Towards an Ontology Driven Enhanced Oil Recovery Decision Support System

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The University of Texas

W3C Workshop on Semantic Web in Oil & Gas Industry, Houston, December 9,10, 2008
Outline

• Background
• Our Focus
• Our Approach
• Pilots
• Some Tentative Visions
• Next Steps
• Acknowledgements
Background

• UT Expertise in Enhanced Oil Recovery
• Knowledge in
  – Professors and Students
  – Dissertations and Papers
  – Laboratory Procedures
  – Laboratory Data
• Need for Integrated Approach
• Industry needs help in Decision-Making
Our Focus

Decision Making Processes in Enhanced Oil Recovery (EOR)

For a given reservoir:

1. Which EOR Methods are most promising?
2. What is the potential for each of the promising EOR Methods?
3. What is the best design for each EOR Method to be applied?
   
   e.g. Best Alkaline, Surfactant, Polymer (ASP) Formulation?

Workflows to be Considered

• Screening
• Laboratory
• Geology
• Simulation
• Field Trial
• Production
Our Approach

• Capture Knowledge
• Focus on EOR and its Workflows
• Build Ontology Pilots
• Create Knowledge Base and Query System
An Ontology Is Often Just the Beginning

Ontologies

- Software agents
- Problem-solving methods
- Domain-independent applications
  
Declare structure

Databases

Knowledge bases

Provide domain description

Pilots

- EOR Screening Ontology Pilot
- Surfactant Selection Workflow
  - Expanded to EOR General Ontology with Chemicals
- EOR Simplified Recovery Calculation Ontology Pilot
- Scale-Up Uncertainty in Reservoir Characterization Pilot
- Risk Management Ontology Pilot
EOR Screening Ontology Pilot
# Depth Limitations

<table>
<thead>
<tr>
<th>EOR Method</th>
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<td>Hydrocarbon-Miscible</td>
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<td>Nitrogen and Flue Gas</td>
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<td>CO₂ Flooding</td>
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<td>Fire Flood</td>
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Permeability Guides...

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Preferred Oil Viscosity Ranges...

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Protégé

EOR Methods

Reservoir

Individual EOR Methods

Individual Reservoirs

Depth

Permeability

Oil Viscosity

Protégé Rules Editor

Protégé Expert System Shell

TORIS Data Base

Rules

hasEORMethod

Protégé

EOR Methods

Reservoir

Individual EOR Methods

Individual Reservoirs

Depth

Permeability

Oil Viscosity

Protégé Rules Editor

Protégé Expert System Shell

TORIS Data Base

Rules

hasEORMethod
CLASS BROWSER
For Project: LakeEORiDxygen0622TORSY

INSTANCE BROWSER
For Class: EOR_Method

ASSERTED Instances
- Alkaline_Method
- CO2Flooding_Method
- FireFlood_Method
- HC-Misc_Method
- NitrogenandFlueGas_Method
- Polymer_Method
- SteamDrive_Method
- Surfactant_Polymer_Method

ASSERTED Types
- EOR_Method
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Reservoir(?x) \land Depth(?x, ?depth) \land Permeability(?x, ?permeability) \land swrlb:greaterThan(?permeability, 20.0) \land swrlb:lessThan(?depth, 7500.0) \land OilViscosity(?x, ?viscosity) \land swrlb:lessThan(?viscosity, 40.0) → has_EOR_Method(?x, Surfactant_Polymer_Method)
SWRL rule and relevant OWL knowledge successfully converted to Jess knowledge.
Number of SWRL rules exported to Jess: 8
Number of OWL classes exported to Jess: 3
Number of OWL individuals exported to Jess: 34
Number of OWL properties assertion axioms exported to Jess: 78
Number of OWL axioms exported to Jess: 0
Look at the "Jess Rules" tab for the Jess rules.
Look at the "Imported Jess Classes" tab for the Jess class definitions.
Look at the "Imported Jess Properties" tab for the Jess property assertions.
Look at the "Imported Jess Individuals" tab for the Jess individual assertions.
Press the "Run Jess" button to run the Jess rule engine.
| Rule-1 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-2 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-3 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-4 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-5 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-6 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-7 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |
| Rule-8 | Reservoir(?x) ∧ Depth(?x, ?depth) ∧ Permeability(?x, ?permeability) ∧ swrlb:greaterThan(?permeability, ?depth) |

