Geological multi-scenario reasoning

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The SIRIUS Center

University of Oslo

www. sirius-labs.no

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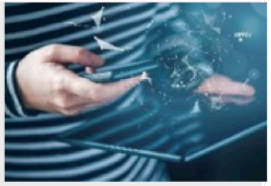
The SIRIUS Centre

- 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

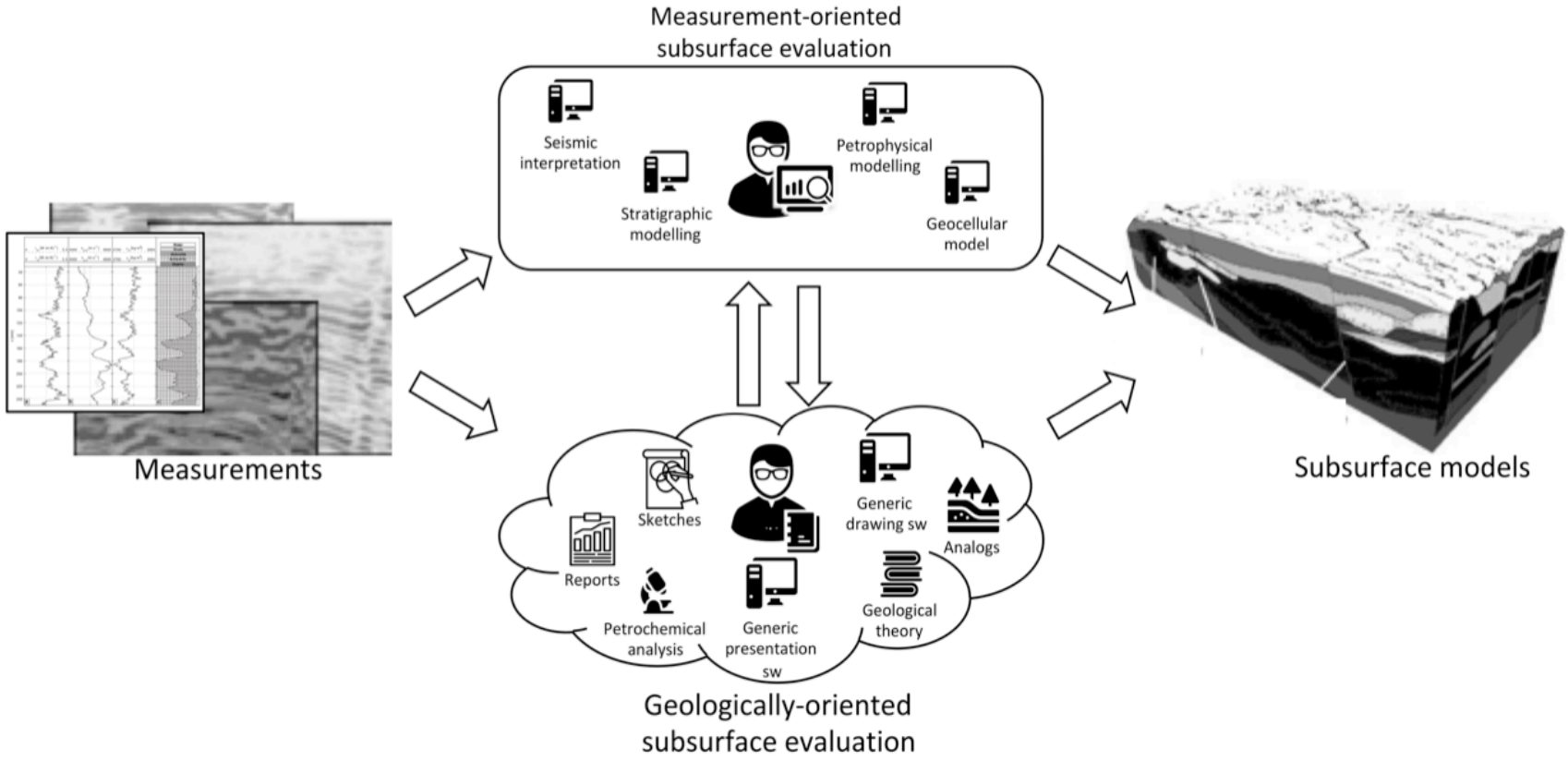
Schlumberger
equinor
SAP
IBM
DNV·GL
EVRY
Dolphin
NUMASCALE
BIGGER DATA ANALYTICS
KADME
Knowledge and data management expertise
OSIsoft.
aibel
TechnipFMC
computas
AkerSolutions
UiO : University of Oslo
simula
SINTEF
NTNU
Norwegian University of Science and Technology
UNIVERSITY OF OXFORD
DEPARTMENT OF COMPUTER SCIENCE
sfi Centre for Research-based Innovation
The Research Council of Norway

