - Specification and Guide.

Arden Syntax

The Arden Syntax is a widely-used and mature markup language for representing, sharing, and processing clinical knowledge, which makes it suitable in the application of expressing rules for use in decision support. The syntax has a long history, but is currently maintained by HL7 International. One of the advantages of the ARDEN syntax is improved human readability which is achieved by its resemblance to natural language. This in turn makes ARDEN code easier for non-technical audiences to interpret.

When used in CDS, Arden code can be embedded in independent files called medical logic modules (MLMs).[1] The improved readability of Arden syntax makes it easier for a clinician to validate the clinical accuracy of any given MLM. MLMs have been widely used and libraries of these modules are available. It is also worth noting that the Arden syntax does not define how it should be integrated within an electronic health record or how an application should use it.

For more information on the Arden Syntax, please refer to the HL7 Implementation Guide for Arden Syntax, Release 1.

FHIR CDS Resource

PlanDefinition is a general FHIR resource which can be used to represent a range of CDS artifacts such as rules, order sets, and protocols.[2] According to the HL7 FHIR specification, a resource contains a set of structured data items that conform to the definition of the resource type and can be used to exchange and/or store data to satisfy a wide range of clinical and administrative healthcare information needs.[3] PlanDefinition is currently defined as a draft resource within FHIR's Clinical Reasoning module. The Clinical Reasoning module is a draft of the Clinical Quality Framework Implementation Guide (or FHIR-Based Clinical Quality Framework). The guidance in this module is prepared as a Universal Realm Specification, which means it is designed to be used Internationally.

The PlanDefinition resource can be used to represent a rule using the Event-Condition-Action pattern. This pattern is defined within the actionDefinition element of the PlanDefinition resource. "A single, top-level actionDefinition represents the overall rule, with the triggerDefinition element used to specify the triggering event(s), the condition element used to specify the applicable condition for the rule, and the actionDefinition itself describing the action to be performed."[4] The PlanDefinition resource is used to describe series, sequences, or groups of actions to be taken, while the ActivityDefinition resource is used to define each specific step or activity to be performed. An example of an XML instance of a PlanDefinition resource that encapsulates a Chlamydia Screening rule is shown below.

```xml
<PlanDefinition>
  <id value="chlamydia-screening-intervention"/>
  <identifier> ⬤⬤ </identifier>
  <version value="2.0.0"/>
  <title value="Chalmydia Screening CDS Example Using Common"/>
  <status value="draft"/>
  <description value="Chlamydia Screening CDS Example Using Common"/>
  <publicationDate value="2015-07-22"/>
  <topic> ⬤⬤ </topic>
  <library>
    <reference value="Library/ChlamydiaScreening_CDS_UsingCommon"/>
  </library>
  <actionDefinition>
    <title value="Patient has not had chlamydia screening within the recommended timeframe..."/>
    <condition>
      <expression value="NoScreening"/>
    </condition>
    <dynamicValue>
      <path value="~"/>
      <expression value="ChlamydiaScreeningRequest"/>
    </dynamicValue>
  </actionDefinition>
</PlanDefinition>
```

Figure 3.1.4-1: Example PlanDefinition XML instance

For more information on this FHIR resource, please refer to http://build.fhir.org/plandefinition.html or http://build.fhir.org/clinicalreasoning-module.html.

---

[1] The Arden Syntax standard for clinical decision support: Experiences and directions, Samwald et. al
[2] http://build.fhir.org/plandefinition.html
[3] https://www.hl7.org/fhir/resource.html
[4] http://build.fhir.org/cqif/cqif-knowledge-artifact-representation.html#event-condition-action-rule

3.2. Guidelines

The two main approaches to preparing clinical guidelines for use in CDS are to use simple markup (also referred to as "semantic tagging"), and to use a standard guideline representation language.

Simple guideline markup involves annotating free-text clinical guidelines using terminology codes that represent its meaning. This enables relevant guidelines to be retrieved based on specific codes recorded in a patient's health record. For more information on this approach, please refer to 3.2.1. Guidelines with SNOMED CT.

An alternative approach is to use a standard guideline representation languages to formally define each guideline. Some examples of standard guideline representation languages, such as the Guideline Definition Language (GDL) and the Guideline Interchange Format (GLIF) are presented in the section 3.2.2. Standards for CDS Guidelines.

3.2.1. Guidelines with SNOMED CT

This section examines how clinical guidelines can be linked to SNOMED CT to enable the automated display of contextually relevant knowledge resources. We begin by reviewing how a guideline can be linked to a SNOMED CT concept using semantic tags. Next we will examine how SNOMED CT concepts can be associated with guidelines using a reference set. Lastly, we will look at the automated display of a contextually relevant guideline, based on the selection of a SNOMED CT concept in a data entry protocol.

Linking Guidelines to SNOMED CT

One approach known as simple markup, involves the application of semantic tags using terminology codes (such as SNOMED CT concept identifiers) to free text clinical guidelines. When using SNOMED CT, concept identifiers (or expressions) are added as document metadata to the appropriate guideline or text within the guideline. For example, when applying semantic tags to asthma management guidelines, we might add the following concept identifiers, to enable the guideline to be linked to a patient's health record that includes a diagnosis of 195967001 | Asthma|, a regime of 406162001 |Asthma management|, or an assessment scale coded with 445531003 |Asthma control questionnaire|(respectively):

Concept
195967001 |Asthma (disorder)|
406162001 |Asthma management (regime/therapy)|
445531003 |Asthma control questionnaire (assessment scale)|

The diagram below depicts the process of tagging the SNOMED CT concepts mentioned above to an Asthma Management Guideline.[1]
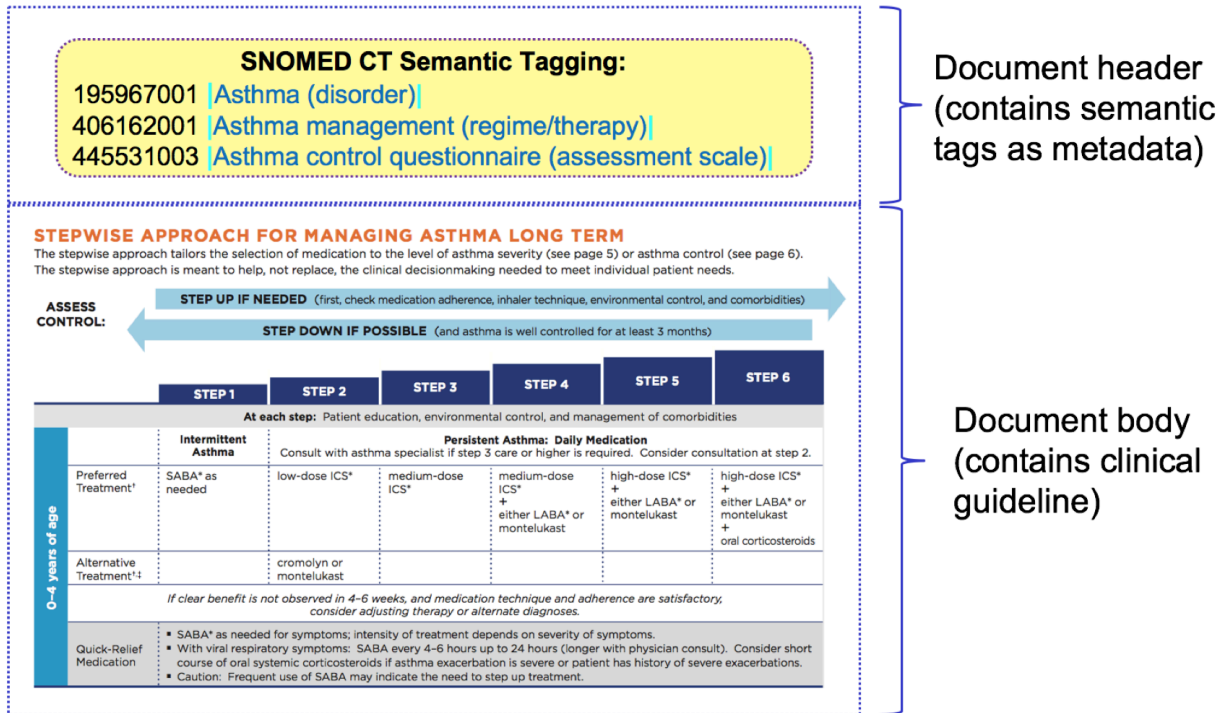
Figure 3.2.1-1: Asthma Management Guideline tagged with SNOMED CT concepts

This tagged resource may then be presented as reference material when a relevant clinical scenario arises. For example, the guidelines shown in Figure 3.2.1-1 could be presented upon the diagnosis of |Asthma|. Additional details on the mechanics of this process are provided below in the Selecting Relevant Guidelines section below.

Linking SNOMED CT to Guidelines

SNOMED CT Annotation Reference Sets can be used as a mechanism to define, share, and distribute links from SNOMED CT components to appropriate guidelines. This approach involves defining one or more links to relevant

guidelines (using a URL) as a string based annotation for each relevant concept. An example of this is shown in Table 3.2.1-1. In this example, the same clinical guideline is relevant to more than one SNOMED CT concept.

Table 3.2.1-1: Concepts which refer to NIH: Asthma Care Quick Reference guideline

refsetId	referencedComponentId	Annotation
719999999107 |Guideline annotation reference set|	195967001 |Asthma (disorder)|	http://www.example.com/asthma_guideline
719999999107 |Guideline annotation reference set|	406162001 |Asthma management (regime/ therapy)|	http://www.example.com/asthma_guideline
719999999107 |Guideline annotation reference set|	445531003 |Asthma control questionnaire (assessment scale)|	http://www.example.com/asthma_guideline

Another example use case is linking a specific clinical field, such as a diagnosis, to an appropriate clinical guideline. Given the more specific scope, it may be possible to avoid repeating the same guideline for multiple SNOMED CT concepts referenced by the reference set. Table 3.2.1-2 below, shows an example in which disorder concepts are linked to appropriate clinical guidelines.

Table 3.2.1-2: Respiratory diagnoses linked to relevant clinical guidelines

refsetId	referencedComponentId	Annotation
719999999107 |Guideline annotation reference set|	195967001 |Asthma|	http://www.example.com/asthma_guideline
719999999107 |Guideline annotation reference set|	32398004 |Bronchitis|	http://www.example.com/bronchitis_guideline
719999999107 |Guideline annotation reference set|	13645005 |Chronic obstructive lung disease|	http://www.example.com/COPD_guideline

Selecting Relevant Guidelines

EHR systems, designed to use clinical guidelines marked up with semantic tags, are able to display relevant guidelines to the user when a subtype (or self) of the semantic tag concept is recorded in the health record.

Below is a generic template that could be used in an EHR system to facilitate the display of an appropriate clinical guideline, when a relevant diagnosis is recorded.

```
IF diagnosis = << [[ + $semanticTag]]
THEN display clinical guideline
```

For example, the above template could be used on a clinical guideline that has the semantic tag 195967001 |Asthma |, generating the CDS rule:

> IF diagnosis = << 195967001 |Asthma|
> THEN display NIH Asthma Care Quick Reference

Using the above CDS rule, if a clinician selects a diagnosis of 195949008 |Chronic asthmatic bronchitis|, the NIH Asthma Care Quick Reference would be displayed because 195949008 |Chronic asthmatic bronchitis|is a subtype of 195967001 |Asthma|.

This enables *contextually relevant* clinical knowledge to be presented to the user, based on the specific codes recorded in the patient's health record. The diagram below illustrates this scenario:
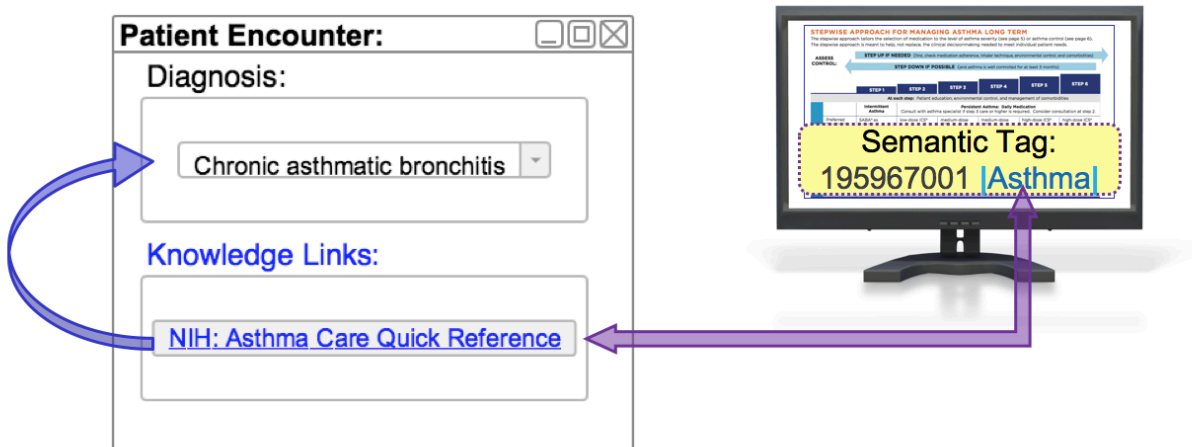
Figure 3.2.1-2: Upon entry of a specific diagnosis, a contextually relevant knowledge resource is presented on the user interface

[1] Asthma Care Quick Reference used for demonstration purposes.

3.2.2. Standards for CDS Guidelines

This section presents some examples of standards used to represent CDS guidelines. Please note that this list is not complete, and other standards and formalisms for representing clinical guidelines do exist.

Guideline Interchange Format

The Guideline Interchange Format (GLIF) is a language for modeling and executing clinical practice guidelines.[1] GLIF uses GELLO, and therefore can make use of SNOMED CT within its language. Users of GLIF have the option of viewing GLIF code in a interactive flowchart to represent guidelines and present pop-up information and instructions. The following screenshot presents the "UI view" of a query / guideline structured in GLIF. This example uses SNOMED CT to answer the questions in the decision shapes:[2]
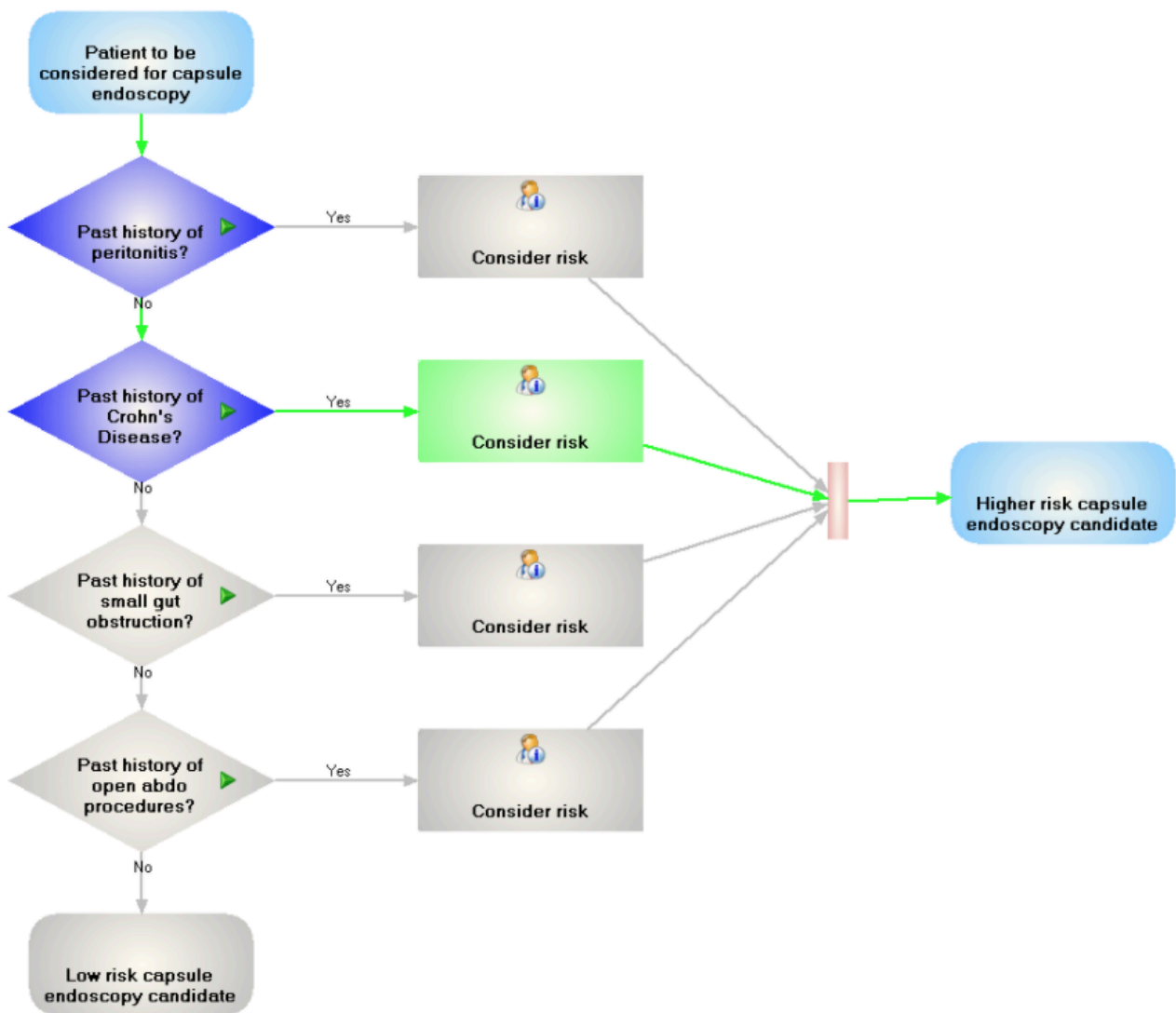
Figure 3.2.2-1: UI view of a query / guideline structured in GLIF

For more information about GLIF, please refer to https://kb.medical-objects.com.au/display/PUB/GLIF.

Guideline Definition Language

The Guideline Definition Language (GDL)[3] is a syntax designed to express clinical logic as rule inputs and outputs. Discrete rules can be combined together to support simple or complex decision making. The specification which accompanies the GDL describes its status as "trial." One of the goals of the GDL is to be able to share CDS artifacts across languages and technical platforms. GDL artifacts can be applied to point of care (POC) decision support and in population health analytics. The GDL uses reference and archetype models from openEHR and in doing so supports information model references that are language independent. For example, it is possible to add language translations without changing the logical definitions in the rule. It is also possible to bind locally defined terms in the guideline to a single concept, multiple concepts, or reference set in any reference terminology as the language considers a reference terminology to be an external resource.

For more information on the Guideline Definition Language, please refer to http://www.openehr.org/releases/CDS/latest/docs/GDL/GDL.html.

---

[1] http://www.openclinical.org/gmm_glif.html
[2] Content and diagram provided by Medical-Objects.
[3] http://www.openehr.org/releases/CDS/latest/docs/GDL/GDL.html#_guideline_definition_language_gdl

3.3. Substrate

An important consideration in the development of a Clinical Decision Support System (CDSS) is the *substrate* over which the knowledge artifacts are authored and executed. When using SNOMED CT in a CDSS, the *substrate* is the SNOMED CT content over which the CDS rules are authored or executed. Because medical knowledge is constantly changing, it is important that the substrate over which CDS is applied is kept current. To support this requirement, SNOMED CT releases regular new versions of the terminology, and retains a history of changes using its strong versioning mechanism. With this in mind, both the SNOMED CT edition and the specific version of that edition (released on a given date) need to be considered in determining the SNOMED CT substrate. For more information on the topic of versioning, please refer to section 11.4 Versioning in the guide Data Analytics with SNOMED CT.

Knowledge Artifact Substrate

When publishing CDS knowledge artifacts, such as rules or guidelines, it is important to clearly indicate the substrate over which the artifacts were authored. The substrate used to author a CDS artifact needs to be considered when determining the appropriate substrate to use in the execution of that artifact.

For example a CDS rule, using the SNOMED CT US edition, dated 20160901 (September 1st 2016), may refer to the concept 5281000124103 |Persistent asthma|. If this rule was executed against the SNOMED CT International Edition (20170131), then this extension concept would not be found, and the rule could not be executed.

Similarly, a CDS rule using the International edition (20170131) may refer to the concept 721039003 |Dual energy computed tomography|. If the rule was executed against the 20160731 International edition (or an older version), then this concept (created in the 20170131 version) would not be found, and the rule could not be executed. This would also be true if the same CDS rule was executed against the US edition (20160901), because this edition is dependent on the 20160731 International edition.

Therefore, CDS knowledge artifacts referencing SNOMED CT concepts must be executed (by the inference engine) using a SNOMED CT substrate that includes the same modules, or a superset of the modules included in the SNOMED CT substrate used to author the artifact. In addition, the SNOMED CT substrate used to execute the CDS artifacts must use the same version, or a more recent version of these SNOMED CT modules, to ensure that all the referenced concepts are present. Please note that if a newer version of the substrate is used to execute the rules, then it is possible that a concept or relationship used at the time of artifact authoring may have become inactive. Edition and version dependencies such as these should be checked when adopting new CDS artifacts or updating a CDS system to use a newer version of SNOMED CT.

Electronic Health Record Substrate

Another consideration when selecting the SNOMED CT substrate on which to execute CDS artifacts, is the substrate used to record data in the Electronic Health Record (EHR).

For example, if a CDS rule is triggered when the diagnosis recorded in the EHR is a descendant of 195967001 |Asthma|, that is: IF < 195967001 |Asthma| THEN ... and this rule is executed over the SNOMED CT International edition, dated 20170131 (January 31st 2017), then EHR records which capture a diagnosis of 5281000124103 |Persistent asthma| from the SNOMED CT US edition (20160901) will be unsuccessful in triggering the CDS rule.

Similarly, if a CDS rule is triggered when the diagnosis recorded in the EHR is a descendant of 19829001 |Pulmonary disease|, that is: IF < 19829001 |Pulmonary disease| THEN ... and this rule is executed over the US edition (20160901), then EHR records which capture a diagnosis of 12240951000119107 |Squamous cell carcinoma of left lung| will be unsuccessful in triggering the CDS rule. This is because the US edition (20160901) is dependent on the International edition (20160731), and the concept referenced above was added to the International edition (20170131).

Therefore, CDS knowledge artifacts must be executed (by the inference engine) using a SNOMED CT substrate that includes the same modules, or a superset of the modules used by the EHR system to record patient data. In addition, the SNOMED CT substrate used to execute the CDS knowledge artifacts must use the same or a more recent version of these SNOMED CT modules, to ensure that all the referenced concepts are present. Please note that if a newer version of the substrate is used to execute the rules, then it is possible that a concept recorded in the EHR may have become inactive. Edition and version dependencies such as these should be checked when implementing new CDS rules over existing EHR data or updating a CDS system to use a newer version of SNOMED CT.

4. Inference Engine

At the heart of a clinical decision support system, the inference engine uses inputs from the user, the record services, and the terminology services to process the machine readable rules, guidelines, or CDS artifacts. It is the job of the inference engine to establish if the CDS conditions have been met and determine the appropriate outcome. It does this by executing queries over the health records and terminology, to test the CDS conditions defined in the CDS rules. Note that it is the communications mechanism which handles the action defined in the CDS rules, but the inference engine determines whether or not the action should be carried out.

The diagram below illustrates the key inference engine interactions described above:
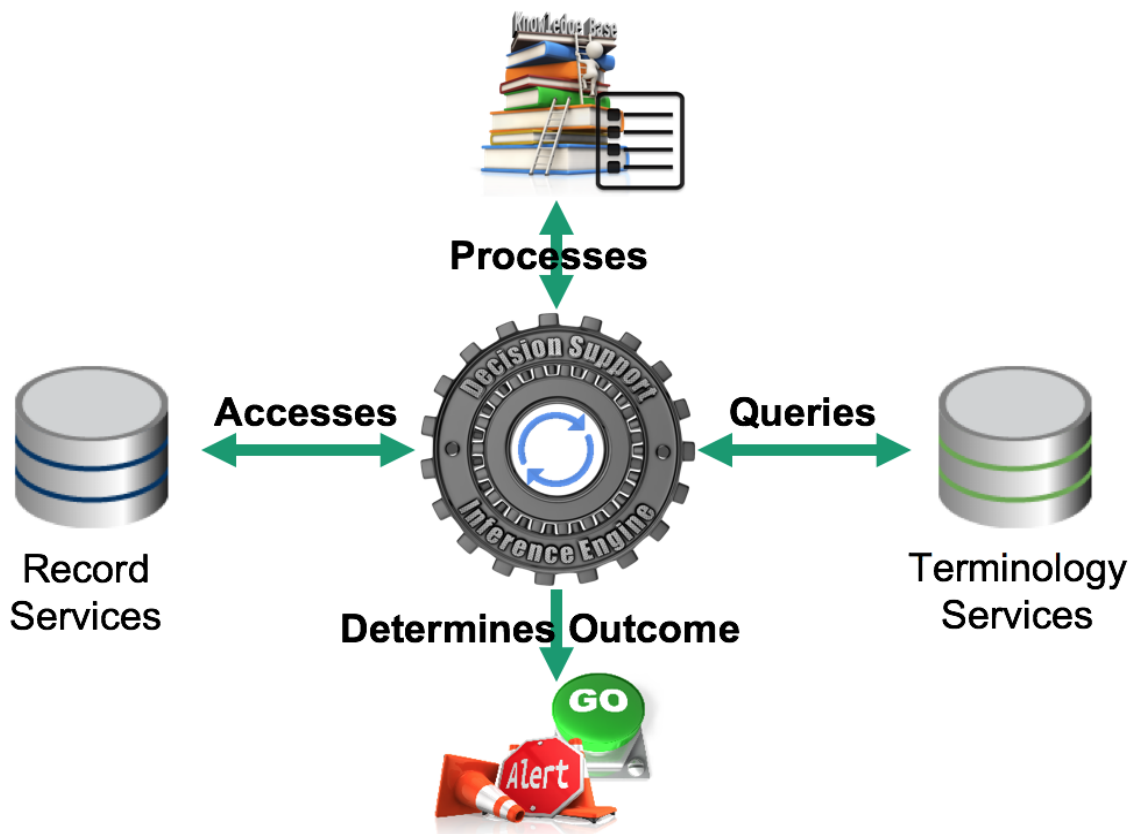
Figure 4-1: Inference engine key interactions

The following topics , which relate to the inference engine, are explored in the following sections:

4.1. Reasoning with SNOMED CT

Features of SNOMED CT can be used in a range of techniques which may then be applied to clinical decision support. For example, these techniques can help to execute decision support logic by assisting the inference engine in evaluating the trigger conditions defined in CDS rules.

