AI and Robotics in Upstream Oil and Gas

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A Bio of Dr. Abdallah Alshehri

- Abdallah Alshehri is a petroleum engineering specialist at Saudi Aramco Advanced Research Center (EXPEC ARC) participating in industry-leading research on reservoir monitoring & surveillance. He received the Ph.D. degree from Georgia Institute of Technology, USA in 2018.

- Currently, He is an expert in reservoir monitoring and surveillance that capitalize on 4th Industrial revolution (4IR) technologies and Artificial Intelligent (AI) technologies. He is the leader of Deep Diagnostic team with Reservoir Engineering Technology Division under EXPEC Advanced Research Center, Saudi Aramco. The function of his team is to create innovative technologies to improve reservoir description and evaluation for better reserves assessment and well placement as well as to enhanced monitoring and surveillance to ultimately improve recovery.

- His research interests include wireless underground sensor networks, in-suite sensing methodologies and applications for oil and gas reservoir monitoring and surveillance.

A Bio of Dr. Klemens Katterbauer

- Klemens Katterbauer is an experienced petroleum engineer and software developer focusing on the development of the latest 4IR technologies for reservoir engineering applications. He completed his PhD at King Abdullah University of Science and Technology and a master in Petroleum Engineering from Heriot Watt University.

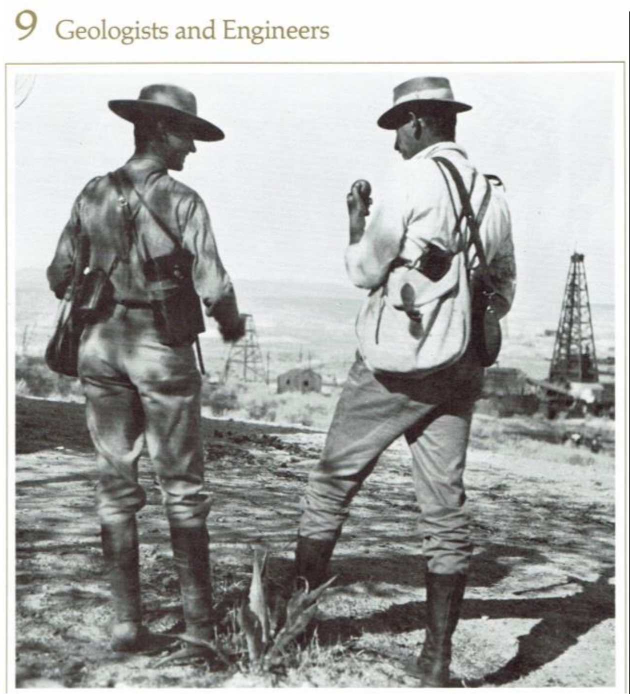
- He has a proven track record having developed enhanced uncertainty frameworks for enhancing oil recovery and strengthening sustainability of existing oil and gas reservoirs. A strong focus was laid on solar and wind energy and provide dedicated solutions for optimizing grid transfer rates, reduce downtimes and enhance efficiency in the power transmission.

- He has developed in recent years major technologies, such as enhanced artificial intelligence technologies for tracking waterfronts in subsurface reservoirs, and forecasting their movements. Furthermore, he has developed robotics systems for enabling real-time logging while drilling as well as subsurface sensing and logging operations.

Outline

- A lookback – At the last 100 years
- New Technologies
- Intelligent Sensor Selection
- Deep Reinforcement Sensor Placement
- Smart Orthogonal Matching Pursuit
- Conclusions

The Last 100 Years



Source: “Spudding In”, Bill Rintoul, 1976

Geologists Ralph Arnold, left, and H R Johnson, in field outfits, near McKittrick. Arnold carries a camera, binoculars, and a field bag for rock samples. Johnson adds a canteen.

So, if we asked someone in 1917 what the industry would be like in 2017, what would they have said?

