Modeling Decision Support Rule Interactions in a Clinical Setting

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Why is this important?

- Rules are not static, isolated entities that react to conditions in their antecedent with no regard or awareness to what other rules may react to, and to whether this reaction—or behavior—may affect them.

Modeling rule interactions using Ontologies and some basic concepts borrowed from Complex Adaptive Systems (CAS).
Modeling Rule Interactions

Why is this important?

- Knowledge about rule behavior and interaction(s) should be captured and modeled at authoring time
- Facilitates knowledge authoring, editing and update
- Fosters consistency in rule implementation and maintenance
- Rules are not static, isolated entities that react to conditions in their antecedent with no regard or awareness to what other rules may react to, and to whether this reaction—or behavior—may affect them.

Modeling rule interactions based using Ontologies and some basic concepts borrowed from Complex Adaptive Systems (CAS).
Modeling Rule Interactions

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Rules are not static, isolated entities that react to conditions in their antecedent with no regard or awareness to what other rules may react to, and to whether this reaction—or behavior—may affect them.
Modeling Rule Interactions

- Decision rules are richer than just isolated entities pre-placed as decision points along an execution flow.
- When aggregated, rules may exhibit more dynamic interactions.
- Such behavior should be explicitly integrated and represented as part of a more comprehensive modeling process.

Modeling rule interactions based using Ontologies and some basic concepts borrowed from Complex Adaptive Systems (CAS).
Ontologies

- Generally used for management of formalized knowledge
- Ontologies refer to a conceptualized and agreed upon collection of entities in some domain of interest
- Entities are unambiguously described by shared, agreed upon vocabulary resulting in an enriched content
- Such content can be communicated and processed by computers.

Ontologies describe objects, concepts and their relationships in a particular area of interest by means of a particular modeling language and terminology.
Ontologies and Content Modeling

- Important for Partners Healthcare as Ontologies support clinical content formalization
- This aligns with ongoing efforts for extraction, modeling, and curation of expert knowledge embedded in a variety of systems.
- A large amount of knowledge is in the form of rules that provide decision support to aid clinicians improve the outcome of treatments by
  - Prompting clinical alerts about the patient current condition;
  - Diagnosis support by highlighting key symptoms and findings;
  - Medication ordering by suggesting appropriate medications and dosages based on the medical condition of a patient;
  - Cost reduction by suggesting effective alternative treatments and medications.
Ontologies and Content Modeling

- Important for Partners Healthcare as Ontologies support clinical content formalization
- This aligns with ongoing efforts for extraction, modeling, and curation of expert knowledge embedded in a variety of systems.
- Development of a Clinical Knowledge Entity Metamodel (CKEM) to support the definition of a set of conventions, elements, and types common to our internal domains.
- The key element in the metamodel is the knowledge Entity represented by a set of “common properties” and “type-specific properties”.

Complex Adaptive Systems (CAS)

- CAS are composed of simple agents and stimulus-response rules to describe an agent’s behavior when placed in an environment.
- Holland defines seven basics common to all CAS. *
- We selected four basics to model *simple interactions* among rules:
  - **Aggregation** as categorization and emergence of complex behaviors of the collective.
  - **Tagging** facilitates formation of aggregates and delimitation of boundaries.
  - **Internal Models** facilitates abstraction of relevant features to each agent.
  - **Building Blocks** allow reusability in terms of repetitions and combinations of simple things to build complex ones.

*Holland JH. Hidden Order: How Adaptation Builds Complexity. Addison-Wesley, 1995*
Ontologies and Content Modeling

- Development of a **Clinical Knowledge Entity Metamodel** (CKEM) to support the definition of a set of conventions, elements, and types common to our internal domains.

- The **key element in the metamodelling** is the **knowledge Entity** represented by a set of “common properties” and “type-specific properties”.

Current Knowledge Management Efforts

- Formalization, or *conceptualization* of extracted content.
- Development of a Clinical Knowledge Entity Metamodel (CKEM) to support the definition of a set of conventions, elements, and types common to our internal domains, e.g., patient demographics, medications, and diagnoses.
- All models derived from the metamodel are declarative in nature, providing the building blocks for a flexible representation of content across all domains.
- The key element in the metamodel is the knowledge *Entity* represented by a set of “common properties” and “type-specific properties”.

