FDPOPTIMIZATION

AI ENHANCED DECISION MAKING

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THE CHALLENGE: WHY IS OPTIMAL PLANNING IMPORTANT?

2050 Net-Zero Emission Pathway

- **Geopolitical** – provide reliable sources of energy
- **Emissions** – increase asset efficiency & reduce CO2e
- **CCUS** – negative emission (storage / mineralization)
- **Energy transition** - Support energy vectors Geothermal/Hydrogen storage
- Rare **minerals** mining exploration

Source Repsol: Commitment to Net Zero Emissions

Even more than before, we need to model, plan, optimize our decisions and do surveillance efficiently

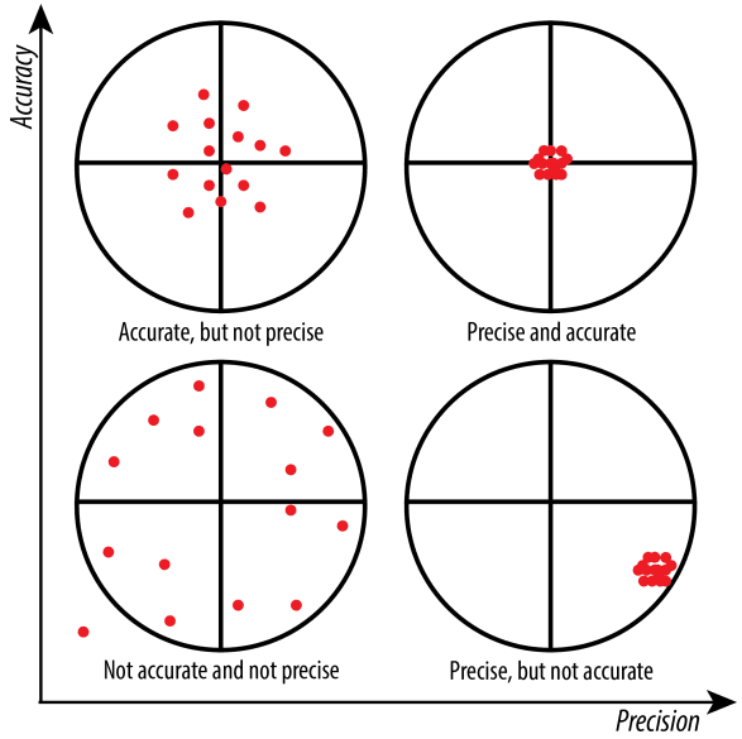
- **Digitalization** / New ways of working - COVID-19 has accelerated the paradigm shift towards cloud computing
- **AI** - starts delivering what has been promising

- Workflows are able to use much larger amounts of simulation time, but this needs to be **efficient**.
- The social responsibility around CO2 emissions has put more emphasis on **multi objective** optimization: i.e. CO2 for EOR and CCUS puts tension into the system

AI ENHANCED DECISION MAKING

Why?

- We define **Field Development Plan (FDP)** as the sequence of drilling and well controlling actions in a field
- **Uncertainty** characterization critical component of any risk assessment. "It is better to be vaguely right than exactly wrong" (Carveth Read, John Keynes)
- Towards an integrated workflow for reservoir modelling and **Value creation,** especially with CO2 for EOR and CCUS
- **Efficiency:** maximizing solutions/simulation time
- **Surveillance**: seeing decision trees rather than decision forests (talk G. Walker)
- **Optimized decisions**: Sequential decision making and Reinforcement Learning
- Support decision making "**Beyond E&P**"



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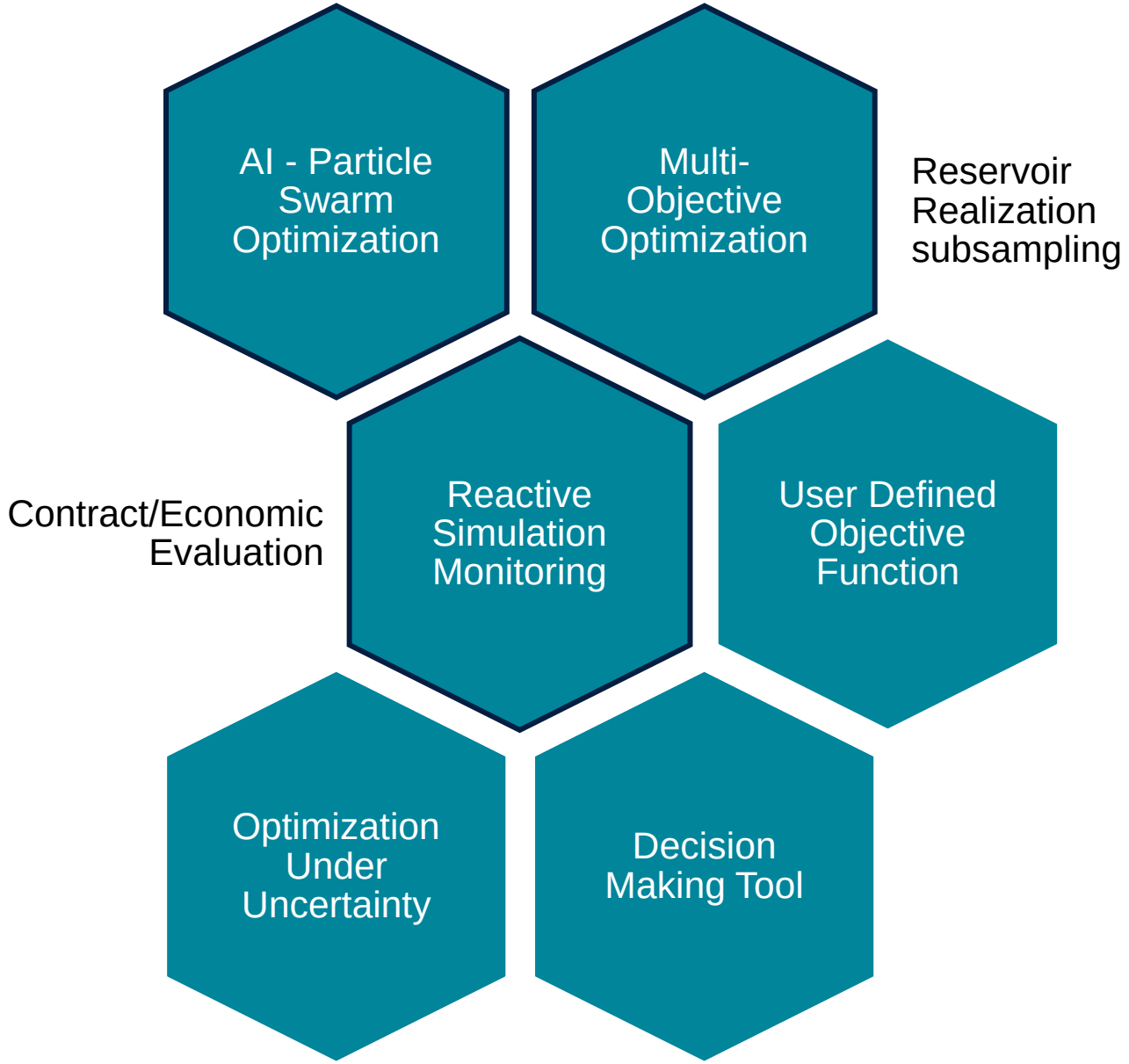
What's New?