This section describes these SNOMED CT techniques with respect to CDS by first providing an overview of the technique, and then presenting an example of how the inference engine can apply the technique to execute a specific CDS rule.

The following SNOMED CT techniques can be used by the CDS inference engine:

4.1.1. Reasoning with Subsets

Overview

A subset is defined in mathematics as a set whose members are all contained in another set. A SNOMED CT Subset typically refers to a collection of components that all come from the same edition of SNOMED CT. This is depicted in the diagram below.

Figure 4.1.1-1: A subset of concepts related to the diagnosis of asthma is selected from the International Edition of SNOMED CT

A SNOMED CT subset may be defined extensionally, by enumerating all of the components in the set or intensionally, by defining a query written using the Expression Constraint Language - Specification and Guide.

Extensionally and intensionally defined subsets can both be represented as SNOMED CT reference sets, which support versioning and traceability. For more information about reference sets, please refer to the Practical Guide to Reference Sets. For additional information on using subsets in queries, please refer to 6.1 Subsets in Data Analytics with SNOMED CT.

Example

This section presents a simple example of a CDS rule defined using a SNOMED CT subset, and explains how this rule could be executed by the CDS inference engine.

CDS Rule

The diagram below shows a simple CDS rule based on the IF-condition-THEN-action pattern. This rule uses a SNOMED CT subset to define the set of diagnoses that should trigger the display of the asthma management guidelines. It can be read as follows - "IF the diagnosis is a member of the Asthma conditions reference set THEN display the asthma management guidelines".

Figure 4.1.1-2: CDS rule which uses fictitious "Asthma conditions ref subset" in its definition

Execution of Rule

When executing this rule, the inference engine checks the given diagnosis for membership in the 239999999106 | Asthma conditions reference set|. The associated SNOMED CT subset is defined extensionally using a simple type reference set, and its members can be queried using a standard SNOMED CT terminology service.

The diagram below illustrates the process followed by the inference engine in executing the CDS condition in the above rule, when the clinician selects a diagnosis of 370220003 |Occasional asthma|. The inference engine checks if this concept is a member of the 239999999106 |Asthma conditions reference set|, and determines that it is not a member. As a result, the condition evaluates to false, and the action is not triggered.
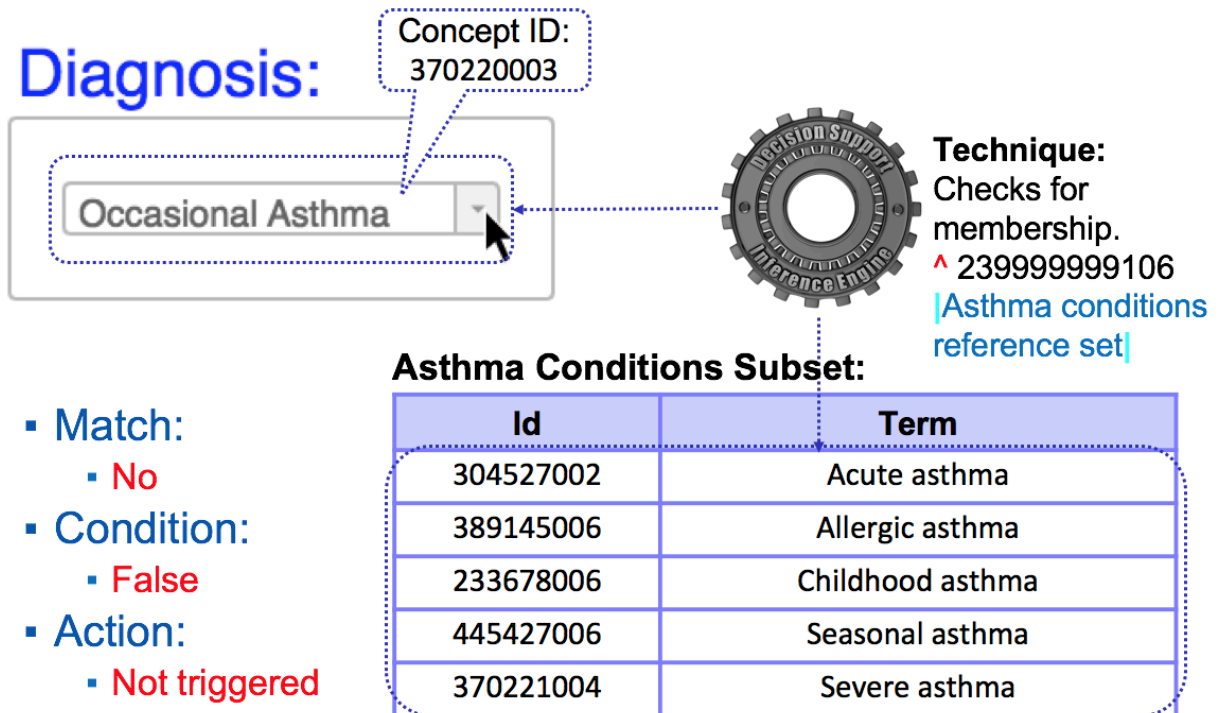
Figure 4.1.1-3: The inference engine compares the diagnosis entered against a predefined Asthma Conditions Subset

4.1.2. Reasoning using Subsumption

Overview

One of the fundamental benefits of SNOMED CT is its built-in polyhierarchy that specifies which concepts are subtypes of others. This hierarchy facilitates the automated grouping of health records which have been encoded using SNOMED CT. The 116680003 |is a| relationships in SNOMED CT form the basis of its subtype hierarchy.

For example, 54441004 |Fracture of shaft of femur| has an 116680003 |is a| relationship to 71620000 |Fracture of femur|, and therefore (as the diagram below illustrates), the concept 54441004 |Fracture of shaft of femur| is subsumed by 71620000 |Fracture of femur|.[1]

Figure 4.1.2-1: Example of subsumption

This also means that if a patient has a 54441004 |Fracture of shaft of femur|, then it is implied (i.e. it is also true) that they have a 71620000 |Fracture of femur|. We can use this principal to aggregate health records that have been encoded with SNOMED CT. By selecting any code that is a subtype of 71620000 |Fracture of femur|, we are selecting all the codes that imply that 71620000 |Fracture of femur| is true (given the appropriate context).

When testing for subsumption, we must also consider the transitivity of the 116680003 |is a| relationship. For example, the diagram below indicates that 426656000 |Severe persistent asthma| is a subtype of 370221004 |Severe asthma| which is a subtype of 195967001 |Asthma|. Therefore 426656000 |Severe persistent asthma| is also a subtype of 195967001 |Asthma|.
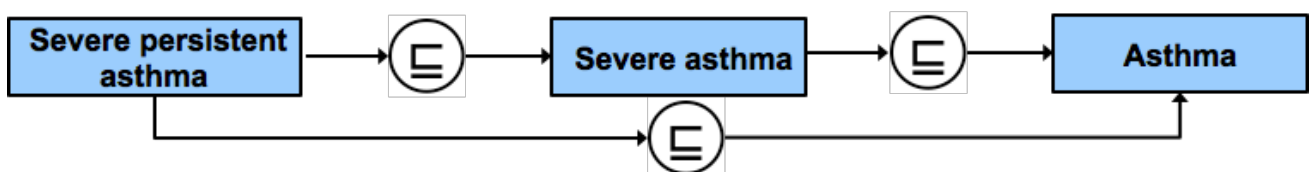
Figure 4.1.2-2: Example of subsumption and transitivity

As previously suggested in the section 1.4. SNOMED CT Features, the hierarchical relationships of SNOMED CT can be leveraged to enable clinical decision support. More specifically, we can apply subsumption testing to make additional determinations. For additional information on subsumption, please refer to 6.2 Subsumptionin Data Analytics with SNOMED CT.

Example

CDS Rule

The diagram below shows a simple CDS rule based on the IF-condition-THEN-action pattern. This rule uses the *descendant or self* operator (<<) from the Expression Constraint Language - Specification and Guide to check if the diagnosis is in the set of concepts that includes 195967001 |Asthma| and all of its subtypes.

Figure 4.1.2-3: CDS rule defined using subsumption

Execution of Rule

When executing this rule, the inference engine tests if the given diagnosis is subsumed by the concept 195967001 | Asthma|. This subsumption testing can be performed using a range of approaches, including using a 7.5.2 Transitive closure implementation. A transitive closure table facilitates rapid testing of all possible 116680003 |is a| relationships, and provides a very effective way of testing concept subsumption in relational databases.

The diagram below illustrates the process followed by the inference engine in executing the CDS condition in the above rule, when the clinician selects a diagnosis of 426979002 |Mild persistent asthma|. The inference engine checks if this concept is a subtype of 195967001 |Asthma|, and determines that it is. As a result, the condition evaluates to true, and the action is triggered.

Diagnosis:

Concept ID:
426979002

Mild Persistent Asthma

Technique:
Test for Subsumption.
<< 195967001
|Asthma|

- Match:
  - Yes
- Condition:
  - True
- Action:
  - Triggered

Transitive Closure Table:

Subtype	Supertype
304527002	195967001
389145006	195967001
426979002	195967001
445427006	195967001
370221004	195967001
	195967001
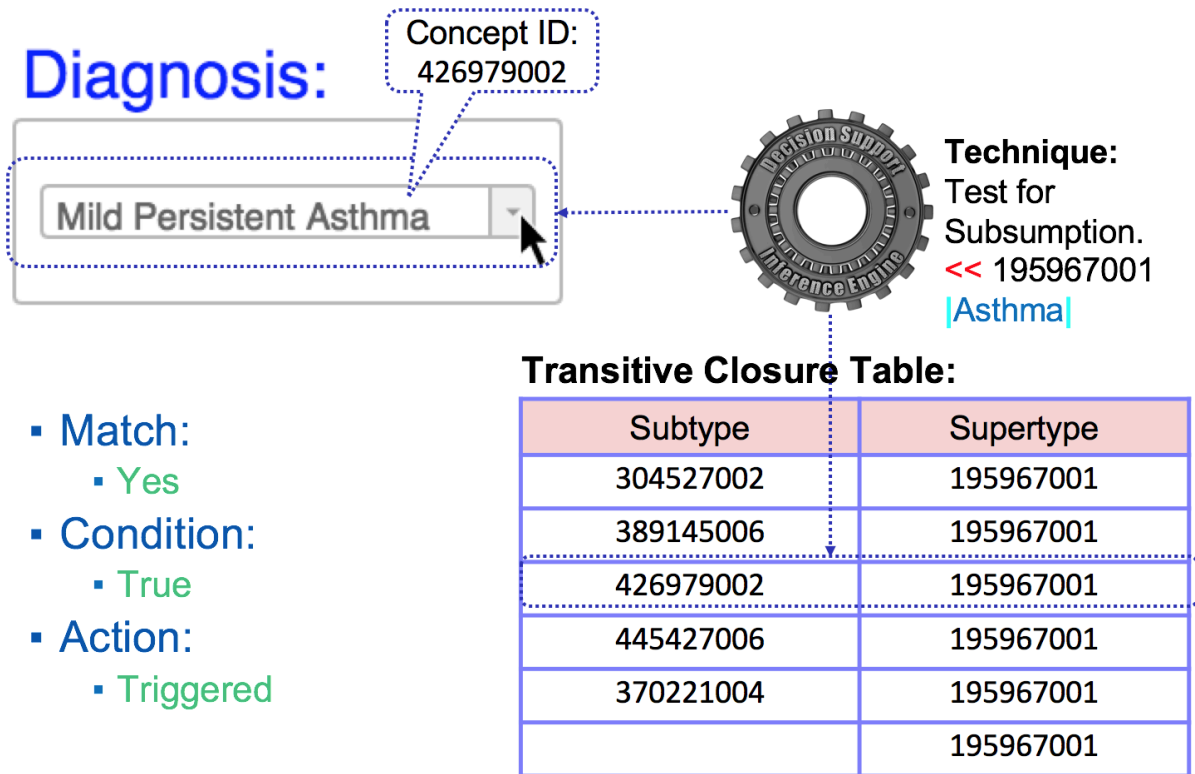
Figure 4.1.2-4: The inference engine checks if the diagnosis entered is a subtype of | Asthma|

ℹ Diagram uses notation from Diagramming Guideline.

4.1.3. Reasoning using Defining Relationships

Overview

In addition to the subtype relationships in SNOMED CT, attribute relationships may be used to support the definition of concepts. Only the relationships that are necessary (i.e. always true) are used as defining relationships in SNOMED CT. This is because these are the ones that produce reliable and consistent inferences. For example:
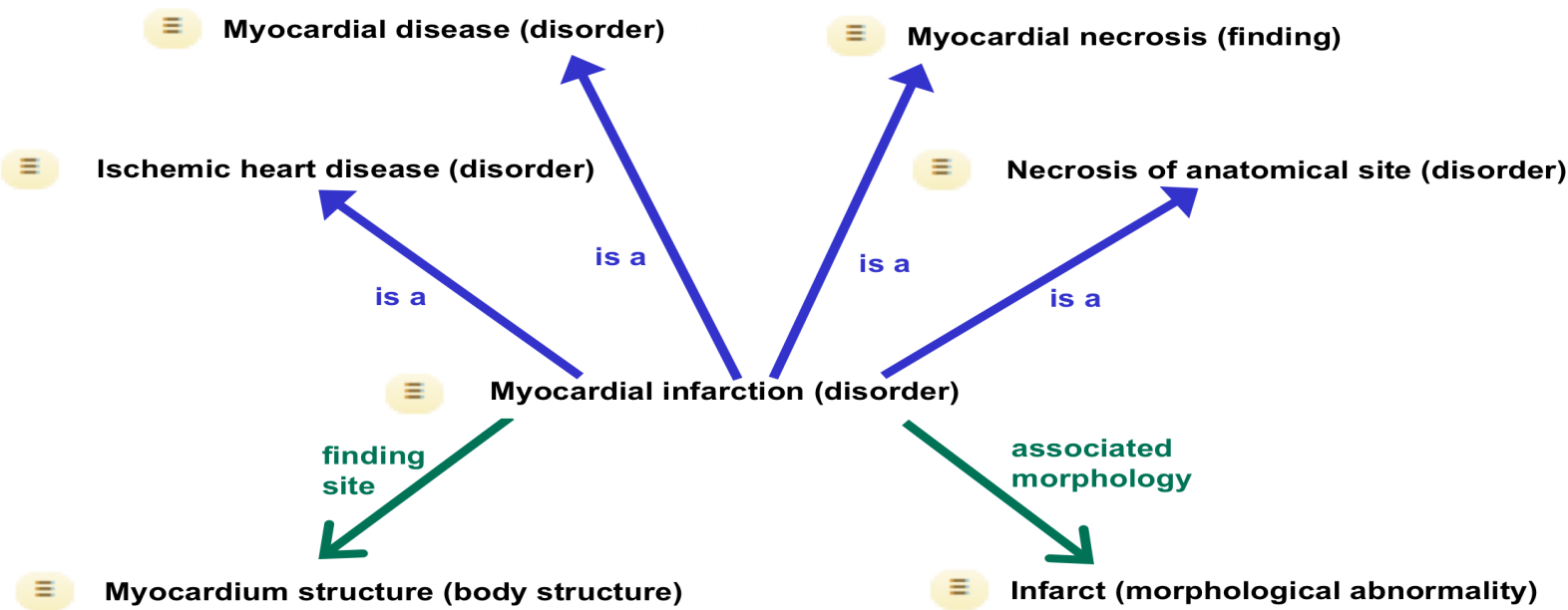
Figure 4.1.3-1: Concept definition consisting of subtype (blue arrows) and defining (green arrows) relationships

The green arrows in the diagram above show that the concept 22298006 |myocardial infarction|has two necessary attribute relationships that represent a characteristic of the meaning of the concept. It always has an 116676008 |

associated morphology|of 55641003 |infarct|, and it always has a 363698007 |finding site|of 74281007 |myocardium structure|. The blue arrows in the diagram above are used to indicate the subtype relationships.

The full definition of a concept consists of both the defining subtype relationships and the defining attribute relationships. There are over 50 attributes in SNOMED CT which can each be used as the "type" of a defining relationship, including 246075003 |causative agent|, 260686004 |method|, and 272741003 |laterality|.

The SNOMED CT Concept Model provides rules about how these attributes can be used to define concepts from different hierarchies. The SNOMED CT Machine Readable Concept Model (MRCM) represents these rules in a form that can be read by a computer and applied to test that CDS criterion comply with these rules.

As previously suggested in section 1.4. SNOMED CT Features, the defining relationships of SNOMED CT can be leveraged to support CDS. For additional information on using SNOMED CT defining relationships in queries, please refer to 6.3 Using Defining Relationships of Data Analytics with SNOMED CT.

Example

CDS Rule

The diagram below shows a simple CDS rule based on the IF-condition-THEN-action pattern. This rule uses attribute refinements in the SNOMED CT Expression Constraint Language to define the set of procedures with a 71388002 | Procedure site|that is a type of 20139000 |Structure of the respiratory system|.
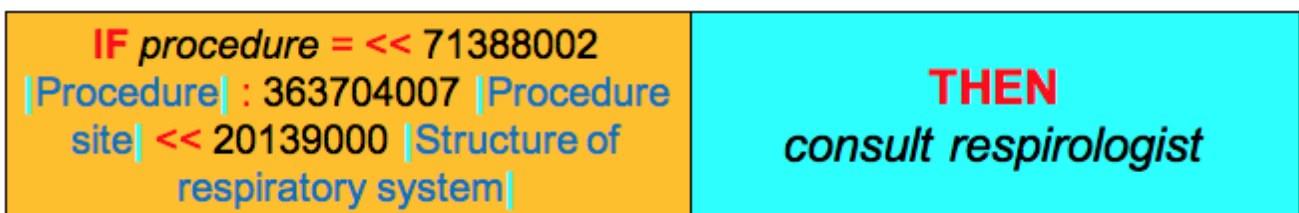
Figure 4.1.3-2: CDS rule which uses a defining relationship in its definition

Using attribute refinements in the CDS rule criteria facilitates richer expressivity and specificity in the rules. For example, we can restrict pharmaceutical/biological products based on their active ingredients, procedures based on their methods, and disorders based on their finding sites.

Execution of Rule

When executing this rule, the inference engine must process the defining relationships of each 71388002 |Procedure |concept to determine which ones have a 363704007 |Procedure site|that is a type of 20139000 |Structure of respiratory system|. These relationships are distributed as part of SNOMED CT's Release Format 2 relationship file, which can be searched by a terminology service to discover relationships that match the given attribute refinement.

The diagram below illustrates the process followed by the inference engine in executing the CDS condition in the above rule, when the clinician selects the therapy 229308003 |Intermittent continuous positive airway pressure|. Once the inference engine has found the defining relationships whose source is 229308003 |Intermittent continuous positive airway pressure|and whose type is 363704007 |Procedure site|, it determines whether the destination of these relationships is either 20139000 |Structure of respiratory system|or a subtype of 20139000 |Structure of respiratory system|(e.g. using a transitive closure table). Since the given procedure has a 363704007 |Procedure site| equal to 20139000 |Structure of respiratory system|, the condition in the rule evaluates to true, and the action is triggered.

Procedure:

Concept ID:
229308003

Intermittent CPAP

Technique:
Examine Defining Relationships.
<< 71388002 |Procedure| : 363704007 |Procedure site| << 20139000 |Structure of respiratory system|

- **Match:**
  - Yes
- **Condition:**
  - True
- **Action:**
  - Triggered

SNOMED CT Relationships Table:

sourceId	destinationId	typeId
229308003	128258000	363702006
229308003	302803009	363702006
229308003	262202000	363703001
229308003	20139000	363704007
229308003	20139000	405813007
229308003	47545007	116680003
229308003	20139000	363704007

Figure 4.1.3-3: The inference engine checks if the diagnosis entered has a defining relationship which states that the |Procedure site| is |Structure of respiratory system| or a subtype.

4.1.4. Reasoning with Description Logic

Overview

Description logic (DL) reasoners can apply additional logic-based techniques to assist with clinical decision support reasoning. Two of the DL techniques supported by SNOMED CT have been briefly described below.

It is also worth pointing out that DL can be applied over the terminology or to the terminology in combination with the record structure. For more information on this topic, please refer to sections 6.4 Description Logic Over Terminology and 6.5 Description Logic Over Terminology and Structure in the guide Data Analytics with SNOMED CT.

Expression Subsumption

SNOMED CT supports the use of postcoordinated expressions to define additional clinical meanings beyond the standard precoordinated concepts. Postcoordinated expressions are comprised of two or more concepts, and are structured in accordance with the compositional grammar. A simple example of a postcoordinated expression is:

399963005 |Abrasion| :
  363698007 |Finding site| = 67269001 |Skin structure of ankle|

This can be read as "an abrasion with a finding site of skin of ankle".

When postcoordinated expressions are used to capture and record clinical meaning in a health record, the CDS inference engine may need to be able to test if one expression subsumes another to execute the CDS rules. For example, it would be reasonable to conclude that the first expression listed below, subsumes the second expression if you were aware that 40196000 |Mild pain| is subsumed by 22253000 |Pain|.

373572006 |Clinical finding absent| :
  246090004 |Associated finding| = 22253000 |Pain|
	⊑	373572006 |Clinical finding absent| :
		  246090004 |Associated finding| = 40196000 |Mild pain|
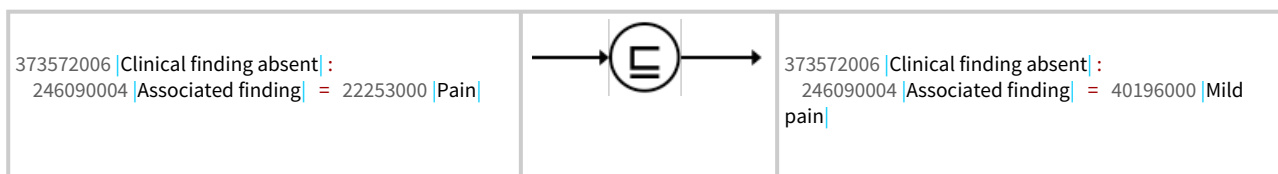
However, many expressions are much more complex than this and may involve multiple focus concepts, attribute groups, and nesting as examples. There are a couple of methods which can be utilized to determine if one expression subsumes another. The first process, which is a manual process, involves 12.4.2 Normalize Expression the expressions , comparing the primitive focus concepts, and then comparing the defining attributes. The other is an automated process which can be used to compare expressions for subsumption. Expressions can be imported into a description logic classifier and classified in the same way as SNOMED CT concept definitions, which tests for subsumption in the process.

