Getting Started with Clinical Quality Language: Technical Implementation for Vendors

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The MITRE Corporation operates the Centers for Medicare & Medicaid Services (CMS) Alliance to Modernize Healthcare (CAMH), a federally funded research and development center (FFRDC) dedicated to strengthening the nation's health care system. MITRE operates CAMH in partnership with CMS and the Department of Health and Human Services.

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Agenda

- Clinical Quality Language (CQL) Architecture
- Creating a Calculation Engine
- Using a CQL Execution Engine
- Lessons Learned
- Resources
- Questions

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Assumptions

- Familiarity with CQL
- Background in language processing
  - Language translation and/or evaluation
- Familiarity with Clinical Data Representation
  - Clinical Data Models
  - Terminology

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CQL Architecture

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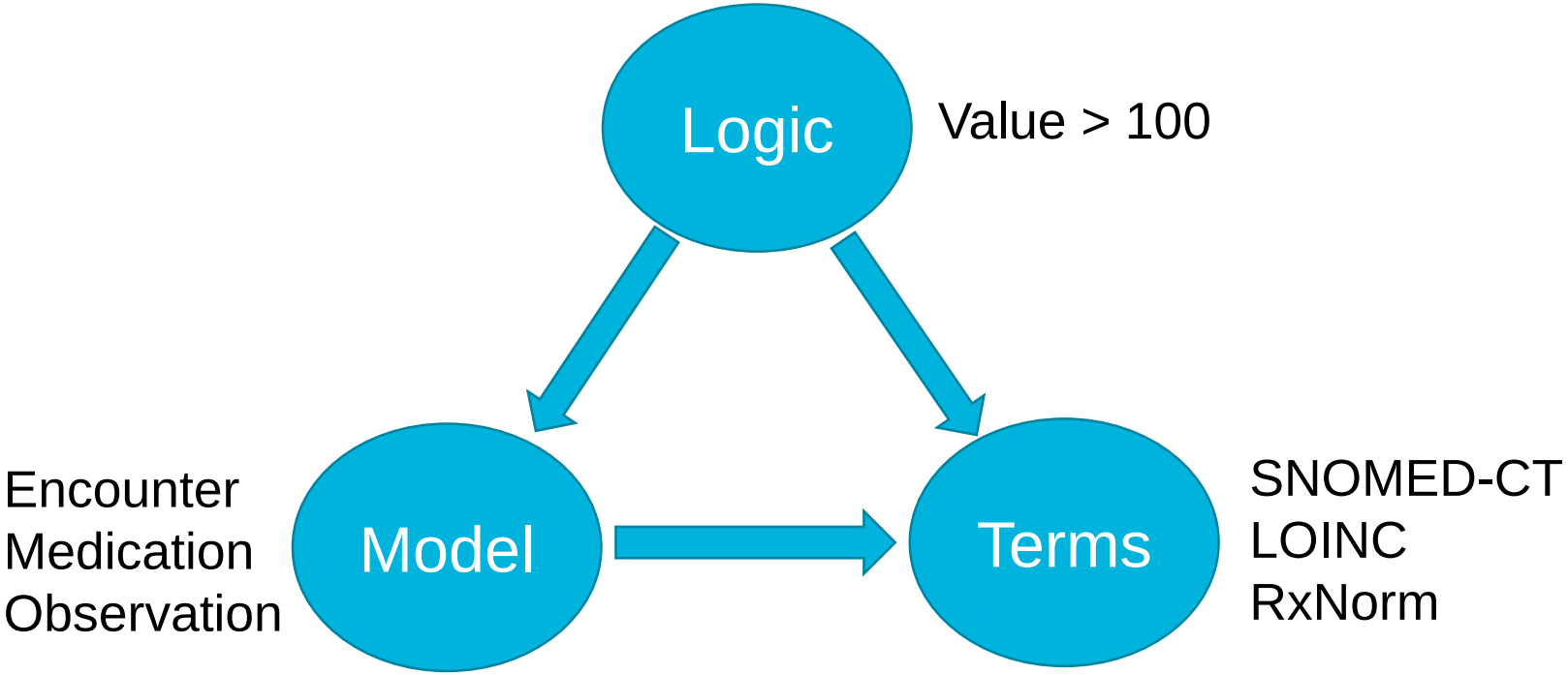
Components of Sharing Logic



Definitions:
SNOMED CT – Systematized Nomenclature of Medicine – Clinical Terms
LOINC – Logical Observation Identifiers Names and Codes

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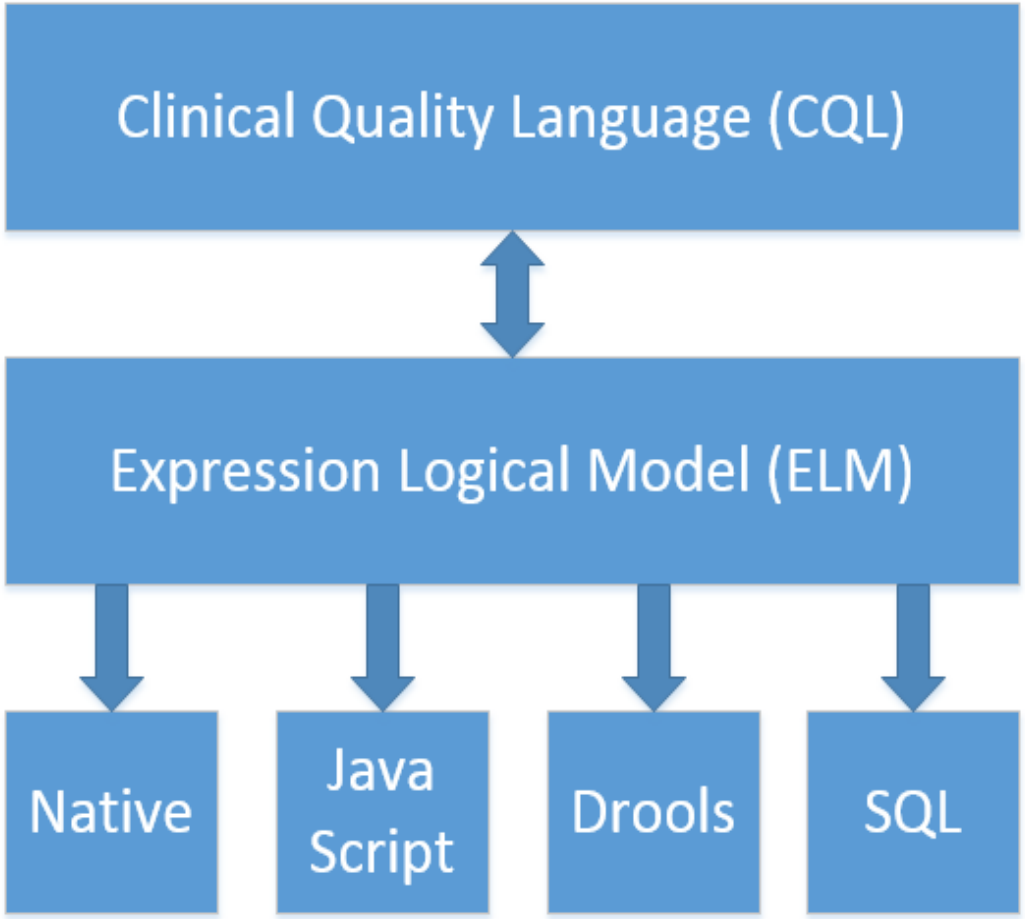
CQL Architecture



Authors use CQL to produce libraries containing human-readable yet precise logic.