*Content* is represented as an aggregation of entities of different types and roles within a domain.
A production rule is a decision rule of the form: 
\[ \text{if } \text{<condition>} \text{ then } \text{<action>}. \]

\text{<condition>} is a Boolean combination of simple expressions.

\text{<action>} part could be an assertion, modification or retraction of facts; or some other side effect.
A Schema for Production Rules
A Schema for Production Rules
A Schema for Production Rules
A Schema for Production Rules
- Data declarations;
- The logic in the antecedent of the rule as Boolean combinations of simpler conditions or ‘primitives’ representing similar medical concepts (encoded using ArdenML);
- An action in the consequent of the rule
Production Rules can be constrained to specific contexts where they apply.
Tags rules in terms of:

- **Membership** – groups rules based on certain characteristic(s).
- **Behavior** – how rules conduct in regard to themselves as well as in relationship to other rules in a given environment.
Modeling Behavior

- Behavior towards self
  1. Always fire
  2. First time only in _____ period of time
  3. Never fire

- Behavior towards others
  1. Always fire
  2. Fire if no one has
  3. Fire first
  4. PrecededBy (rule)
  5. PrecededBy(group)

Behavior towards others takes precedence over behavior towards self.

Rules can have multiple memberships with specific behaviors.
Current Use Case: Laboratory Results Alerts

- Production rules for CDS
- Simple rules of the form:

  \[\text{If} \ (\text{Latest}|\text{LastN}..) \ <\text{LabResultValue}>, \ <\text{ComparisonOp}>, \ <\text{ThresholdValue}|\text{ValueRange}|\text{Interpretation}> \]

  \[\text{Then} \]

  \[\text{Action} \]

  ... for specific Sites, Venues, Gender, Age groups, and Age Ranges

- Examples:
  - Latest Alkaline Phosphatase 5 times above the normal limit (AgeGroup= ADULTS)
  - Latest Acetaminophen result above threshold, first time only in an interval of 14 days, all age groups.
  - Latest Rapid plasma reagin (RPR) interpretation, first time only in an interval of 12 months, all age groups.
Properties of Production Rules

- Production rules are entity types in the metamodel
  - Generic properties
    - Metadata properties
    - Shared properties
  - Rule-Specific properties
    - Data declarations
    - Rule logic
- Rule specific-properties are declarative and consistent with the metamodel
- Rule specific-properties are modeled using (a subset of) ArdenML Syntax
  - Open Standard for representing clinical knowledge
  - XML Schema defines the syntax of expressions
Rule-Specific Properties

- Data declarations
  - Data statements (declarations)
  - Domain where the data statement(s) apply
  - Data statement constraints

- Rule logic
  - Combination of Boolean expressions
  - Constraints that may apply to these expressions (Pend)
  - An action, currently in the form of an assignment if the rule is triggered
  - Rule availability constraints
  - Rule execution constraints
Grouping Rules

**electrolytes**
- potassium,
- sodium,
- chlorides,
- magnesium,
- bicarbonate

**Rule Execution Constraints:**

**Behavior-Self:**
Always fire

**Behavior-Others:**
Fire if no one has

**Membership Expression:**
Electrolytes
Behavior from Separate Groups

**electrolytes**
- potassium,
- sodium,
- chlorides,
- magnesium,
- bicarbonate

**Rule Execution Constraints:**
- **Behavior-Self:**
  - Always fire
- **Behavior-Others:**
  - Fire if no one has

**Membership Expression:**
- Electrolytes

**chemistry**
- creatinine
  ...

**Rule Execution Constraints:**
- **Behavior-Self:**
  - Always fire
- **Behavior-Others:**
  - Always fire

**Membership Expression:**
- Chemistry
Multiple Memberships & Behaviors (1/2)

**Rule Execution Constraints:**

**Behavior-Self:**
First time only in ___ period of time

**Behavior-Others:**
Always fire

**Membership Expression:**
Oncology

**oncology**
platelets (low)
Multiple Memberships & Behaviors (2/2)

**Rule Execution Constraints:**

**Behavior-Self:**
First time only in ___ period of time

**Behavior-Others:**
Always fire

**Membership Expression:**
Oncology

**Rule Execution Constraints:**

**Behavior-Self:**
Always fire

**Behavior-Others:**
Always fire

**Membership Expression:**
Hematology
Rule Execution Flow

Rule Execution Constraints:

Behavior-Self:
N/A

Behavior-Others:
Preceded By()

Membership Expression:
Immunization/VaccineX/Contraindication

Rule Execution Constraints:

Behavior-Self:
N/A

Behavior-Others:
Preceded By (Contraindication)

Membership Expression:
Immunization/VaccineX/PreviousValid...
Data Declarations

Production Rule Template

Unique Identifier: Acetaminophen_Rule

Generic Properties:
Metadata Properties:
Shared Properties:

Rule-Specific Properties

Data Declarations:

**Domain:** LaboratoryResult

**Assignments:**
- LOINC_CODES_FOR_LAB := (3298-7)
- LIST_OF_STATUS := (complete, preliminary)
- LabResultThresholdValue := 50 mcg/L

**Read:** LatestLabResultValue := **Latest Mapping** LaboratoryResult.ResultValue

**Where Apply**

And (ResultType Is In LOINC_CODES_FOR_LAB
     ResultStatus Is In LIST_OF_STATUS)

**Data Statement Constraints:** (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

*Latest lab result against threshold value, first time only within a time interval*

*Domain (class in the PIM) where the statement(s) apply*

*Assignments: variable declarations*

*Read: Indicates retrieving patient information from record*

*Context where these data declarations apply*
**Rule Logic**

**Rule Logic:**

*If Apply*

LatestLabResultValue \( \geq \) LabResultThresholdValue

*Then*

**Assignment:** Alert := LEVEL 1

---

**Rule Availability Constraints:**

\{(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)\}

*Context where the rule applies.*

**NOTE:** this context must include all context(s) where the data statements apply.

---

**Rule Execution Constraints:**

*Used to model rule behavior.*

---

**Behavior-Self:**

First time only in 14-day period of time

**Behavior-Others:**

Always fire

**Membership Expression:**

Toxicology
Rule Execution Constraints

**Rule Logic:**

**If Apply**

```
LatestLabResultValue GT LabResultThresholdValue
```

**Then**

**Assignment:** Alert := LEVEL 1

**Boolean expression**

**Action:** Assign a level to an alert flag

**Rule Availability Constraints:**

(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

**Context where the rule applies.**

NOTE: this context must include all context(s) where the data statements apply.

**Rule Execution Constraints:**

**Behavior-Self:**

First time only in 14-day period of time

**Behavior-Others:**

Always fire

**Membership Expression:**

Toxicology

Latest lab result against threshold value, **first time only** within a time interval
Summary

- Simple model can represent rule interactions.

- Precedence inside a group can be combined with precedence among rules to model rule execution flow.

- Richer conceptual representation of production rule behavior will facilitate authoring and improve consistency in rule representation and maintenance.
Thank you!
Context: Age Groups

**Generic Properties:**
- Knowledge Management – Partners eCare

**Metadata Properties:**
- Shared Properties:

**Rule-Specific Properties**

**Data Declarations:**
- Domain: LaboratoryResult
  - Assignment: LOINC_CODES_FOR_LAB := (3298-7)
  - Assignment: LIST_OF_STATUS := (complete, preliminary)
- Read: LatestLabResultValue := Lastest Mapping LaboratoryResult.ResultValue
  - Where Apply
  - And (ResultType Is In LOINC_CODES_FOR_LAB ResultStatus Is In LIST_OF_STATUS)
- Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

---

**Data declaration common to ANY AgeGroup**

---

**Data declaration of threshold value for PEDI AgeGroup**

- Domain: LaboratoryResult
- Assignment: LabResultThresholdValue := 50 mcg/L
- Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI)

---

**Data declaration of threshold value for ADULT AgeGroup**

- Domain: LaboratoryResult
- Assignment: LabResultThresholdValue := 100 mcg/L
- Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ADULT)

---

**Rule Logic:**

- If Apply
  - LatestLabResultValue GT LabResultThresholdValue
- Then
  - Assignment: Alert := LEVEL 1

**Rule Availability Constraints:**
- (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)
Context: Age Groups and Age Ranges

