Geological multi-scenario reasoning

The SIRIUS Center
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The SIRIUS Centre

- Eight years’ financing from RCN
- 14 Industrial Partners (11 in 2017)
- 5 Leading Academic Institutions
- Centre for Research-Based Innovation
- Funding for 20 Ph.D. students
- Innovation through prototypes and pilots
- 45 affiliated researchers
Research programs build foundations for...

<table>
<thead>
<tr>
<th>Analysis of Complex Systems</th>
<th>Ontology Engineering</th>
<th>Scalable Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic Integration</td>
<td>Data Science</td>
<td>Industrial Digital Transformation</td>
</tr>
</tbody>
</table>

... Beacons addressing industry challenges

<table>
<thead>
<tr>
<th>Geological Assistant</th>
<th>Subsurface Data Access &amp; Analytics</th>
<th>Digital Twins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Digital Planning</td>
<td>Digital Field &amp; Reservoir Management</td>
<td>Digital Field Development</td>
</tr>
</tbody>
</table>
“The current digital tool set does not speak the geologists’ language. We need something like a geological assistant.” – Chief exploration geologist, workshop fall 2016
A method and tool to support geological reasoning through historical narratives

• Explore and create *multiple scenarios*

• Capture how scenarios change with *evidence, observations* and *assumptions*

• Yes/No, *How* and *Why*

• Detect *inconsistencies* in assumptions
What is reasoning?

Migration time

- Older than F1
  - No accumulation
- Younger than F1
  - F1 sealing
  - Accumulation
  - F1 non-sealing
    - No accumulation
Use case

User: Explorationist

Goal: Leads maturation

Geological settings: a series of rotated fault blocks represented by 3 geological units:

- Base seal / lateral seal, reservoir / carrier bed and top seal, deposited in a marine depositional environment, as submarine fan.
  - The submarine fan is represented from proximal (west) to distal (east) by: feeder channel, distributary channel, interchannel (channel-lobe transition zone), lobe, lobe fringe and basin plain
- Source rock
  - Has generated oil and gas
- Migration pathways
  - Carrier beds and / or faults
- Migration
  - Requires migration pathway, correct timing and fill-spill model
- Traps
  - Require sealing faults or lateral seal
- Well X – no accumulation
Is it possible to have an *accumulation* in GU11, while having *no accumulation* in GU8?

- **GU8**
  - Reservoir = distributary channel = porous and permeable
  - GU11 = distributary channel, interchannel or lobe
    - Migration before trap formation
      - No accumulation in any of the traps
        - GU5 = porous and permeable
    - Migration after trap formation
      - GU5 = non-porous and non-permeable
      - GU5 non-porous and non-permeable and F0 sealing
        - GU5 porous and permeable but F0 sealing
        - GU5 porous and permeable and F0 non-sealing
          - Migration after trap formation
            - Migration pathway present
              - F1 non-sealing and no lateral seal present
                - GU11 can have accumulation if Trap is present
                - GU11 can have accumulation if Trap is present
      - No migration pathway
        - GU5 non-porous and non-permeable and F0 sealing
          - GU5 porous and permeable and F0 non-sealing
        - Migration after trap formation
          - Migration pathway present
            - No trap
  - No accumulation
    - Migration after trap formation
      - No migration pathway
        - GU5 non-porous and non-permeable and F0 sealing
          - GU5 porous and permeable and F0 non-sealing
        - Migration after trap formation
          - Migration pathway present
            - No trap
  - Migration before trap formation
    - No accumulation in any of the traps
      - GU5 = porous and permeable
        - Migration before trap formation
          - No accumulation in any of the traps
            - GU5 = porous and permeable

**Not true**
Under the hood: method behind the multi-scenario reasoning engine

- Apply **formal methods** and **logic-based techniques** to subsurface evaluation
- Underdetermination is captured as discrete scenarios with branches of potential alternatives
- *Dynamically* compute scenarios based on **formal semantics** of geological processes
- With a rigorous semantic basis
  1. assumptions are explicit and consequences traceable
  2. permits automated analysis and verification
Rewriting logic (RL) in a nutshell

- A formal framework for specifying distributed and concurrent systems

- *Rewrite theory* $\mathcal{R} = (\Sigma, E, R)$
  - $\langle \Sigma, E \rangle$ represents the equational theory
  - $R$ are the *concurrent transitions* $t \to t'$

- Concurrent rewriting logic deduction

- Together with geologists, we define $\mathcal{R}_{geo}$
RL is a good fit for geological scenario reasoning

- The subsurface is dynamic over geological time
- Geological processes are concurrent ... and we do not know their exact timing
- \( \varepsilon \) - representation distance

- Scenarios are created on-the-fly from *proto-scenarios* by rewriting logic deductions in \( \mathcal{R}_{geo} \)
• Input data containing observations and known facts
• Expands the unknowns into multiple concrete proto-scenarios based on a logical formalization of geological knowledge
Assist explorationists by:

- Explore, explain and constrain scenarios based on observations, evidence and assumptions
- Manage assumptions
- Give variation in solutions, discover inconsistencies, prove invariants
- Decision support early in the work process
- Browse, filter and visualize the results
THE GEOLOGICAL ASSISTANT SYSTEM STARTS:

Choose (1) Narrowing down the search space (2) Back to the previous search space (3) Showing the summary of a specific category, or press the ENTER key for quitting:
The type of hydrocarbon is oil & gas.