The First Well Log

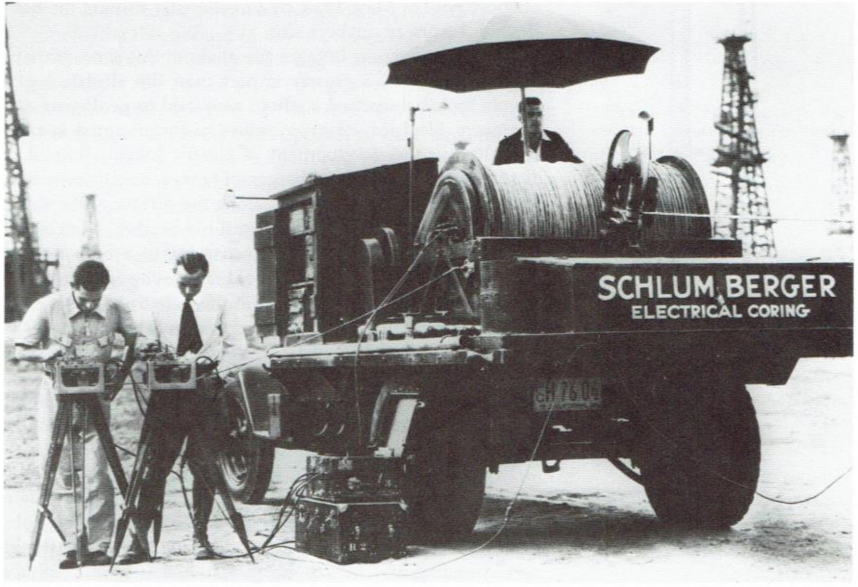
1927 Henri-Georges Doll joins the company, initially part-time Doll and his team record the **first electrical resistivity well log** in Pechelbronn, France A new term was coined to describe the results of this multi-depth survey: it was called an electrical resistivity well log.

1929 Subsurface surveying is carried out in Argentina, Ecuador, India, Japan, the Soviet Union, Venezuela and the USA . The **USA's first ever well log is performed in Kern County, California**

1931 This was followed by another breakthrough, with the **introduction of the Spontaneous Potential (SP) log**.

Source: http://www.slb.com/about/history/1920s.aspx

Electric Logs



Gilbert Deschatre and Jacques Gallois with the first electrical logging truck in California, 1933

- Jacques Gallois made the first electric log run in California at Shell's Boston Land Company No 1 at Westhaven near Huron, Kings County, on August 15, 1929.

Source: "Spudding In", Bill Rintoul, 1976

Donkey, Grasshopper, Horse-head, Thirsty Bird, and Pump Jack

Sketched by Walter Trout in 1925, a prototype of his counterbalanced pump jack was in an oilfield before the end of the year.

1925 Beam Pump

Walter Trout was working in Texas for Lufkin Foundry & Machine in 1925 when he sketched out his idea for the now familiar counterbalanced oil well pump jack. Before the end of the year, the prototype was installed and working near Hull, Texas, in a Humble Oil Company oilfield.