FDPO[TechLab]

Petrel plugin, Delfi compliant, designed to **augment Petrel Capabilities** in decision making under uncertainty



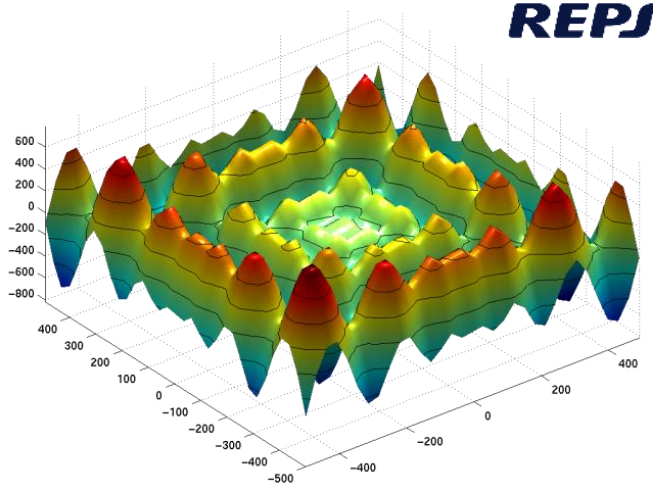
OPTIMIZER (I)

Exploration efficiency

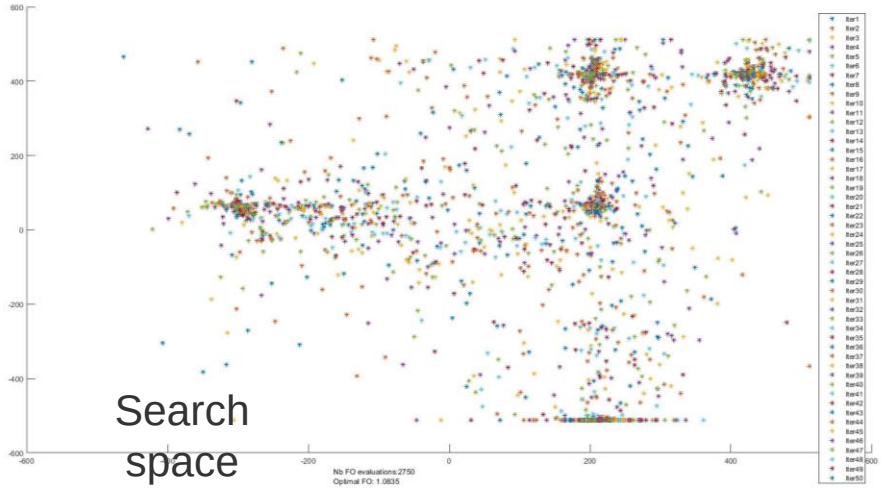
A **Particle Swarm Optimizer** framework has been implemented under Petrel Uncertainty and Optimization workflows.

Some key features that make it differential:

- Converge fast yet with a **good exploration / exploitation ratio**.
- An internal **AI-based engine** estimates the area of higher value and higher uncertainty.
- Provides a robust uncertainty quantification. **Converges to multiple optima** avoiding oversampling close to a single point



Schwefel function



Search space exploration

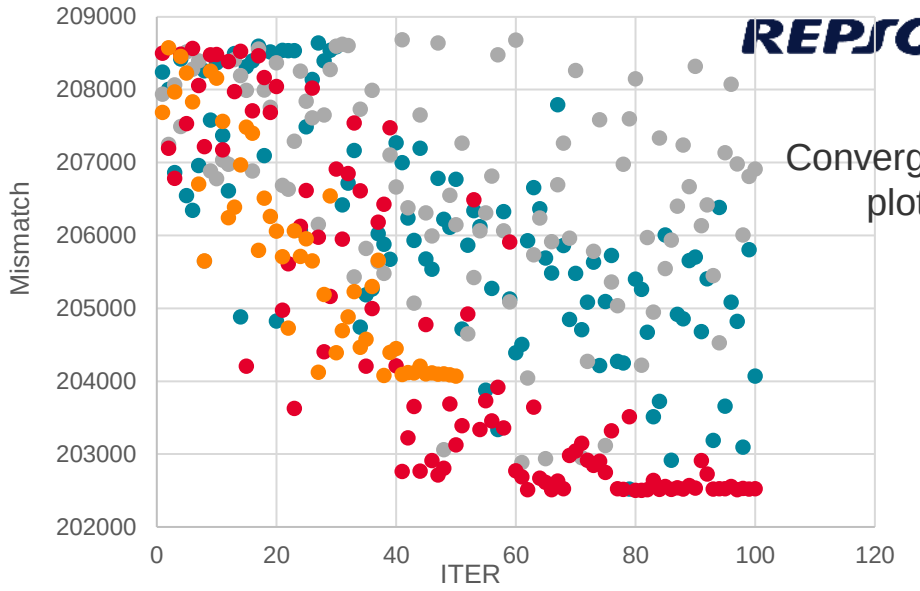
OPTIMIZER (II)

Multi-Objective Optimization

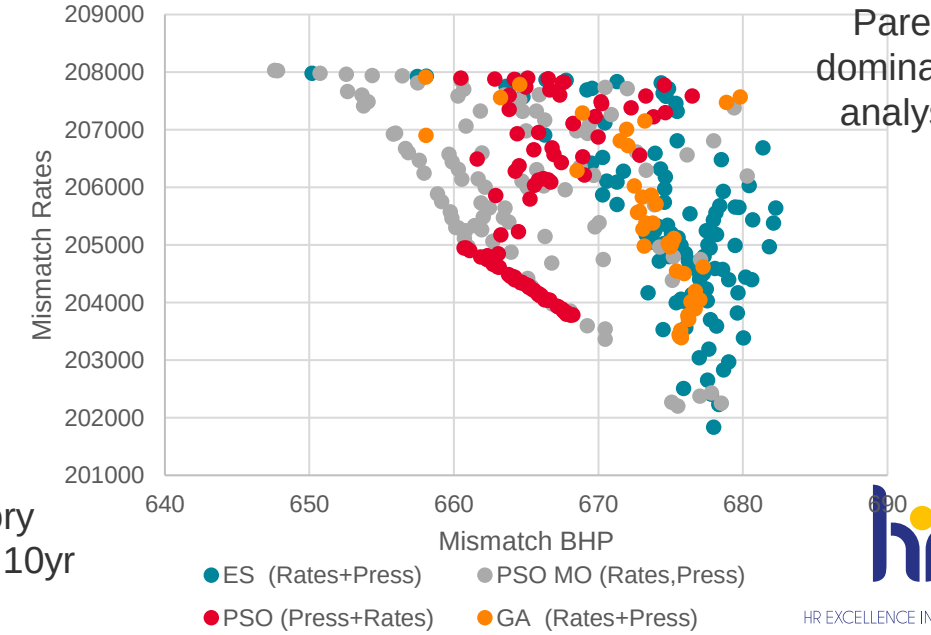
- Complex decisions often imply **multiple objectives** (MO).
- The optimizer is capable to converge to the best **pareto front** (best solutions)

Where is it relevant?