Research programs build fundations for…

Analysis of Complex Systems		Ontology Engineering		Scalable Computing	
Semantic Integration		Data Science		Industrial Digital Transformation	

… Beacons addressing industry challenges

Geological Assistant		Subsurface Data Access & Analytics		Digital Twins	
Integrated Digital Planning		Digital Field & Reservoir Management		Digital Field Development	

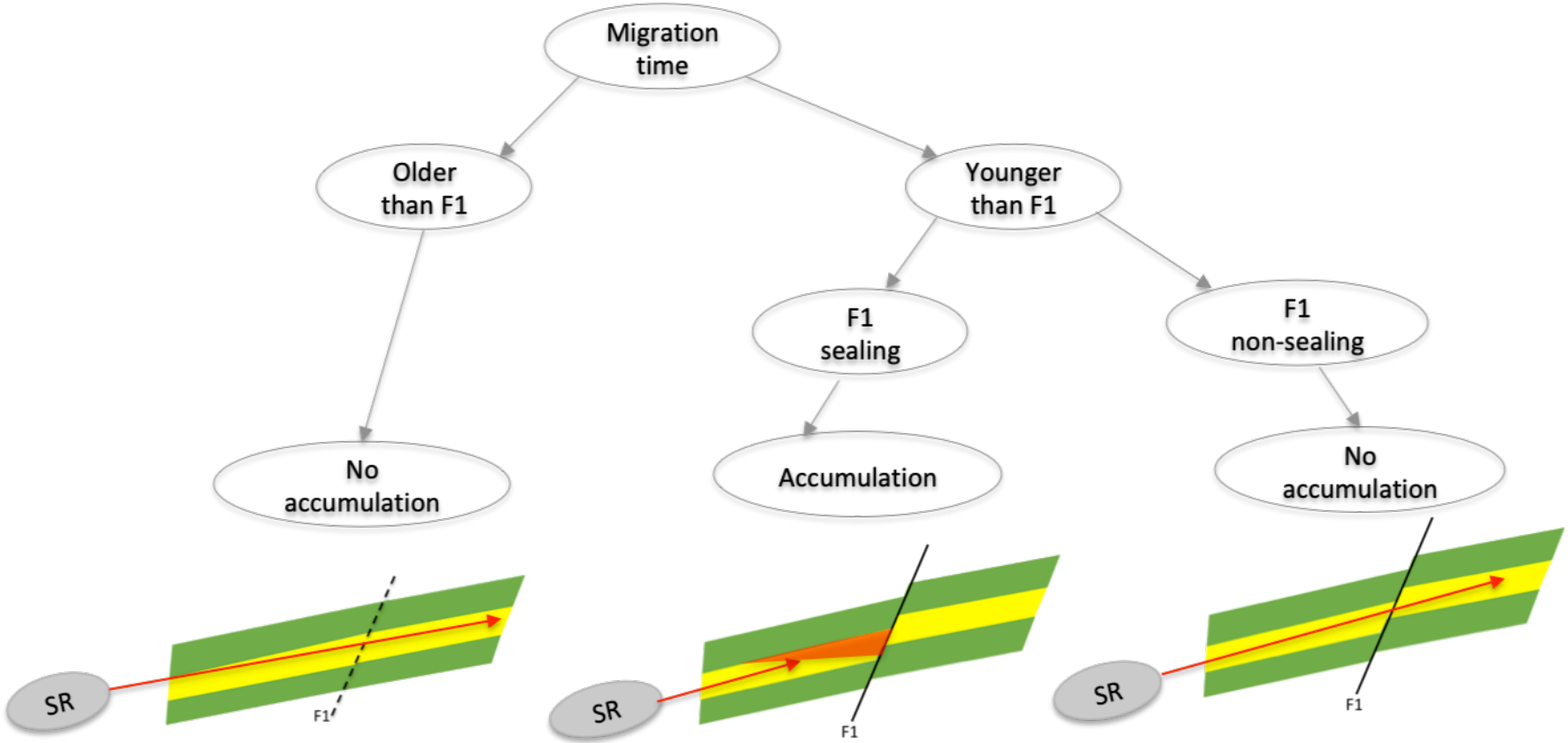