Property Chaining

The transitive nature of the 116680003 |is a| attribute allows us to make subtype inferences. This topic was explored in the section on Reasoning using Subsumption. In some cases, different types of attribute relationships may be related to one another in such a way that additional inferences are possible. For example (using fictitious concepts) if Lucy 619999999100 |Has sister|Beth, and Beth 629999999107 |Has daughter|Jane, then Lucy 639999999109 |Has niece|Jane. The chain from 619999999100 |Has sister|to 629999999107 |Has daughter| implies 639999999109 |Has niece|. This rule can be expressed as:

619999999100 |Has sister|	o	629999999107 |Has daughter|	→	639999999109 |Has niece|
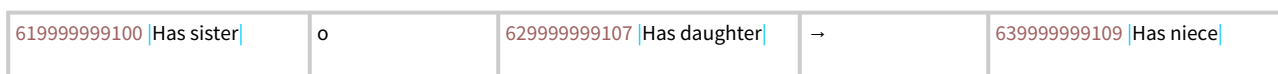
At present, the only property chain recognized in the International Edition of SNOMED CT is from |Direct substance| to |Active ingredient|and can be expressed as such:

363701004 |Direct substance|	o	127489000 |Has active ingredient|	→	363701004 |Direct substance|
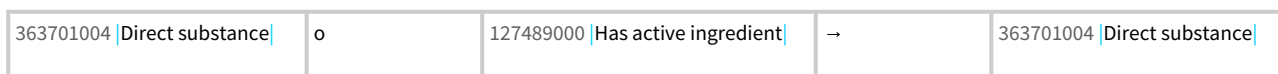
This can be used to provide a link from product administration (as part of a procedure) to substance administration. Additional property chains can be added at the local implementation level, if required.

4.2. Accessing Clinical Records

This section describes the approaches that inference engines use to access EHR records for CDS. The CDS rules that an inference engine executes typically include references to EHR records and terminology. There are two general approaches to accessing health records from these CDS artifacts. The first is the direct access approach, in which a reference to the physical store is used. A simple example of this would be a reference to a patient diagnosis in a database table. The other approach is to base the CDS references on a common logical information model, and then map this to one or more physical datastores, as required. This approach enables a more standardized approach to the development of CDS rules and other artifacts. These two approaches are described in more detail below, along with some of the advantages, challenges, and examples. Please note that standards for accessing clinical records will be discussed in section 4.2.1. Standards for Accessing Clinical Records. Approaches to access the terminology which will be discussed in section 4.3. Accessing Terminology.

Direct Access

Perhaps the most obvious approach to accessing health records is to use direct references to the locations in the clinical record store that will be used in a CDS rule. Many consider this the more common approach for point of care (POC) decision support today. For example, the pointers within a CDS rule could be expressed to reference a schema, table, and column in an SQL database. This approach requires a detailed knowledge of how the EHR data is stored to achieve an appropriate outcome from CDS tools. The challenge with this approach is that it can be more difficult to share CDS artifacts across institutions that may use different physical data stores.

Logical Model

The logical model approach aims to standardize all references to EHR data, by specifying a common logical information model upon which all CDS rules are defined. This enables CDS rules to be shared and reused in different physical implementations. However, an additional transformation is usually required for each physical EHR store, to convert the logical references into physical ones. Examples of the logical model approach are presented in section 4.2.1. Standards for Accessing Clinical Records.

4.2.1. Standards for Accessing Clinical Records

This section presents some examples of standards for accessing clinical records. Please note that this list is not complete, and other standards and formalisms for accessing clinical records do exist.

Clinical Information Modeling Initiative

The HL7 Clinical Information Modeling Initiative (CIMI) is an HL7 International working group, which aims to improve the interoperability of healthcare systems by providing a shared open library of implementable clinical information models.[1] CIMI clinical models, which are defined using computable formalisms such as the Archetype Definition Language (ADL) and Archetype Modeling Language (AML), are based on a common reference model using a common set of data types. CIMI models also have formal bindings to standard terminologies, including SNOMED CT and LOINC. SNOMED CT has been selected as the primary reference terminology for CIMI's clinical models. A number of CDS efforts within HL7 International are expected to use CIMI clinical models as the basis for referencing clinical data within CDS artifacts. For more information on CIMI please refer to Clinical Information Modeling Initiative (opencimi.org) and Clinical Information Modeling Initiative (HL7 work group).

Quality Information and Clinical Knowledge model

The Quality Improvement Core (QICore) Implementation Guide is a U.S. realm-specific CDS initiative that references a logical model called the Quality Information and Clinical Knowledge (QUICK) model. The QUICK model (which is expected to be aligned with CIMI formalisms) will provide a uniform way for clinical decision support and quality measures in the U.S. to refer to clinical data.[2] The QUICK logical model is defined as a series of QICore specific FHIR profiles. It provides a way for applications to access data using FHIR interfaces. Several of these QICore profiles have bindings to SNOMED CT value sets in their definition. For example, the Condition model (shown below) binds a 'SNOMED CT Body Structure' value set to the data element 'bodySite'.

!

Figure 4.2.1-1: QUICK Conditions model

The QUICK logical model provides the basis upon which the FHIR RESTful interfaces refer to clinical data in a CDS service. For more information on QICore please refer to Quality Improvement Core (QI-Core) Implementation Guide.

Virtual Medical Record

The Virtual Medical Record (vMR) for CDS is an HL7 standard, which describes a standardized "virtual interface" for CDSSs to refer to the data in clinical records. The vMR logical data model is based on the HL7 V3 RIM (Reference Information Model). Developing CDS rules can be time-consuming and costly. Hence, the key goal of the vMR is to provide a simplified common information model upon which sharable CDS resources can be developed.[3] To implement the vMR, each EHR system must create a virtual interface that exposes its clinical data in the

standardized vMR format, to facilitate shared CDS logic working across multiple EHR systems.[4] An example of an expression, written in terms of the HL7 vMR, which could be used in a CDS rule, is shown below. This expression asserts that a patient has a condition of 195967001 |Asthma| that has a status of 55561003 |Active|.

Example from HL7 Version 3 Standard: Clinical Decision Support; Virtual Medical Record (vMR) Logical Model, Release 2

```
clinicalstatement[xsi:type="vmr:Problem" and

    /templateId[root="2.16.840.1.113883.3.1829.11.7.2.5"] and

    /conditionCode[codeSystem="2.16.840.1.113883.6.96" and code="195967001"] and

    /conditionEffectiveTime[/low[value<="20130814"]] and

    /conditionStatus[codeSystem="2.16.840.1.113883.6.96" and code="55561003"]

    ]
```

Figure 4.2.1-2: vMR expression example

The vMR's data model includes clinical findings, problems, allergies, adverse advents and patient history. The vMR was also optimized to permit CDS languages such as GELLO to reference a standard model of clinical data. For more information about the HL7 vMR please refer to the HL7 Version 3 Standard: Clinical Decision Support; Virtual Medical Record (vMR) Logical Model, Release 2.

GELLO

GELLO[5] is an object-oriented programming language that can be used to support access to health record data in CDS. It has been adopted by ANSI and HL7 as a language used in CDS and GELLO Release 2 now part of the HL7 v3 product suite.

GELLO provides a standardized interface and query language for accessing data in health information systems. Expressions can also be defined to compare data values and attributes. These values and attributes can then be used in decision support knowledge resources such as rules and guidelines. GELLO works hand in hand with the Virtual Medical Record (vMR). A major advantage of this approach is that GELLO code can be used in different environments where health data is stored using a variety of formats and technologies.

Using GELLO with the vMR ensures that the code does not alter the physical medical record. It can also be used to answer complex queries and to query a reference terminology such as SNOMED CT. The example screen shot below illustrates how SNOMED CT refinements can be used in a GELLO expression:

```
 1  imports SnomedCT
 2
 3  Let utterances:Sequence(SnomedUtterance) =
 4    Sequence{
 5      SnomedUtterance{code='31978002'},
 6      SnomedUtterance{code='65363002'},
 7      SnomedUtterance{code='46866001 |Fracture of lower limb (disorder)| :'+
 8        '    { 363698007 |Finding site (attribute)| = 12611008 |Bone structure of tibia (body structure)|,'+
 9        '      116676008 |Associated morphology (attribute)| = 72704001 |Fracture (morphologic abnormality)| }
10      }
11
12  utterances->collect(u|
13  Tuple{
14      utterance=u,
15      validate=u.validate(),
16      canonical_form_short = u.canonical_form(false),
17      preferred_name=u.preferred_name(),
18      top_level_concept_id=u.top_level_concept_id(),
19      verbose_form=u.verbose_form(),
20      synonyms=u.synonyms()
21      })
```

Figure 4.2.1-3: GELLO expression using SNOMED CT refinement

For more information about GELLO, please refer to HL7 Version 3 Standard: GELLO, A Common Expression Language, Release 2 or http://gello.org.

---

[1] http://www.hl7.org/Special/Committees/cimi/overview.cfm

[2] http://hl7.org/fhir/us/qicore/2016Sep/index.html

[3] HL7 Decision Support Service (DSS) and Virtual Medical Record (vMR) Standards, and OpenCDS Open-Source Implementation presentation, Kawamoto

[4] http://www.hl7.org/implement/standards/product_brief.cfm?product_id=338

[5] https://kb.medical-objects.com.au/display/PUB/GELLO

4.3. Accessing Terminology

As references to terminology codes may exist in both health records and CDS artifacts, the inference engine needs to be able to access terminology services to execute CDS logic. Furthermore, to maximize the benefits of using SNOMED CT, additional terminology operations, such as finding descendants of a concept and finding the value of a defining relationship, can be used. For example, a CDS rule may refer to all the descendants of 56265001 |Heart disease| to ensure that a specific cardiology CDS rule is applied to all applicable diagnoses. Similarly, a CDS rule may need to find all the active ingredients in a medication, to ensure that a contra-indication does not occur.

This section discusses some of the options that a CDS inference engine can use to access terminology content.

Terminology Services

As discussed in section 2.1. EHR System Architecture, terminology services are those services required to load, update, access and make effective use of terminology content. Terminology services provide important functions to CDSSs, such as term searching (i.e. synonyms), definitional and reference set querying, and retrieval of map data. It is also useful if Terminology Services support the execution of the Expression Constraint Language, as this is a standardized way of representing terminology queries in CDS rules. For more information on Terminology services, please refer to the SNOMED CT Terminology Services Guide.

SNOMED CT APIs

An application programming interface (API) for a SNOMED CT enabled terminology server can be used to execute SNOMED CT searches and queries. The principle benefit of using a terminology server API is the reusability. Other systems are able to access terminology services without having to re-implement their functionality. Another key benefit is that the internal workings of the solution can be modified, improved, upgraded without impacting the external interfaces. For example, SNOMED CT can be updated, without necessitating any changes to the external systems which use terminology services. A number of commercial terminology servers offer proprietary APIs that enable SNOMED CT search and query. These include Dataline's SnAPI solution and B2i's Snow Owl Terminology Server.[1] The following diagram depicts how the individual terminology services interact with the terminology store:
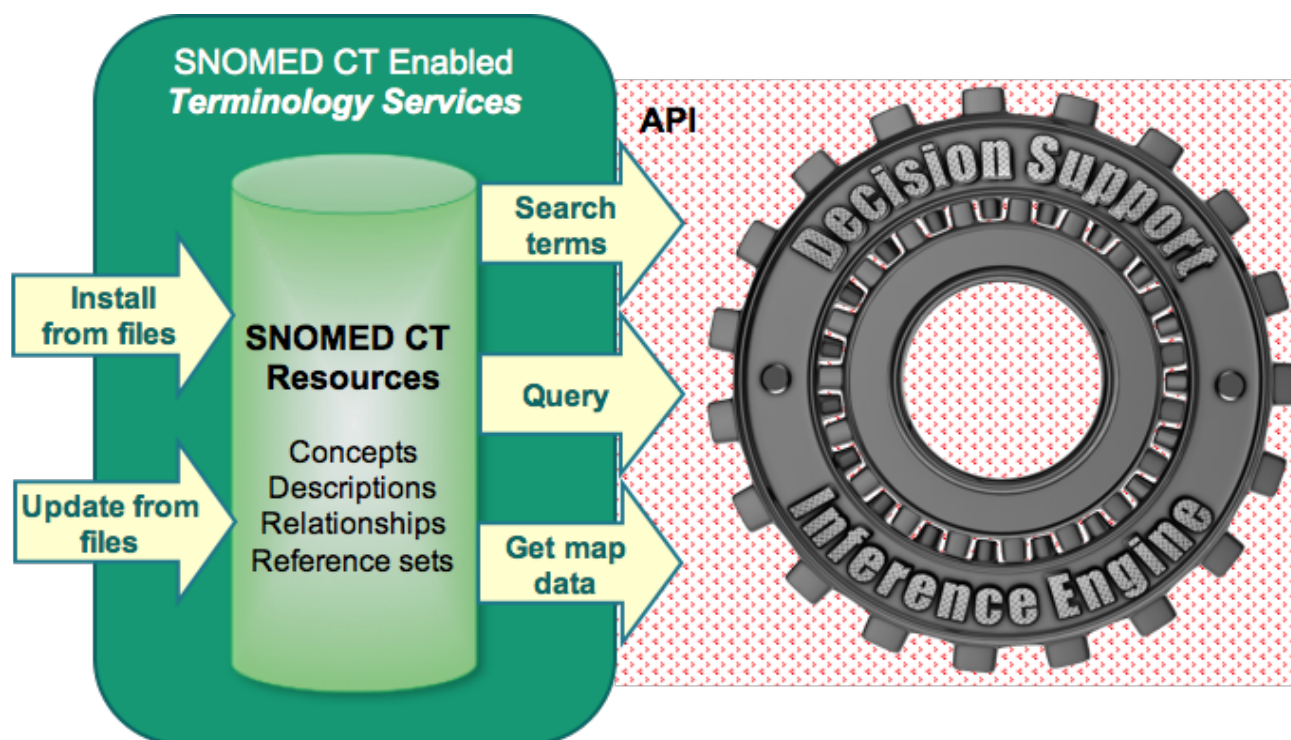
Figure 4.3-1: Terminology services and terminology store interactions

Services that load the terminology data into the server, either for installation or updating are illustrated on the left, while services which search and query over the installed terminology content are depicted on the right. The diagram also shows how the services depicted on the right could be made available to other services and components such as a CDS inference engine through the use of an API.

Standardized Terminology APIs

Standardized APIs for terminology services are also available. For example, HL7's specification for a FHIR Terminology Service, which is described as a service that lets healthcare applications make use of codes, code systems, and value sets without having to become experts in the fine details of terminology. [2] The services provided include code lookup and validation, value set expansion, subsumption testing, and maintaining a transitive closure table. HL7 has also published Common Terminology Services 2 (CTS2) which provides a standardized API that supports access to terminology servers which may contain a variety of code systems, including SNOMED CT.

---

[1] http://snomed.org/analytics
[2] http://hl7.org/fhir/terminology-module.html

5. Communications

Overview

The purpose of the communications mechanism is to handle CDS communications into and out of the system. Examples of user inputs include entry of clinical data, and the selection of a proposed drug, order set, or treatment regime. Examples of outputs include CDS interventions such as alerts, guidelines, diagnostic refinements, and smart forms. These outputs are typically delivered to the u ser interface. SNOMED CT has limited involvement in the communications mechanism of CDS as most of the codes and features will be used by the knowledge base and inference engine. That being said, it is possible that SNOMED CT terms are used at the user interface level as part of the data entry process. For more information on using SNOMED CT to support data entry, please refer to the SNOMED CT Search and Data Entry Guide. SNOMED CT can also be used in the CDSS outputs. For example, using the relevant terms in the alert messages, populating smart forms with SNOMED CT codes, or linking terms in CDS guidelines to other appropriate clinical knowledge sources.

The figure below depicts the key interactions of the CDS communications mechanism.
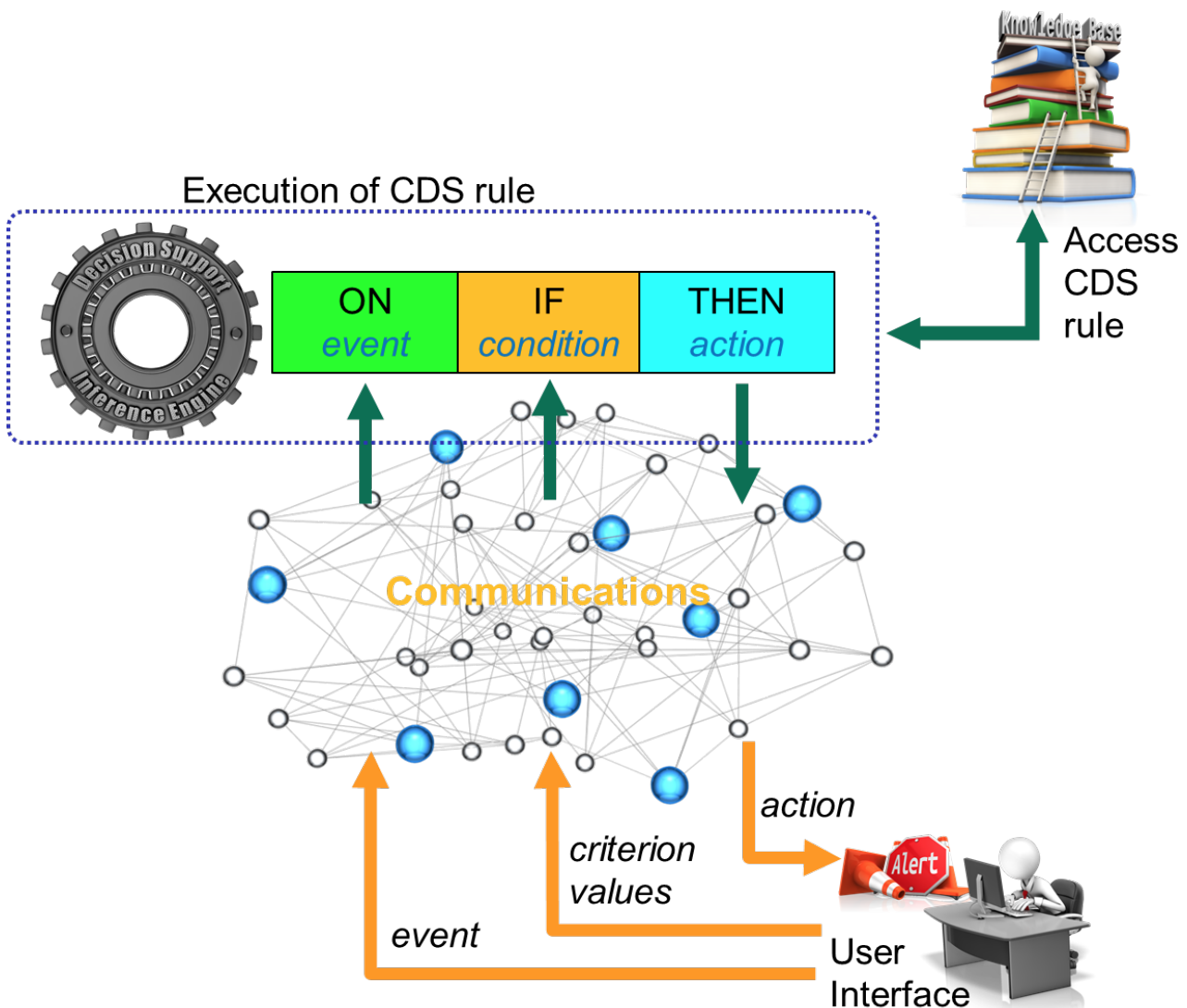
Figure 5-1: Communications key interactions

Once the inference engine has determined that an intervention is appropriate, the communications mechanism takes over and handles its delivery. Conversely, user inputs are also delivered into the CDSS by the communications mechanism. Note that guidelines or knowledge resources may reference externally hosted content, which may be accessed by the user via a link. An example of this would be a PubMed[1] citation for biomedical literature.

Note that the diagram also shows how the internal CDSS communications (associated with the external inputs and outputs) are related to the components of the CDS rule. The communication 'inputs' feed into the event (from "ON event") and the condition (from "IF condition") components of the rules, while the 'outputs' are the result of the action (from "THEN action") that is performed if the event occurs and condition is true.

Example

The following screenshot[2] was generated from an EHR with CDS capabilities. This illustrates what a typical CDS intervention may look like.
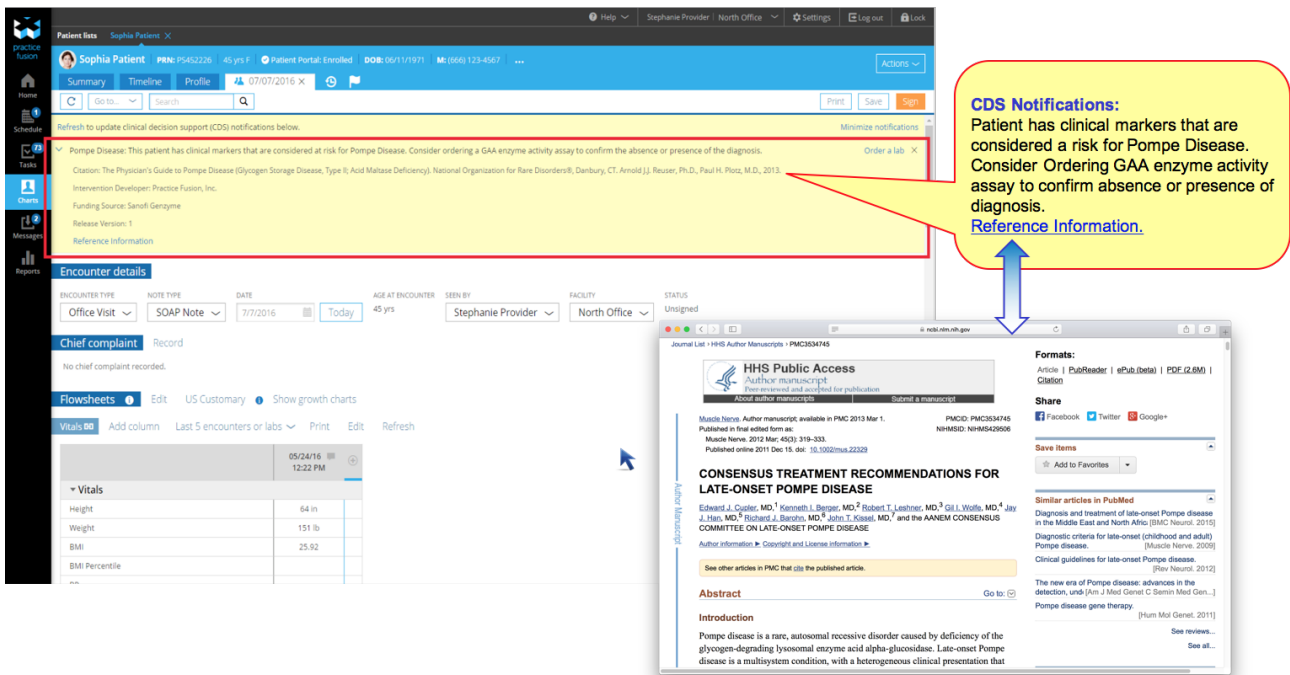
Figure 5-2: User Interface depicting CDS intervention which links to knowledge resource

Note that the contents of this alert have been magnified for the purpose of this illustration. Characteristics of this alert include:

- It appears at the top of the screen using fonts and colors that help to distinguish it from other content. (Alerts, by design, are intended to be noticed.)
- It includes mechanisms to process the intervention as appropriate (e.g. to acknowledge, accept or discard the alert). In this case, the alert my be closed (by clicking the X) or the suggestion to order a lab test may be accepted (by clicking on "order a lab").
- It provides a link to applicable reference information (as illustrated above by the PubMed[3] screenshot.)
- It includes an option to "minimize notifications". This option allows the user to minimize the number of alerts displayed, by selecting the types of alerts they wish to receive in their user preferences.

Alert Fatigue

Alert fatigue[4] is an unwanted side effect of CDS. Alert fatigue occurs when clinicians become overwhelmed by or desensitized to CDS alerts because of their sheer number, intrusive nature, or non-relevance to a clinical situation. The danger of alert fatigue is that the clinician will miss something important as a result. Strategies are required to minimize alert fatigue. Some of the interesting ideas proposed by thought leaders in CDS include:

- Increasing the specificity of alerts;
- Allowing users to customize CDS alerts by types of interventions
- Using a human factors approach to designing alerts

SNOMED CT is able to help with the first two items above. Firstly, it can be used to increase the specificity of the CDS conditions that trigger the alerts. And secondly, it can be used to distinguish between different types of interventions to enable customization to occur. Please refer to False Positives and False Negatives in the section Context in CDS Rules for more information on minimizing alert fatigue.

---

[1] https://www.ncbi.nlm.nih.gov/pubmed/
[2] Screenshot provided by Practice Fusion.
[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534745/
[4] Uses content from: https://psnet.ahrq.gov/primers/primer/28/alert-fatigue

5.1. Standards for CDS Communications

An example of a standard which relates to CDS communications is provided below.

CDS Hooks

CDS Hooks is a relatively new CDS initiative which aims to automate the launching of applications that assist with decision support. CDS Hooks are designed around the premise of a clinician initiating a triggering activity within the EHR. When the triggering activity occurs, the EHR automatically sends a notification in real time to a decision support service (DSS).[1] This notification is considered the "hook" to the decision support logic. An example of a triggering activity would be a clinician writing a prescription. Some pre-defined hooks have already been developed and new hooks can be defined and added to the catalogue as required. Once the DSS is aware of the specific event, it may generate a response in the form of a "card" to be displayed in the UI of the EHR. An example of an "information" card might be one that contains pricing data about a proposed drug. The DSS could then propose a more cost effective "suggestion" card as an alternative. The other type of card the DSS may offer is an "app link" card which, as the names suggests, provides a link to an external application that can assist with further decision support. This architecture eliminates the need for the user to be aware of specific decision support applications that may be useful. The final outcome or choice, initiated by the app link card process, can then be automatically transferred to the appropriate field(s) in the EHR. A clinician has the option to accept or decline any suggestions present in the card. References to external knowledge resources may also be present in CDS Hooks cards.