- History Matching with multiple data types or multiple reservoirs at once
- History Matching data and maximize forecast uncertainty spread
- Optimization of production and CO2 reinjection
- Optimization in a join venture for each partner NPV (win/win)



Convergence plot



Pareto dominance analysis

Reservoir History matching: 7 wells 10yr use case

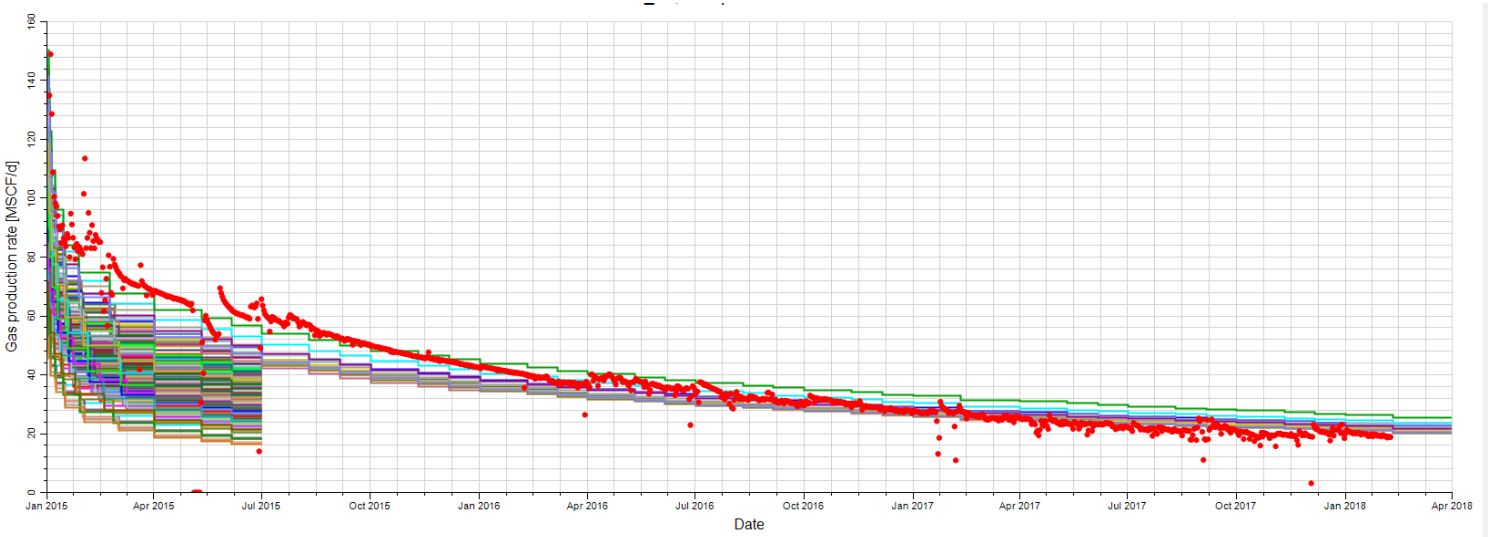
REACTIVE SIMULATION MONITORING

Maximize simulation value

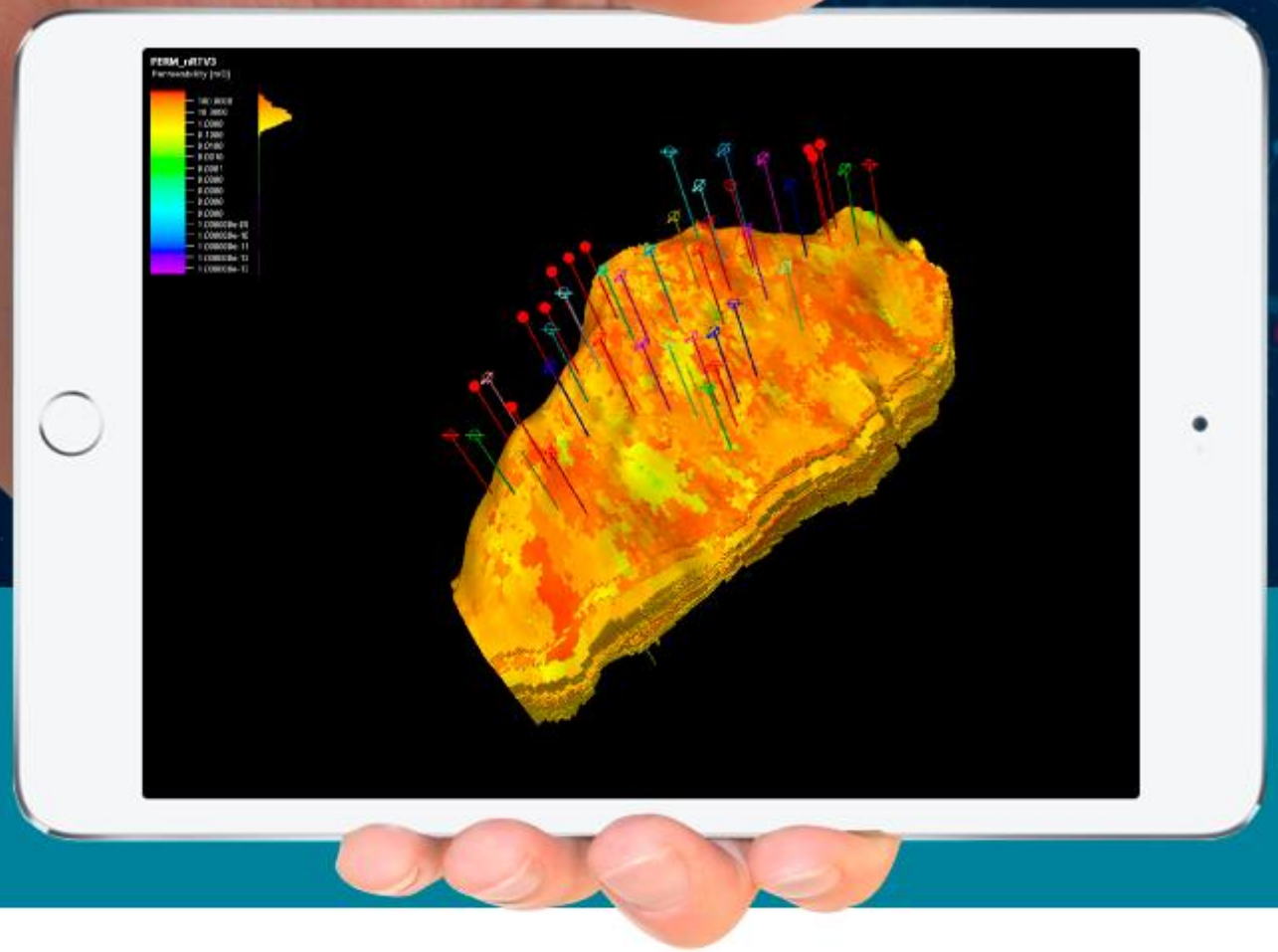
- How many simulations are worth during a parameter exploration?