"The current digital tool set does not speak the geologists' language. We need something like a geological assistant." – Chief exploration geologist, workshop fall 2016

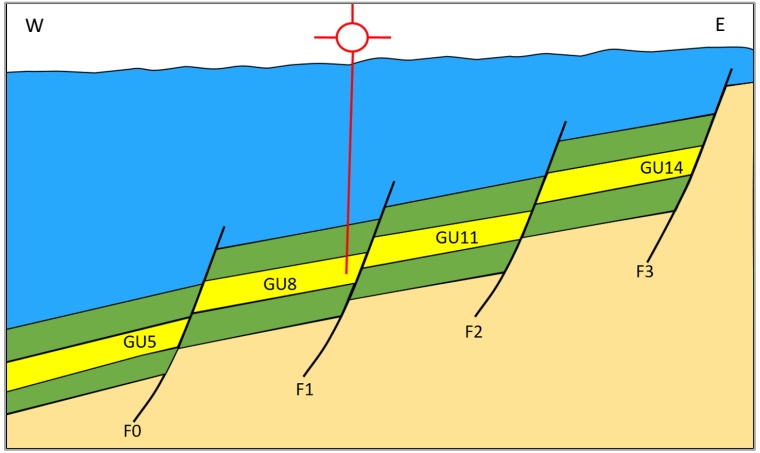
A method and tool to support geological reasoning through historical narratives

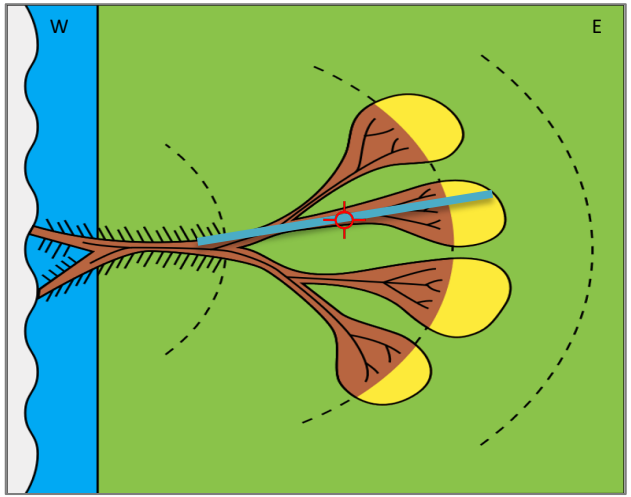
- Explore and create *multiple scenarios*
- Capture how scenarios change with *evidence, observations* and *assumptions*
- Yes/No, *How* and *Why*
- Detect *inconsistencies* in assumptions

What is reasoning?