ELM XML documents contain machine-friendly rendering of the CQL logic. This is the intended mechanism for distribution of libraries.

Implementation environments will either directly execute the ELM, or perform translation from ELM to their target environment language.

Definitions:
SQL – Structured query language

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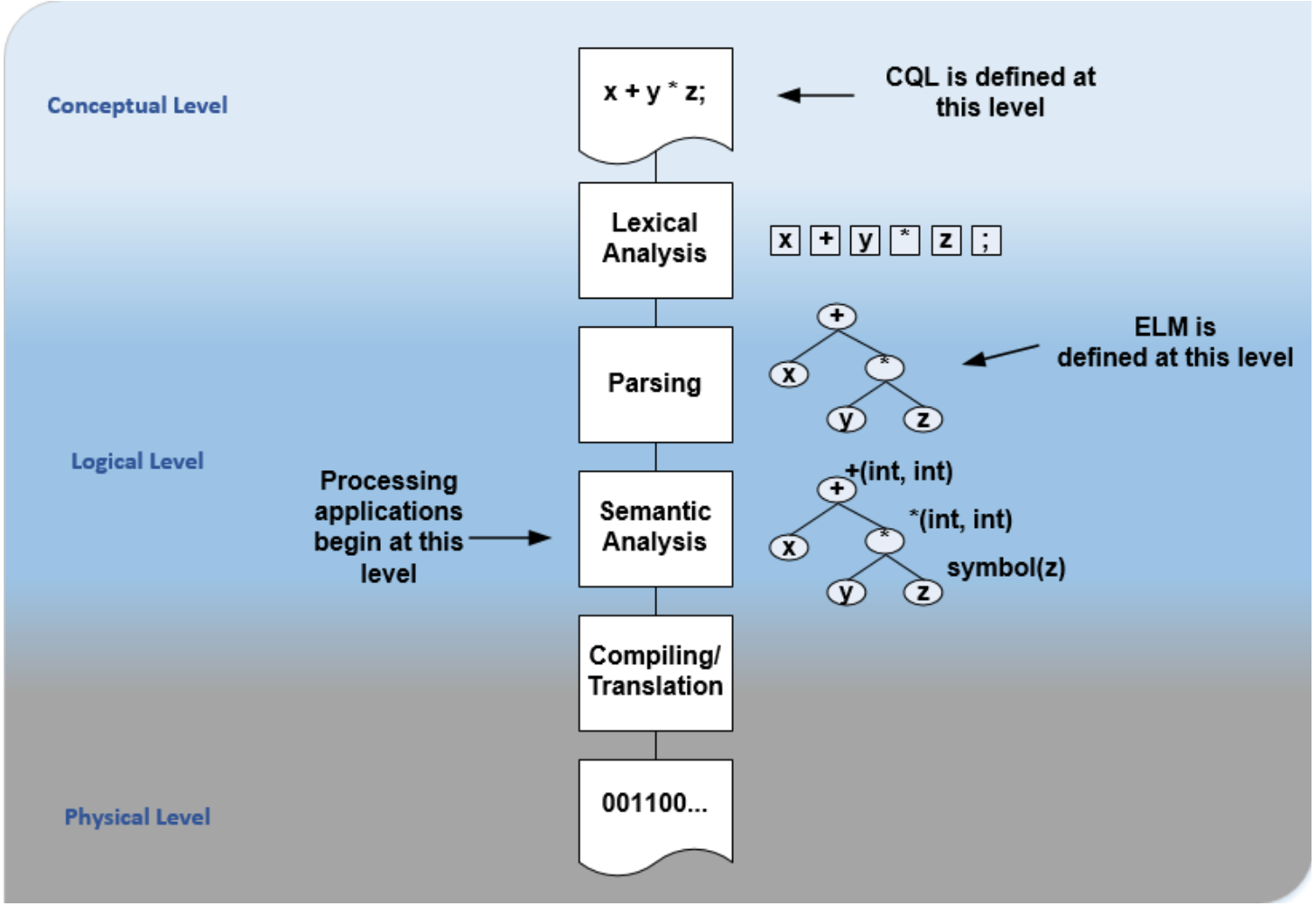
CQL-to-ELM Translation



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Expression Logical Model (ELM)

- A “byte-code” representation of CQL logic: carries sufficient semantics to enable execution independent of the CQL that produced it
- A “canonical” representation in terms of more primitive operations: focused on supporting implementation use cases such as evaluation and translation

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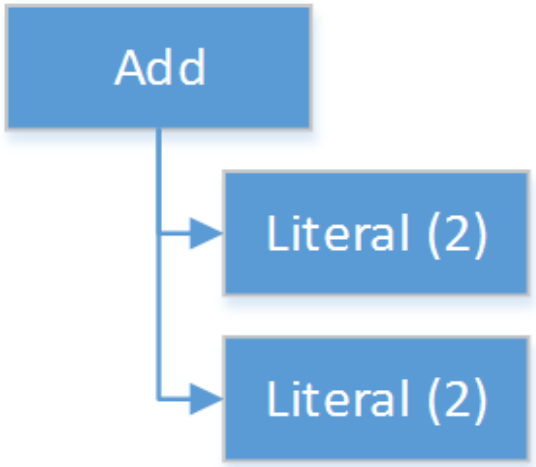
ELM Representation

- ELM expressions are built as trees of nodes, where each kind of expression is represented by a different node type

- For example, 2 + 2 is represented as:



ELM Representation (cont.)