Successful run of rule engine.
Number of reclassified individuals: 0
Number of inferred property assertion axioms: 97
Look at the "Inferred Individuals" tab to see the inferred individuals.
Look at the "Inferred Property Assertion Axioms" tab to see the inferred property assertion axioms.
Press the "Jess->OWL" button to translate the asserted facts to OWL knowledge.
<table>
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<tr>
<th>Ena...</th>
<th>Name</th>
<th>Expression</th>
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Successfully transferred inferred facts to OWL model.
Number of individuals reclassified: 0
Number of property assertion axioms inferred: 97
The image shows a snapshot of the Protégé ontology editor. The class hierarchy and instance browser are visible, with the current class selected as 'Reservoir'. The instance editor is for 'HEMLOCK', an instance of 'Reservoir'. Properties like 'Depth', 'OilViscosity', 'Permeability', and 'has_EOR_Method' are displayed with values and methods. The interface includes a tab for 'owl:Thing' and 'owl:Reservoir', indicating the project and classes involved.
CLASS BROWSER
For Project: LakeEORScreening0622TORYSI
Class Hierarchy
- owl:Thing
  - rdf:List (53)
  - temporal:Entity
  - swrla:Entity
  - swrl:Atom
  - swrl:BuiltIn (224)
  - swrl:Imp (8)
  - swrl:Variable (4)
  - EOR_Method (8 / 8)
  - Reservoir (26 / 26)

INSTANCE BROWSER
For Class: Reservoir
- Asserted
- Inferred
- Assumed
- Has_EOR_Method
  - HC-Misc_Method
  - Polymer_Method
  - NitrogenandFlueGas_Method
  - CO2Flooding_Method
  - Alkaline_Method
  - Surfactant_Polymer_Method

INDIVIDUAL EDITOR
For Individual: ARUK_RIVER (instance of Reservoir)
- Property Value
  - has_EOR_Method
    - HC-Misc_Method
    - Polymer_Method
    - NitrogenandFlueGas_Method
    - CO2Flooding_Method
    - Alkaline_Method
    - Surfactant_Polymer_Method
  - Depth 6300.0
  - OilViscosity 2.5
  - Permeability 100.0
EOR Screening Ontology Pilot – Summary

- Use of SWRL.
- Use of Expert System Engine (JESS)
- Large numbers of reservoirs screened at once
- Relatively simple structure in ontology
Surfactant Selection Workflow
Workflow Driven Ontologies (WDO)

Leonardo Salayandía, University of Texas at El Paso
Contains subclasses that are used to specify workflow actions and control flow.

Contains subclasses used to represent primitive data concepts of a domain, as well as classes used to compose complex data constructs that are both consumed by and derived from workflow actions.

Contains 2 or more workflows

Actions (Services, algorithms, application functionalities)

Alternative outputs for a method
EOR General Ontology with Chemicals
n1:EOR_Methods

n1:are

n1:Thermal_EOR_Methods

n1:Non-Thermal_EOR_Methods
Surfactant Formulation Workflow and EOR Ontology with Chemicals Pilot – Summary

• Complex
• Basis for Decision Support System
• Organization of Concepts in Domain
• Workflow-based Ontology
• Work in progress
EOR Simplified Recovery Calculation Ontology
Oil_Rate\_versus\_Time

\textit{is\_calculated\_from}

\textit{can be}

\begin{itemize}
  \item Time
  \item Oil\_Rate
\end{itemize}

\textit{is\_calculated\_from}

\textit{can be}

\begin{itemize}
  \item Heterogeneous\_Dimensionless\_Time
  \item Pore\_Volume
  \item Steady-State\_Injection\_Rate
  \item Heterogeneous\_Peak\_Oil\_Cut
\end{itemize}
Simplified Recovery Calculation
Ontology Pilot –
Summary

• Large Complex Calculation
• Essentially one Property
  – “is calculated from”
• Errors, insights found when ontology and CMAP created
• Previously available only to students to read.
• Now available to software agents
Scale-Up Uncertainty Ontology
Motivation

EOR

Uncertainty in Scale up

Experimental scale

Physical scale
Workflow

Non-Linearly Averaging – Second Porosity

1. Transform the secondary porosity to another variable space that is linearly additive.

2. Normal score transform the second porosity data and compute semi-variograms. Construct a licit 3D variogram model with sill standardized to be 1.0.

3. Calculations of representative elementary volume and variance of mean using the 3D point-scale variogram from Step #2.

4. Computation of up-scaled variogram via linear volume averaging.

5. Use of the up-scaled variogram from Step #4 to perform conditional simulation.

6. Backtransform simulated values to secondary porosity units → scale up uncertainty.
Example of Instances in the Ontology

Semi-Variogram_Modelling

Three_D_Variogram_analysis

Non-stationary_or_trend_calculations

Calculated_REV

variance_of_mean

statistical_measures

grid_spec

Computation_of_up-scaled_variogram_via_linear_volume_averaging

area

linearly_averaging

Use the up-scaled variogram with the sampled set of conditioning data to perform conditional simulations

hascalcstep must be

iscalcf from must be

semi-variogram

Sample_multiple_sets_of_conditioning_data_values

total_posority

variance_of_mean

circled

hascalcstep must be
<table>
<thead>
<tr>
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<th>Expression</th>
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<tbody>
<tr>
<td>Rule-1</td>
<td>uncertainty_model(?u) ∧ hasindex(?u, index_1) -&gt; sqwrl:select(?u)</td>
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</tr>
<tr>
<td>Rule-2</td>
<td>uncertainty_model(?u) ∧ hasindex(?u, index_1) ∧abox:isIndividual(?u) → sqwrl:select(?u) ∧ sqwrl:orderBy(?u)</td>
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<tr>
<td>Rule-3</td>
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<td>Rule-4</td>
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<td>uncertainty_model(?c) ∧ hasIndex(?c, index_3) ∧ abox::individual(?c) → sqwrl:select(?c) ∧ sqwrl:orderBy(?c)</td>
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**Three D Variogram analysis**