Use case





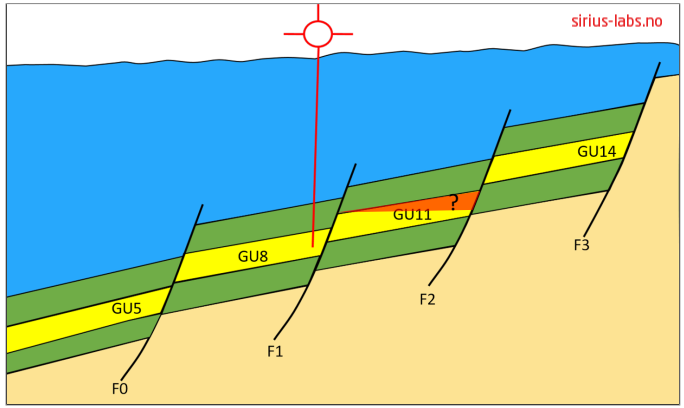
User: Explorationist

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

GU5 = feeder channel or distributary channel

GU5 = porous and permeable

No accumulation

Migration before trap formation

No accumulation in any of the traps

Migration after trap formation

GU5 non-porous and non-permeable

No migration pathway

GU5 non-porous and non-permeable and F0 sealing

Not true

Migration after trap formation

GU5 porous and permeable but F0 sealing

Migration pathway present

GU5 porous and permeable and F0 non-sealing

Migration pathway to GU11 present

GU11 can have accumulation if Trap is present

GU11 porous and permeable

No trap

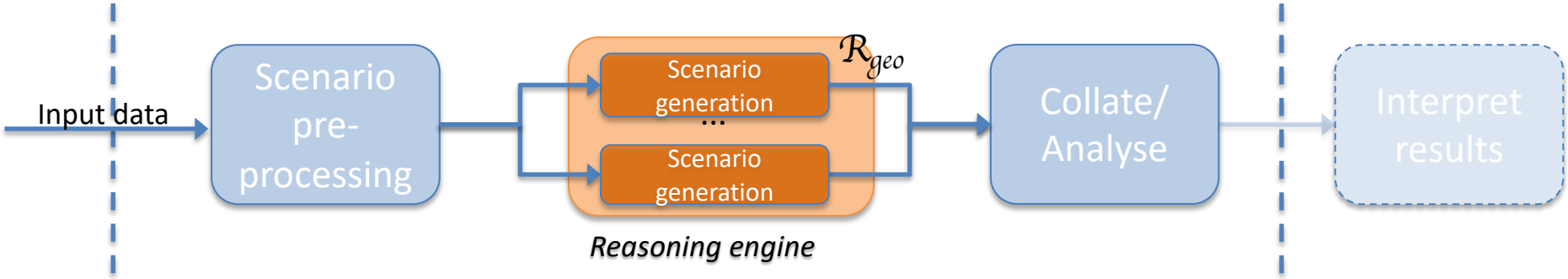
F1 non-sealing and no lateral seal present

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

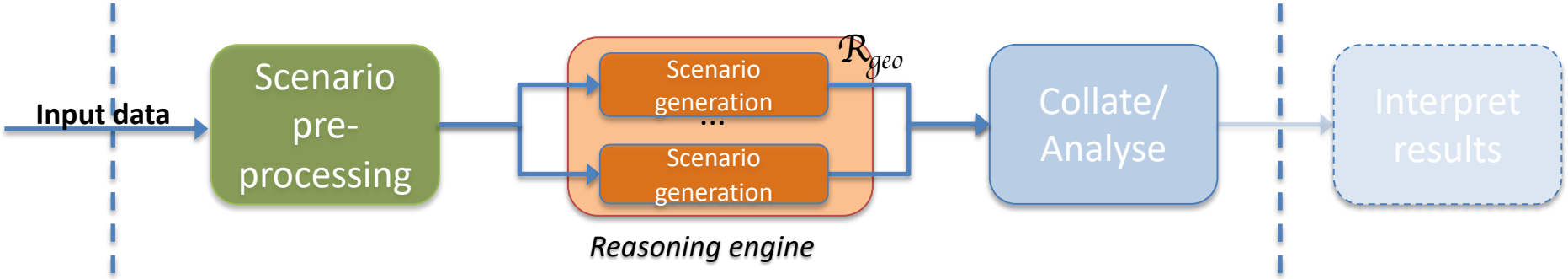
- A formal framework for specifying distributed and concurrent systems
- *Rewrite theory* $\mathcal{R}$ **= (Σ, E, R)**
  - **(Σ, E)** represents the equational theory
  - **R** are the *concurrent transitions* **t → t'**
- Concurrent rewriting logic deduction
- Together with geologists, we define $\mathcal{R}_{geo}$