- In general, operations and functions in CQL have an equivalent ELM representation

CQL Operator or Function	ELM Node Type
=	Equal
and	And
+	Add
Ceiling()	Ceiling

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Type Categories

- Primitive types
  - Boolean
  - String
  - Integer
  - Decimal
  - DateTime
  - Time
- Collection types
  - List<T>
- Structured types
  - Class types (defined by a data model)
  - Tuple (anonymous class types)
- Interval types
  - Interval<T> (must be an ordered type)

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Data Access

- All data access is done through Retrieve
  - Type information (data type and optional “template” identifier)
  - Code filter (a valueset or a set of codes)
  - Date filter (a date range)
  - Path information (id, code, date)

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Simple Retrieve

- Pharyngitis Diagnoses:

```
["Diagnosis": "Acute Pharyngitis"]
```

- ELM Retrieve:

```
<operand  xsi:type="Retrieve"
        dataType="qdm:Diagnosis"
        templateId="Diagnosis"
        codeProperty="code">
    <codes name="Acute Pharyngitis" xsi:type="ValueSetRef"/>
</operand>
```


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Specifying Data Models

- Each data model is described with “model info”
- Describes the types available in the model
- Also defines “primary code path” for each retrievable type
- Specifies the “patient” type
- *NOTE: Model info is not required by ELM, it’s only required to translate CQL to ELM*

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Model Info Example

```
<ns4:typeInfo xsi:type="ns4:ClassInfo"
    name="QDM.Diagnosis"
    identifier="Diagnosis"
    label="Diagnosis"
    retrievable="true"
    primaryCodePath="code"
    baseType="QDM.QDMBaseType">
  <ns4:element name="onsetDatetime" type="System.DateTime"/>
  <ns4:element name="abatementDatetime" type="System.DateTime"/>
  <ns4:element name="anatomicalLocationSite" type="System.Concept"/>
  <ns4:element name="severity" type="System.Concept"/>
</ns4:typeInfo>
```


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System Model

- System.Any – Base type for all types
- System.Boolean
- System.Integer
- System.Decimal
- System.String
- System.DateTime
- System.Time
- System.Quantity – e.g., 3 'gm'
- System.Code – code, system, version, display
- System.Concept – codes, display

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CQL Library

- Named, versioned groupings of CQL components

```
library CMS55 version '1'

using QDM

valueset "Inpatient": '2.16.840.1.113883.3.666.5.307'

parameter "Measurement Period" default Interval[@2014-01-01T00:00:00.0, @2015-01-01T00:00:00.0)

context Patient

define "Inpatient Encounters":
    ["Encounter, Performed": "Inpatient"] E
        where E.lengthOfStay <= 120 days
            and E.dischargeDatetime during "Measurement Period"
```


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Library Example

```
<library xmlns="urn:hl7-org:elm:r1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema"
    xmlns:t="urn:hl7-org:elm-types:r1"
    xmlns:qdm="urn:healthit-gov:qdm:v4_2">
  <identifier id="CMS55" version="1"/>
  <schemaIdentifier id="urn:hl7-org:elm" version="r1"/>
  <usings>
    <def localIdentifier="System" uri="urn:hl7-org:elm-types:r1"/>
    <def localIdentifier="QDM" uri="urn:healthit-gov:qdm:v4_2"/>
  </usings>
  <parameters>
    <def name="Measurement Period" accessLevel="Public">
  </parameters>
  <valueSets>
    <def name="Inpatient" id="2.16.840.1.113883.3.666.5.307" accessLevel="Public"/>
  </valueSets>
  <statements>
    <def name="Patient" context="Patient">
    <def name="Inpatient Encounters" context="Patient" accessLevel="Public">
  </statements>
</library>
```


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Parameter Definition

```
<def name="Measurement Period" accessLevel="Public">
  <default lowClosed="true" highClosed="false" xsi:type="Interval">
    <low xsi:type="DateTime">
      <year valueType="t:Integer" value="2014" xsi:type="Literal"/>
      <month valueType="t:Integer" value="1" xsi:type="Literal"/>
      <day valueType="t:Integer" value="1" xsi:type="Literal"/>
      <hour valueType="t:Integer" value="0" xsi:type="Literal"/>
      <minute valueType="t:Integer" value="0" xsi:type="Literal"/>
      <second valueType="t:Integer" value="0" xsi:type="Literal"/>
      <millisecond valueType="t:Integer" value="0" xsi:type="Literal"/>
    </low>
    <high xsi:type="DateTime">
      <year valueType="t:Integer" value="2015" xsi:type="Literal"/>
      <month valueType="t:Integer" value="1" xsi:type="Literal"/>
      <day valueType="t:Integer" value="1" xsi:type="Literal"/>
      <hour valueType="t:Integer" value="0" xsi:type="Literal"/>
      <minute valueType="t:Integer" value="0" xsi:type="Literal"/>
      <second valueType="t:Integer" value="0" xsi:type="Literal"/>
      <millisecond valueType="t:Integer" value="0" xsi:type="Literal"/>
    </high>
  </default>
</def>
```


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Patient Context

```
10
11  context Patient
12
```

```
<def name="Patient" context="Patient">
  <expression xsi:type="SingletonFrom">
    <operand dataType="qdm:Patient" templateId="Patient" xsi:type="Retrieve"/>
  </expression>
</def>
```


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Expression Example

```
define "Inpatient Encounters":
    ["Encounter, Performed": "Inpatient"] E
        where E.lengthOfStay <= 120 days
            and E.dischargeDatetime during "Measurement Period"
```

```
<def name="Inpatient Encounters" context="Patient" accessLevel="Public">
  <expression xsi:type="Query">
    <source alias="E">
      <expression dataType="qdm:EncounterPerformed" templateId="EncounterPerformed" codeProperty="code" xsi:type="Retrieve">
        <codes name="Inpatient" xsi:type="ValueSetRef"/>
      </expression>
    </source>
    <where xsi:type="And">
      <operand xsi:type="LessOrEqual">
        <operand path="lengthOfStay" scope="E" xsi:type="Property"/>
        <operand value="120" unit="days" xsi:type="Quantity"/>
      </operand>
      <operand xsi:type="In">
        <operand path="dischargeDatetime" scope="E" xsi:type="Property"/>
        <operand name="Measurement Period" xsi:type="ParameterRef"/>
      </operand>
    </where>
  </expression>
</def>
```


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Creating a Calculation Engine