The screen shot[2] below captures part of a CDS hook. Note that the condition the clinician is treating is represented using the SNOMED CT code for 396275006 |Osteoarthritis|.
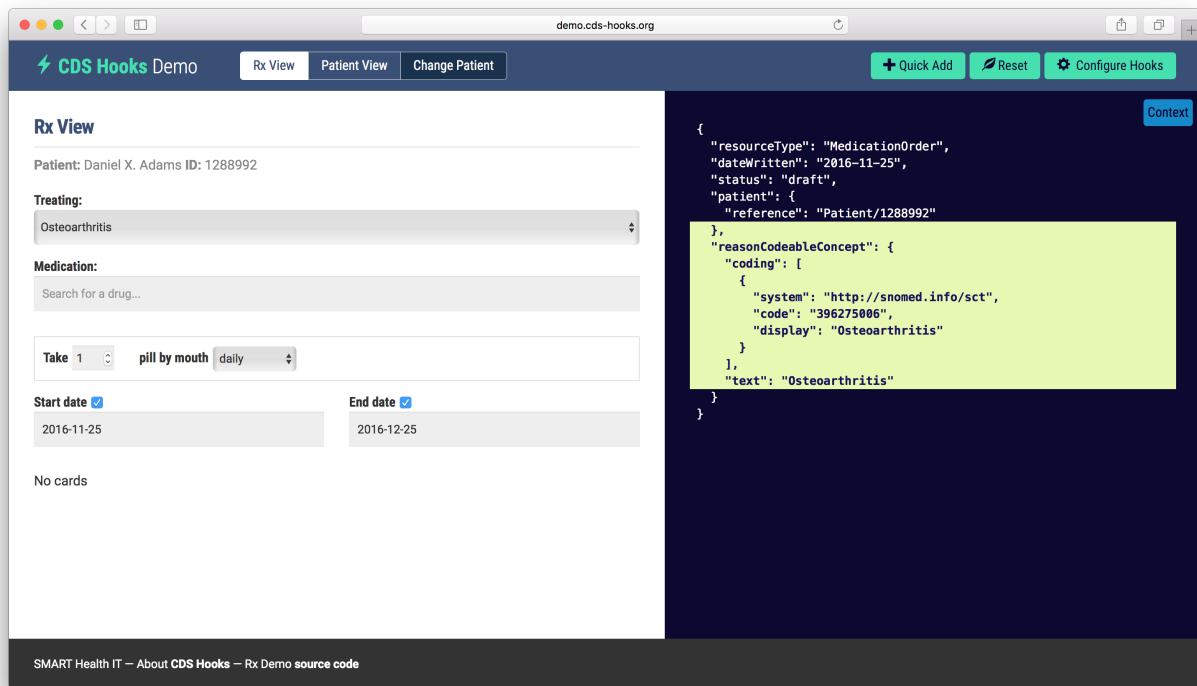
Figure 5.1-1: CDS Hooks demonstration tool

For more information about CDS Hooks, please refer to http://cds-hooks.org/.

---

[1] HL7 definition of DSS: "A Decision Support Service takes in patient data as the input and provides back patient-specific assessments and recommendations."

[2] Screen shot from CDS Hooks Demo

Appendix A - Decision Support Case Studies

As discussed in this guide, SNOMED CT is increasingly being used in clinical decision support (CDS) systems to support healthcare providers in making well informed clinical decisions.

This appendix presents two sets of case studies, which demonstrate the use (or planned use) of SNOMED CT in clinical decision support systems.

- Organizational Case Studies describes a range of organizations that use SNOMED CT for clinical decision support;
- Vendor Case Studies describes a number of commercial products that use SNOMED CT to enable clinical decision support.

Organizational Case Studies

This section describes a range of organizations that have used SNOMED CT for clinical decision support. The organizations that have contributed to this review include:

EBMPracticeNet

In Belgium, the construction of a national electronic point-of-care information service, EBMPracticeNet, was initiated in 2011 to optimize quality of care by promoting evidence-based decision-making... All Belgian health care professionals get free access to an up-to-date database of validated Belgian and nearly 1000 international guidelines, incorporated in a portal that also provides EBM information from other sources than guidelines, including computerized clinical decision support that is integrated in the EHRs. [1]

For more information please visit https://www.ebmpracticenet.be.

Overview

EBMPracticeNet is a consortium of Belgian organizations whose mission is to develop a national online knowledge base of clinical practice guidelines based on evidence-based medicine (EBM). The project is funded by RIZIV-INAMI, the Belgian national health insurer. The consortium acknowledges that clinical decision support systems play a vital role in the implementation of evidence-based medicine. EBMPracticeNet is very active in the development, evaluation, and distribution of evidence based CDS knowledge, mainly for use in primary care settings. Their users include family physicians, nurses, physical therapists, occupational therapists, pharmacists, speech therapists, patients, and eventually dentists. Clinicians will access the system through their EHRs with an Infobutton (called "EvidenceLinker") which links coded diagnoses to relevant guidelines on the platform. The consortium is in the process of conducting an analysis to compare several terminologies to gauge which may be best suited for using encoded health records from a primary care setting with CDS services. An early version of the analysis report has identified SNOMED CT as the terminology with the most comprehensive coverage and best suited to unambiguously describe the concept.

Technology

The EBMPracticeNet consortium hosts a platform of clinical practice guidelines. Seventy five of these are from Belgium, and an additional 1000 international guidelines have been developed by Duodecim, the Finnish developers of EBM guidelines. The knowledge resources from Duodecim have been translated from its language of origin into both Dutch and French, and localized for Belgium using a variant of the ADAPTE framework. Currently all guidelines are accessible through the EHR using the EvidenceLinker, which suggests relevant guidelines based on the coded diagnosis. The EvidenceLinker currently uses ICPC-2 codes for this linkage. Additionally, EBMPracticeNet uses Duodecim's EBMeDS as the engine in their clinical decision support system, which is currently in the pilot phase. A depiction of the architecture is shown below.
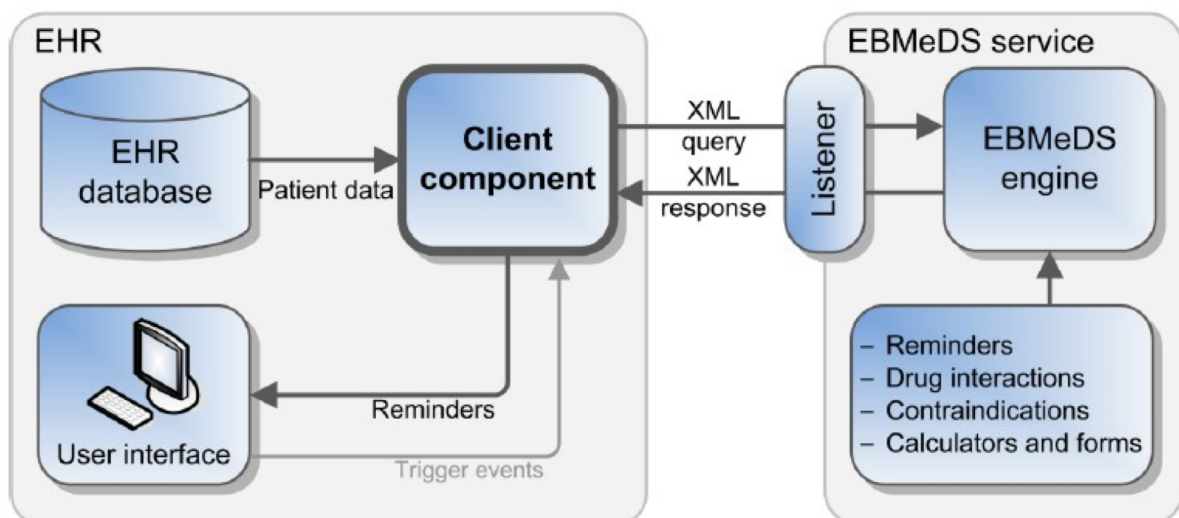
Figure 1: EBMeDS architecture

SNOMED CT

All EBMPracticeNet guidelines are associated with metadata which includes the relevant diagnosis codes for the ICPC-2 and ICD-10 classification systems. Mapping work is being considered that would add the appropriate SNOMED CT codes to this metadata. The SNOMED CT codes could then be used to link diagnoses to relevant clinical guidelines using EvidenceLinker. This EvidenceLinker feature is already available in all commercially available EHR systems in Belgium, which will help to facilitate rapid deployment. The CDSS engine, EBMeDS, has been designed to process SNOMED CT encoded health records.

EBMPracticeNet: A Bilingual National Electronic Point-Of-Care Project for Retrieval of Evidence-Based Clinical Guideline Information and Decision Support

Kaiser Permanente

> Founded in 1945, Kaiser Permanente is one of the nation's largest not-for-profit health plans, serving more than 11.3 million members, with headquarters in Oakland, California.[1] The (Kaiser Permanente HealthConnect) system facilitates communication between our members and health professionals to help make getting well and staying healthy easy and convenient. It improves member safety and quality of care by providing access to comprehensive patient information and the latest best practice research in one place. [2]
>
> For more information please visit https://healthy.kaiserpermanente.org/.

Overview

Kaiser Permanente (KP) has a long history with SNOMED CT, dating back to the 1990s when they collaborated with the College of American Pathologists (CAP) on the development of SNOMED RT (Reference Terminology). KP was also one of the first healthcare organizations to implement a SNOMED CT enabled health record (EHR). KP HealthConnect (KPHC), Kaiser Permanente's enterprise electronic medical record, was developed by Epic and hosts the records of over 10 million patients.[3] KPHC uses a set of clinician and patient friendly terminologies, collectively known as the Convergent Medical Terminology (CMT), with SNOMED CT as its core reference terminology.[4] KP has made their contributions to SNOMED CT available to the broader community by donating CMT to SNOMED International and the US National Library of Medicine (NLM).

KP HealthConnect

KP loads SNOMED CT in its native RF2 format into the HealthConnect EMR system. The EMR "Chart Search" functionality can execute a global search for diagnoses, procedures, and laboratory results against a given patient. All patient encounters that match the resulting criteria are displayed to the clinician. This provides a global summary of all encounters which relate to a given condition. This function takes advantage of the hierarchical structure of SNOMED CT. KP also maps the "clinician friendly" terms used in the EMR to SNOMED CT to meet Meaningful Use and Health Information Exchange reporting requirements.

Value Sets

Value sets are an integral part of terminology management services at Kaiser Permanente. Value set identification, development, deployment, and maintenance is performed using a custom tool developed within KP. This "Subset Management" tool utilizes the native ontological structure of SNOMED CT and adds KPHC local terminology as additional artifacts within the terminology model. The formal concept definitions of SNOMED CT are used to define and generate the required value sets. The "CMT Query" tool also uses the hierarchy of SNOMED CT and description logic reasoning to identify value sets of clinician friendly terms used in patient clinical encounters. These value sets are also used within KPHC to drive business intelligence (including CDS), support workflow, and enable data reporting and analytics. As shown in the screen shot below, the queries used to define value sets leverage SNOMED CT defining relationships, such as those using the attributes 363698007 |Finding site|and 116676008 |Associated morphology|.
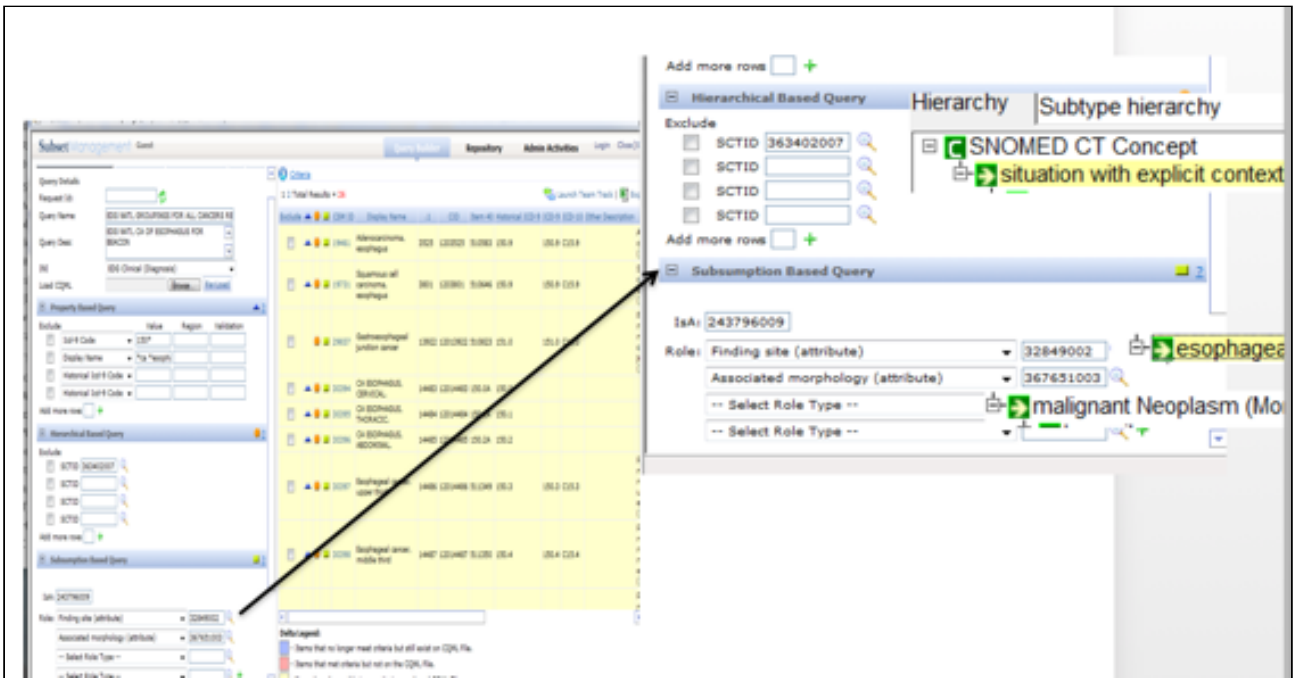
Figure 1: KP Query Tool enables subset management using SNOMED CT's hierarchy and defining relationships

Clinical Decision Support

KP uses the native functions provided by Epic to define and maintain CDS rules. This accounts for all criteria used in the rules, such as inclusions and exclusions. A screen shot of the tool used to define these criteria is shown below.
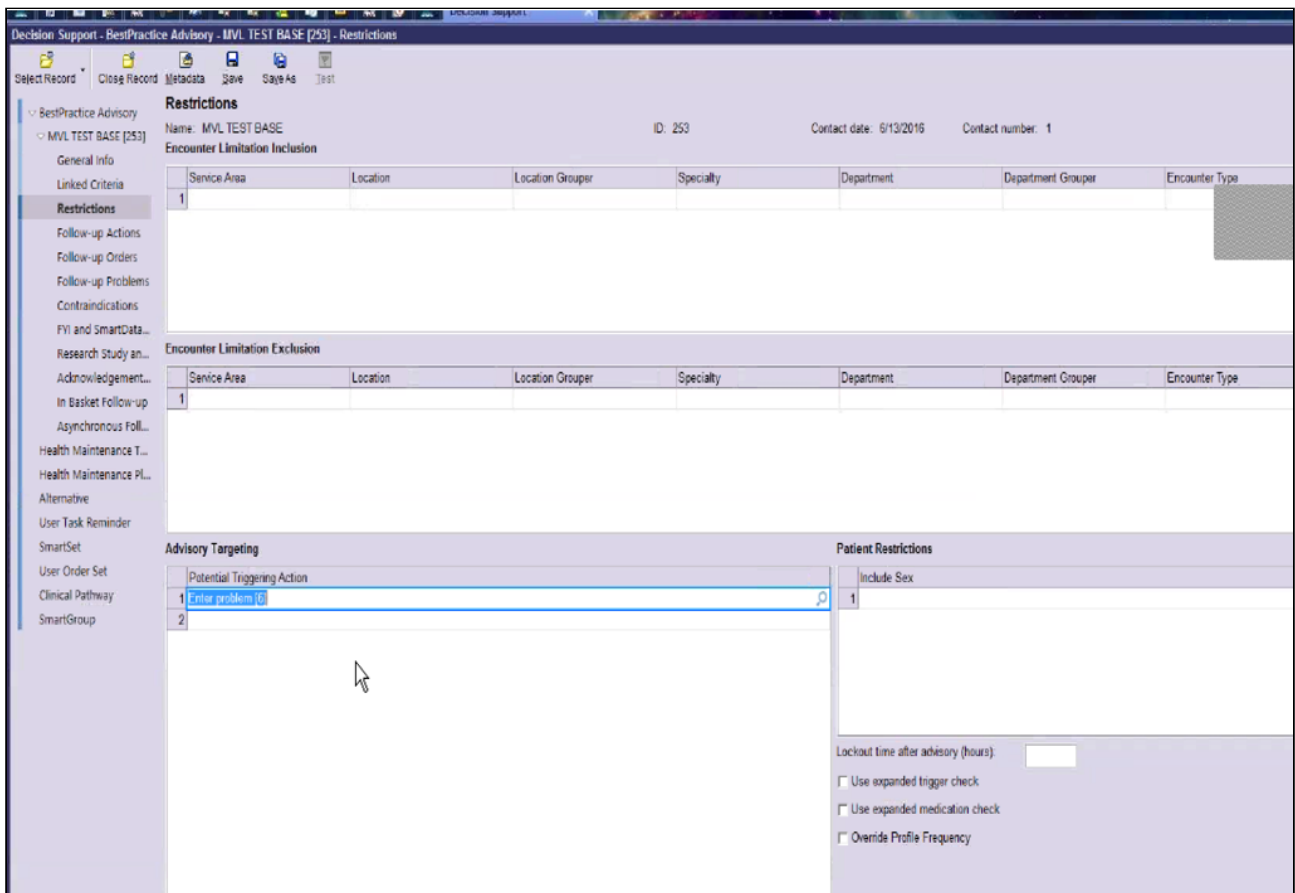
Figure 2: KP uses Epic's built-in functions to define CDS rules (in this case a best practice advisory).

Clinical decision support at Kaiser Permanente leverages the value sets developed by their CMT team. For example, a CDS rule which uses value sets associated with 195967001 |Asthma|and 33252009 |beta-blocker|drugs is used to

trigger an alert when specific conditions are met in the patient encounter, diagnosis, or problem list. The diagram below shows the associated value sets used in this rule.
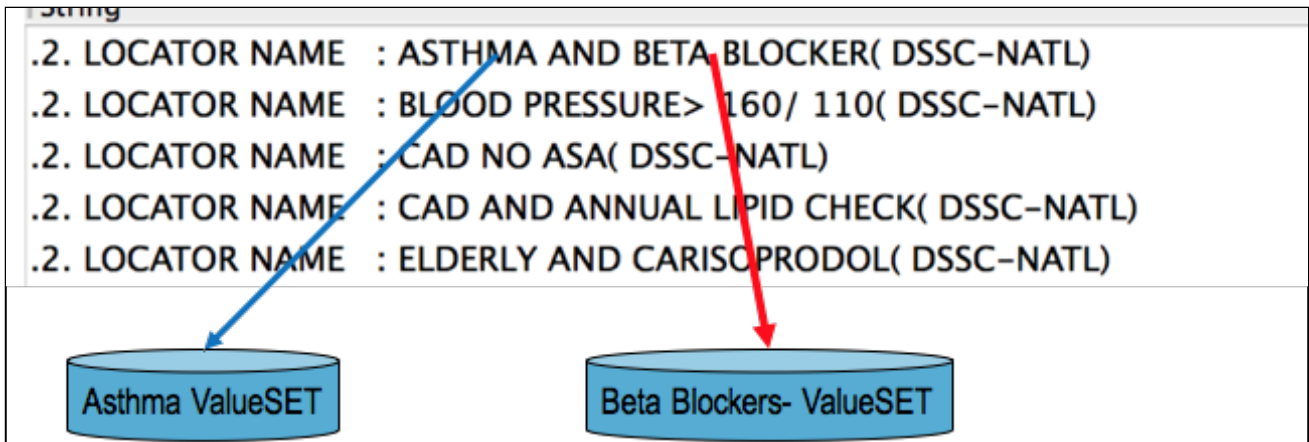
Figure 3: An example of an alert that uses SNOMED CT value sets in business intelligence and CDS at KP

---

[1] https://share.kaiserpermanente.org/article/fast-facts-about-kaiser-permanente/
[2] https://share.kaiserpermanente.org/total-health/connectivity/
[3] https://share.kaiserpermanente.org/total-health/connectivity
[4] https://www.nlm.nih.gov/research/umls/cmt/cmt_faq.html#q1

National Institutes of Health: Intramural Research Program

The Intramural Research Program is the internal research program of the National Institutes of Health. With 1,200 Principal Investigators and more than 4,000 Postdoctoral Fellows conducting basic, translational, and clinical research, the IRP is the largest biomedical research institution on earth.[1]

For more information please visit: https://www.nih.gov/.
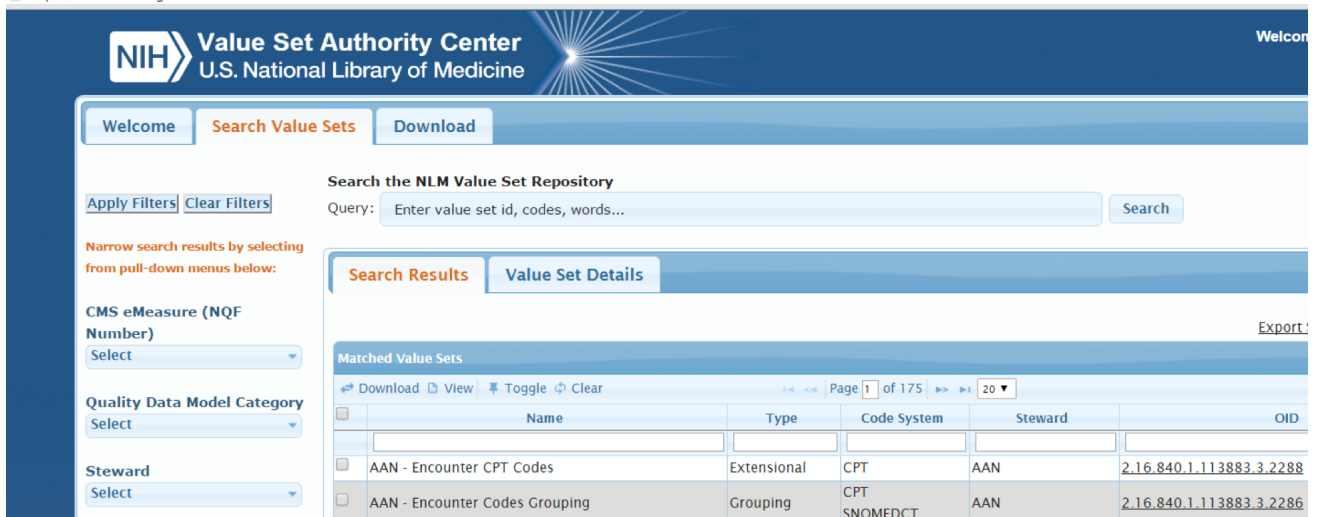
Overview

The National Institutes of Health (NIH) is a federally sponsored biomedical research program in the United States. The NIH is made up of 27 separate institutes and centers.[2] The Intramural Research Program's (IRP) programs are embedded in 24 of the NIH Institutes. [3] One of those institutes, the National Library of Medicine (NLM) is the world's largest biomedical library and the SNOMED CT National Release Center for the United States. The NLM curates an extensive collection of medical knowledge in various formats which is used by millions of people around the world. Across the IRP, some of their Principal Investigators (PIs) use SNOMED CT in their research. A selection of the Intramural Research Program's initiatives which relate to SNOMED CT and CDS, are briefly described below.

Value Set Authority Center

[4] The Value Set Authority Center (VSAC), managed by the NLM, is a service designed to maintain and distribute the value sets defined in electronic Clinical Quality Measures (eCQMs). Each VSAC value set consists of codes and terms from clinical vocabularies such as SNOMED CT, RxNorm, LOINC and ICD-10-CM . Value sets derived from SNOMED CT are used to support the calculation of data quality measures which in turn provide feedback to clinicians about the quality of care. Note that VSAC is a project administered by NLM, but the actual data quality computations are done at individual healthcare sites.