  .... The ones needed that bring new information

- **Reactive Simulation Monitoring** in real-time checks the active simulations and early terminates all the suboptimal ones
- And **all viable simulations go to forecast**. We are interested in value and uncertainty



Single well history matching. Parameter exploration.
90% simulation stopped



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#RepsolTechLab from science to real business

FDPO[Techlab]

(**F**ield **D**evelopment **P**lan **O**ptimization)

Enhance subsoil uncertainty characterization and field value optimization.

Applications:

History Matching (HM) and Field Development Plan Optimization (FDPO). Subsoil ensemble representation for risk analysis. Well location optimization. Support for decision-making.

Benefits:

- Reduce time-to-decision and computational resources usage yet with an improved subsoil understanding
- Increase variety of History Matching models for better Uncertainty Characterization
- Improved decision making under uncertainty with flexible formulation and multi-objective optimization
- Up to 60% workflow runtime reduction by early termination of implausible simulation
- Integrated as plugin of commercial platforms.

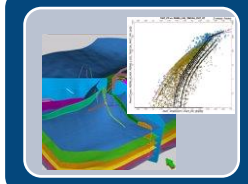
HISTORY MATCHING

Use Case

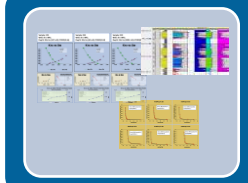
Main Challenges

Large production and pressure history.
Water injection for pressure support
various equilibrium zones; 10+ sub-zones

Facies modeled using MPS and SIS Algorithms:
Multiple facies' classes Vsh and Porosity modeled using SGS constraint by facies
Permeability modeled by SIS (CoK porosity)



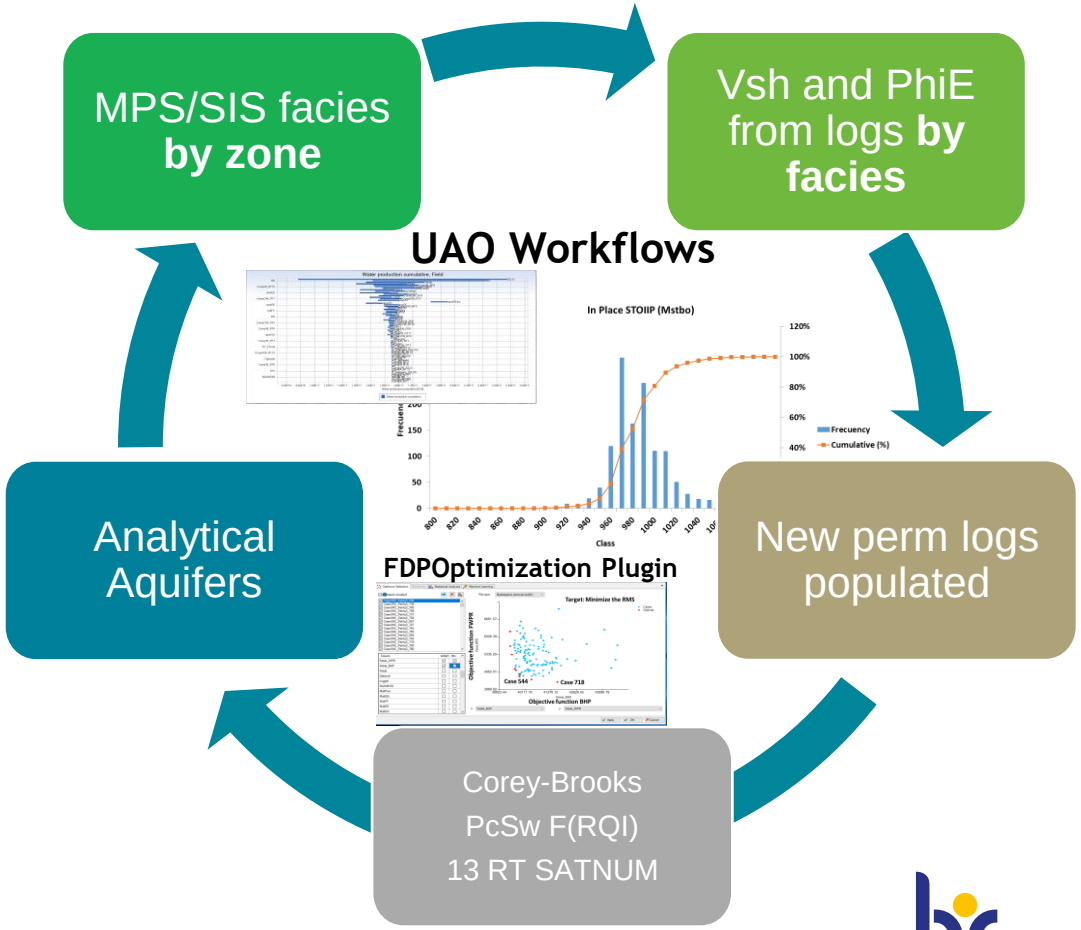
High Structural complexity
Multiple blocks



10+ commingled production zones
10+ RT classes
PcSw and Krs models as function of RQI

Large numbers of uncertainty variables >70
Large STOIIP, but unexpected early WBT
Multiple inverses correlation variables in the data analysis