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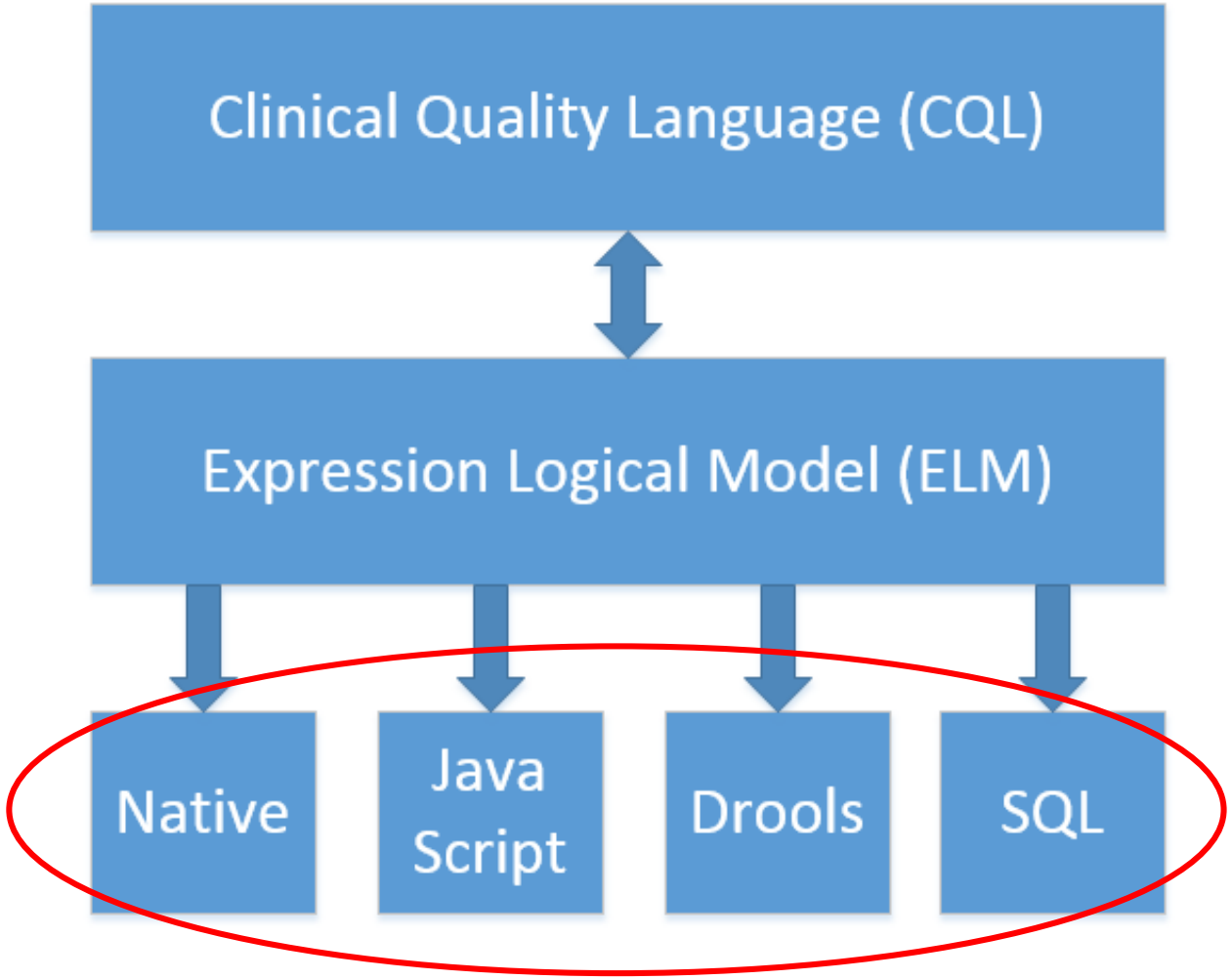
Evaluation Approaches



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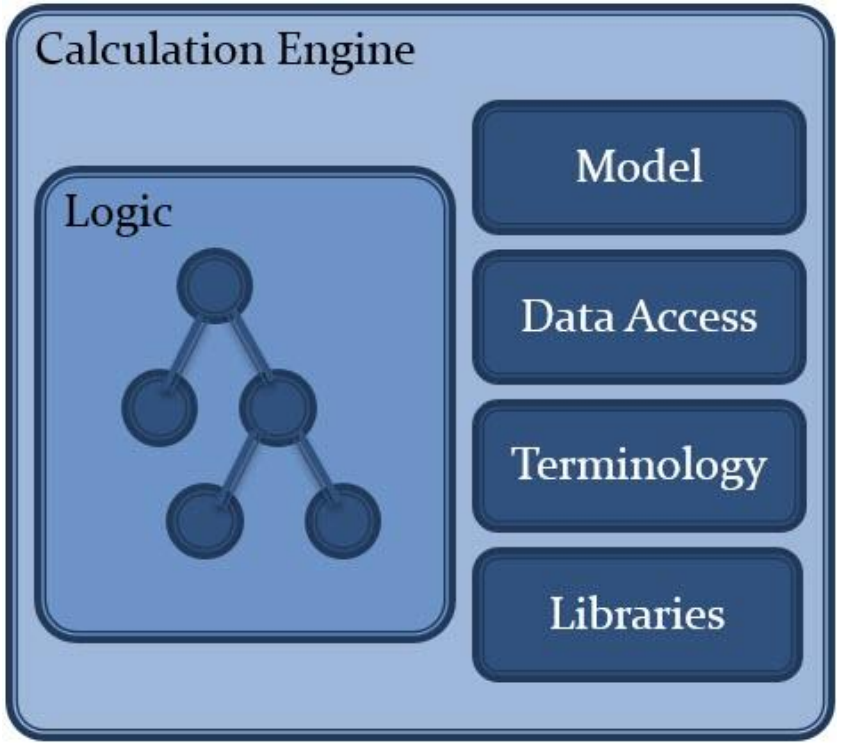
CQL Evaluation Architecture

Calculation of CQL involves the following conceptual components:



Calculation Engine is what performs the measure calculations

Logic is the description of how the measure calculates against the clinical information, for example, patient records

Model is the structured representation of clinical information that is used to calculate the measure

Data Access is how records of clinical information are retrieve from the underlying system, for example, an Electronic Health Record (EHR)

Terminology is concerned with determining whether clinical information is related to the measure logic through looking at coded values

Libraries enable the reuse of measure logic across measures and decision support artifacts

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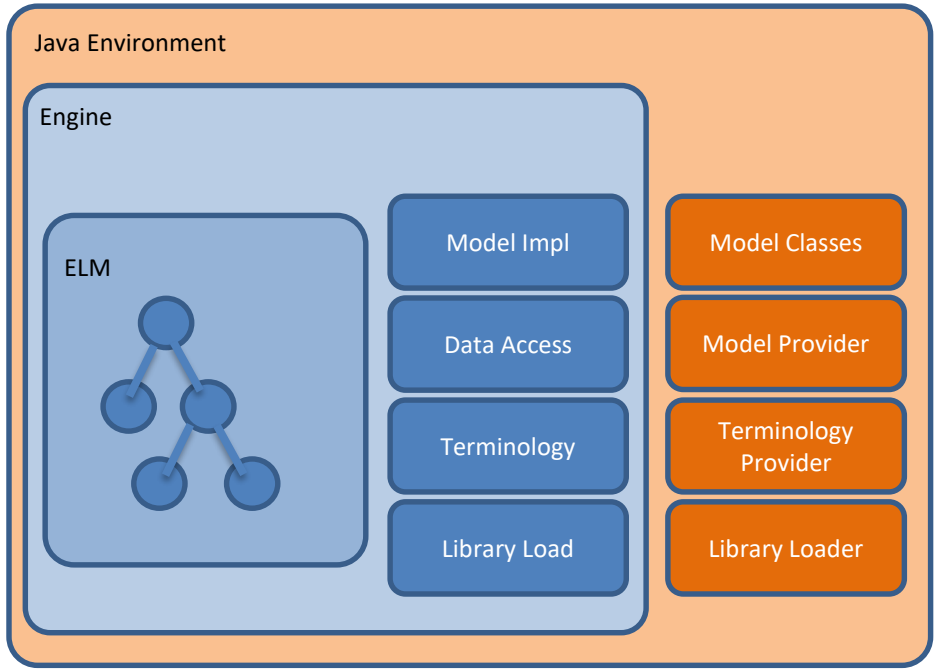
Java-Based CQL Evaluation