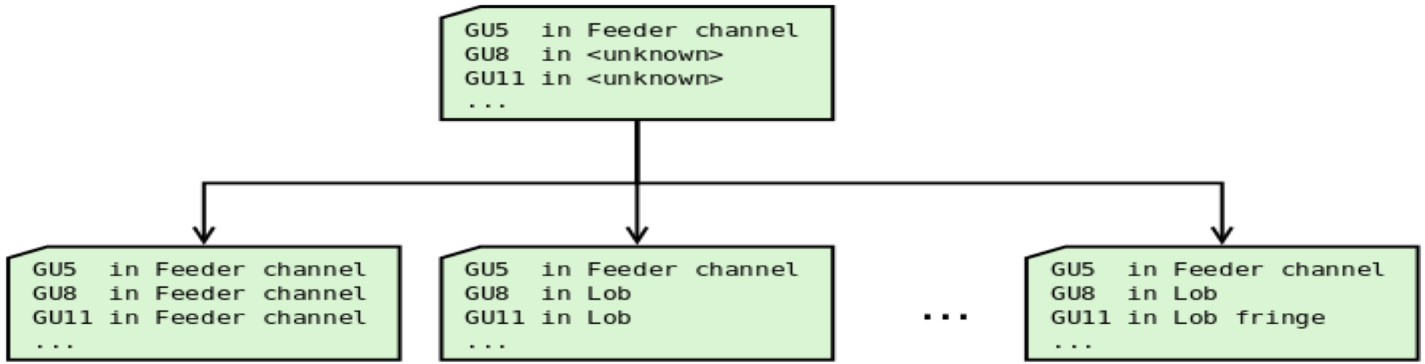
RL is a good fit for geological scenario reasoning

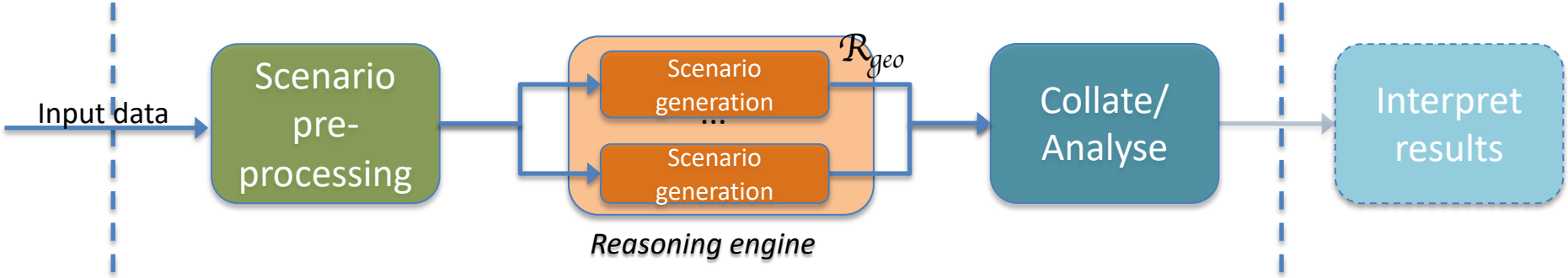
- The subsurface is dynamic over geological time
- Geological processes are concurrent … and we do not know their exact timing
- ε - representation distance