Figure 1: VSAC NLM Value Set Repository

Medline Plus Connect

Medline Plus Connect is an Infobutton resource which accepts requests for information on diagnoses (problem codes), medications, and lab tests, and returns related information from MedlinePlus. The API is available as a web application or as a web service, which can be integrated with an EHR. MedlinePlus accepts SNOMED CT problem codes as input and provides CDS in the form of *targeted information prescription*. The example below shows how the Medline Plus Connect request and response are structured. Note that the response includes the title and link of the matched topic and may include synonyms, attribution acknowledgements, and related links.

Example: A patient diagnosed with 13645005 |Chronic obstructive lung disease (disorder)|:

HTTP Request:

https://apps.nlm.nih.gov/medlineplus/services/mpconnect_service.cfm?
mainSearchCriteria.v.cs=2.16.840.1.113883.6.96&mainSearchCriteria.v.c=13645005

(Note: 2.16.840.1.113883.6.96 is the OID for SNOMED CT.)

Response:

```
<feed xmlns=" http://www.w3.org/2005/Atom "  xmlns:xsi=" http://www.w3.org/2001/XMLSchema-instance "
 xml:base=" https://apps.nlm.nih.gov/medlineplus/services/ "  xml:lang="en">
   <title type="text"> MedlinePlus Connect </title>
   <subtitle type="text"> MedlinePlus Connect results for SNOMED CT 13645005 </subtitle>
    <author>
       <name> U.S. National Library of Medicine </name>
       <uri> https://www.nlm.nih.gov </uri>
   </author>
   <updated> 2017-03-31T06:03:00Z </updated>
   <category scheme="mainSearchCriteria.v.c"  term="13645005"/>
   <category scheme="mainSearchCriteria.v.cs"  term="SNOMEDCT"/>
   <category scheme="mainSearchCriteria.v.dn"  term=" "/>
   <category scheme="informationRecipient"  term="PAT"/>
   <id/>
    <entry>
      <title> COPD </title>
      <link href=" https://medlineplus.gov/copd.html "  rel="alternate"/>
       <id>
         tag: https:, 2017-31-03:https://medlineplus.gov/copd.html
      </id>
      <updated> 2017-03-31T06:03:00Z </updated>
       <summary type="html">
```

<p>COPD (chronic obstructive pulmonary disease) makes it hard for you to breathe. The two main types are chronic bronchitis and emphysema. The main cause of COPD is long-term exposure to substances that irritate and damage the lungs. This is usually cigarette smoke. Air pollution, chemical fumes, or dust can also cause it.</p> <p>At first, COPD may cause no symptoms or only mild symptoms. As the disease gets worse, symptoms usually become more severe. They include</p> A cough that produces a lot of mucus Shortness of breath, especially with physical activity Wheezing Chest tightness <p>Doctors use lung function tests, imaging tests, and blood tests to diagnose COPD. There is no cure. Treatments may relieve symptoms. They include medicines, oxygen therapy, surgery, or a lung transplant. Quitting smoking is the most important step you can take to treat COPD. </p> <p class="**NLMattribution**"> NIH: National Heart, Lung, and Blood Institute</p> <p class="**NLMrelatedLinks**">
Blood gases (Medical Encyclopedia)
Breathing Better with a COPD Diagnosis - NIH (National Heart, Lung, and Blood Institute) - PDF
Chronic obstructive pulmonary disease (Medical Encyclopedia)
Chronic obstructive pulmonary disease - adults - discharge (Medical Encyclopedia)
Chronic obstructive pulmonary disease - control drugs (Medical Encyclopedia)
Chronic obstructive pulmonary disease - quick-relief drugs (Medical Encyclopedia)
COPD -- how to use a nebulizer (Medical Encyclopedia)
COPD -- managing stress and your mood (Medical Encyclopedia)
COPD and other health problems (Medical Encyclopedia)
COPD flare-ups (Medical Encyclopedia)
COPD: Are You at Risk? - NIH (National Heart, Lung, and Blood Institute) - PDF
Day to day with COPD (Medical Encyclopedia)
How to breathe when you are short of breath (Medical Encyclopedia)
Pulmonary function tests (Medical Encyclopedia)
Smoking and COPD (Medical Encyclopedia)
Using oxygen at home (Medical Encyclopedia)
</p>
    </summary>
  </entry>
</feed>

Figure 2: MedlinePlus Infobutton Manager: request and response

The requests conform to the HL7 Context-Aware Knowledge Retrieval (Infobutton) Knowledge Request URL-Based Implementation Guide. A screen shot of the application's response to a request for information on |Asthma| is provided below:

Figure 3: MedlinePlus Connect web application response to request for information on problem code 195967001 | Asthma (disorder) |

Observational Health Data Sciences and Informatics (OHDSI)

Some NLM researchers also participate in external projects which utilize SNOMED CT. One such project is OHDSI. This collaborative uses SNOMED CT to integrate diagnostic data. This semantic data integration is then used by research studies which in some cases serves as input into the authoring of CDS knowledge artifacts.

One of the programs related to OHDSI is Innovation in Medical Evidence Development and Surveillance (IMEDS), which includes a number of projects led by NIH researchers, such as:

- NIH Investigators
- Ferdinand Dhombres (NIH)

---

[1] https://irp.nih.gov/about-us/what-is-the-irp
[2] https://en.wikipedia.org/wiki/National_Institutes_of_Health
[3] https://www.irp.nih.gov/about-us/our-programs
[4] Based on content from https://vsac.nlm.nih.gov/

Pharmacy Health Information Technology Collaborative

The Pharmacy HIT Collaborative is a coalition of nine professional pharmacy associations and additional members representing the pharmacy profession in all matters related to health information technology. [1] A primary focus of the Pharmacy HIT Collaborative is "to assure the meaningful use of standardized electronic health records (EHR) that supports safe, efficient, and effective medication use, continuity of care, and provide access to the patient-care services of pharmacists with other members of the interdisciplinary patient care team." [2]

For more information please visit http://www.pharmacyhit.org/.

Overview

The Pharmacy Health Information Technology Collaborative (PHIT Collaborative) is a body of pharmaceutical organizations which operates in the United States and was formed in 2010. As the name suggests, they focus on the pharmacists providing patient care services and assess how information technology can be used to support their processes and workflows. Health information technology standards and clinical terminology are used to promote interoperability and to support their strategy of collecting, documenting, and preparing information for sharing with other service providers. Much of the work the PHIT Collaborative does is guided by the Centers for Medicare & Medicaid Services (CMS) medication therapy management regulations and Meaningful Use (MU) reporting requirements.

Use of SNOMED CT

The PHIT collaborative has been working towards the standardization of clinical pharmacy documentation which includes the use of SNOMED CT to record events such as a 404684003 |Clinical finding|, 71388002 |Procedure|, or 243796009 |Situation with explicit context|. This has resulted in a number of SNOMED CT value sets being published in the National Library of Medicine (NLM) Value Set Authority Center (VSAC), such as the one shown in the figure below.

Figure 1: Pharmacy HIT Collaborative value set for "Reasons for Interventions Related to Medication Management, Nonadherence"

A major benefit of using SNOMED CT in clinical pharmacy documentation is that SNOMED CT supports the calculation of electronic Clinical Quality Measures (eCQMs). This ensures that pharmacists are included in the overall measurement of quality in the US health care system and more recently, outcomes-based payment models.

CDS Use Cases

In addition to improved interoperability and calculation of eCQMs, the standardization of clinical pharmacy documentation can help to enable decision support and the Pharmacy HIT Collaborative is looking at some potential scenarios. One of the central components of pharmacy documentation includes identification of drug therapy problems. Once a medication problem has been identified, a pharmacist can intervene to optimize a patient medication regimen. But in some US jurisdictions, the direction to adjust a medication must come from the prescribing physician. Clinical decision support could be a huge benefit in these cases by acting on the recommendations of a pharmacist. More specifically, CDS could be used to help identify drug therapy issues, to propose actions, and to notify prescribers.

Using clinical decision support in the documentation of medication adverse reactions, allergies, intolerances and interactions could also benefit pharmacists and their patients. For example, SNOMED CT concepts subsumed by 62014003 |Adverse reaction caused by drug|and 272141005 |Severities|could be used to document adverse reactions . When prescribers are managing medication regimens, improved clinical decision support alerts could provide a mechanism to outline the risk of prescribing a medication based on past experience.

Medication outcomes could also be documented using SNOMED CT. For example, SNOMED CT could be used to document the outcomes of a patient who is involved in clinical trials for a new medication. Lack of an adverse reaction may have multiple explanations, including that the patient may not be adherent to the medication due to cost or the inconvenience of frequent administrations. Documenting the reason why a therapy failed could provide useful information for future prescribing events.

---

[1] http://www.pharmacyhit.org/index.php/news-releases/2016-archive/november-2016-press-release
[2] http://www.pharmacyhit.org/

Sundhedsplatformen

The 'Sundhedsplatformen' is a new EHR-system which is currently being rolled out in eastern Denmark where it replaces a large number of outdated and disjointed IT systems. It gives the staff a common digital solution for communication and use of data. Through its workflow-related construction the 'Sundhedsplatformen' introduces new ways to perform clinical work, and creates the basis for treatment which considers international best practices.[1]

For more information please visit https://www.regionh.dk/sundhedsplatform.

Overview

Sundhedsplatformen[2] which translates to *the health platform*, is a jurisdictional electronic health record (EHR) in Denmark with decision support capabilities. The system, provided by Epic, operates in the Capital and Sealand regions of Denmark, which cover a population of approximately 2.6 million people (almost half of the population of Denmark). The system uses SNOMED CT as the basis for its diagnosis-related decision support services. The first clinical rollout of the system was performed in May 2016. When the rollout is complete at the end of 2017, the system will provide services for up to 45,000 clinical users.

Standards and Technology

One of the design considerations of this system is to capture and store clinical data as structured content (as opposed to unstructured or free text). This use of structured health data reduces the need for mapping and creates many opportunities including clinical decision support. In terms of terminology, Denmark's national classification system, called *Sundhedsvæsenets Klassifikations System* (SKS) , is based on ICD-10 and a range of other classification systems. Traditionally, SKS has been used for statistical aggregation and for billing purposes. Although not designed for clinical use, SKS was selected as the primary classification system for the Sundhedsplatformen project to maintain the legacy requirements associated with billing and classification. There was therefore a need to represent both procedures and diagnoses within SKS.

Use of SNOMED CT

It is worth noting that SNOMED CT is already used in many existing clinical databases and registries throughout Denmark. So from an interoperability perspective, there was incentive for the regional EHR to incorporate SNOMED CT in its implementation approach. As previously mentioned, Epic's diagnosis-related decision support system is widely based on SNOMED CT. For example, the ability to traverse SNOMED CT's hierarchy is a key component of all diagnosis-related decision support in the Epic system.[3] Since the region chose SKS as the classification system, there was a need to map their local concepts to SNOMED CT to be able to perform decision support. Over 20,000 diagnosis concepts from SKS were mapped to SCT over a period of 8 months. The mapping was performed through several steps, the first of which was based on the international SNOMED CT to ICD-10 map. Compared to the alternative (i.e. mapping from scratch), this approach was a major help and significantly increased the speed and ease of the mapping process.

---

[1] https://www.regionh.dk/sundhedsplatform/om-sundhedsplatformen/Sider/default.aspx
[2] Case study uses content from Sundhedsplatformen presentation for Canada Health Infoway, May 17, 2016 . (Account needed to access file.)
[3] https://galster.dk/gert/docs/20161013_ESObs_Sundhedsplatformen.pdf

University of Utah

The University of Utah School of Medicine is widely recognized for interdisciplinary research in the genetics of disease, cancer, biomedical informatics, infectious diseases, and other areas of leading-edge medicine.[1] Innovation is a key priority of the Biomedical Informatics Core (BMIC), and information technology is critical to advancing the conduct of clinical and translational research.[2]

For more information please visit http://medicine.utah.edu/.

Overview

The Department of Biomedical Informatics at the University of Utah is an internationally recognized leader in both research and education in the field of medical informatics.[3] The university has been a major contributor to the development of health information standards and open source initiatives, many of which have been leveraged in their own solutions, including their clinical decision support systems.

Standards, Architectures, Techniques

As a major contributor to the development of the OpenCDS collaborative, the University of Utah has been able use the architecture from OpenCDS to provide a service-based approach to their CDSS and clinical quality measurement efforts. As part of this effort, they have made use of HL7 International's Decision Support Service (DSS). The University also played a key role in the development of OpenInfobutton, an opensource web service and reference implementation of HL7's infobutton standard. Infobuttons are context-sensitive links, which can be embedded in EHR systems as buttons or tabs. OpenInfobutton was funded by the US Veterans Health Administration (VHA) and developed by researchers at the VHA, Duke University, and the University of Utah.

Using SNOMED CT

SNOMED CT value sets are used to map to clinical concepts referenced in the University's CDS rules. SNOMED CT value sets are also used to configure patient problem lists in OpenInfobutton. Since the Infobutton standard uses SNOMED CT for problem lists, SNOMED CT concept identifiers are embedded in the requests and responses between the EHR and OpenInfobutton architecture, as shown in the figure below.
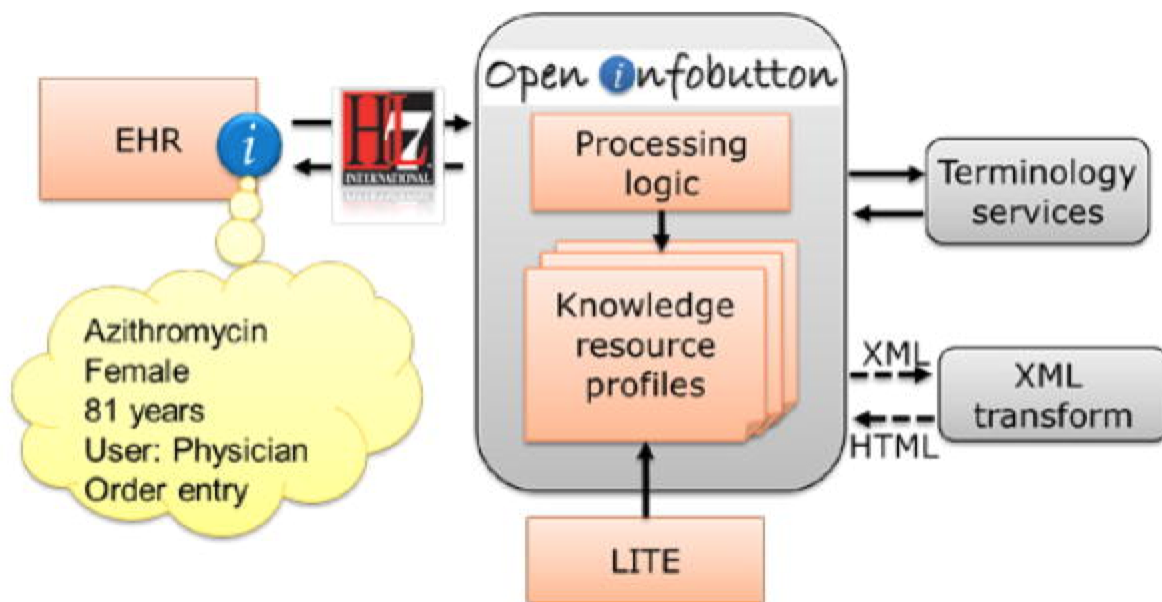
Figure 1: Infobutton architecture which uses SNOMED CT for patient problem lists

The University has benefited from using a standardized clinical reference terminology which can be used across clinical domains. By using SNOMED CT in OpenInfobutton, the University has improved the interoperability between EHR systems and knowledge resources, by providing more efficient access to the indexed knowledge content.

---

[1] http://medicine.utah.edu/
[2] http://medicine.utah.edu/ccts/bmic/
[3] http://medicine.utah.edu/bmi/

Vendor Case Studies

This section describes a number of commercial products that use SNOMED CT to support their clinical decision support systems. The vendors that have contributed to this review include:

B2i Healthcare

> B2i Healthcare is a boutique software engineering firm specialized in SNOMED CT® and healthcare information standards and exchange. We provide products to simplify SNOMED CT adoption and offer software development services to support your healthcare IT needs.[1] "Analyzing observational medical data that was collected during real world patient observation can add to the evidence that supports clinical decision making… and provide guidance to analyze how existing care methods have performed over millions of patients in different clinical settings."
>
> For more information please visit https://b2i.sg/.

Overview

B2i Healthcare (B2i) provides tools and services to help maximize the features of SNOMED CT. Snow Owl, their flagship product, is a clinical terminology platform which has been deployed in over 3000 locations in 84 countries.[1] In 2015, SNOMED International procured the Snow Owl Terminology Server as a key component of its terminology authoring platform.

Snow Owl Meaningful Query (MQ) is a scalable, big data platform for performing queries and analytics over electronic health records. Snow Owl MQ supports patient cohort selection for clinical trials and observational data analysis by exploiting the semantics of SNOMED CT to find answers to clinical questions and thus provide evidence to support decision-making. Snow Owl MQ includes the following modules:

- **The terminology search and browse interface** supports the creation of subsets based on semantic or manual criteria,
- **The patient cohort builder** enables electronic health records to be filtered using demographic or terminology criteria,
- **The analytics module** supports the statistical processing of and information retrieval from patient data.

Use of SNOMED CT

The terminology search module within Snow Owl MQ leverages the SNOMED CT concept model to build attribute-based, complex queries over the terminology. This can be seen in the screen shot below where a query using the attributes |Pathological process|, |Finding site|, and |Associated morphology| has been dynamically executed to create an exportable subset.
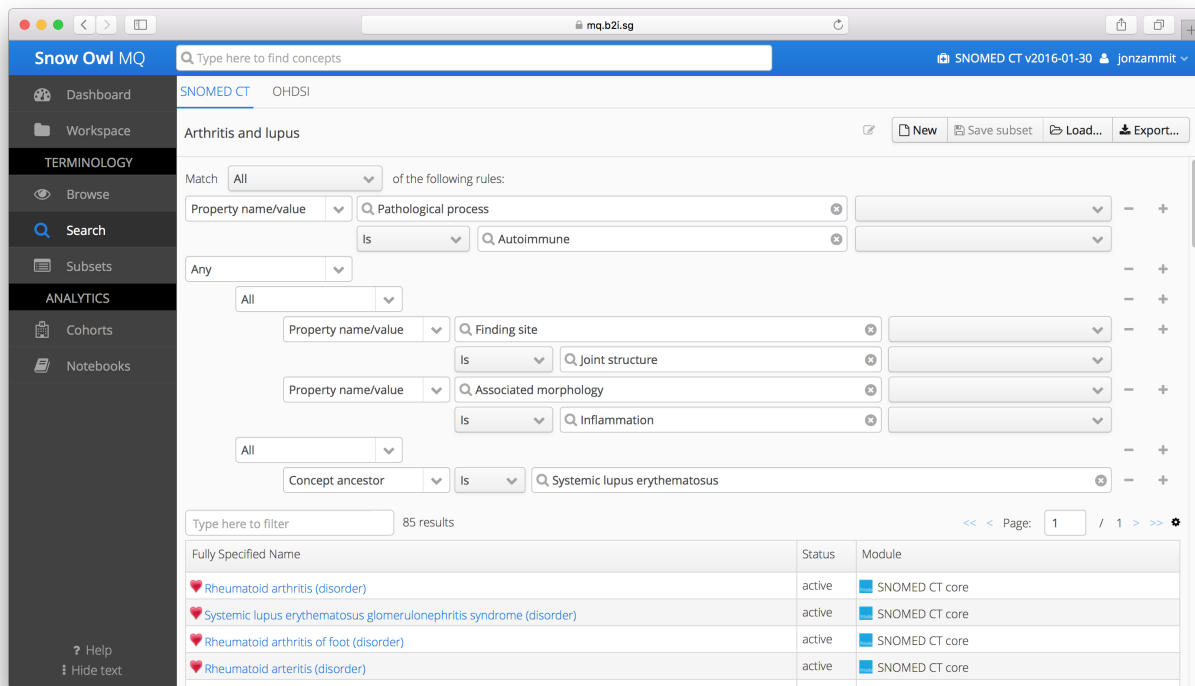
Figure 1: Results of attribute-based query are shown in the search module

The search interface facilitates the retrieval of concepts based on their clinical meaning, as represented using SNOMED CT's defining relationships . This provides a mechanism to create subsets dynamically, based on their intensional definition. This semantic approach to subset definition also supports automatic updating when a new version of SNOMED CT is released. For convenience, Snow Owl MQ provides a terminology browser to search SNOMED CT and other terminologies.

As shown in the screen shot below, the cohort builder module uses the previously defined subsets in combination with temporal constraints and demographic filters.
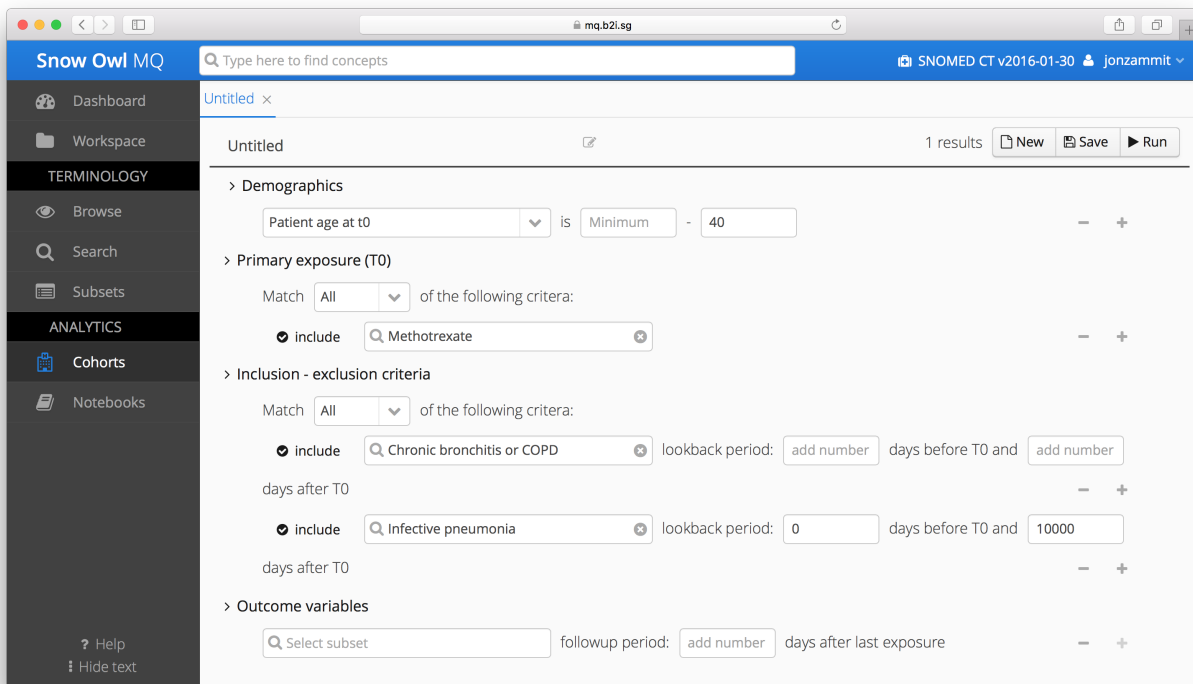
Figure 2: Patient cohort builder which uses subsets defined from SNOMED CT content

A patient list is generated by simply executing the query. These patient records can then be explored in more detail. To further analyze the patient data of the selected cohorts, the semantic notebook functionality in the analytics module executes statistical analysis on the data in real time.

Additional Standards and Formalisms

Patient records in Snow Owl MQ are aligned with the Observational Medical Outcomes Partnership (OMOP) Common Data Model. In addition to searching and browsing SNOMED CT, Snow Owl MQ uses all of the

terminologies that are part of the OMOP Standardized Vocabularies (including RxNorm, LOINC, ICD-10, ICD-9-CM, HCPCS and others).

Benefits

Based on B2i's experience, SNOMED CT's concept model helps to support dynamic subset creation, and in turn, flexible selection of patient cohorts. B2i has also found that patient records encoded with SNOMED CT are embedded with the clinical knowledge to help answer complex clinical questions that can then support new decision-making algorithms. By leveraging SNOMED CT, Snow Owl MQ supports real-time cohort creation and observational data analysis to quickly validate clinical hypotheses.

---

1. https://b2i.sg/ [a b]

British National Formulary

> BNF Publications are published jointly by the British Medical Association and the Royal Pharmaceutical Society. BNF Publications reflect current best practice as well as legal and professional guidelines relating to the uses of medicines. Content includes:
>
> - Guidance on the drug management of common conditions
> - Details of medicines with special reference to their uses, cautions, contra-indications, side-effects, doses, and relative costs
> - Guidance on prescribing, monitoring, dispensing, and administering medicines[1]
>
> For more information, please visit: https://www.bnf.org/

Overview

The BNF is used by a wide range of health professionals including pharmacists, General Practitioners (GPs), Dentists, and specialists in hospitals and in private practice. The publication is used in 129 countries around the world and is available in print and online via MedicinesComplete.[1] The BNF has commenced work on mapping content to SNOMED CT to strengthen their ontology and support integration with other systems. Adopting SNOMED CT is also in line with the National Health Service (NHS) implementation of SNOMED CT.

