Evaluating Semantic Technology to Enhance EHR Visualization

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Conflict of Interest

Jonathan Nebeker, M.D.
Has no real or apparent conflicts of interest to report.

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Has no real or apparent conflicts of interest to report.
Agenda

• Learning Objectives
• Motivation
• Background
• Purpose
• Methodology
  – Analyze Existing Ontologies
  – Construct Ontology
  – Evaluate Ontology
• Summary of Findings
• Next Steps
Learning Objectives

• Explain the advantages and disadvantages of applying Semantic Web technology for enhanced visualization and clinical decision support in EHR systems
• Describe the Clinical Information Ontology, developed as part of this effort, and how it builds on existing clinical terminologies and ontologies
• Appraise the Clinical Information Ontology for its usefulness in EHR visualization using nine clinical use cases spanning diabetes, congestive heart failure, angina, and depression in inpatient and outpatient scenarios
• Describe findings to characterize the value of Semantic Web technology for enhanced EHR visualization and clinical decision support in general
How Benefits of Health IT Were Realized

Address gaps in current EHR visualization

Methods for enhanced visualization of EHR data for providers

Applies semantic formalisms in the architecture
Motivation

- Explore technology to support patient-centered, care plan-centered visualization and reasoning
Our Patient: Kael

- 71 years old
- Coronary heart disease
- Hypertension
- High cholesterol
What is Semantic Web Technology?

“The Semantic Web is an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.”

Tim Berners-Lee, 2001

• The **Semantic Web** is enabled through standards by the World Wide Web Consortium (**W3C**)  
  - Promote common data formats and exchange protocols over the Web using formalisms  
  - Provide infrastructure for:  
    - Publishing semantically meaningful information  
    - Reasoning over the formalisms
What is Ontology?

- An explicit, formal specification of a shared conceptualization
  - Concepts
  - Relations
  - Hierarchies over them
  - Axioms

Definition 1 Ontology

An ontology is a 6-tuple $O = \langle C, R, \leq_C, \leq_R, \sigma, A \rangle$, such that:

- $C$ is a nonempty set of classes: $\{C_1, C_2, \ldots, C_n\}$,
- $R$ is a nonempty set of relations: $\{R_1, R_2, \ldots, R_n\}$,
- $C, R$ are disjoint,
- $\leq_C$ is a class hierarchy, a partial order on $C$,
- $\leq_R$ is a relationship hierarchy, a partial order on $R$,
- $\sigma : R \rightarrow C \times C$, representing relationships between classes,
- $A$ is a set of class axioms, possibly empty: $\{A_1, A_2, \ldots, A_n\}$. 
Ontology Spectrum

From less to more expressive

- Conceptual Model
  - RDF/S
  - XTM
  - Extended ER

- Thesaurus
  - ER
  - DB Schemas, XML Schema

- Taxonomy
  - Relational Model, XML

Logical Theory
- First Order Logic
- Description Logic
- OWL
- UML

Modal Logic
- Is Disjoint Subclass of
- with transitivity property

Strong semantics

Is Subclass of
- Semantic Interoperability

Has Narrower Meaning Than
- Structural Interoperability

Is Sub-Classification of
- Syntactic Interoperability

Weak semantics

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Purpose

- Provide evidence-based research to inform the design of the future Veterans Health Administration (VHA) Electronic Health Record (EHR) system
- Investigate the applicability of Semantic Web technology to model clinical concepts in support of enhanced EHR capabilities and visualization
Methodology

• Analyze current ontologies and terminologies
• Develop clinical use cases
• Create or adapt a Clinical Care Ontology
• Evaluate Clinical Care Ontology using clinical use cases
• Evaluate applicability of Semantic Web technology in context of clinical use cases
Analyze Current Ontologies

• Ontologies defined in RDF and/or OWL did express clinical concepts needed to support patient care
  – Open Biological Ontologies – OBO
  – General Medical Science (OGMS)
• Upper ontologies contain useful concepts relevant to this work
  – Basic Formal Ontology (BFO)
  – Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)
• Many ontologies could be linked to the Clinical Care Ontology, effectively serving as instance data
  – Disease Ontology (DO)
  – Systematized Nomenclature for Medicine – Clinical Terms (SNOMED-CT)
  – International Classification of Diseases (ICD)-9 or ICD-10.
• Gaps were identified in the representation of Care Plan, Goal, and Preference
Develop Clinical Use Cases

• Inpatient Care
  – Angina
    • Patient presenting to ED with angina, diagnosed with STEMI
    • Telemetry unit care post stent placement through discharge
  – Congestive Heart Failure (CHF)
    • Patient presenting to ED in acute respiratory distress, diagnosed with exacerbation of CHF
    • IMC care through discharge

• Outpatient Care
  – Diabetes
    • Newly diagnosed diabetic patient, with follow up care and annual eye exam
  – Depression
    • Management of patient with chronic depression
Create Clinical Care Ontology

- Focus on support to clinical use cases
  - Condition
  - Goal
  - Care Plan
  - Intervention
- Construct quantitative and qualitative value spaces to track patient progress toward goals
- Map value spaces to Goal
- Define Preference(s) on Goal and Intervention
- Establish a sparse scaffolding of upper-level ontology distinctions to ease future mapping to foundational ontologies
Clinical Care Ontology – Care Plan and Goals

Legend
- Intervention
- Encounter
- Observation

CarePlan

Initial Patient State

Plan CarePlan

Schedule CarePlan

Execute CarePlan

Final Patient State

Condition

Assessment

Diagnose

Incremental Goal

Patient Goal State

Success!