Main Workflows

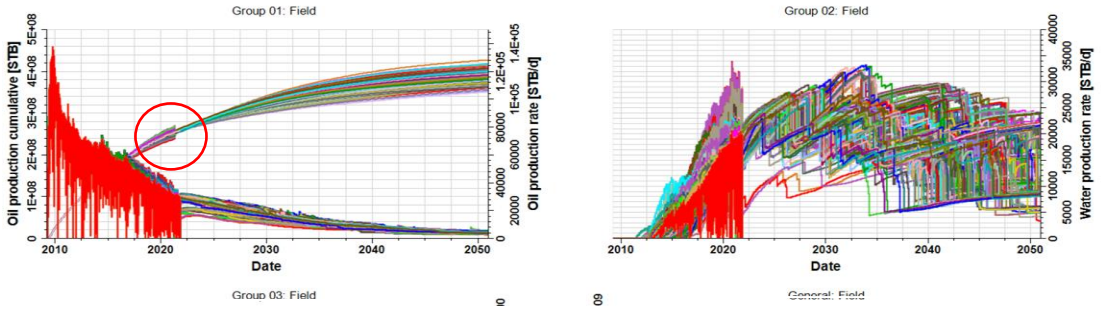


HISTORY MATCHING

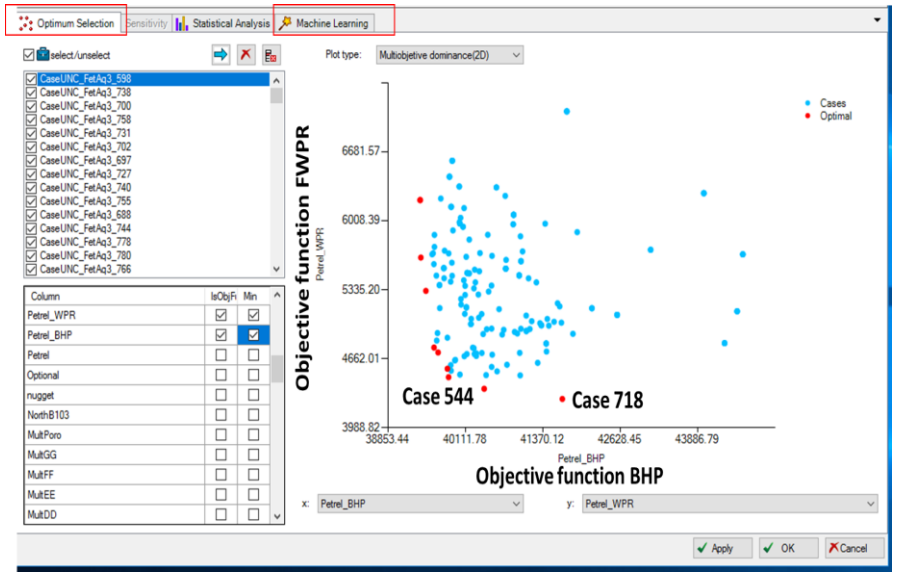
Use Case results

- +50% time reduction in uncertainty screening analysis
- High quality results
- Best optima Identification. Drill down and improve processing of the results obtained
- Do not sacrifice uncertainty for accuracy

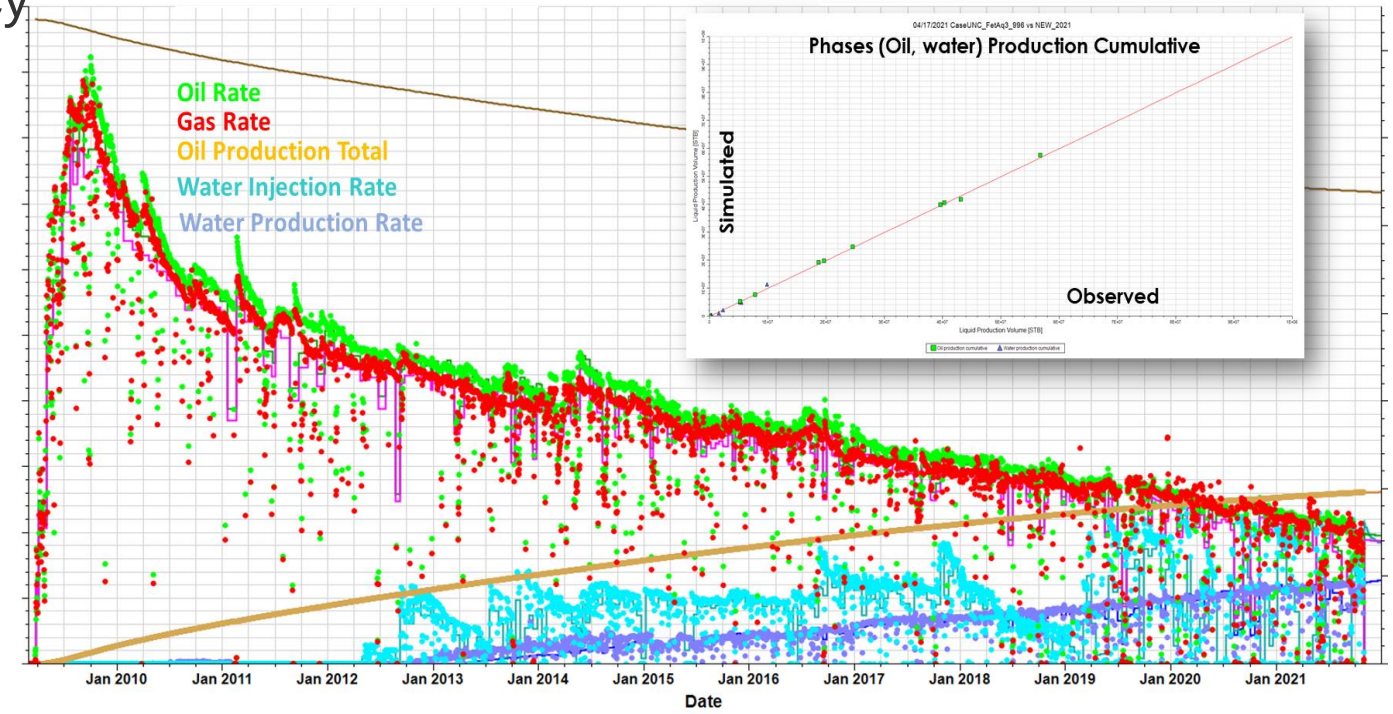
Early termination of simulations by the RSM



Full Field HM Results



Well HM (Liquids Phases)

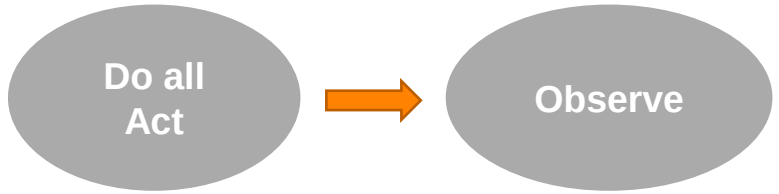


SEQUENTIAL DECISION MAKING

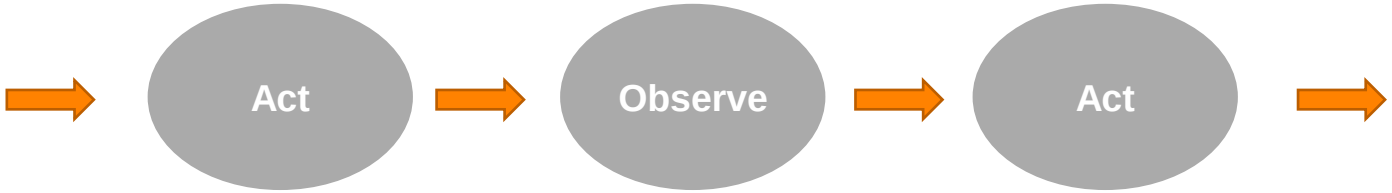
How can AI help?