---MIGRATION PATHWAY---
There is no migration pathway.

---SUBMARINE FAN---
GeoUnit 5 was deposited in interChannel.
GeoUnit 5 is non-permeable and non-porous.
GeoUnit 8 was deposited in interChannel.
GeoUnit 8 is non-permeable and non-porous.
GeoUnit 11 was deposited in interChannel.
GeoUnit 11 is non-permeable and non-porous.
GeoUnit 14 was deposited in interChannel.
GeoUnit 14 is non-permeable and non-porous.

---FAULT TYPE---
Fault 0 is non-sealing.
Fault 1 is non-sealing.
Fault 2 is non-sealing.
Fault 3 is non-sealing.

---MIGRATION TIME---
Migration happened after Fault 3 was ceased.
Migration happened after Fault 0 was ceased.
Migration happened after Fault 1 was ceased.
Migration happened after Fault 2 was ceased.

---TRAP---
GeoUnit 5 cannot be trapped.
<Reason>: There is no trap-formation for GeoUnit 5 because GeoUnit 5 is a bad quality reservoir. Even though there are #topSeal and #lateralSeal formed completely by shale.
GeoUnit 8 cannot be trapped.
<Reason>: There is no trap-formation for GeoUnit 8 because GeoUnit 8 is a bad quality reservoir. Even though there are #topSeal and #lateralSeal. The lateral seal is formed by GeoUnit 11, which is a bad quality reservoir, and possibly together with shale.
GeoUnit 11 cannot be trapped.
<Reason>: There is no trap-formation for GeoUnit 11 because GeoUnit 11 is a bad quality reservoir. Even though there are #topSeal and #lateralSeal formed completely by shale.
GeoUnit 14 cannot be trapped.
<Reason>: There is no trap-formation for GeoUnit 14 because GeoUnit 14 is a bad quality reservoir. Even though there are #topSeal and #lateralSeal formed completely by shale.

---ACUMULATION---
GeoUnit 5 does not have accumulation.
GeoUnit 8 does not have accumulation.
GeoUnit 11 does not have accumulation.
GeoUnit 14 does not have accumulation.

---HISTORY OF HYDROCARBON MIGRATION AND ACCUMULATION---
oil & gas was generated by Kerogen Type II in GeoUnit 4.

3024 scenarios.

What you have chosen to keep in the search space: #

Choose (1) Narrowing down the search space (2) Back to the previous search space (3) Showing the summary of a specific category, or press the ENTER key for quitting: 1
Scenario explanation based on observations, evidence, assumptions

GeoUnit 4 is the source rock.
--HYDROCARBON--
The type of hydrocarbon is oil & gas.

--MIGRATION PATHWAY--
GeoUnit 4 -> GeoUnit 5 -> Fault 0 -> GeoUnit 8
--SUBMARINE FAN--
GeoUnit 5 was deposited in a feeder channel.
GeoUnit 5 is permeable and porous.
GeoUnit 8 was deposited in a distributary channel environment.
GeoUnit 8 is permeable and porous.

--FAULT TYPE--
Fault 0 is non-sealing.
Fault 1 is non-sealing.

--MIGRATION TIME--
Migration happened after Fault 0 was ceased.
Migration happened after Fault 1 was ceased.

--TRAP--
GeoUnit 5 can be trapped and the trapped was formed.
Besides, GeoUnit 5 is permeable and porous.
GeoUnit 8 cannot be trapped.
Even though GeoUnit 8 is permeable and porous.

--ACCUMULATION--
GeoUnit 5 has accumulation.
The accumulation in GeoUnit 5 can be filled to spill.
GeoUnit 8 does not have accumulation.

--HISTORY OF HYDROCARBON MIGRATION AND ACCUMULATION--
oil & gas was generated by Kerogen Type II in GeoUnit 4.
Pathway formation from GeoUnit 4 to GeoUnit 5 through oil & gas migrated through rocks in contact from GeoUnit 4 to GeoUnit 5.
Pathway formation through fault 0 from GeoUnit 5 to GeoUnit 8.
SR present and generated oil and gas.

Reservoir present and of good quality, deposited in a distributary channel environment.

GU11 is non-sealing and no lateral seal present (GU11 is porous and permeable).

Migration pathway present, represented by GU4, GU5, F0 and GU8.
GU5 filled to spill.

Trap absent - F1 is non-sealing and no lateral seal present (GU11 is porous and permeable).
Future research outlook

I. Combining research into formal methods with research into interdisciplinary use and adoption

II. Develop design theory for a new class of reasoning technologies
Thank you.
Geological assistant

- Explore, explain and constrain scenarios based on observations, evidence and assumptions
- Give variation in solutions, discover inconsistencies, prove invariants
- Decision support during the work process
- Manage assumptions
- Browse, filter and visualize the results