Source: http://aoghs.org/technology/oil-well-pump/

Core Analysis

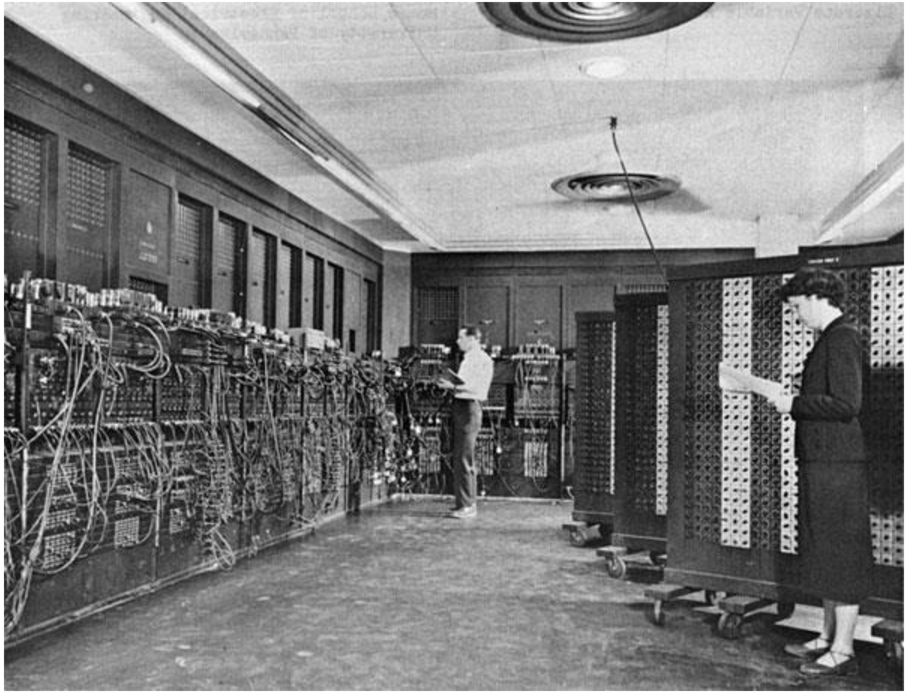
1936

Core analysis as commercial service introduced by Core Laboratories in1936

Source: http://www.corelab.com/corporate/history/

Computer Development

1943-46



Source: http://www.computerhope.com/issues/ch000984.htm

- ENIAC occupied about 1,800 square feet and used about 18,000 vacuum tubes,
- Weighing almost 50 tons
- Many still consider the ENIAC to be the first digital computer because it was fully functional

Computers

1950-88

1950 - First stored program computer, the UNIVAC 1101 is considered to be the first computer that was capable of storing and running a program from memory.

1953 - IBM's first computer IBM publicly introduced the **701**; its first commercial scientific computer.

1956 - The TX-O (Transistorized Experimental computer) is the first transistorized computer to be demonstrated at MIT

1981 - IBM introduced its first personal computer called the IBM PC. The computer had 16 KB of memory, which was expandable to 256 and utilized MS-DOS

1988 - Cray Research introduced the Cray Y-MP®, the world's first supercomputer

Source: http://www.computerhope.com/issues/ch000984.htm

Technology Development

1929 Controlled Directional Drilling
H. John Eastman introduces controlled directional drilling.

1933 Tricone Roller-Cone Drill Bit
Hughes introduces the first tricone roller-cone drill bit.

1941 Horizontal Well Drilling
Alexander Grigoryan, a Soviet driller, directs the first horizontal well drilling in Azerbaijan.

1949 Hydraulic Fracturing
First commercial hydraulic fracturing treatment performed in Stephens County, Oklahoma and Archer County, Texas. (Halliburton)

Source: http://www.spe.org/industry/history/timeline.php

Technology Development

1949 Offshore Drilling
The first offshore mobile drilling platform, the Breton Rig 20 performs in up to twenty feet of water (Hayward-Barnsdall)

1954 Jack-up Drilling Rig
Colonel Leon B Delong builds the first jack-up drilling rig (Delong Corporation)

1958 Maritime Pipelaying
The first purpose-built pipelay vessel goes into use (Brown & Root).

1961 Subsea Wells
First subsea well completed (Shell)

Source: http://www.spe.org/industry/history/timeline.php

Technology Development

1962 Semisubmersible Drilling
First semisubmersible drilling rig (Blue Water and Shell)

1966 Thermal Decay Time Tool
Thermal-decay-time tool developed for through-tubing production logging (Schlumberger)

1967 Oil Sands Production
Commercial production begins from Athabasca Oil Sands in Alberta, Canada (Sun)

Source: http://www.spe.org/industry/history/timeline.php

Technology Development

1972 Mud-pulse Telemetry
Mud-pulse telemetry introduced, enabling accurate determination of bit location while drilling (Teleco)