Contents of the BNF

BNF reference material is published in electronic format as the BNF Online via the MedicinesComplete platform. This subscription-based content includes information on drugs including indications, dosages, contraindications and advice on disease management. Identifiers from the NHS dictionary of medicines and devices (dm+d) are currently represented in the BNF for drugs and preparations. In addition, the BNF uses internal identifiers for content (e.g. a drug monograph). The hierarchical structure for all content is organized by therapeutic use and drug classification. The therapeutic use hierarchy is then organized by body systems (e.g. cardiovascular system) at its top level. Drug monographs, and drug class monographs are listed underneath relevant therapeutic uses and organized in the body system hierarchy. These monographs contain the indications, contraindications, side-effects, medicinal forms, and other information specific to a particular drug or drug class.

IPRATROPIUM BROMIDE

Evidence Grading ON

http://dx.doi.org/10.18578/BNF.229441824

Last update: 21 February 2016

Sub-sections

Indications and dose

Reversible airways obstruction

By inhalation of aerosol

Child 1 month–5 years

20 micrograms 3 times a day.

Child 6–11 years

20–40 micrograms 3 times a day.

Child 12–17 years

20–40 micrograms 3–4 times a day.

Figure 1: Fragment of drug monograph for ipratropium bromide

Future Plans

BNF Publications have begun to explore how SNOMED CT could be introduced to achieve a range of benefits. Mapping from drugs in the BNF to concepts in the dm+d SNOMED CT extension has been completed. All drugs are associated with one or more Virtual Therapeutic Moiety (VTM) if available, or Virtual Medicinal Product (VMP) if no VTM is available. All medicinal products are associated with the appropriate Actual Medicinal Product (AMP). Because SNOMED CT drug product concepts have defining relationships to their corresponding active ingredients

(in the 105590001 |Substance|hierarchy), a map from the BNF to substances is not required. For example, an *aspirin + codeine* product in the BNF will be mapped to 412096001 |Aspirin + codeine (product)|, and this concept has two 127489000 |Has active ingredient|relationships - one to 105590001 |Aspirin (substance)|and the other to 387494007 |Codeine|. Similarly, work has commenced to map indications, side effects, and procedures to concepts in the 404684003 |Clinical finding|and 71388002 |Procedure|hierarchies.

The BNF is also working on an initiative to make use of standardized terms, which will supplement the free text fields used within the content. Indications are now being entered in a controlled vocabulary which makes use of drop down lists mapped to SNOMED CT subsets. This will result in more consistency to fields where the free text is drawn from Summary of Product Characteristics (SPC) material. A similar project is planned for side-effects. Once the aforementioned mappings and standardized terms have been implemented, SNOMED CT codes will be added as metadata to the appropriate BNF content. This will subsequently enable clinical decision support to be implemented using SNOMED CT by 3rd party vendors. A 2014 public consultation proposal published by the National Institute for Health and Care Excellence (NICE) acknowledged that "the huge increase in the use of technology such as clinical decision support as well as online and mobile digital devices, offers an unparalleled opportunity to build on the BNF's valued position in prescribing and enhance its potential". [2]

---

[1] https://www.medicinescomplete.com/about/ [a b]
[2] https://www.fpm.org.uk/policypublications/nicebnfcons

Duodecim

> Duodecim Medical Publications Ltd publishes information content for medical and healthcare professionals in the form of traditional printed products but also as electronic databases, solutions integrated into healthcare systems and an online learning environment.[1] Evidence-Based Medicine Guidelines (EBMG) is designed to provide you with the information you need quickly and using a single search term. Designed for use at the point of care, the guidelines are delivered in a format that makes it easy for a clinician to make a decision regarding treatment.[2]
>
> For more information please visit http://www.duodecim.fi/english/.

EBMeDS

The Evidence-Based Medicine electronic Decision Support system (EBMeDS) was developed by Duodecim. It is a platform-independent service, which can be integrated with any EHR that uses structured patient data. EBMeDS contains over 40,000[3] decision support rules which can be used to generate reminders, therapeutic suggestions, order sets and diagnosis-specific links to guideline sets and other online resources. EBMeDS can also be used to automatically populate calculators and forms with patient-specific data, and to generate summary views and dashboards. In addition to real-time use, the EBMeDS decision support rules can also be run as batch scripts on patient populations to generate reports that measure quality and analyze care-gaps. The rules of EBMeDS are based on the data in the EBMG collection, with several 3rd party resources also used for evidence collection.

Using SNOMED CT

EBMeDS receives encoded patient data from EHRs. The coded data pertains to several *data groups* including diagnoses, medications, vaccinations, investigation results, surgical procedures, and risk factors (such as smoking). Although multiple coding systems are supported, only SNOMED CT and the Read code system are accepted for all data groups. Within EBMeDS, all codes are mapped to internal aliases. For example, for the concept *serum or plasma creatinine* includes codes from 10 different coding systems. Duodecim is expecting to derive additional benefits from using SNOMED CT when more EHRs are able to provide SNOMED CT encoded records as outputs.

Deployments

At present, EBMeDS is used mainly in Finland. Duodecim is planning to offer a cloud-based centralized EBMeDS service in the near future, but currently the application is integrated into the local EHR environments. Belgium has a national license for EBMeDS as part of the EBMPracticeNet implementation in Belgium. Several pilots and scientific studies are being performed in Italy, Denmark, Estonia, the United States and the UK.

---

[1] http://www.duodecim.fi/english/
[2] http://www.duodecim.fi/english/duodecim/duodecim-medical-publications-ltd/
[3] http://www.ebmeds.org/web/guest/home?n_id=11411&lang=en

First Databank

FDB (First Databank)... is the leading provider of drug knowledge that helps healthcare professionals make precise medication-related decisions... FDB enables our information system developer partners to deliver a wide range of valuable, useful, and differentiated solutions. As the company that virtually launched the medication decision support category, we offer more than three decades of experience in transforming drug knowledge into actionable, targeted, and effective solutions that improve patient safety and healthcare outcomes. [1]

For more information please visit http://www.fdbhealth.com/. [2]

Overview

First DataBank (FDB) were in the first wave of suppliers to recognize the potential of SNOMED CT and begin to integrate support for SNOMED CT into their existing clinical decision support solutions. Their primary use of SNOMED CT in the patient's electronic health record (EHR) is to detect safety issues arising from certain combinations of medications, diagnoses and drug adverse reaction histories. In 2006 FDB introduced support for products and packs encoded using the NHS SNOMED CT UK Drug Extension. In the following year FDB launched new modules within the Multilex drug knowledge base supporting Drug-Condition Checking and Drug Sensitivity (Allergy) checking for the SNOMED CT EHR.

System vendors implementing Multilex decision support within SNOMED CT-enabled medical record applications include CSC (Lorenzo system), EPIC and JAC in secondary care, and CSE Servelec (*RiO system)* in community/mental health. Currently only pre-coordinated expressions are supported by the live Multilex SNOMED CT based decision support solutions.

Drug-Condition Contraindication Checks

The contraindications module alerts the clinician when a medication proposed to treat a disorder is incompatible with another of the patient's disorders or clinical states. For example a beta blocker like propranolol might be prescribed to treat someone with high blood pressure. However if that patient also has asthma, their asthma might significantly worsen or a dangerous acute attack might be produced by the drug.

Thousands of such drug-condition contraindications exist and nearly all medications have at least one. Without point of care decision support, the clinician must rely on memory or search reference sources for each drug prescribed. Also there is a risk that a contraindicating condition may be in the record but unknown to the prescribing clinician.

In a SNOMED CT enabled EHR, both the drugs (e.g. 318353009 |propranolol hydrochloride 40mg tablet|) and the conditions (e.g. 370219009 |moderate asthma|) are encoded.

Internally FDB maintain their own local ontology representing only those conditions relevant to prescribing decision support (e.g. asthma, gastric ulcer, heart disease, pregnancy). The items in this ontology are linked to SNOMED CT codes as required to support this (contraindication checking) use case. These SNOMED CT links range from the obvious, such as linking 195967001 |asthma| to FDB's 'asthma', to the more subtle, such as linking 447413000 |drainage of amniotic fluid using ultrasound guidance| to FDB's 'pregnancy'.

FDB reviews the relevant SNOMED CT domains (i.e. |Clinical finding|, |Procedure| and |Situation with explicit context|) for concepts applicable to drug-condition checking. The FDB linking tool uses the SNOMED CT |is a| hierarchy and a SNOMED CT derived transitive closure table to locate and suggest links from the FDB ontology to SNOMED CT concepts. Other SNOMED CT relationships also help find related concepts via the browser but discovery is mainly by clinical knowledge combined with description based searches assisted by the rich synonym content of SNOMED CT.

Drug Sensitivity (Allergy) Checks

The sensitivities module alerts the clinician when a proposed drug for a patient is *either* stated in that patient's record to have caused a previous adverse reaction *or* when an adverse reaction has occurred to a similar drug and

thus likely to elicit a similar adverse response. For example, a patient allergic to penicillin is likely to react to most other drugs containing a β-lactam ring in their molecular structures.

In a similar way to how FDB links SNOMED CT conditions to its own internal ontology, SNOMED CT concepts which suggest allergy or previous adverse reactions to a medication are also linked to an internal FDB ontology for representing medication ingredients. This ontology is designed specifically to support allergic and adverse reaction cross-reactivity.

---

[1] About First Databank (FDB)
[2] Please note that the case study on this page is an excerpt from the Data Analytics with SNOMED CT guide.

Infermedica

> The quicker healthcare professionals and patients can arrive at a correct diagnosis, the better. This is what has motivated Infermedica to build an API-centric clinical decision support system that can power third-party applications. Infermedica's primary use cases are implementing intelligent symptom checkers, adaptive patient intake and pre-screening forms, and clinical decision support features. The platform has already attracted over 1200 developers and the API has been used to provide over one million health assessments online.
>
> For more information please visit http://www.infermedica.com/.

Overview

Infermedica is a developer of healthcare software, based in Poland, that was established in 2012.[1] Infermedica has designed a diagnostic engine which uses artificial intelligence (AI) and can be integrated into third party EHRs and other health applications. Their technology is accessed through their Infermedica API which analyzes anonymized patient data in real-time and provides clinical recommendations, such as verifiable symptoms or orderable lab tests. Clinical decision support alerts which act on the probable diagnoses can also be implemented. Behind the API, Infermedica uses a proprietary statistical knowledge base which contains the CDS algorithms developed by their clinical experts. A modeling tool called "MetaBase" allows the system to be further refined to meet the needs of specific users. The process of content development is also supported by machine learning algorithms which operate on real patient records. This architecture is depicted in the figure below.
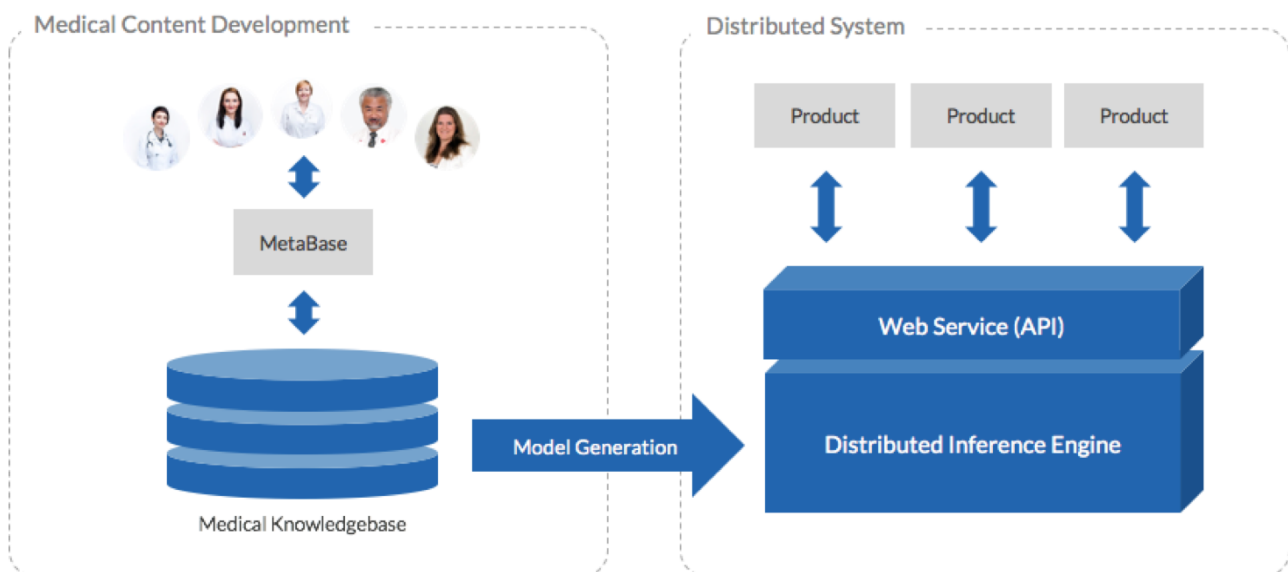
Figure 1: Infermedica API system architecture

Using SNOMED CT

Infermedica has started to incorporate SNOMED CT into their core medical ontology and API interface. The inputs into the Infermedica service are being mapped from SNOMED CT, and the outputs of the service are being mapped to SNOMED CT. This allows them to integrate the system with SNOMED CT coded patient records. An example extract of the output map is shown in the figure below.

```
// OUTPUT
{
  // ...
  "conditions": [
    {
      "id": "c_33",
      "name": "Influenza",
      "probability": 0.6942
    },
    {
      "id": "c_284",
      "name": "Pyelonephritis",
      "probability": 0.1827
    },
    {
      "id": "c_72",
      "name": "Acute bronchitis",
      "probability": 0.1425
    }

    // ...
  ]
}
```

```
// OUTPUT
{
  // ...
  "conditions": [
    {
      "id": "SCTID:6142004",
      "name": "Influenza (disorder)",
      "common_name": "Influenza",
      "probability": 0.6942
    },
    {
      "id": "SCTID:45816000",
      "name": "Pyelonephritis (disorder)",
      "common_name": "Pyelonephritis",
      "probability": 0.1827
    },
    {
      "id": "SCTID:10509002",
      "name": "Acute bronchitis (disorder)",
      "common_name": "Acute bronchitis",
      "probability": 0.1425
    }

    // ...
  ]
}
```

Figure 2: Examples of Infermedica internal diagnosis codes mapped to SNOMED CT

SNOMED CT integration will allow the medical team to develop new knowledge base artifacts for conditions, symptoms and risk factors based on SNOMED CT concepts and their defining relationships. Informedica also plans to use postcoordinated expressions with attribute value refinements to create new representations of clinical meanings that are processable by a computer. These additional clinical meanings will be assigned local codes, and will be used to develop CDS rules in the knowledge base. As the diagnostic engine is primarily focused on symptoms, conditions, and risk factors, it is expected that subsets of SNOMED CT content will be developed that focus on these areas. There are also plans for Infermedica's inference engine to utilize subsumption testing.

Deployments

The Infermedica API has been used within a number of other commercial products for insurers and health systems, as well as other solutions developed by Infermedica such as DxMate. As shown in the screen shot below, DxMate is a prototype diagnostic clinical decision support tool which has already been used by thousands of clinicians.

SNOMED International

DxMate — Patient: Jul 21 2016 11:40 AM

Report feedback   Demo   EN

Findings — Suggested

Neu

Signs and symptoms — 6

Neural tenderness	
Unilateral or bilateral trigeminal neuralgia (Vth cranial nerve) (unilateral or bilateral trigeminal neuralgia (Vth cranial nerve))	
Retrobulbar neuritis	
Malum perforans, Neurotrophic ulcer, Trophic ulcer (malum perforans, Neurotrophic ulcer, Trophic ulcer)	
Presence of neurofibromas	
Mendel-Bechterev sign (extension and dorsal flexion of hallux after tapping the dorsal aspect of the foot with a neurological hammer)	

Laboratory tests — 7

Biochemistry — 1

Neutrophil gelatinase-associated lipocalin (NGAL)   N

Blood count — 4

Absolute neutrophil count (ANC)	N
Percentage of neutrophils (%neutro)	N
Detection of hypersegmented neutrophil nuclei in peripheral blood smear	
Toxic granulation of neutrophils	

Selected findings

Abdominal pain	
Black stools	
Vomiting	
Abdominal pain, chronic	
Lethargy	
Serum lipase (LPS) activity	N
Heart rate (HR)	N
Total serum iron (TSI)	N

Common conditions

Bleeding peptic ulcer (K27.0)	94%
Choledocholisthiasis (gallstones, biliary colic) (K80)	28%
Irritable bowel syndrome (IBS) (K58)	17%
Diverticulosis (K57)	7%
Cholecystitis (K81.0)	4%
Alcoholic liver disease (K70)	4%
Kidney stones (renal colic) (N23)	3%
Urinary tract infection (N39.0)	3%
Painful menstruation (dysmenorrhea) (N94.6)	3%

Rare conditions

Alcohol withdrawal syndrome (F10.239)	41%
Hyperthyroidism (E05)	26%
Acute pancreatitis (K85)	19%
Pancreatic cancer (C25)	16%
Pregnancy (Z32.1)	11%
Colon cancer (colorectal cancer) (C78.5)	11%
Hyperparathyroidism (E21)	10%
Myocarditis (I40)	9%
Acute stimulant (amphetamine, cocaine) overdose (T43.6)	8%

Figure 3: DxMate, a prototype CDS application built using the Infermedica APIInfermedica also provides an online symptom checker and a chat-bot called Symptomate which serves as an alternative to "Googling" your health information, and helps patients make better decisions regarding their symptoms. The chat-bot is shown in the figure below.
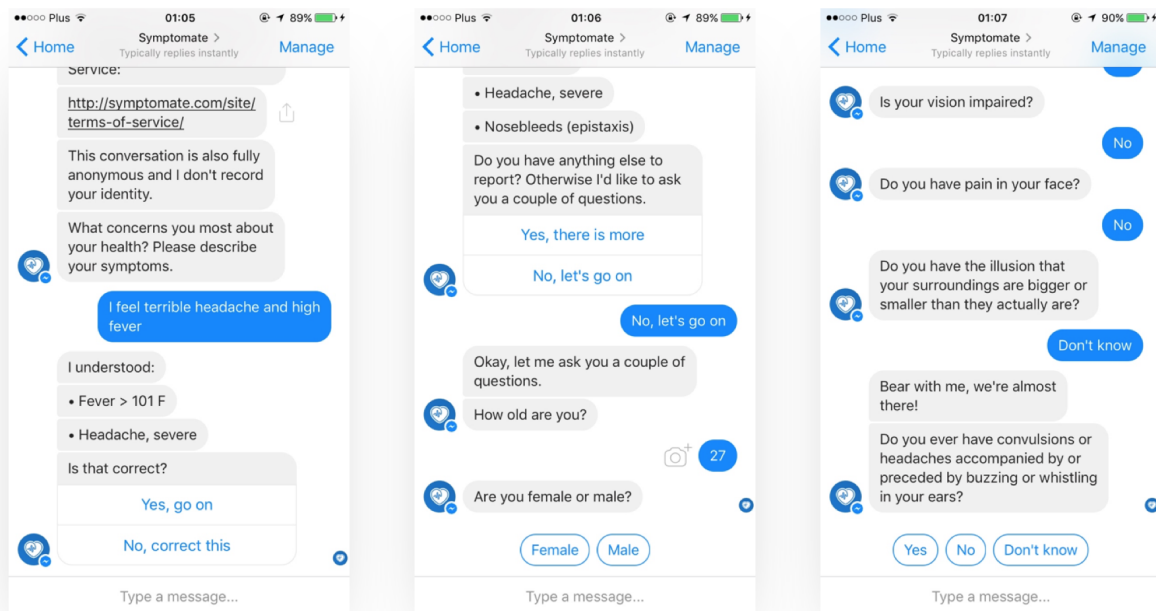
Figure 4: A symptom checker chat-bot developed by Infermedica

Benefits

As a key standard in health information data exchange, SNOMED CT facilitates interoperability between platforms from different vendors. Support for SNOMED CT in the inputs and outputs of Infermedica's API will help to simplify integrations with existing platforms. Using the Infermedica API in tandem with existing electronic health record (EHR) systems will help offer medical professionals with intelligent data-driven suggestions, relevant questions and tests to order, and likely diagnoses for consideration.

SNOMED CT provides Infermedica with a rich dictionary of terms which can be used to improve search and Natural Language Processing (NLP) capabilities. The available translations will facilitate support for additional languages. Usage of SNOMED CT in Infermedica's clinical content editing tool will also help to improve interoperability.

---

1 https://www.linkedin.com/company/infermedica

M*Modal

> "M*Modal is a next-generation healthcare technology and services company committed to transforming the physician documentation experience with artificial intelligence powered solutions that span the documentation lifecycle from capturing the complete patient narrative to coding. M*Modal solutions help over 250,000 physicians with the smarter creation of higher-quality clinical notes directly in any EHR, thereby creating time to care."
>
> For more information please visit: https://mmodal.com/

Overview

M*Modal's suite of clinical documentation solutions bring forward a seamless platform that delivers back-end transcription, front-end speech recognition, mobile documentation, Computer-Assisted Physician Documentation (CAPD), virtual scribing, and Natural Language Understanding (NLU) driven Clinical Documentation Improvement (CDI) and coding workflows. The M*Modal Fluency® platform has been deployed at thousands of facilities including leading healthcare providers and is designed to improve clinical and financial outcomes while enhancing physician workflows to free up time for patient care.

M*Modal Fluency

Built on proprietary NLU and learning technologies, the M*Modal platform aggregates, abstracts and presents clinical information, both structured and unstructured. M*Modal Fluency has a built-in clinical reasoning layer which uses natural language to deliver information to different stakeholders through task-specific, real-time workflow applications. By combining NLU with speech recognition technology, M*Modal embeds clinical intelligence and flexibility into front-end physician workflows while leveraging existing systems for sustainable improvement. Utilizing the company's single platform, M*Modal solutions also deliver clinical insights to inform back-end CDI, coding and quality processes. This closed-loop approach provides back-end users visibility into physician behavior and lets back-end correction workflows inform physician documentation practices.

Part of the M*Modal Fluency platform, Fluency Direct[TM] is a cloud-based front-end speech recognition solution for hospitals and larger clinics that speech enables the EHR.[1] Physicians can freely dictate narrative in real-time into the patient record, as well as edit and sign reports using speech commands. Its built-in CAPD functionality delivers real-time and context-specific feedback to physicians on quality and compliance for better documentation and optimized physician experience.[2] SNOMED CT is a central component of M*Modal's NLU technology and is widely used within its solutions. SNOMED CT provides a rich ontology for capturing patient conditions in clinical documentation. Using a proprietary M*Modal information model (MIM), all related concepts are organized in a simple tabular fashion which then facilitates clinical decision support reasoning. SNOMED CT's flexible extension mechanism has also been leveraged to represent new clinical ideas.

Natural Language Understanding (NLU)

The M*Modal NLU platform was developed using the Unstructured Information Management Architecture (UIMA) framework. The propriety solution is able to detect document structure, establish sentence boundaries, and consider temporality and negation. Clinical information is processed and inserted into clinical information models using predefined terminologies, such as SNOMED CT. The algorithms within the solution support a range of use cases including clinical documentation improvement, coding support, and clinical decision support.

Information Models and Terminology

The data elements within M*Modal's proprietary information models (MIMs) are bound to a range of standard ontologies, including SNOMED CT, RxNorm, LOINC, ICD, and CPT codes. Models representing findings, disorders, organs, and devices use SNOMED CT while laboratory MIMs use LOINC and medications MIMs use RxNorm. Complex MIMs such as "action course" use a combination of terminologies. The aforementioned ontologies are used to create value sets for use in various clinical scenarios.

Use of SNOMED CT

SNOMED CT is used as the primary reference terminology within the M*Modal Content Management System. In addition to its use in defining value sets, SNOMED CT is used as the basis for defining new clinical ideas through M*Modal's concept level information models. For example, |finding site| and |laterality| relationships on any given *concept* are used to automatically populate the information models, while |course| and |distribution| are populated with SNOMED CT codes using relationships defined outside SNOMED CT directly in the MIMs.

Clinical Decision Support

M*Modal uses SNOMED CT in a number of clinical decision support use cases, including those described below.

Lung Nodules Classification and Physician Feedback

Clinical Finding MIM

Concept level information models are represented as a series of name-value pairs as shown in Figure 1 below.