Where do I drill my next well?
How do I maximize the CO2 reinjected?
How do I reduce my environmental impact and make an economic viable development?

Static reasoning



Sequential reasoning



SEQUENTIAL DECISION MAKING

How can AI help?

- **Field Development Plan Optimization**
- **Uncertainty propagation**
  - Does it make sense to apply the same production strategy to all realizations?
  - What if the realizations are clearly bimodal in behavior? E[NPV] The expected NPV value will provide a suboptimal decision criteria
- **Data Assimilation**
  - Future observation can disprove (falsify) some realizations
  - New observation and reservoir surveillance modify the uncertainty characterization **(talk G. Walker - seeing decision trees rather than decision forests)**
  - Observation can be production series, seismic survey, well logs,….

We need a framework that reconciles **Planning** / **Surveillance**

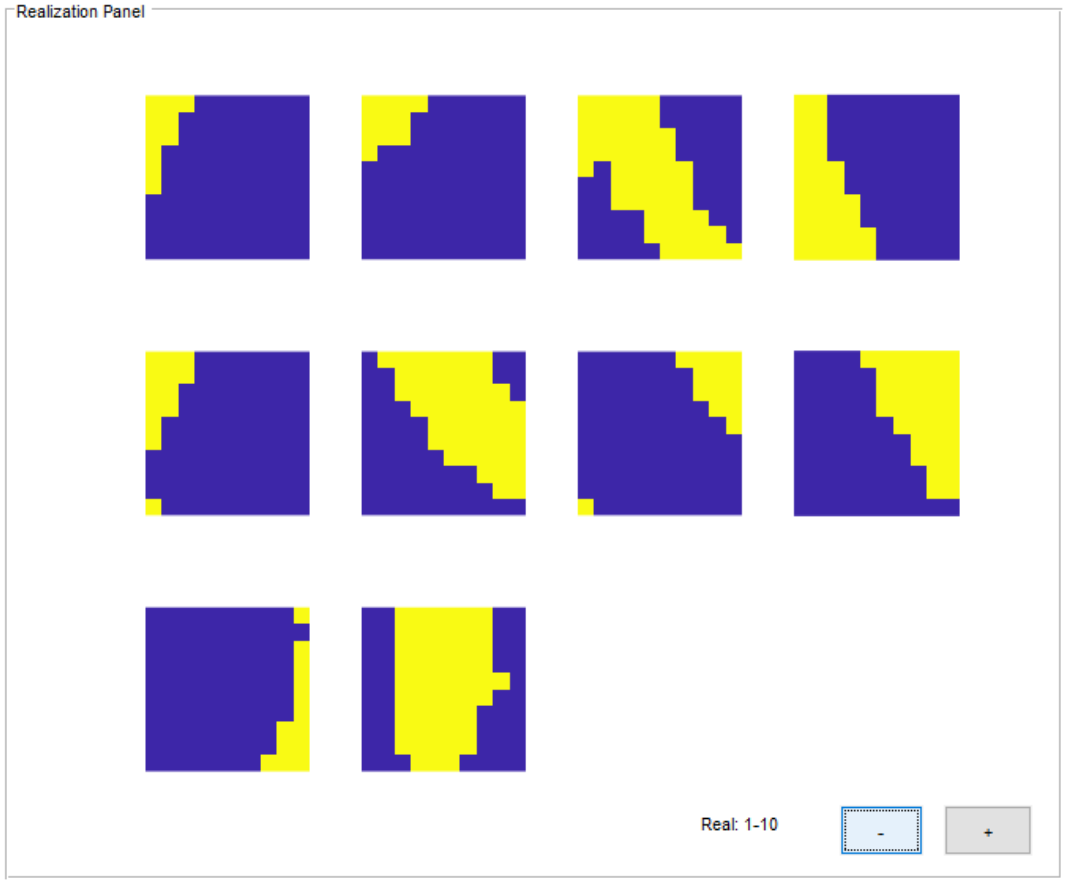
What about **Value of Information** and **reactive decision making**?

… to Field Development Policy Optimization considering as policy the playbook of best actions to make given the history of actions and observations

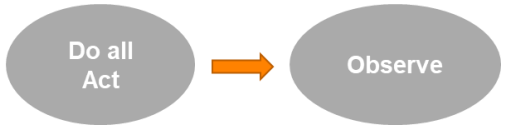
AI ENHANCED DECISION MAKING

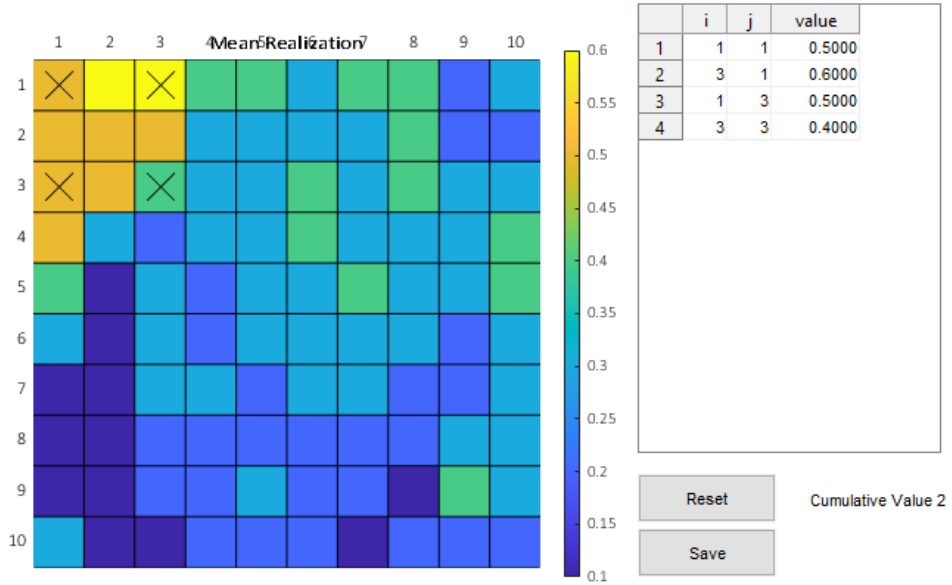
Field Development Plan Optimization - Intuition

Where do I drill my next well?