Calculation Engine – Generic Java implementation

Logic – is implemented as a deserialization of the ELM into a tree of “executable” nodes

Model – The model for this generic engine is effectively any Java classes, supported with a Runtime to model the “System” types

Data Access – Modeled with a “DataProvider” interface that corresponds to the “retrieve” in ELM

Terminology is – Modeled with a “TerminologyProvider” interface that provides basic terminology services (expand, isMember, lookup)

Libraries – Modeled with a LibraryLoader interface

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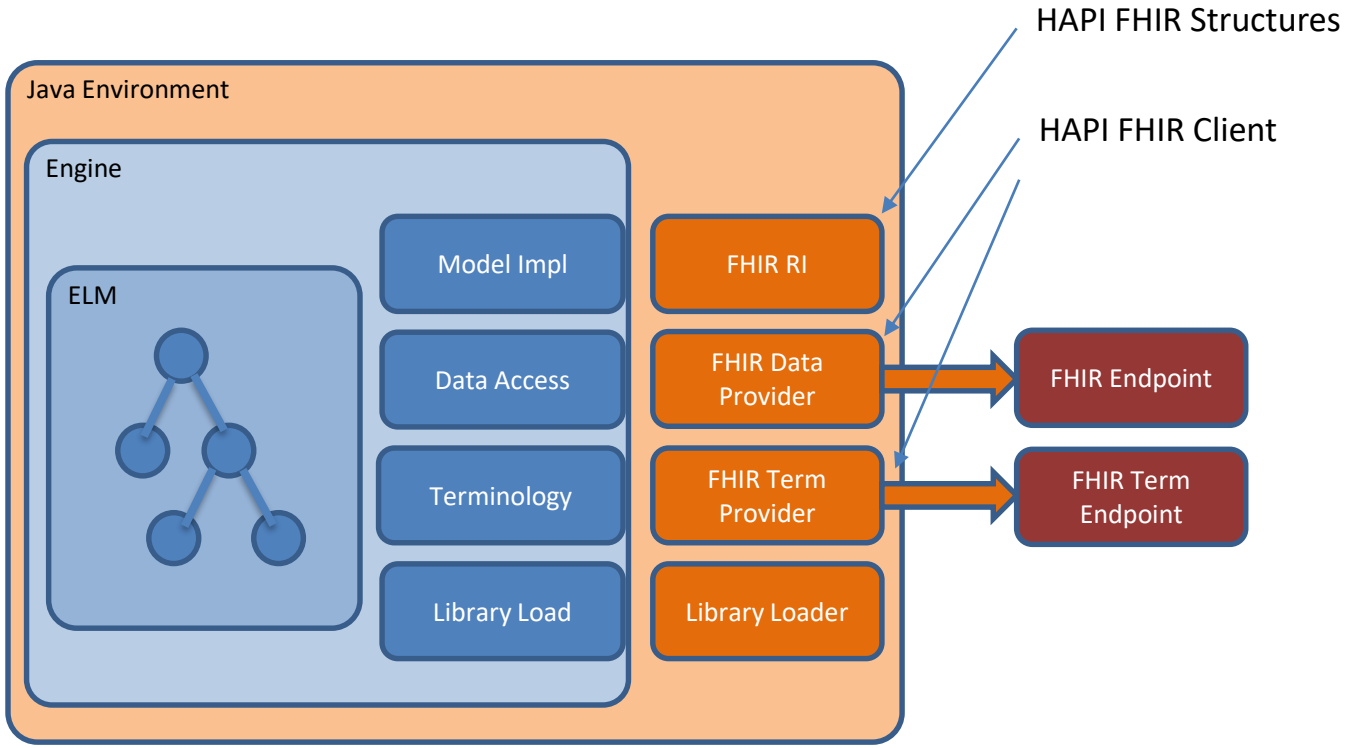
FHIR-CQL Execution



- Uses HAPI FHIR classes for the Model Implementation
- FHIRDataProvider to communicate with a FHIR data endpoint
- FHIRTerminologyProvider to use a FHIR terminology endpoint

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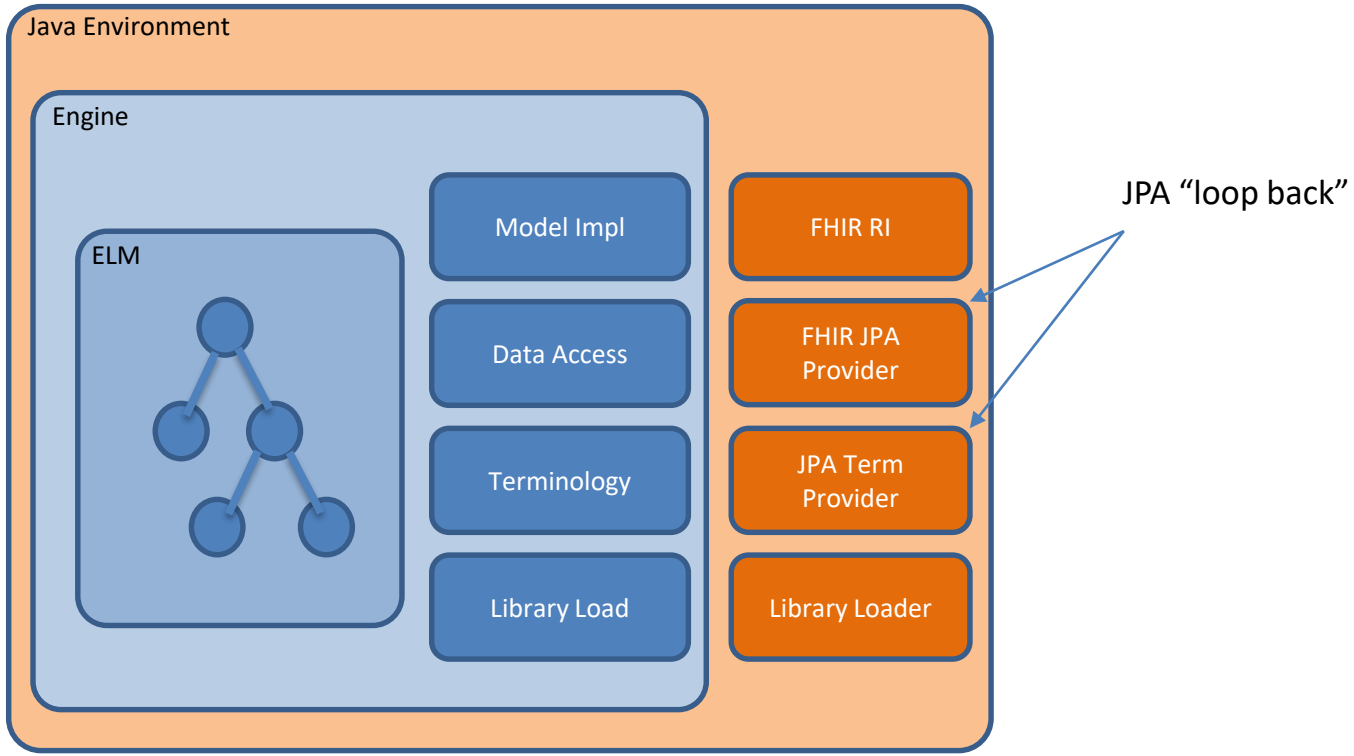
HAPI FHIR JPA Plugin