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Clinical Care Ontology – Care Plan and Goal
Representing Our Patient

All persons in the scenario are fictitious with characteristics intended to represent the role NOT actual individuals.
Clinical Care Ontology - Quantitative Value Spaces
Clinical Care Ontology – Qualitative Value Spaces
Clinical Care Ontology – Mapping Value Spaces

Example: Blood Pressure (mmHg) Value Space

- ZeroPositiveIntegerValueSpace
- BloodPressureValueRange
- BloodPressureReferenceRange: 60 to 120
- DiastolicBloodPressureReferenceRange: 60 to 80
- SystolicBloodPressureReferenceRange: 90 to 120

{healthy adult humans}

NominalBloodPressureValueSet:
- "hypotensive": SPB/DBP <= 90/60
- "normal": 90/60 < SPB/DBP <= 120/80
- "pre-hypertensive": 120/80 < SPB/DBP <= 140/90
- "hypertensive": 140/90 < SPB/DBP
Clinical Care Ontology - Preference

Legend
- subclassOf
- property
- instanceOf
- property chain
Evaluate the Ontology

• Evaluations accomplished across three sprints

<table>
<thead>
<tr>
<th>Sprint</th>
<th>Ontology State</th>
<th>Findings</th>
</tr>
</thead>
</table>
| 1      | Draft version w/ core concepts (Patient, Encounter, Intervention, Observation) | • Ensured ontology was consistent  
• Ensured basic competency questions could be answered  
• Need more structure to represent Care Plan, Goal and Intervention  
• Identified more complex queries that cross class boundaries |
| 2      | Added basic constructs of Goal                      | • Need to map Goal to value spaces to track progress towards Goals  
• Identified need to create a notional visualization for patient history and progress towards goal to ensure ontology can support these information needs  
• Additional effort will be required to determine the effectiveness or physiologic effects of interventions |
| 3      | Added Goals mapped to value spaces and the structure for Preferences | • Revealed areas where a rule layer will be needed  
• Need to determine the best way to structure complex goals and represent sub-goals  
• Consider how interpretations of test results best modeled (e.g., an ECG impression)? |
Summary of Findings

- Semantic Web technologies *can* be used for enhanced EHR capabilities
  - Supports use cases and future VHA EHR visualization
  - Provides finer automated reasoning over quality spaces
  - Builds foundation for advanced reasoning
  - Enables discovery of new information

- Semantic Web technologies come at a cost
  - Introduces considerable complexity
  - Should be used in cases where complex, dynamic visualization of data is required

- A rule layer and rule-reasoning should be added to take full advantage of the ontology

- Outcome of this research resulted in:
  - Ability to track patient progress toward goals in care plan
  - Much richer event structure (e.g., who/what the participants are, what classes they need to be from, etc.)
  - Structure to support the notion of one event or state preceding, succeeding, or overlapping another
  - Providers’ ability to view patients as having or constituting a state
Integration of Ontology into EHR Architecture

Forms need to be developed to take advantage of the structure of Care Plans and Goals.

Existing services need to be modified to invoke queries to the ontology using new ontology query layer.

New services may be necessary to utilize Care Plans and Goals.

Database elements must be mapped to appropriate concepts in ontology.

New database elements may be necessary to support Care Plans and Goals.

Ontology should be mapped to existing vocabulary.
Reasoning for Patient-centered Clinical Decision Support

All persons in the scenario are fictitious with characteristics intended to represent the role NOT actual individuals.
Notional Visualization of Patient Progress toward Goals

**Goal**
- Move from obese to overweight
- Achieve target weight of 190 in 4 months
- Current weight: 230
- Target weight: 190

**Interventions**
- Low fat, 12 calorie/day diet
- 1 hour cardio 5 x/week
- Nutritional and Wellness Class

**Observations**
- Weight
- Blood sugar
Research Questions Answered

• How does the ontology perform for the clinical use cases?
  – Ontology was able to support the majority of queries required
  – Areas in which rule layer is needed were identified
• How do diagnostic procedures best fit within the schema?
  – Ontology represents Procedure as subclass of Intervention
  – Need more analysis of events and workflow related to diagnosis process
• How are actions and actors best represented in the model?
  – Actions and actors should be represented as separate entities distinct from clinical concepts
• How does the ontology perform in terms of consistency, completeness, and appropriateness?
  – Ontology seems appropriate to support advanced EHR capabilities, but more work is needed to determine applicability and value to broader set of dynamic EHR visualizations
• Do the concepts and relationships among the clinical information objects provide a framework that sufficiently represents a mental model of healthcare in the specific settings?
  – By providing a reality-based ontology of the clinical domain, common foundational knowledge available to every role
  – More work needed to explore differences in mental models of users
Next Steps

• Add rule layer to the architecture for richer capability
• Incorporate Clinical Care Ontology into VHA prototype
  – Evaluate ontology further, particularly with regard to value in supporting additional dynamic visualizations
• Continue to refine Clinical Care Ontology
  – Incorporate more detail on mental models
  – Expand on Preference
  – Refine to support VHA prototyping efforts
• Continue to develop a reasoning system
• Share results broadly
Summary of Benefits of Health IT

Address the difficulty of slow and inaccurate information retrieval and difficulty in finding and reviewing data in today’s EHR systems.

Contribute to progress in Treatment and Clinical practice, since it focuses methods for enhanced visualization of EHR data.

Apply ontologies that provide automated reasoning capabilities in support of enhanced EHR visualization.
Questions?

Thank you!

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