- 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

```
Last login: Wed Sep  4 11:12:24 on ttys001
moose:~ crystal$ cd PycharmProjects/geoAssistant/
moose:geoAssistant crystal$ python3 interactive-mode.py

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 Geo
Unit 11, which is a bad quality reservoir, and possiblly 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.
--ACCUMULATION--
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 feederChannel.
GeoUnit 5 is permeable and poro
GeoUnit 8 was deposited in dist
GeoUnit 8 is permeable and poro
--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 forme
<Reason>: There is fault-dependent trap-formation
Besides, GeoUnit 5 is permeable and porous.
GeoUnit 8 cannot be trapped.
<Reason>: There is no trap-formation for GeoUnit 8
Even though GeoUnit 8 is permeable and porous.
--ACCUMULATION--
GeoUnit 5 has accumulation.
  The accumulation in GeoUnit 5 can be filled to m
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 thro      al contact
oil&gas migrated through rocks in-contact from Geo      and there was      lt-dependent accumulation in GeoUnit 5
pathway formation through fault 0 from GeoUnit 5 t      cks are not in-
oil&gas migrated through fault 0 from GeoUnit 5 to      e was no accum      ause NO TRAP COULD BE FORMED FOR GEOUNIT 8
**********************************************************
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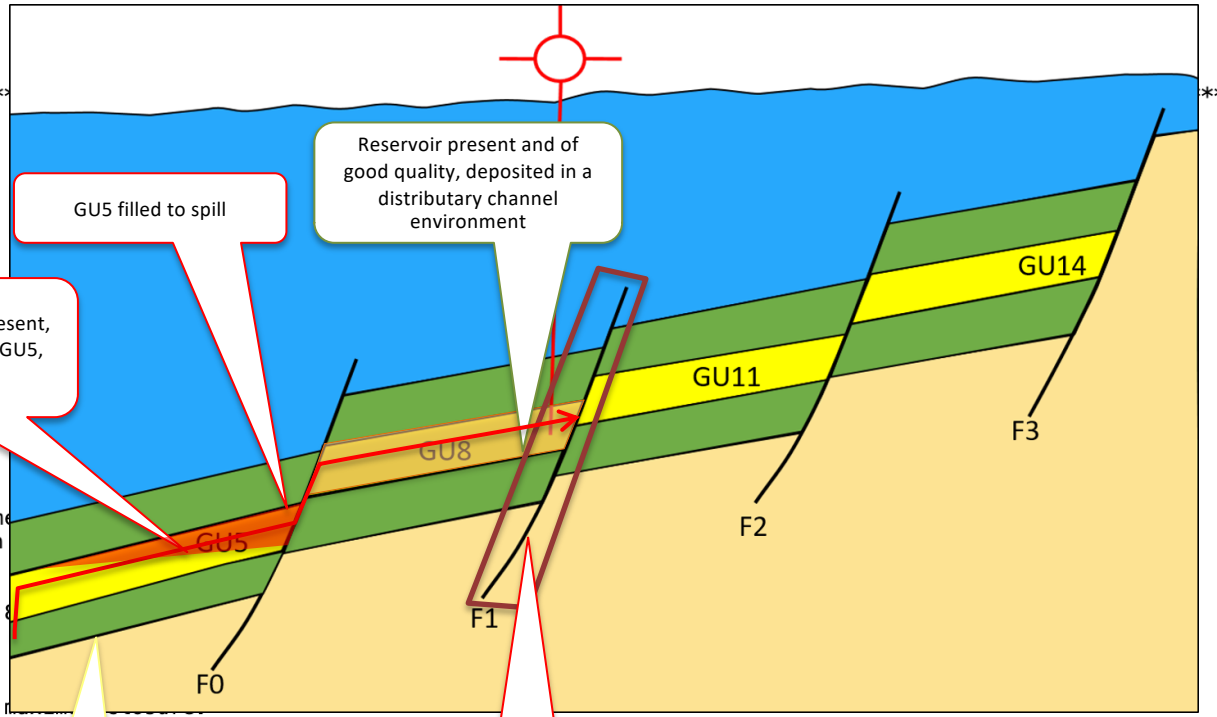

Future research outlook

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