- Uses a FHIRJPAProvider to “loop back” into the HAPI FHIR Server
- Provides a FHIRLibraryLoader that can load libraries from the HAPI FHIR Server

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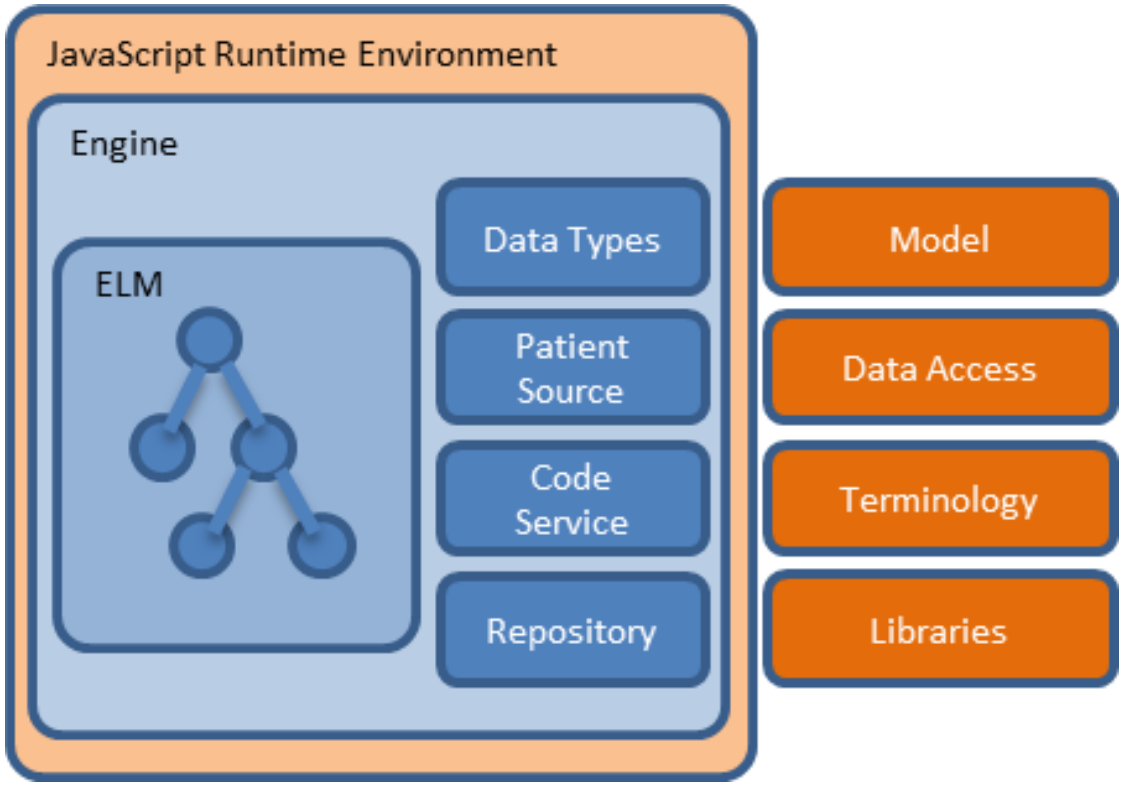
JavaScript-Based CQL Evaluation



Data Types – Built-in clinical models for this engine

Patient Source – An interface class provided on execution, that implements ”get” functions to access data from the passed in patient model

Code Service – Interface that provides basic terminology services (expand, isMember, lookup)

Repository – Loads multiple libraries in for execution

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Using a CQL Execution Engine

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Introduction

- Software Developer on the Bonnie eCQM Testing Tool
- Replaced existing QDM-Logic Execution Engine with CQL Execution Engine
- Contributed to the JavaScript CQL Execution Engine

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Open Source JavaScript Execution Engine

- Easily run Server-side or Client-side
- Developed in CoffeeScript. Transpiled to JavaScript
- Only uses data passed in at execution
- Expects patients to be QDM-based
  - Defined in the QDM ModelInfo files
- Returns a list of patients and their calculation values for each named expression

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Execution Engine Requirements and Example

- Requirements:
  - Measurement Period
  - ELM JSON
  - Value Sets
  - Patient Source

```
parameters = {
  "MeasurementPeriod": new cql.Interval(
    new cql.DateTime(2016, 1, 1, 0, 0, 0, 0),
    new cql.DateTime(2017, 1, 1, 0, 0, 0, 0)
  )
}
lib = new cql.Library(measureElm)
codeService = new cql.CodeService(valueSets)
executor = new cql.Executor(lib, codeService, parameters)
results = executor.exec(patientSource)
```


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Execution Engine Results

- All definition expressions passed in will be executed
- Results return 2 objects:
  - A list of Patients and their calculation values for each named definition expression
  - A list of Patients and their calculation values for each sub-component of a definition

```
define "Initial Population":
    "In Demographics" and exists "Qualifying Encounters"
```


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Execution Engine Results (cont.)