1978 Measurement-While-Drilling
Measurement-While-Drilling technology introduced (Teleco)

1980 Electrical Submersible Pump
First variable-speed electrical submersible pump (Hughes-Centrilift)

1982 3D Seismic
3D seismic processing begins (Veritas)

Source: http://www.spe.org/industry/history/timeline.php

Technology Development

1983 Logging While Drilling
First quantitative Logging While Drilling resistivity sensor (Halliburton)

1984 Steerable Drilling
Steerable drilling system introduced (Norton Christensen)

1991 3D Seismic
3D seismic model processed at supercomputer workstation

1994 4D Seismic
First 4D seismic performed (CGG)

Source: http://www.spe.org/industry/history/timeline.php

Technology Development

1997 Subsalt Development
Mahogany field on Ship Shoal Block 349 in US Gulf of Mexico becomes first commercial subsalt development. (Phillips)

2001 Subsea Christmas Tree
First 15,000-psi working-pressure subsea Christmas tree installed (Cameron)

2011 Extended Reach Well
World's longest extended reach (ERD) well drilled on Russia's Sakhalin Island, with a length of 40,502 feet (Exxon)

Source: http://www.spe.org/industry/history/timeline.php

AI in Oil and Gas

Source: Valustrat.com

AI Market Dynamics

Increasing demand for advanced solutions in diagnostics, drilling, quality maintenance, predictive maintenance and planning will be driving artificial intelligence

Increasing investment in advanced technologies and automation processes in oil and gas field operations, which offer significant revenue opportunities.

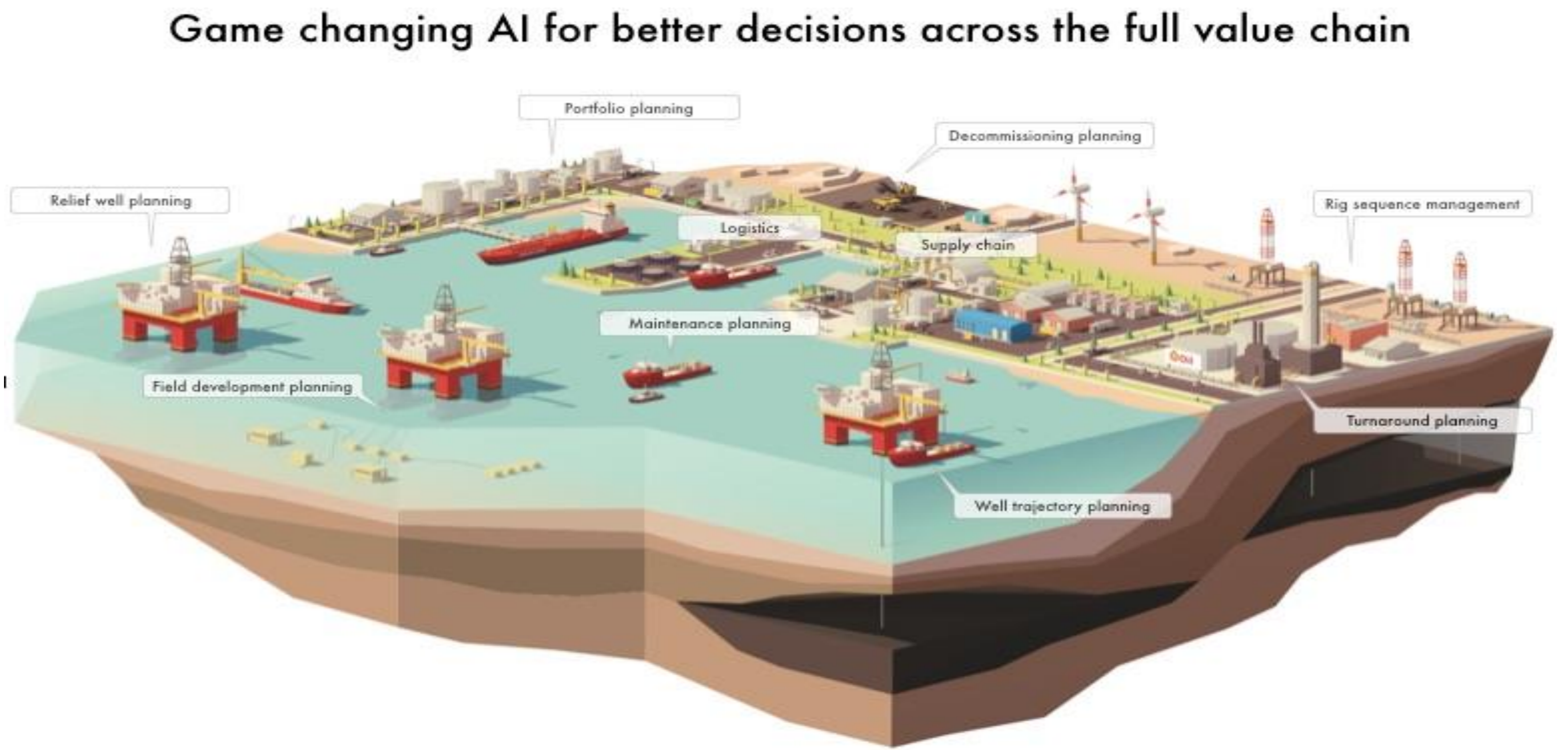
Lack of skilled professionals for AI based operations. Expected to hinder the achievement of high efficiencies possible with AI solutions.