Mim Key	Mim Value
review.comment	
component.code	35702001
component.codeSystem	2.16.840.1.113883.6.96
component.codeSystemName	SNOMED-CT
component.displayName	Solid (qualifier value)
site.code.code	362900002
site.code.codeSystem	2.16.840.1.113883.6.96
site.code.codeSystemName	SNOMED-CT
site.code.displayName	Entire middle lobe of lung (body structure)
site.laterality.code	24028007
site.laterality.codeSystem	2.16.840.1.113883.6.96
site.laterality.codeSystemName	SNOMED-CT
site.laterality.displayName	Right (qualifier value)
site.review.accept	
site.identifier.extension	-7099384924317494715879688040425202020265
measurement.measurements.Measurement.code.code	cm
measurement.measurements.Measurement.code.codeSystem	2.16.840.1.113883.6.8
measurement.measurements.Measurement.lowValue	0.4
measurement.measurements.Measurement.highValue	0.4
measurement.measurements.Measurement.review.accept	
measurement.measurements.Measurement.identifier.extension	-9058923503843504439-3912274754562339826
measurement.measurements.Measurement.code.code	cm
measurement.measurements.Measurement.code.codeSystem	2.16.840.1.113883.6.8
measurement.measurements.Measurement.lowValue	0.5
measurement.measurements.Measurement.highValue	0.5
measurement.measurements.Measurement.review.accept	
measurement.measurements.Measurement.identifier.extension	-9217337898676560578-1085841696191657137
measurement.measurements.Measurement.code.code	cm
measurement.measurements.Measurement.code.codeSystem	2.16.840.1.113883.6.8
measurement.measurements.Measurement.lowValue	0.4
measurement.measurements.Measurement.highValue	0.5
measurement.measurements.Measurement.review.accept	
measurement.measurements.Measurement.identifier.extension	-8006679859590123331489923383040163923
measurement.review.accept	
course.code	260388006
course.codeSystem	2.16.840.1.113883.6.96
course.codeSystemName	SNOMED-CT
course.displayName	No status change (qualifier value)
code.code	27925004
code.codeSystem	2.16.840.1.113883.6.96
code.codeSystemName	SNOMED-CT
code.displayName	Nodule (morphologic abnormality)
certainty.code	CERTAIN

Figure 1: Finding information model using SNOMED CT concepts

This finding information model can capture additional information about any SNOMED CT Clinical Finding or Disorder. In this case, the model is interpreting the clinical narrative of "*4-5 mm solid, lobulated, parenchymal nodule right middle lobe previously 4-5 mm*" and mapping the text to the following SNOMED CT concepts:

Finding: 27925004 |Nodule (morphologic abnormality)|

Site: 362900002 |Entire middle lobe of lung (body structure)|

Laterality: 24028007 |Right (qualifier value)|

Component: 35702001 |Solid (qualifier value)|

The size was captured with the measurement engine as 4-5 mm and compared to the previous size of 4-5 mm resulting in the interpretation of unchanged size which is then mapped to the SNOMED CT concept:

Course: 260388006 |No status change (qualifier value)|

ValueSets

Population of the information model is also helped by defining value sets of permitted concepts. For example, Figure 2 below shows a list of concepts which are considered legitimate finding sites for lung nodules.

Concept

- ▲ ⒢ [SNOMED-CT - 264017007] Entire hilum of lung (body structure)
  - Ⓢ Hilum of lung
  - ▲ 🗟
    - ⒢ [SNOMED-CT - 181216001] Entire lung (body structure) - Part of
    - ⒢ [SNOMED-CT - 5a03e694-3eb5-489c-a702-aa93c6aded2b] Hilum (body structure) - Isa
- ▲ ⒢ [SNOMED-CT - 226895d5-0c84-4f1b-a286-5d66d83076f0] Lingula of lung (coordination)
  - Ⓢ Lingula of lung
  - ▲ 🗟
    - ⒢ [SNOMED-CT - 181216001] Entire lung (body structure) - Part of
    - ⒢ [SNOMED-CT - 3a9ef633-f8f9-44fa-a402-a7d51af448c1] Lingula (body structure) - Isa
- ▲ ⒢ [SNOMED-CT - 314791004] Entire base of lung (body structure)
  - Ⓢ Base of lung
- ▲ ⒢ [SNOMED-CT - 303549000] Entire lower lobe of lung (body structure)
  - Ⓢ Lower lobe of lung
  - Ⓢ lower lung
  - ▲ 🗟
    - ⒢ [SNOMED-CT - 181216001] Entire lung (body structure) - Component
    - ⒢ [SNOMED-CT - 98162ed7-10d8-4e34-a569-0c6ed1f94834] Lower lobe (body structure) - Isa
- ▲ ⒢ [SNOMED-CT - 362900002] Entire middle lobe of lung (body structure)
  - Ⓢ Middle lobe of lung
  - Ⓢ intermediate lobe of lung
  - Ⓢ mid-lung
  - Ⓢ midlung
  - ▷ 🗟
- ▲ ⒢ [SNOMED-CT - 303548008] Entire upper lobe of lung (body structure)
  - Ⓢ Upper lobe of lung
  - Ⓢ upper lung
  - ▲ 🗟
    - ⒢ [SNOMED-CT - 181216001] Entire lung (body structure) - Component
    - ⒢ [SNOMED-CT - c9917151-cf62-4686-aa31-d3fc8ab79a59] Upper lobe (body structure) - Isa
- ▲ ⒢ [SNOMED-CT - 314790003] Entire apex of lung (body structure)
  - Ⓢ Apex of lung
  - Ⓢ apical area of lung
- ▲ ⒢ [SNOMED-CT - 278983006] Fissure of lung (body structure)
  - Ⓢ Fissure of lung
  - Ⓢ horizontal fissure
  - Ⓢ major fissure
  - Ⓢ minor fissure
  - Ⓢ oblique fissure
  - Ⓢ pulmonary fissure
  - ▷ 🗟

Figure 2: Lung site value set
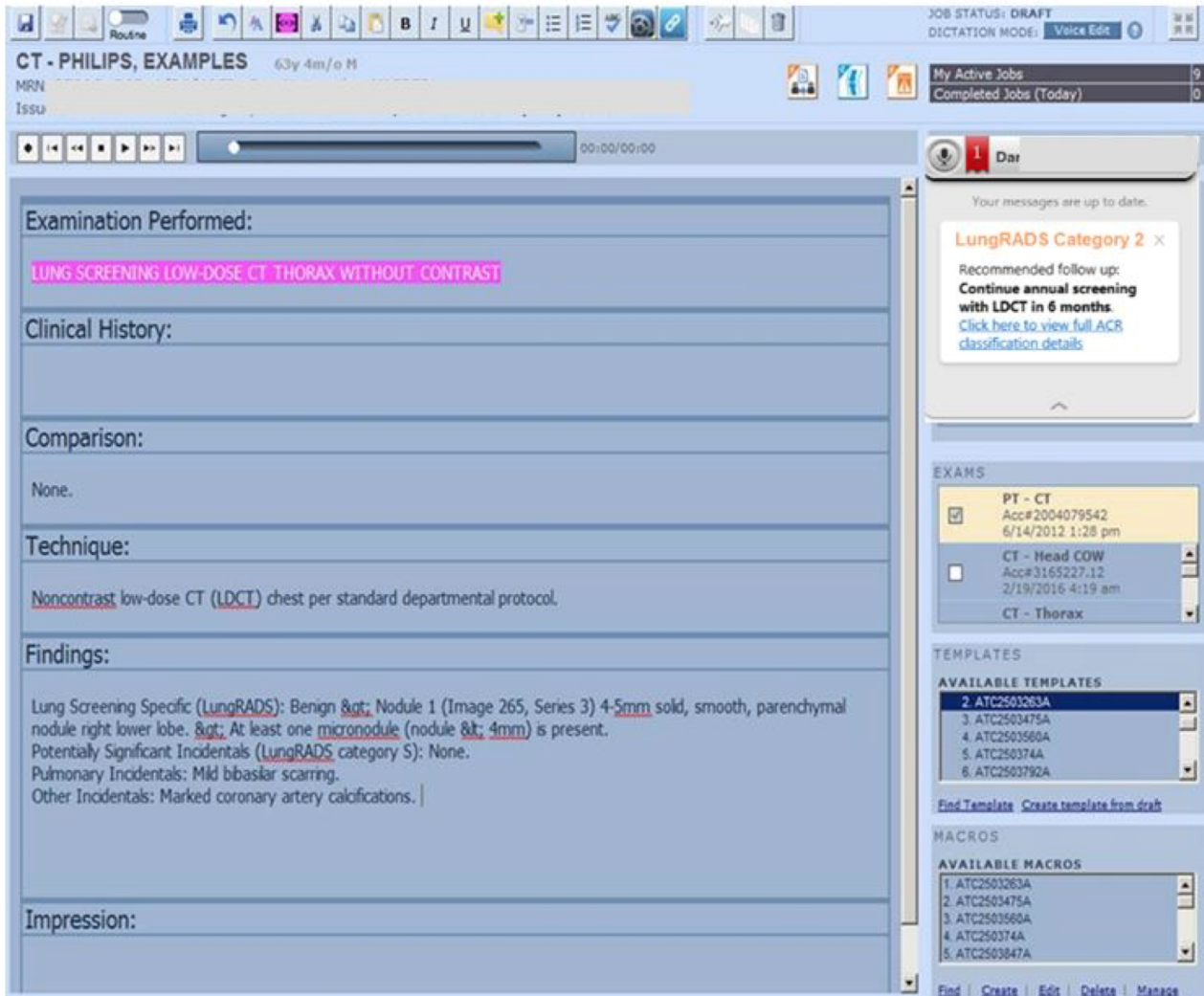
In cases where the lexical forms are required by NLU and not represented in SNOMED CT, a synonym may be added. Postcoordination may also be used to define new clinical ideas. Value sets based on SNOMED CT content are used to gather evidence of clinical confidence for a specific condition. For example, "Signs and Symptoms of Exacerbation of Congestive Heart Failure (CHF)" is a value set which leverages the SNOMED CT hierarchy. 49 SNOMED CT concepts and their descendants are used to define this value set, a fragment of which is shown in Figure 3 below.

Concept	
▷ **G** [SNOMED-CT - 271825005] Respiratory distress (finding)	
▷ **G** [SNOMED-CT - 390870001] Short of breath dressing/undressing (finding)	
▷ **G** [SNOMED-CT - 421129002] 4+ pitting edema (finding)	
▷ **G** [SNOMED-CT - 445341001] Firm pitting edema (finding)	
▷ **G** [SNOMED-CT - 39950000] Dyspnea, class III (finding)	
▷ **G** [SNOMED-CT - 72365000] Dyspnea, class II (finding)	
▷ **G** [SNOMED-CT - 422177004] Dyspnea associated with acquired immunodeficiency syndrome (disorder)	
▷ **G** [SNOMED-CT - 40617009] Artificial respiration (procedure)	
▷ **G** [SNOMED-CT - 267036007] Dyspnea (finding)	
▷ **G** [SNOMED-CT - 297216006] Increasing breathlessness (finding)	
▷ **G** [SNOMED-CT - 248549001] Labored breathing (finding)	
▷ **G** [SNOMED-CT - 161939006] Breathless - moderate exertion (finding)	
▷ **G** [SNOMED-CT - 48409008] Respiratory crackles (finding)	
▷ **G** [SNOMED-CT - 60845006] Dyspnea on exertion (finding)	
▷ **G** [SNOMED-CT - 102572006] Edema of lower extremity (finding)	
▷ **G** [SNOMED-CT - 407588003] Unable to complete a sentence in one breath (finding)	
▷ **G** [SNOMED-CT - 421346005] 3+ pitting edema (finding)	
▷ **G** [SNOMED-CT - 46775006] Respiratory distress syndrome in the newborn (disorder)	
▷ **G** [SNOMED-CT - 271809000] Peripheral edema (disorder)	
▷ **G** [SNOMED-CT - 17216000] Dyspnea, class I (finding)	
▷ **G** [SNOMED-CT - 73322006] Dyspnea, class IV (finding)	
▷ **G** [SNOMED-CT - 248548009] Nocturnal dyspnea (finding)	
▷ **G** [SNOMED-CT - 62744007] Orthopnea (finding)	
▷ **G** [SNOMED-CT - 420829009] 1+ pitting edema (finding)	
▷ **G** [SNOMED-CT - 55442000] Paroxysmal nocturnal dyspnea (finding)	

Figure 3: Signs and symptoms of exacerbation of CHF value set

Clinical Decision Support

CDS interventions are presented to clinicians via web-based applications, such as Fluency for Imaging™ (FFI), M*Modal's speech reporting and workflow management solution. Computer-Assisted Physician Documentation (CAPD) technology presents radiologists with real-time, automated quality-improvement feedback. In Figure 4 below, a clinical decision support notification is presented to a radiologist while dictating a CT lung screening study which had the same finding as described in Figure 1 above. The clinical reasoning reaches a conclusion that the patient has "*Unchanged solid nodule < 6mm*" which is classified as "LungRads Category 2" based on American College of Radiologists (ACR) recommendations and follow-up of "*Repeat (low dose CT scan) LDCT in 6 months*".

Figure 4: M*Modal Fluency for Imaging application with CDS feedback through CAPD technology

Critical Findings Physician Feedback and Tracking

ACR guidelines also stipulate that critical findings have to be reported back to the ordering physician in a timely fashion. In some high priority cases, the follow up must be completed within an hour. M*Modal delivers real-time feedback to the radiologist on the critical finding as the report is created. Moreover, M*Modal Scout™, the company's radiology business intelligence and analytics solution, has the ability to track critical finding occurrences and compliance of radiologists in communicating them which drives continuous improvement.

Figure 5 below is a screen capture of a dashboard which indicates how often a particular critical finding was found, and how often the radiologist fulfilled the follow up requirements. All critical findings in this application are identified using SNOMED CT codes defined in a value set.
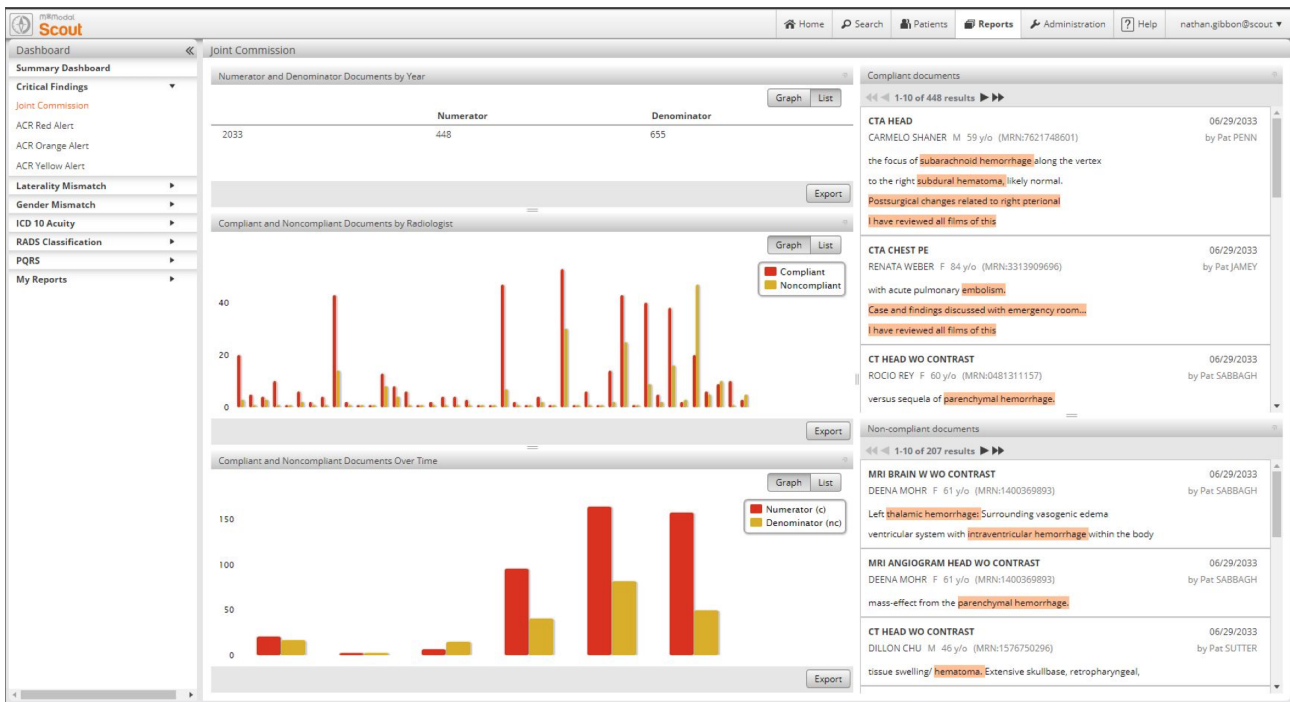
Figure 5: Critical finding dashboard showing compliant and non-compliant reporting of critical findings found

Clinical Documentation Improvement (CDI)

The CDI use case leverages M*Modal's CDS reasoning layer to identify encounters that do not capture clinical diagnosis at the appropriate level of specificity in concepts such as laterality, acuity, severity, episode of care, risk of mortality, etc., to support ICD-10 and quality requirements. The M*Modal system delivers these insights to CDI Specialists in the back end to automate chart review while also generating summarized supporting evidence of clinical indicators that include information on vital signs, labs, symptoms/diseases, medications, social history, etc. as shown in Figure 6 below.

Figure 6: M*Modal evidence sheet of clinical indicators to support the back-end CDI Specialist workflow

As mentioned earlier, the same clinical reasoning is also leveraged to provide real-time feedback to physicians at the front-end of the documentation creation process to identify gaps in documentation and variance in patient care for a closed-loop approach.

---

[1] https://mmodal.com/resources/product-brochures/mmodal-fluency-direct/
[2] https://mmodal.com/

Medical-Objects

Our team has a dedicated view towards creating practical and quality products for the health care industry. This united view towards products and services has seen rapid growth in our target market. Medical-Objects is now used by over 40,000 health care providers Australia wide.[1] Due to Medical-Objects expertise in an integrated standards based suite of technologies, we can work with you to electronically capture, persist, decision support, and report across the full clinical complexity of your enterprise.[2]

For more information please visit https://www.medical-objects.com.au.

Overview

Medical-Objects Pty Ltd (MO) is an Australian company that specializes in electronic messaging and clinical applications. They are also active in healthcare standards development and have been key contributors to HL7 GELLO and GLIF. MO works closely with business, government, and health professionals to provide clinical tools which help with connectivity, integration, and workflow. MO has developed several CDS tools including:
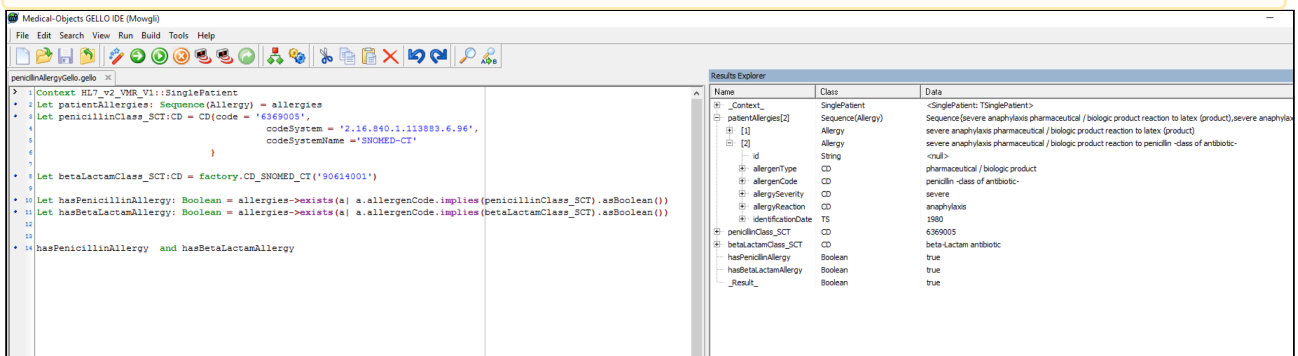
- A GELLO Release 2 (R2) editor, engine, and   RESTful web service. (The GELLO editor is shown below in Figure 3.)
- A GLIF editor, engine, and web service. (The GLIF editor is shown below in Figure 4.)
- An ISO 13606 archetype template editor

GELLO

GELLO R2 i s an ANSI and HL7 standard for clinical decision support. It makes use of a virtual medical record (VMR) to abstract and present clinical data. As a language, GELLO is both declarative and functional and can query SNOMED CT and other reference terminologies.

The screenshots below illustrate the use of an *implies* method which uses SNOMED CT subsumption with the ISO 21090 CD datatype (concept descriptor). Note that *allergies* in line 2 of the screen shot below, comes from the vMR instance.

Note that for all screen shots below, the images can be enlarged by clicking on the body of the image.

Figure 1: A fragment in Medical-Object's GELLO editor
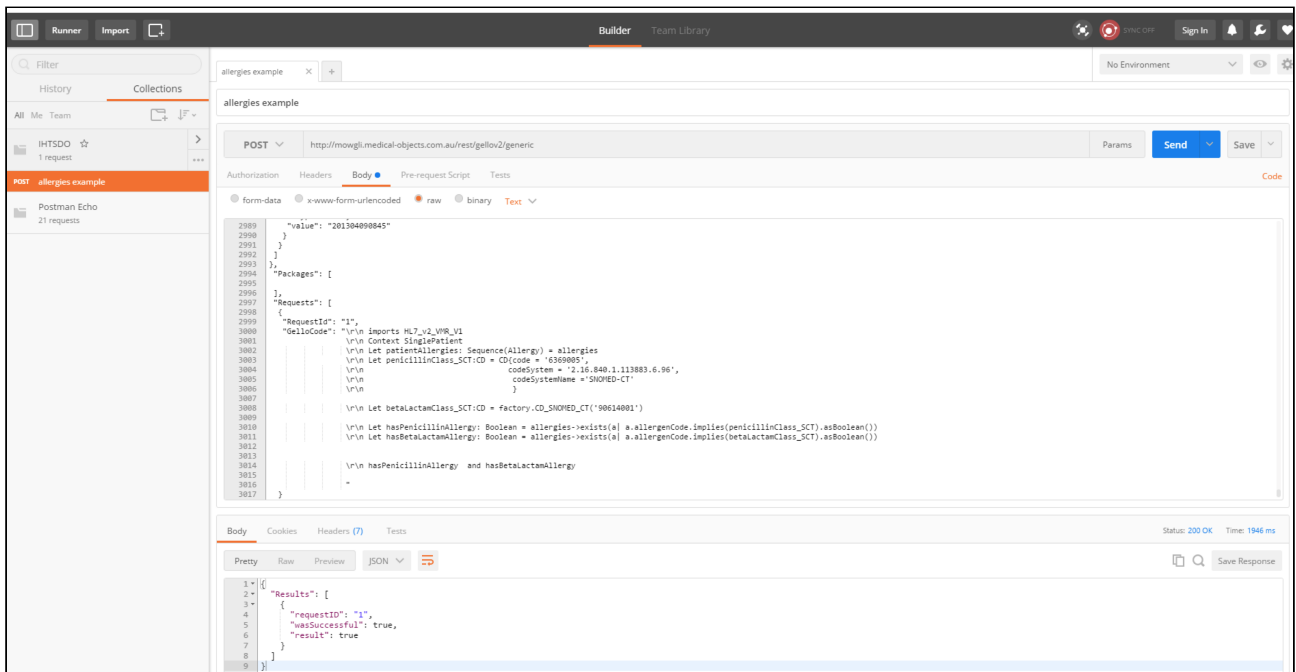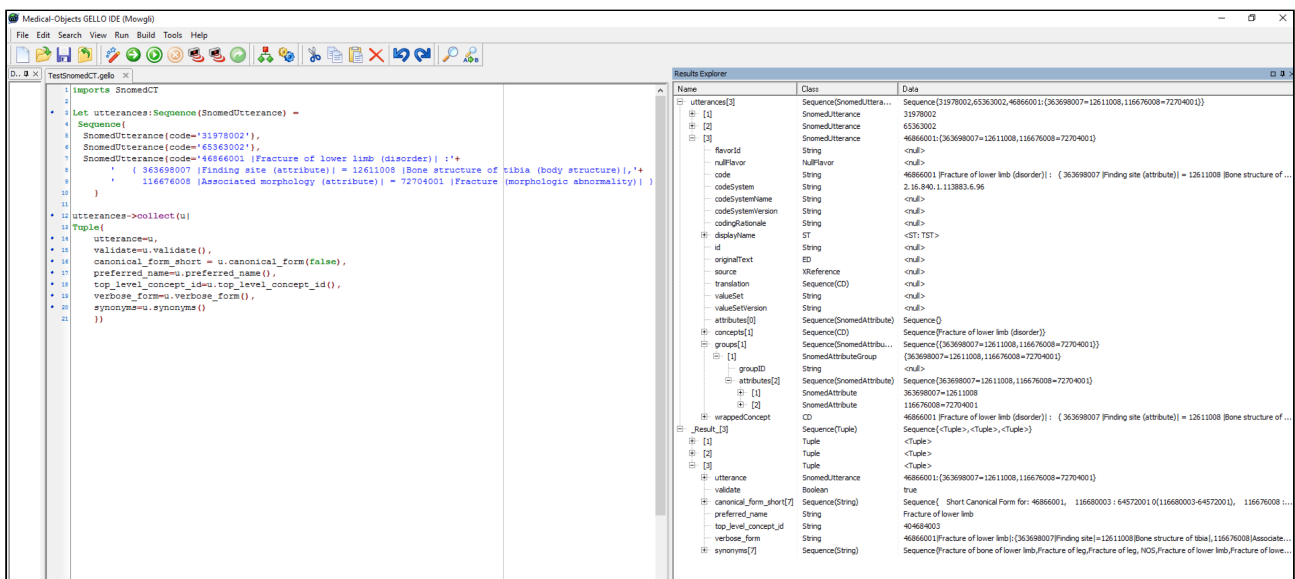
Figure 2: The same GELLO query running on Medical-Object's web service

MO is in the process of migrating its GELLO R1 SNOMED CT object to the new GELLO R2 format. The screen shot below captures some of the added functionalities. Note the use of SNOMED CT attribute relationships in the language, specifically |Finding site| and |Associated morphology|.