Data Declarations:
Domain: Demographics
Read: PatientAge := Mapping demographics.PatientAge
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

Domain: LaboratoryResult
Assignment: MinAge := 1 day
Assignment: MaxAge := 4 days
Assignment: aValue := 40 micro IU/ml
Assignment: ThresholdValue := aValue Where Apply And (PatientAge GE MinAge)
Assignment: aValue := 25 micro IU/ml
Assignment: ThresholdValue := aValue Where Apply And (PatientAge GE MinAge)
Assignment: aValue := 10 micro IU/ml
Assignment: ThresholdValue := aValue Where Apply And (PatientAge GE MinAge)

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI)
Context: Age Groups and Age Ranges

Rule-Specific Properties

Data Declarations:
Domain: Demographics
Read: PatientAge := Mapping demographics.PatientAge

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

Domain: LaboratoryResult

Simple assignment
Assignment: ThresholdValue := 40 micro IU/ml

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PED, Range(1 day, 4 day))

Domain: LaboratoryResult

Simple assignment
Assignment: ThresholdValue := 40 micro IU/ml

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PED, Range(4 day, 8 day))

Domain: LaboratoryResult

Simple assignment
Assignment: ThresholdValue := 25 micro IU/ml

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PED, Range(8 day, 18 year))

Domain: LaboratoryResult

Simple assignment
Assignment: ThresholdValue := 10 micro IU/ml

Get age, for ANY AgeGroup
Break PEDI AgeGroup into age ranges
Context: Age Groups and Age Ranges

Rule-Specific Properties

Data Declarations:
Domain: Demographics
Read: PatientAge := Mapping demographics.PatientAge

Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

Domain: LaboratoryResult
Assignment: ThresholdValue := 40 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(1 day, 4 day))

Domain: LaboratoryResult
Assignment: ThresholdValue := 25 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(4 day, 8 day))

Domain: LaboratoryResult
Assignment: ThresholdValue := 10 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=Any) AND (Gender=Any) AND (AgeGroup=PEDI, Range(8 day, 18 year))

Domain: LaboratoryResult
Assignment: ThresholdValue := 0.1 mIU/l
Data Statement Constraints: (Site=ANY) AND (Venue=Any) AND (Gender=Any) AND (AgeGroup=ADULT)

Domain: LaboratoryResult
Assignment: LOINC_CODES_FOR_LAB := (3016-3)
Assignment: LIST_OF_STATUS := (complete, preliminary)
Read: LatestLabResultValue := Lastest Mapping LaboratoryResult.ResultValue
Where Apply
And ( ResultType Is In LOINC_CODES_FOR_LAB
ResultStatus Is In LIST_OF_STATUS )
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)
Context: Age Groups and Age Ranges

Current Logic

Rule Logic:

If Apply
Or (  
    And (  
        PatientAge GE MinAge  
        PatientAge LT MaxAge  
        LatestLabResultValue GT ThresholdValue  
    )  
    And (  
        PatientAge GE MinAge  
        LatestLabResultValue LT ThresholdValue  
    )  
)

Rule Availability Constraints:  
(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

Desired Logic

Rule Logic:

If Apply
Or (  
    (AgeGroup=PEDI, Range(X, Y))  
    LatestLabResultValue GT ThresholdValue  
    LatestLabResultValue LT ThresholdValue  
)  

Attach context

(AgeGroup=ADULT)

Rule Availability Constraints:  
(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)
Age Groups and Age Ranges

- Age ranges must be non-overlapping and “continuous” within the Age Group.

- **PEDI Group** is defined for ages [0 years, 18 years)
  - Range 1 is [1 day, 4 days),
  - Range 2 is [4 days, 8 days),
  - Range 3 is [8 days, 18 years)

- Note: there is nothing defined for [0 day, 1 day), but it is OK

- **NOT OK** to only have Ranges 1 and 3
Age Groups and Age Ranges

Domain: LaboratoryResult
Assignment: ThresholdValue := 40 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(1 day, 4 day))

Domain: LaboratoryResult
Assignment: ThresholdValue := 25 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(4 day, 8 day))

Domain: LaboratoryResult
Assignment: ThresholdValue := 10 micro IU/ml
Data Statement Constraints: (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(8 day, 18 year))

Rule Logic:

If Apply
Or (LatestLabResultValue GT ThresholdValue)
LatestLabResultValue LT ThresholdValue

Rule Availability Constraints:
(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

Based on the patient age, only one of these will be instantiated

The applicable age range is “carried over” as a constraint for the logic expression
Rule Execution Constraints

Rule Execution Constraints:
Used to model rule behavior.