Static reasoning





Given 10 reservoir realizations representative of the subsoil. What is my best production strategy configuration?
Yellow= 1 Blue = 0
Constrain: min_interwell_dist = 1 pixel

AI ENHANCED DECISION MAKING

Field Development Plan Optimization - Intuition

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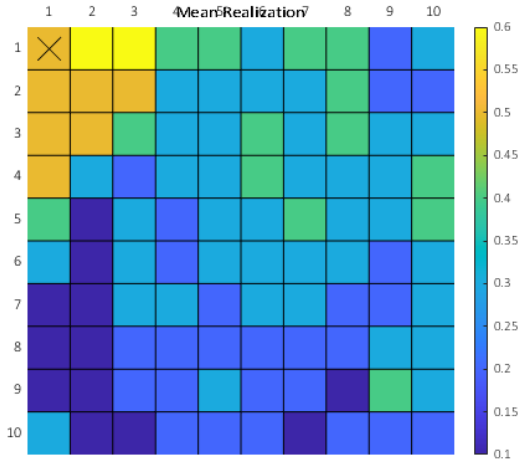
Where do I drill my next well?

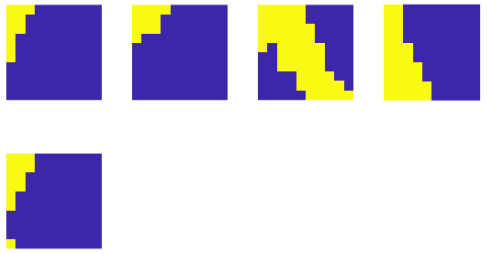
Sequential reasoning → Act → Observe → Act →

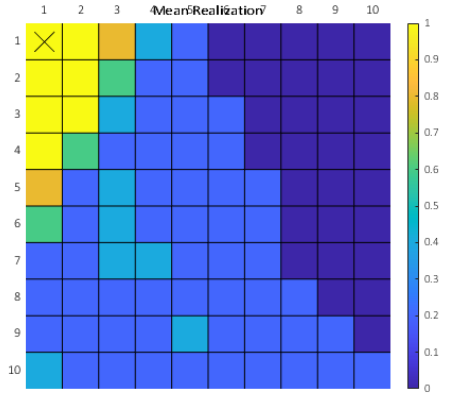
Let us place the first well



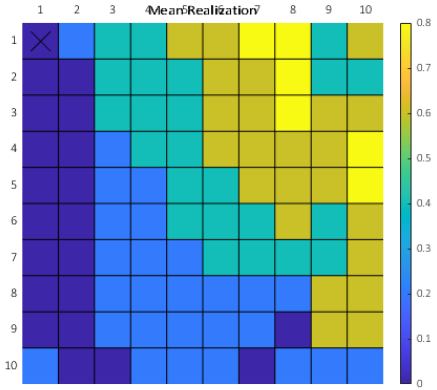
What do we observe?

if act(1,1) obs (1)





if act(1,1) obs (0)



My understanding has changed.

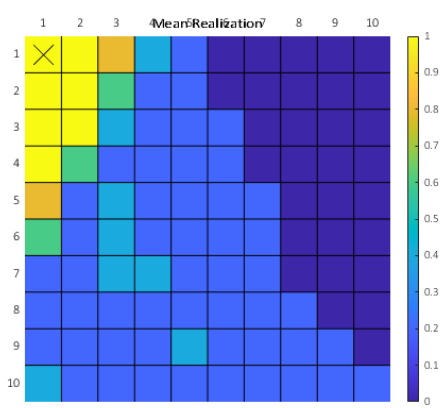
How should I use this for my next decision?

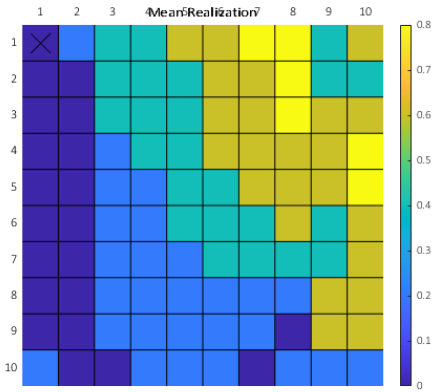
AI ENHANCED DECISION MAKING

Field Development Plan Optimization - Intuition

Where do I drill my next well?

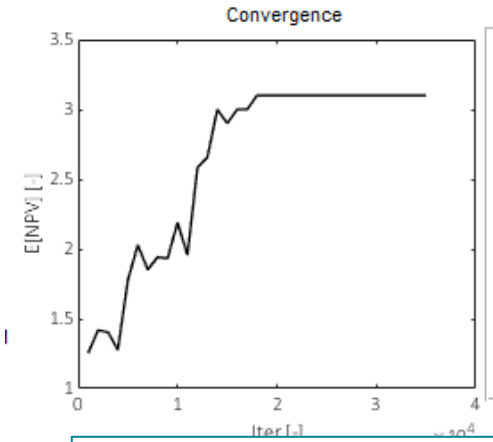
Sequential reasoning → Act → Observe → Act →



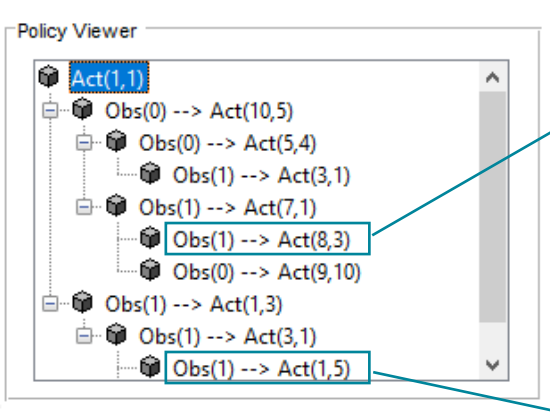


Let's act again on the field with the current status and my new understanding to maximize my future value….

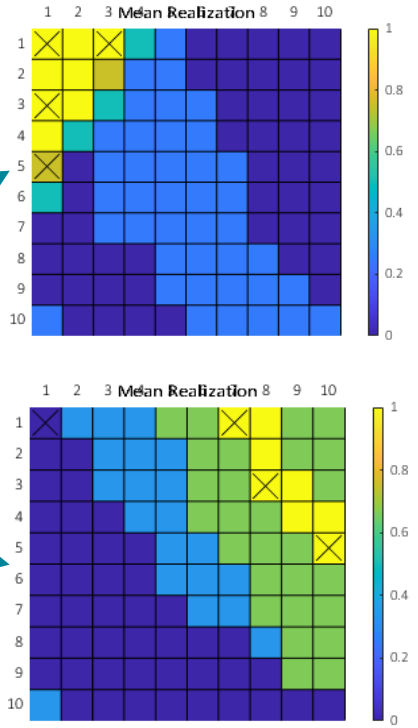
…. Or better let's an optimizer generate a decision tree → the optimal tree



Pseudo-learning curve



Policy



DYNAMIC PLAN OPTIMIZATION

Reinforcement Learning application

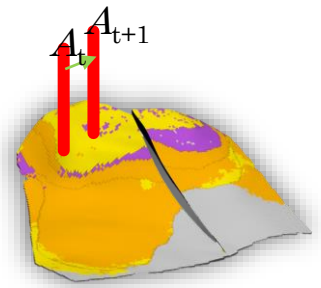
Objectives: Introduce reinforcement learning (RL) in asset planning optimization.