Figure 3: GELLO R2 object which illustrates the use of SNOMED CT attribute relationships

MO has found that being able to write GELLO queries to access both the information model (e.g. VMR, archetypes) and the terminology model (e.g. SNOMED CT) has been extremely useful.

GLIF

GLIF (GuideLine Interchange Format) is a clinical guideline representation protocol for exchanging clinical guidelines. It uses GELLO (and therefore can use SNOMED CT) in its automated decisions and state declarations. To the user it looks like a smart flowchart of guidelines and sub-guidelines with an interactive interface presenting such things as pop up didactics. The diagram below depicts a user interface view of a SNOMED CT based query in GLIF:
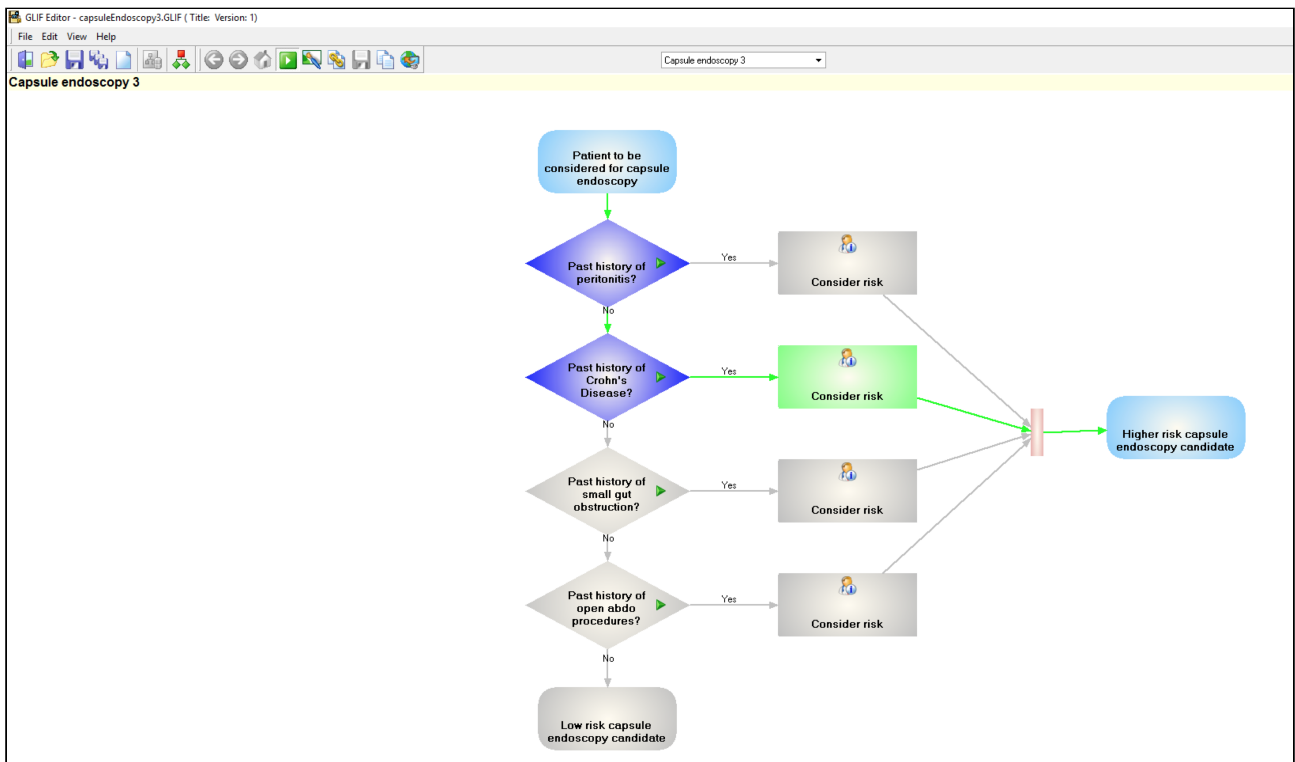
Figure 4: SNOMED CT based guideline, represented in GLIF

Deployments

GLIF and GELLO are incorporated into the Medical-Object's *Explorer* EHR software. The diagram below is a screenshot of a guideline, that is represented in GLIF, being used.
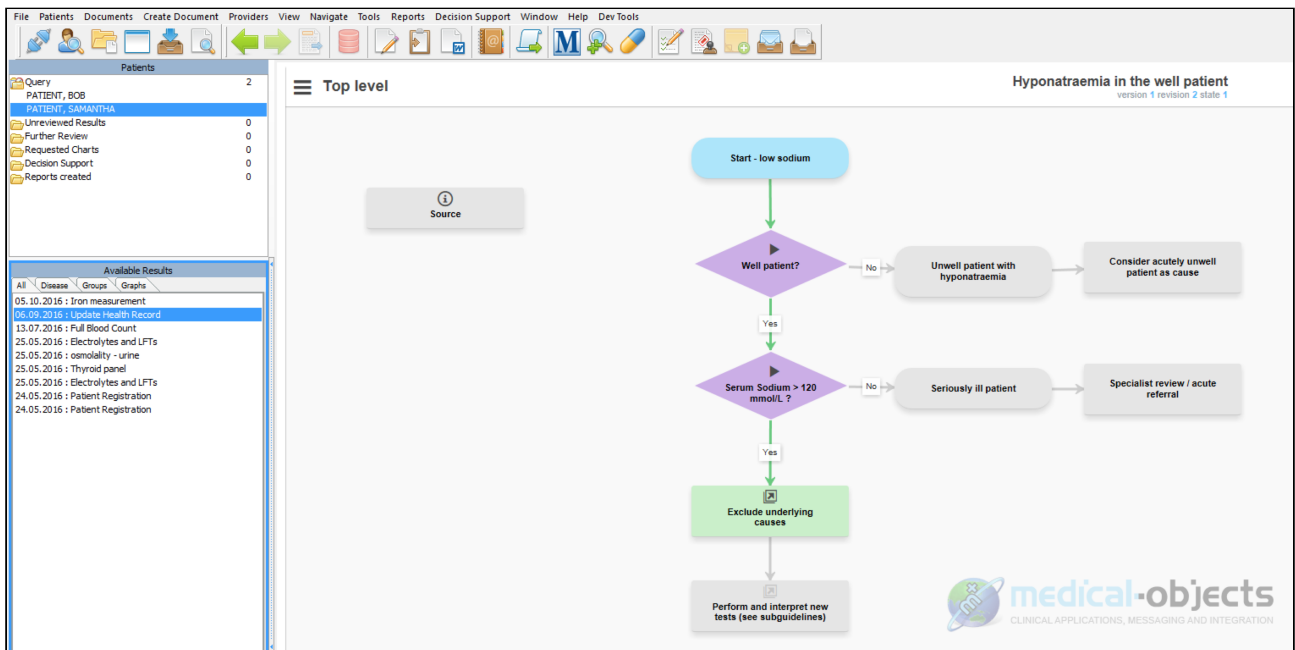
Figure 5: Explorer is one of Medical-Object's clinical application which uses GLIF

Terminology-enabled GELLO was made available as part of MO's contribution to the Veterans Health Administration (VHA) CHIO Innovation project. MO has started to see some adoption of SNOMED CT based querying of GELLO in pathology laboratory panel archetypes.

An example gastroenterology archetype is shown in the sequence of figures below. This archetype is currently in development for a gastroenterology clinic. If an endoscopy is being performed for a Barrett's esophagus type of lesion, then visibility G ELLO displays relevant extra nodes. (Note: Visibility GELLO can be used for developing smart forms to show or hide nodes depending on values entered elsewhere.)

Figure 6: Diagnostic procedure archetype which uses GELLO visibility nodes (to display additional fields)

Figure 7: Barrett's esophagus is entered in the node named 'lesion' using a SNOMED CT concept

Diagnostic procedures

Site	
Device	○ Forceps ○ Snare
Method	○ Cold ○ Hot
Purpose	
Lesion	Barrett's esophagus
Number of biopsies taken	0
Extent of Barrett's (Prague C and M)	

Figure 8: Which then displays additional elements in the data collection form

---

[1] https://www.medical-objects.com.au/company-information/about-us/
[2] https://www.medical-objects.com.au/solutions/clinical-decision-support/

Orion Health

Orion Health is an award-winning, global provider of healthcare information technology advancing population health and precision medicine solutions for personalised care across the entire health community.[1] Orion Health's solutions capture the vast amounts of heath data available and provide the tools to support healthcare professionals and health insurers who manage their members' wellness programmes to make more effective decisions - through applying analytics and employing care management and patient engagement.[2]

For more information please visit https://orionhealth.com .

Overview

Orion Health currently has four products which leverage SNOMED CT for Clinical Decision Support. These are:

- Global Drug Model (GDM);
- Orion Health Medicines;
- Orion Health Problem List; and
- Clinical Decision Support (CDS) application.

To allow for multiple customers to be supported worldwide, these products adopt a modular approach to terminology deployment. A customer selects the relevant data loader for their jurisdiction and the experience is customized for their region automatically. When deployed in SNOMED CT member countries, this process involves loading the relevant SNOMED CT National Edition and local medication codes. Drug data is represented using a common model based on SNOMED CT. This enables customers already using SNOMED CT coding to migrate to these products very quickly. Other local medication codes can be translated to the SNOMED CT equivalent representation using integrated mappings. Orion's Medicines platform provides support for terminologies from the UK, Australia, New Zealand, USA and France, as well as support for other customers with local data sets.

SNOMED CT offers a range of significant benefits to Orion Health's CDS solutions. SNOMED CT's relationships and drug class information are used to optimize the drug database during the import process. Orion Health has also developed several algorithms which allow for extremely fast retrieval of medication data, traversal of the medication hierarchy and testing for concept subsumption. These SNOMED CT features are used extensively by the Clinical Decision Support APIs and are therefore a core part of Orion Health's CDS applications. These products also provide the ability to add new medications that are not predefined in the terminology, such as extemporaneous medications, clinical trial drugs or medications obtained in a different country. New medications can be fully modeled within the GDM concept hierarchy, and assigned a valid SNOMED CT extension identifier using the customer's assigned namespace.

The Amadeus Clinical Portal as shown in the diagram below provides a single point of access for clinicians to manage patient information. This portal integrates the CDS products mentioned above, including the Medicines and Problem List applications. All Orion Health's CDS applications expose their data using FHIR's RESTful APIs. The use of SNOMED CT in these products also facilitates easier translation to standard messaging formats, such as HL7 CDA or other message structures mandated by local jurisdictions.

Figure 1: Clinical Portal

Global Drug Model

The *Global Drug Model* (GDM) enables Orion's software to be deployed worldwide. This application standardizes and normalizes data sets from many different countries into a single data model. Customers upload their local SNOMED CT edition into GDM via an application that runs inside the Orion Health Clinical Portal. GDM processes the data and then publishes it using HL7 FHIR's RESTful APIs. The processing performed by GDM makes heavy use of the

SNOMED CT defining relationships, as well as discovering data about drug classes that is present in the terminology releases. This application facilitates a number of clinical decision support functions, including duplicate therapy checking and linking to relevant drug monographs. The use of SNOMED CT concepts in the GDM is illustrated in the screenshot shown in the diagram below.

Figure 2: Global Drug Model

Orion Health Medicines

Orion Health Medicines supports an authoritative medication list for each patient, and enables its curation, reconciliation and management. The Medicines application uses the FHIR APIs from GDM to allow the discovery and validation of medications. Patients can also manage their own list of medications via the Orion Health Patient Portal or the Orion Health Engage mobile application.

Orion Health Problem List

Orion Health Problem List is a centralized and web-based list of patient problems. It enables healthcare providers to view, create and change clinical information, procedures, psychosocial and cultural issues that may affect the care of the patient, as well as safety and security concerns that may be relevant to medical staff caring for the patient. The Problem List application also integrates with GDM via the FHIR APIs, and enables clinicians to record allergies, adverse reactions and intolerances at the drug class level. The Problem List application is fully integrated with SNOMED CT, with a variety of fields using SNOMED CT subsets.

Clinical Decision Support

The *Clinical Decision Support* (CDS) application is a new product that integrates with the three applications mentioned above, as well as other third party decision support applications. The CDS application provides APIs to support duplicate drug therapy checking, drug allergy checking, links to drug monographs and additional drug information, and grouping of similar medications based on a common ingredient or therapeutic moiety.

For example, when new medications are added to a patient's medication list, they are automatically screened against the current list of medications for that patient using the CDS Duplicate Therapy API. This check ensures that the clinician is advised of existing medications with the same ingredients. Clinicians viewing medications are able to access drug monographs and any other additional information listed against a medication. The medication list is also screened using the CDS Drug Allergy API, which presents a warning if a drug allergy or intolerance to a particular medication or drug class is detected. These checks use data traversal algorithms that were developed by Orion Health for fast traversal of the SNOMED CT concept hierarchy and defining relationships. The warnings have been specifically designed to minimize alert fatigue. The Orion Health Problem List application is shown below in the diagram below with an adverse reaction alert.

Figure 3: Problem List with CDS alert functionality

Practice Fusion

Practice Fusion is a free web-based electronic health record (EHR) company founded in 2005, operated and privately owned by Practice Fusion, Inc. in San Francisco, California. The SaaS startup provides physicians and medical professionals with free, advertising-supported EHR and medical practice management technology that includes charting, scheduling, e-prescribing, medical billing, lab and imaging center integrations, referral letters, Meaningful Use certification, training, support and a personal health record for patients.[1] Practice Fusion is the #1 cloud-based electronic health record (EHR) platform for doctors and patients in the U.S., with a mission of connecting doctors, patients and data to drive better health and save lives.[2]

For more information please visit http://www.practicefusion.com/.

Terminology

Practice Fusion's EHR uses the Health Language Enterprise Terminology Management Platform[3] from Wolters Kluwer[4] to support the management of its terminology content. This terminology platform enables Practice Fusion's patient health records to be encoded using SNOMED CT, ICD-9, ICD-10 and a range of other code systems. Practice Fusion's EHR uses a physician friendly library of terms, together with mappings to SNOMED CT, ICD-9 and ICD-10, to support the selection of appropriate clinical concepts at the user interface.

Practice Fusion has chosen to make SNOMED CT codes and descriptions available for viewing in the user interface. As shown in the screen shot below, when recording a diagnosis a provider can examine the mappings between the user interface term, ICD-9, ICD-10 and SNOMED CT. This approach has received positive feedback from their users as it provides an additional layer of validation when selecting a concept to record in the patient's health record. Since 2014, all diagnoses recorded in Practice Fusion's EHRs have included the associated SNOMED CT codes.

Figure 1: Adding a diagnosis in Practice Fusion's EHR

Clinical Decision Support Advisories

Practice Fusion includes a feature called Clinical Decision Support (CDS) advisories.[5] When a new encounter is entered, the patient's record is processed against a rule engine with specific criteria to determine whether the patient requires a clinical intervention. If the patient requires an intervention, one or more yellow alerts will appear at the top of the encounter. These alerts can be resolved by following an appropriate sequence of events such as ordering a lab test or completing a screening or assessment.

Practice Fusion creates and maintains value sets which include, SNOMED CT concepts to support criteria for their CDS advisories. SNOMED CT codes recorded in the patient's record are tested for membership in relevant SNOMED CT value sets, to determine which CDS advisories should be triggered. All diagnosis related value sets and some procedural value sets used by their CDS advisories contain SNOMED CT concepts. In addition, Practice Fusion uses SNOMED CT to define their encounter and attribute value sets.The SNOMED CT value sets used by Practice Fusion's advisories are mostly defined intensionally using SNOMED CT's hierarchy and (in some cases) SNOMED CT's defining relationships. This allows the value sets to be easily updated (by re-executing their intensional definition) when a new version of the terminology is adopted. Practice Fusion has found that SNOMED CT's polyhierarchy provides a significant advantage when defining these value sets, because similar concepts can easily be grouped together by including all descendants of a common supertype.

SNOMED CT is particularly useful for rare diseases, enabling expression of diagnoses requiring a high degree of specificity and which may not be sufficiently defined in ICD. For example, the screen shot below illustrates a CDS advisory that is triggered when clinical markers considered high-risk for 274864009 |Pompe disease|, are detected in the patient's health record. Using the hierarchy of SNOMED CT, appropriate value sets were defined that help to identify those patients for which a GAA enzyme assay order should be considered to confirm the presence or absence of the diagnosis.
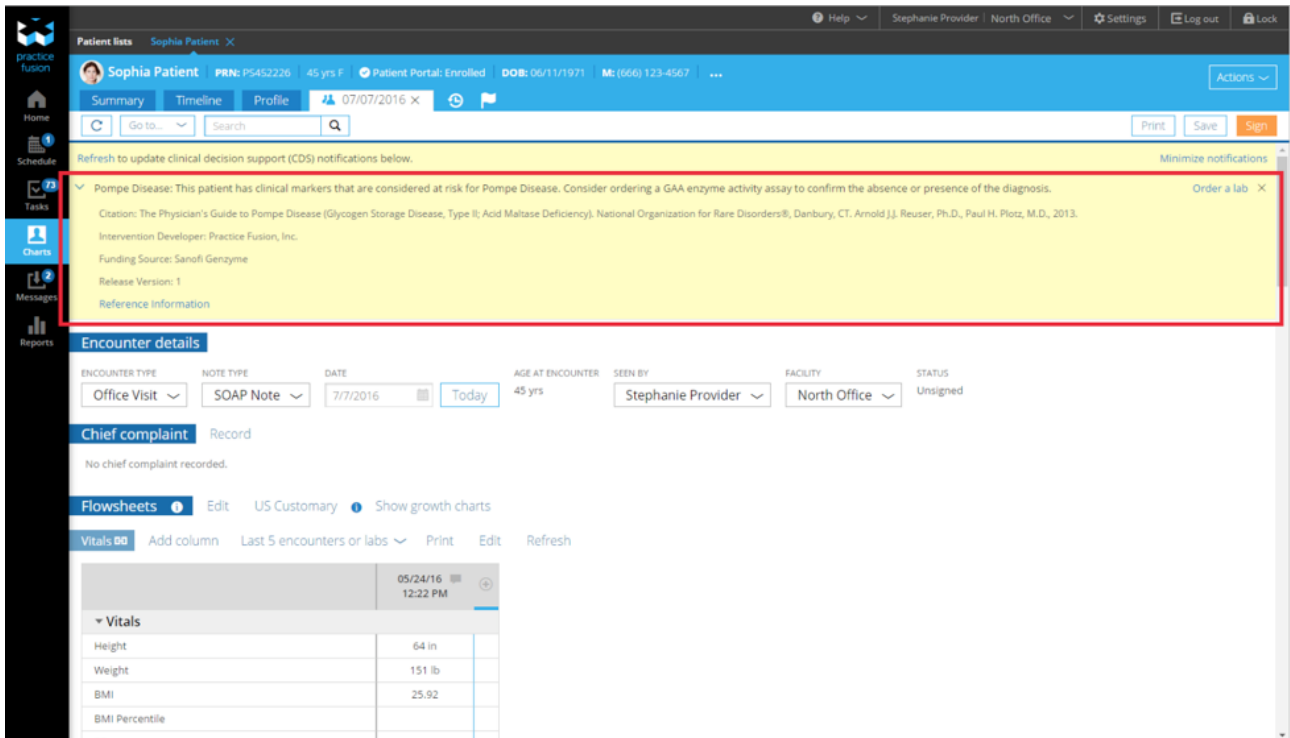
Figure 2: CDS advisory for Pompe Disease

Examples of other advisories that use SNOMED CT value sets in their criteria include:

- Patient requires screening for clinical depression and follow-up plan
- Patient has poor control of hemoglobin A1C and needs a new lab test
- Patient has diabetes and is due for an eye exam
- Patient has hypertension that is not adequately controlled
- Patient has Chronic Obstructive Pulmonary Disorder (COPD) and requires spirometry test
- Patient has COPD and requires bronchodilator
- Patient has asthma and no record of pharmacological treatment
- Patient has asthma and should be evaluated for asthma control every 6 months

- Patient is over 40 with urinary incontinence and requires a care plan
- Patient has clinical markers considered high-risk for paroxysmal nocturnal hemoglobinuria (PNH) according to the International Clinical Cytometry Society (ICCS) guideline and PNH flow cytometry should be considered

Practice Fusion has also used SNOMED CT to represent procedures for follow up actions, such as assessments and interventions. CDS advisories are often linked to Clinical Quality Measures (CQM) in the Practice Fusion workflow. When a provider fulfills the requirements associated with a specific CDS advisory, they will get credit for fulfilling the requirements of the associated CQM, such as completing a specific assessment. Using SNOMED CT for these assessments facilitates the capture and storage of the associated treatment plans.

---

[1] https://en.wikipedia.org/wiki/Practice_Fusion/
[2] http://www.practicefusion.com/about-practice-fusion/
[3] http://www.healthlanguage.com/
[4] http://wolterskluwer.com/
[5] http://knowledgebase.practicefusion.com/knowledgebase/articles/484996-what-are-clinical-decision-support-cds-advisorie

SimulConsult

Medical professionals can get a "simultaneous consult" about their patient's diagnosis using SimulConsult's diagnostic decision support software in three ways... The database used by the software has > 6,200 diagnoses, and is most complete for genetics, neurology and increasingly pediatric rheumatology.[1] As a clinician gets advice to consider various tests, it is very helpful to get straightforward access to information about genetic testing that is available in a way that is not confusing to the clinician.[2]

For more information, please visit http://www.simulconsult.com/.

Overview

SimulConsult is a developer of diagnostic decision support software based in the United States. They provide solutions which cover three main functionalities:

- **Clinical Diagnostic Decision Support:** Uses signs, symptoms, and clinical knowledge from a peer-reviewed database to suggest tests and present a differential diagnosis as shown in Figure 1 below.
- **Loss of Heterozygosity:** Supports the analysis of microarrays**.**
- **Genome-Phenome Analyzer:** Analyzes and reports on whole exome and genome testing.

Summary for a 10 year old boy with:

Pertinent positive findings

Onsets can be at an age, by an age, or unknown

Req'd	Onset	Finding	Pertinence
	@10	Dysarthria or abnormal sound character	
	@10	Ataxia	
	≤10	Vibration or joint position sense decreased	
			high→

Pertinent negative findings

Absent	Finding	Pertinence
X	Muscular atrophy or hypoplasia	
X	Intellectual disability	
X	CT or MRI: pan-cerebellar atrophy or hypoplasia	
X	MRI: white matter abnormality	
X	Seizures	
		high→

Differential diagnosis

Disease	Probability
FRDA: Friedreich ataxia	
Vitamin E deficiency	
AVED: ataxia with vitamin E deficiency	
Post-infectious acute cerebellar ataxia	
Abetalipoproteinemia	
ARSACS: AR spastic ataxia of Charlevoix-Saguenay	

Figure 1: Clinical findings and diseases can be represented using SNOMED CT content in SimulConsult.

By using SNOMED CT in the electronic reports generated by their software, SimulConsult has been able to achieve improved interoperability with other systems and EHRs.

Standards and Guidelines

Diseases in SimulConsult are linked to Online Mendelian Inheritance in Man (OMIM), a catalog of Human Genes and Genetic Disorders, and additional knowledge resources from the National Library of Medicine (NLM). Tests are linked to "gene test advice" , provided by the NLM . Much of the frequency-based information is based on GeneReviews content.[3] It is also possible to assess a diagnosis based on the patient's findings, which indicates the frequency as well as the absence or presence of findings.

Using SNOMED CT

Although SimulConsult does not use SNOMED CT codes to drive decision support logic, their solution links to SNOMED CT through mappings provided by SimulConsult's terminology partner, Intelligent Medical Objects (IMO). IMO assigns proprietary codes to findings and diseases, which are then mapped to SNOMED CT. SimulConsult can be configured to use SNOMED CT terms to display |clinical findings| and |diseases| in the outputs of their software, such as patient summaries or genome analysis reports.

---

[1] http://www.simulconsult.com/
[2] http://osp.od.nih.gov/sites/default/files/resources/Segal_0.pdf
[3] SimulConsult leverages National Library of Medicine information to improve medical diagnosis