Behavior-Self:
Self *Occurred Not Within Past* 14 DAYS
First time only in 14-day period of time

Behavior-Others:
Self *Occurs Always*
Always fire even if other rules have

Membership Expression:
Toxicology
Group of rules this rule belongs to

But …

PEDI Group is defined for ages [0 years, 18 years)
Range 1 is [1 day, 4 days),
Range 2 is [4 days, 8 days),
Range 3 is [8 days, 18 years)

For these two age ranges, should the interval for the rule firing should be shorter??
Issues

- **Validation**
  - Constraints in data declarations are “subcontexts” of the context where the rule applies. E.g. A is a subset of B, meaning that A is contained in B.
  - Age groups must be adjacent to each other and fully contained in the age group they are defined.
  - Similarly, if logic statements in the rule logic have constraints, these constraints must be “subcontexts” in relationship to the context where the whole rule applies.
  - If applicable, context(s) in data statements must be paired with logic expressions in the rule logic by means of their defined constraints.
  - Age groups and rule behavior???

- **Execution**
  - Can rules represented in this manner be executed in Datalog?
Authoring & Displaying Production Rules
Margarita Sordo
Authoring Production Rules

- Capture content consistently, explicitly documenting everything – or as much as possible - so content can and cataloged, curated, deployed…
- (Ideally) Authoring process should be guided, intuitive, requiring a minimum knowledge from user.

- Underlying schema provides the structure, but too complex, and not intuitive.
- Requirements for authoring more complex than for displaying content.
ArdenML Schema

Rule logic represented as an expression compatible with ArdenML.

Set of properties common to all production rules.

One or many expressions that represent constraints on the availability of the entity. Constraints are ArdenML expressions.

Execution constraints represented as expressions compatible with ArdenML.

Data StatementType (extension)

Assignment

Argument

Logic StatementType

Assign

For

While

Conclude

Call

hasAvailabilityConstraint

hasExecutionConstraint
Assignment
Assignment/Apply

- Show schema
Templates for Authoring and Displaying Rules

- Show template for display.
  - A lot of conditionals to navigate the grammar, but since the XML is already created, there is no need for validation.

- Show partial template for authoring and explain issues.
  - Limitations of “out-of-the-box” StyleVision for handling the underlying grammar.
  - Need something more intuitive that guides the user through the rule authoring process.
  - Handling grammar needs to be done programmatically.

- Suggestions for authoring rules through an UI?
  - Have Semedy done something similar?
Constraints & Production Rules
Margarita Sordo
Constraints

**Domain:** LaboratoryResult

**Assignment:** ThresholdValue := 25 micro IU/ml

**Data Statement Constraints:** (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=PEDI, Range(4 day, 8 day))

**Domain:** LaboratoryResult

**Assignment:** LOINC_CODES_FOR_LAB := (3016-3)

**Assignment:** LIST_OF_STATUS := (complete, preliminary)

**Read:** LatestLabResultValue := Lastest Mapping LaboratoryResult.ResultValue

Where Apply

And

ResultType is in LOINC_CODES_FOR_LAB
ResultStatus is in LIST_OF_STATUS

**Data Statement Constraints:** (Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

**Rule Logic:**

If Apply

Or

LatestLabResultValue GT ThresholdValue
LatestLabResultValue LT ThresholdValue

(AgeGroup=PEDI, Range(X, Y))

(AgeGroup=ADULT)

**Rule Availability Constraints:**

(Site=ANY) AND (Venue=ANY) AND (Gender=ANY) AND (AgeGroup=ANY)

**Rule Execution Constraints:**

**Behavior-Self:**

Self *OccurredNot WithinPast* 14 DAYS

**Behavior-Others:**

Self *Occurs Always*

**Membership Expression:**

Toxicology
Constraints in data statements → If not null → Constraints in logic expressions

Constraints in data statements consistent_with Constraints in rule execution

Constraints in rule availability