A. Non-stationary or trend calculations
B. Calculations of REV
C. Sample multiple sets of conditioning data values
D. Computation of up-scaled variogram via linear volume averaging
E. Conditional simulations
F. Linear averaging
## SWRL Rules

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<th>Expression</th>
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<tbody>
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<td>Rule-3</td>
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<td>4</td>
<td>Rule-4</td>
<td>uncertainty_model(?c) ∧ hasIndex(?c, index_2) ∧ abox.isIndividual(?c) → sqwrl:select(?c) ∧ sqwrl:orderBy(?c)</td>
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</tbody>
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### Instructions

1. Transform the secondary porosity to another variable space that is linearly additive.
2. Normal score transform the variable and compute semivariograms. Calculate semivariogram of logarithms and construct a 3D variogram model.
3. Calculate REV.
4. Compute up-scaled variogram via linear volume averaging.
5. Conditional data sets.
6. Use the up-scaled variogram to perform conditional simulation nonlinearly averaging 19.

---

**Save as CSV...**  **Rerun**  **Close**
Scale-Up Ontology
Pilot –
Summary

• Captured Knowledge of Different Scale-Up Methods
• Use SQWRL to answer queries on steps involved in particular scale-up procedure
EOR Ontology: Risk Based Decision Making Pilot
A Procedure for Assessing the Value of Oilfield Sensors
Portfolio Decisions

Estimate the value of implementing sensors in four different advanced hydrocarbon recovery scenarios.

Mature Onshore

Deepwater

Tight Gas

Unfractured

Fractured

Frac

Frac

Side

Top

Radial

Linear

Heavy Oil
Decision Tree
Mature Reservoir

VoS = 0.384 - 0.234 = 0.15 MM$

Initial Prod. Rate (bbl/D) | Decline Rate (%/yr) | Prob. | Outcome (MM$/pattern)
--- | --- | --- | ---
5 | 5 | 0.0095 | 1.33
25 | 15 | 0.0005 | 1.02
5 | 5 | 0.9405 | 0.120
5 | 15 | 0.0495 | 0.058
15.6 | 5 | 0.25 | 0.599
15 | 5 | 0.25 | 0.405
5.2 | 5 | 0.475 | -0.0306
15 | 15 | 0.025 | -0.095
25 | 5 | 0.04816 | 1.350
Continue WF | 15 | 0.15291 | 1.039
0.129 MM$ | 0.332 MM$ | 0.7574 | 0.138
No Sensor | 0.234 MM$ | 0.0416 | 0.0765
Sensor | 0.384 MM$ | 0.3975 | 0.634
CO$_2$ Flood | 0.384 MM$ | 0.30 | 0.440
5.2 | 5 | 0.29 | -0.0040
15 | 15 | 0.0125 | -0.061

VoS = 0.384 - 0.234 = 0.15 MM$
Framework of Classes

owl:Thing
Risk Based Decision Making

---

Portfolio Decisions

Alternatives

Outcomes

Consequences

Probability
Mature Reservoir Instances
null
Risk Management Ontology Pilot – Summary

• General Risk Management Concepts
• Specific Application
• Captured all numbers and meanings from published SPE paper
• Now available to software agents
Some Tentative Visions
A Vision for an Ontology-Based EOR Intelligent Decision Support System
Possible Queries for Decision Support System

- What EOR Methods should be considered for this reservoir?
- How do we calculate the oil recovery vs. time when this EOR Project is implemented?
- What is the total porosity/permeability of the reservoir and what is their uncertainty?
- If chemical flooding, what chemicals should be considered as candidates for surfactants, co-surfactants, alkali, polymers, co-solvents for this particular chemical flooding project?
- What is a rough estimate of the net present value (NPV) of this EOR Project?
- How much uncertainty is associated with the prediction of performance in the field?
- Given that chemicals are available and the NPV is acceptable, what is the chemical EOR formulation that we should simulate?
- How do we calculate the value of doing more lab work before going into production with this EOR method?
- Should we do a pilot test in the field?
- How do we decide whether to skip a step in the process to accelerate production?
Next Steps

• Use Lessons from Pilots to Design the Ontology – Based EOR Decision Support System.

• Prepare Software Development Plan including Knowledge Capture and Ontology Development
Thanks to the Co-Authors

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• Sanjay Srinivasan
• Fan Yang
• Mark W. Kroncke

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Schlumberger

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