- Does not calculate final population results
  - Definitions of the Populations are specified in the HQMF file
  - Ex: IPP, DENOM, NUMER…

- Functions in CQL are not executed
  - To execute, call in a define statement
  - Measure Population Observations are functions in CQL
    - Not included in define statements by default

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Bonnie Execution Engine Workflow

Engine Parameters:
- ELM (JSON)
- Patient Source (JSON)
- Value Set Code Service
- Measurement Period

Execution Engine

Result Object:
- Named definition Patient Results
- Sub-component Patient Results

Match Results to Populations:
- HQMF Definitions
- Patient Result Map

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Wrapping Patient Data Model to match ModelInfo QDM

```
<ns4:typeInfo xsi:type="ns4:ClassInfo" name="QDM.MedicationAdmin
    <ns4:element name="authorDatetime" type="System.DateTime"/>
    <ns4:element name="relevantPeriod" type="interval&lt;System.
    <ns4:element name="dosage" type="System.Quantity"/>
    <ns4:element name="supply" type="System.Quantity"/>
    <ns4:element name="frequency" type="System.Code"/>
    <ns4:element name="route" type="System.Code"/>
    <ns4:element name="reason" type="System.Code"/>
    <ns4:element name="negationRationale" type="System.Code"/>
```

```
class CQL_QDM.MedicationAdministered extends CQL_QDM.QDMDatatype
  ###
  @param {Object} entry - the HDS data criteria object to convert
  ###
  constructor: (@entry) ->
    super @entry
    @_authorDatetime = CQL_QDM.Helpers.convertDateTime(@entry.start_time)
    @_dosage = @entry.dose
    @_frequency = @entry.frequency
    @_negationRationale = @entry.negationReason
```

⋮

```
  @returns {Date}
  ###
  authorDatetime: ->
    @_authorDatetime
```


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The Measure Authoring Tool (MAT) Package

- Human readable .html page
- HQMF .xml file
- Measure .cql file
- Support Library .cql files
- ELM files in XML representation
- ELM files in JSON representation

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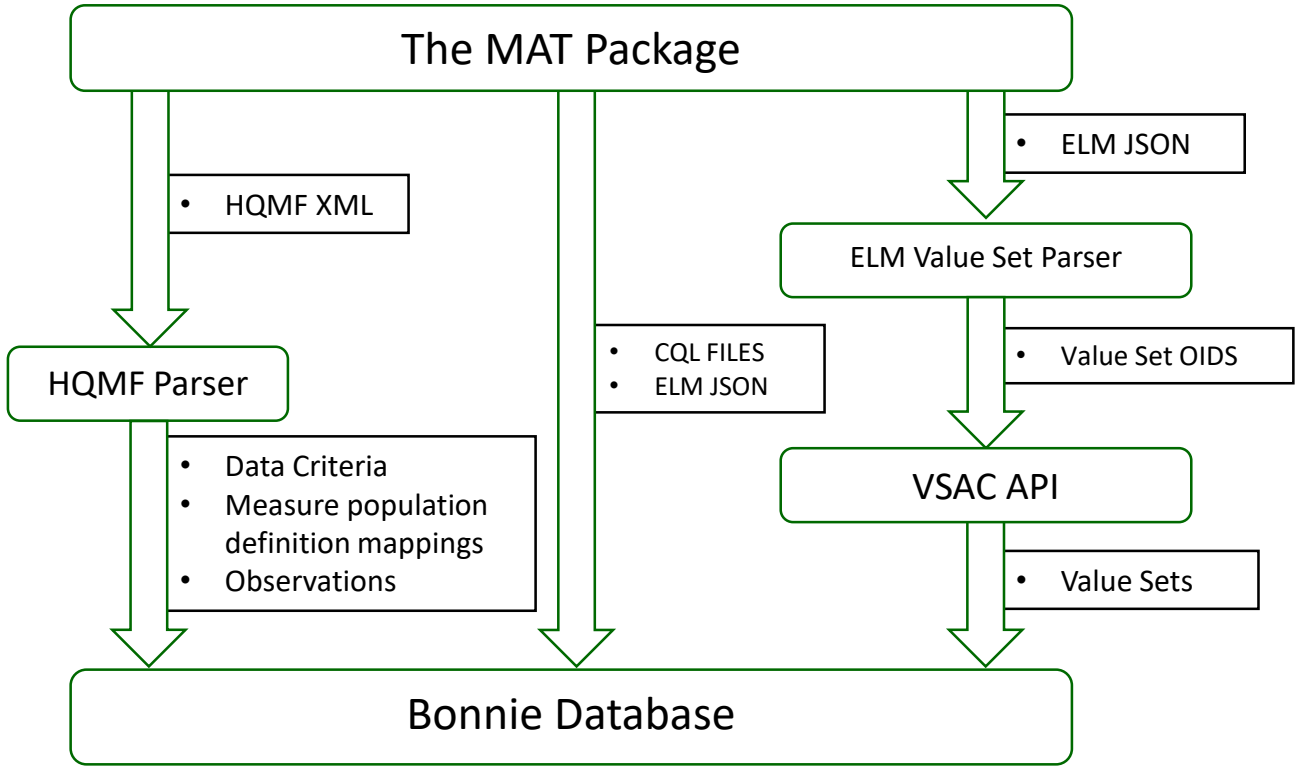
Processing the MAT Package



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MAT Export Package: The HQMF File

HQMF Document Structure

HQMF Header

- HQMF Document Attributes
- Author
- Measure Processing Metadata
- Measure Period

HQMF Body

- Measure Description
- Data Criteria
- Population Criteria
  - Stratifier Criteria Entry
- Measure Observations

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Using HQMF to Map Populations to Define Statements

```
<component typeCode="COMP">
  <denominatorExclusionCriteria classCode="OBS" moodCode="EVN">
    <id extension="denominatorExclusions" root="8B930DAE-A323-4264-ABF5-B4230B38484E"/>
    <code code="DENEX" codeSystem="2.16.840.1.113883.5.4" codeSystemName="Act Code"/>
    <precondition typeCode="PRCN">
      <criteriaReference classCode="OBS" moodCode="EVN">
        <id extension="PneumococcalVaccinationCoverageforOlderAdultsPVC.&quot;Exclusions&quot;"
            root="9ACFE781-E42F-47B0-8276-5C842B006D2F"/>
      </criteriaReference>
    </precondition>
  </denominatorExclusionCriteria>
</component>
```

Library name

Definition name

```
define "Exclusions":
    exists ( ["Procedure, Performed": "Chemotherapy"] Chemotherapy
            where Chemotherapy.relevantPeriod overlaps "Measurement Period"
    )
        or exists ( ["Procedure, Performed": "Bone Marrow Transplant"] BMT
                where BMT.relevantPeriod overlaps "Measurement Period"
        )
        or exists ( ["Diagnosis": "Anaphylactic Reaction to Pneumococcal Conjugate Vaccine"] Reaction
                where Reaction.prevalencePeriod before end of "Measurement Period"
        )
        or exists { ( "hospice or using hospice services" ) }
```


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Filtering Execution Engine Results

```
▶ localIdPatientResultsMap: {5a74ad8008fa18119b3566c2: {…}}
▼ patientResults:
  ▼ 5a74ad8008fa18119b3566c2:
    Denominator: true
    Denominator Exceptions: false
    Initial Population: false
    ▶ Most Recent Delivery: ProcedurePerformed {entry: {…}, _codes: {…}
    ▶ Most Recent Delivery Overlaps Diagnosis: [ProcedurePerformed]
    Numerator: true
    ▶ Patient: {birthDatetime: DateTime, gender: "M"}
    ▶ SDE Ethnicity: []
    ▶ SDE Payer: []
    ▶ SDE Race: []
    ▶ SDE Sex: [PatientCharacteristicSex]
    ▶ __proto__: Object
  ▶ __proto__: Object
▶ populationResults: {}
```