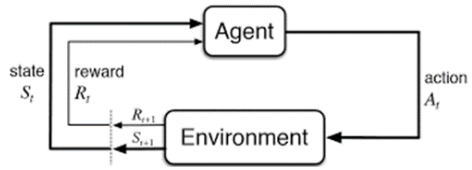
Features:

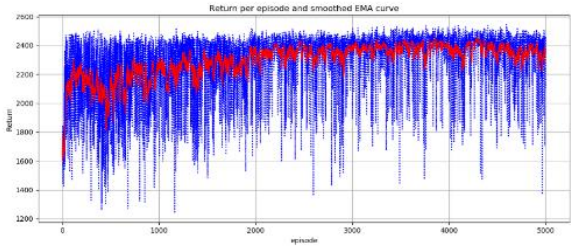
- Training of an agent capable of maximize field output under uncertainty, learn dynamically from action and observation
- **Partial observability**
- Optimal **reactive** decision making.
- **Sequential**: Allows assimilating data of new observations to decide for next action
- **Global optimization**: look for the final value over the short term reward
- **Self learning**: Train a decision network to generate always the best action given the current and history of observation
- **AI optimization**: Even when the combination of variables become too vast DRL outperform any global optimization

Agent and Environment – Chess & FDPO

RL is based on the idea of an agent (decision maker / player) capable to perform actions (drill a well / move) over an environment (asset / chess board) and retrieve feedback of its state (well production / adversarial move) and a reward (value $ / win the game)







Train AI

The Decision network in a fraction of simulations can evaluate all optimal sequences stabilizing its pseudo-learning curve to the max value

Curtesy of: De Paola et al. SPE-201254-MS

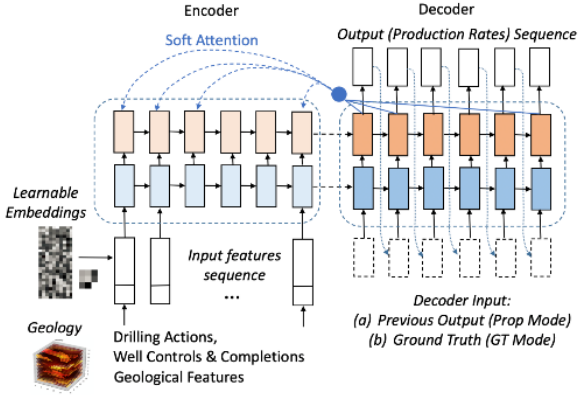
RESERVOIR SIMULATION PROXY MODEL

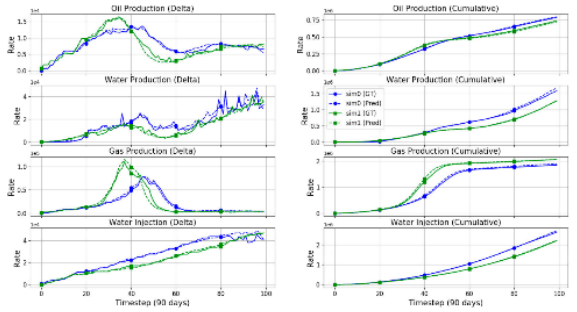
Deep Learning application - Speedup reservoir simulations

Objectives: Build a proxy model useful for field development plan optimization and history matching capable for high speed up and high accuracy

Features :

- ad-hoc deep learning seq-to-seq network architecture capable of 1% error for field well timeseries and 40000x speedup
- Generation of an end-to-end environment that can substitute expensive reservoir simulation



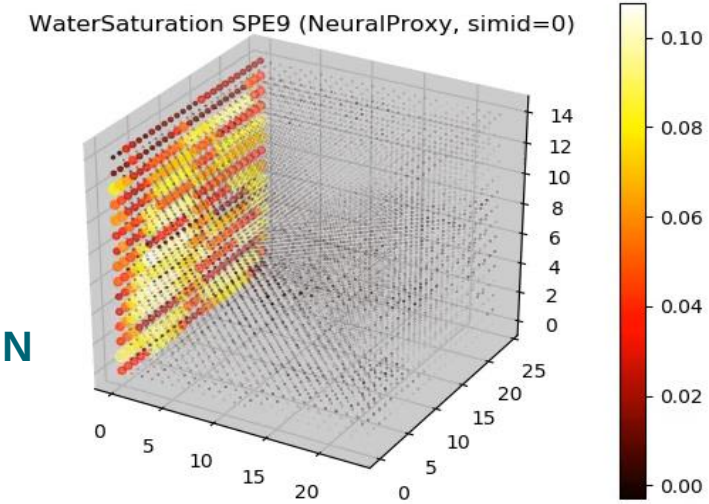


Deep Learning seq-to-seq

Mapping decision sequences to output sequence Drilling actions to production dynamic responses. Suited for forecast

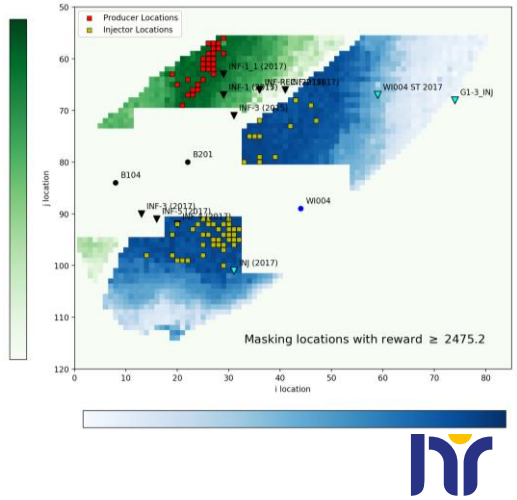
Deep Learning CNN-RNN

proxy model suited for History match cases



Opportunity maps

Brute force analysis to evaluate well drilling sequence best map 600000 simulation overnight



Curtesy of: Navratil et al. SPE-201775-MS

ACKNOWLEDGMENT

Partners

Software product used in the presentation and available upon request:

FDPOptimization (contact: Giorgio De Paola giorgio.depaola@repsol.com)

RAEW (Reservoir Analytics 4 Early Warning) (contact: Greg Walker gxwalker@repsol.com)

DPO (Dynamic Planning Optimization) (contact: Giorgio De Paola giorgio.depaola@repsol.com)

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