- HQMF + CQL Population Map
- HQMF Population Filtering

```
DENEXCEP: 0
DENOM: 0
IPP: 0
NUMER: 0
```


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Bonnie Execution Engine Workflow Recap

Engine Parameters:
- ELM (JSON)
- Patient Source (JSON)
- Value Set Code Service
- Measurement Period

Execution Engine

Result Object:
- Named definition Patient Results
- Sub-component Patient Results

Match Results to Populations:
- HQMF Definitions
- Patient Result Map

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Lessons Learned

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Lessons Learned

- Engine Architecture
- “Direct” deserialization
- DataProvider interface
- TerminologyProvider interface
- Data Access Layer and “context”
- Patient Model
- Function Execution

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Lessons Learned: Engine Architecture

- Problem
  - How can we quickly **build a performant and flexible native evaluation engine**?
- Success
  - By **"direct" deserialization** of an ELM document **into a graph of "executable" nodes**
- Discussion
  - Considered a **"visitor" pattern**, but that would mean **run-time determination of execution**. For the number of node types in ELM, that **would be significant**
  - Considered **transpiling to Java or JavaScript**, but would require **significant Runtime libraries and significant effort**. Would result in **better performance** though
- Recommendation
  - **Performance** using this approach **is favorable**, but also **benefits from caching**
  - There are **some places** in ELM that **could provide better typing** (STU comments in progress)

Lessons Learned: “Direct” Deserialization

- Problem
  - **Using “direct” deserialization**, we want to be able to **use generated classes**, but also provide **override implementations of the “execute” method**
- Success
  - Generate **all classes as descendants of a base “Executable” class**
  - **Read ELM directly into descendants of generated ELM classes**
    - Provide engine implementation
- Discussion
  - Requires a **JAXB override** to tell the factory what class to use for each node type in ELM
  - **Create an ObjectFactoryEx descended from generated ObjectFactory**
    - Override “create” methods to return descendant classes
  - **Set the ObjectFactoryEx in the JAXB context**

Lessons Learned: DataProvider Interface

- Problem
  - How do we implement an engine that can **deal with arbitrary data models** as required by the CQL specification?
- Success
  - **Define a DataProvider interface** that completely **characterizes the data access layer**:
  - The DataProvider Interface is **based on the ELM Retrieve**
    - Context – What patient is being evaluated
    - DataType – What data type is being requested (and profile)
    - Code Filter – What code filter to apply
    - Data Filter – What date-range to apply
  - Results in a **clean interface for data access**

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Lessons Learned: DataProvider Interface (cont.)

- Considerations
  - **Requires an abstraction layer between it and the data source** (e.g., Object Adapter)
    - i.e., an interface through which the engine can perform all get/set functionality
  - The **engine must be able to uniquely determine the DataProvider** responsible for any given instance at run-time

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Lessons Learned: TerminologyProvider Interface

- Problem
  - How can we **enable the engine to use any terminology service**?
- Success
  - Define a very simple **Terminology interface**
    - In – Is a given code a member of a given value set
    - Expand – Retrieve the codes in a given value set
    - Lookup – Retrieve the code for a given code and code system
  - **Based on the FHIR Terminology Service CapabilityStatement**
- Discussion
  - **Valuesets should be cached locally for performance**
    - Implications for maintenance

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Lessons Learned: Data Access Layer and “context”

- Problem
  - How do we **implement Patient context** as required by the CQL specification?
  - CQL Context: all expressions in a given context are evaluated with respect to that context
    - e.g., Medications returns only medications for a given patient
- Success
  - The **Data Access Layer is responsible for enforcing this expectation**
    - FHIR is straightforward: translates to a “patient” or “subject” parameter in the URL
    - Other models: the data access layer needs to understand the relationship between each data type and the patient
      - **ModelInfo doesn’t currently represent this. May need to extend ModelInfo to capture this information**

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Lessons Learned: Patient Model

- Problem
  - The execution engine expects a **patient model aligned with the QDM model** specified in the ModelInfo file (a calculable representation of the expected model).
- Success
  - **Created a wrapper library** around the Bonnie data model to map it to the specified QDM Model
- Recommendation
  - **Build a wrapper library** around the application's data model to map it to the specified QDM Model

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Lessons Learned: Function Execution

- Problem
  - **Functions are not automatically executed by the execution engine**
  - Measure Population Observations are represented as functions
  - Bonnie needed the Measure Population Observations to execute automatically
- Solution
  - Created a CQL definition snippet that called the Measure Population Observation to ensure it gets executed by the execution engine
- Recommendation
  - If it's necessary to have a **CQL function execute automatically, wrap it in a CQL definition**

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Resources

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Resources

- CQL Specification - CQL Release 1, Standard for Trial Use (STU) 2
  - http://www.hl7.org/implement/standards/product_brief.cfm?product_id=400
- eCQI Resource Center
  - CQL Space, including the QDM v5.3 and v5.3 Annotated
    - https://ecqi.healthit.gov/cql
  - Check the eCQI Resource Center Events page and CQL Educational Resources page for more information
    - https://ecqi.healthit.gov/ecqi/ecqi-events
    - https://ecqi.healthit.gov/cql/cql-educational-resources
- CQL Formatting and Usage Wiki
  - https://github.com/esacinc/CQL-Formatting-and-Usage-Wiki/wiki
- CQL GitHub Tools Repository
  - https://github.com/cqframework/clinical_quality_language
- Jira for tracking CQL Related Issues
  - https://oncprojectracking.healthit.gov/support/projects/CQLIT

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Resources (cont.)

- JavaScript Open Source execution engine:
  - https://github.com/cqframework/clinical_quality_language/tree/master/Src/coffeescript/cql-execution
- Java Open Source execution engine:
  - https://github.com/DBCG/cql_engine
- HQMF Parser:
  - https://github.com/projecttacoma/cqm-parsers
- QDM ModelInfo Files
  - https://github.com/cqframework/clinical_quality_language/tree/master/Src/java/qdm/src/main/resources/gov/healthit/qdm
- Measure Authoring Tool
  - https://www.emeasuretool.cms.gov/
- Bonnie Testing Tool
  - https://bonnie.healthit.gov/

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Other Related Presentations at HIMSS 2018

Bonnie: Tips for Debugging Clinical Quality Language eCQMs	Cypress: New Features, Clinical Quality Language Support, and Burden Reduction	CMS eCQM Strategy: The Future of eCQMs (Gallery Walk)	CMS eCQM Strategy: The Future of eCQMs (Gallery Walk)
3/7/18	3/7/18	3/7/18	3/8/18
9:30-10am PT	10-10:30am PT	2-3:30pm PT	10:30am-12pm PT
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