Source: Transparency market research

5G & Cloud Technologies for Oil and Gas

Source: Crudemix Africa

AI Across the Value Chain in Upstream O&G

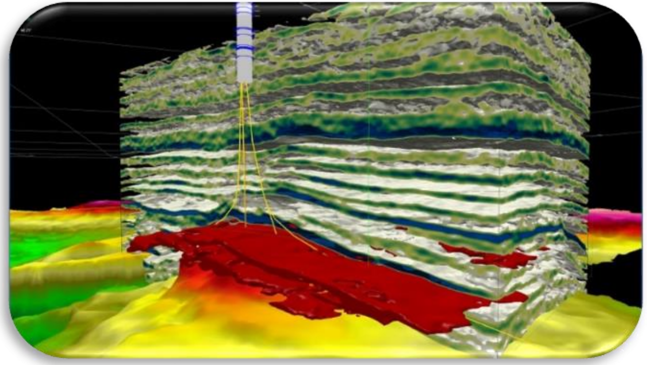


Source: White Space Energy

Fractures and Flow Patterns Detection in Carbonate Reservoirs Using Intelligent Sensor Selection in a Deep Learning and Uncertainty Framework

1. Background
2. Subsurface reservoir sensors
3. FracBots technology
4. Challenges – sensing
5. Real-time intelligent sensor selection
6. Sensor optimization problem
7. Results
8. Conclusions

Background



Example of reservoir section

Reservoir fracture illustration

Measuring properties in the reservoir represents a major **challenge** due to the **sparsity** of measurements and **lack of direct measurements**

In-situ reservoir measurements are key to obtain a greater insight farther of the wellbore

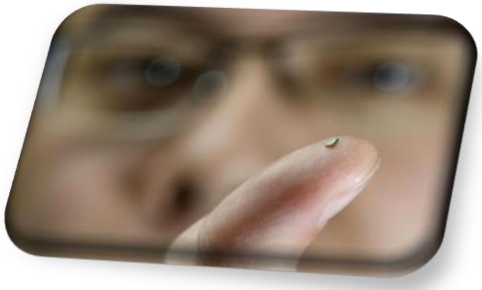
Solution:

- Small scale reservoir sensors are transported into the reservoir and will provide temperature and pressure data

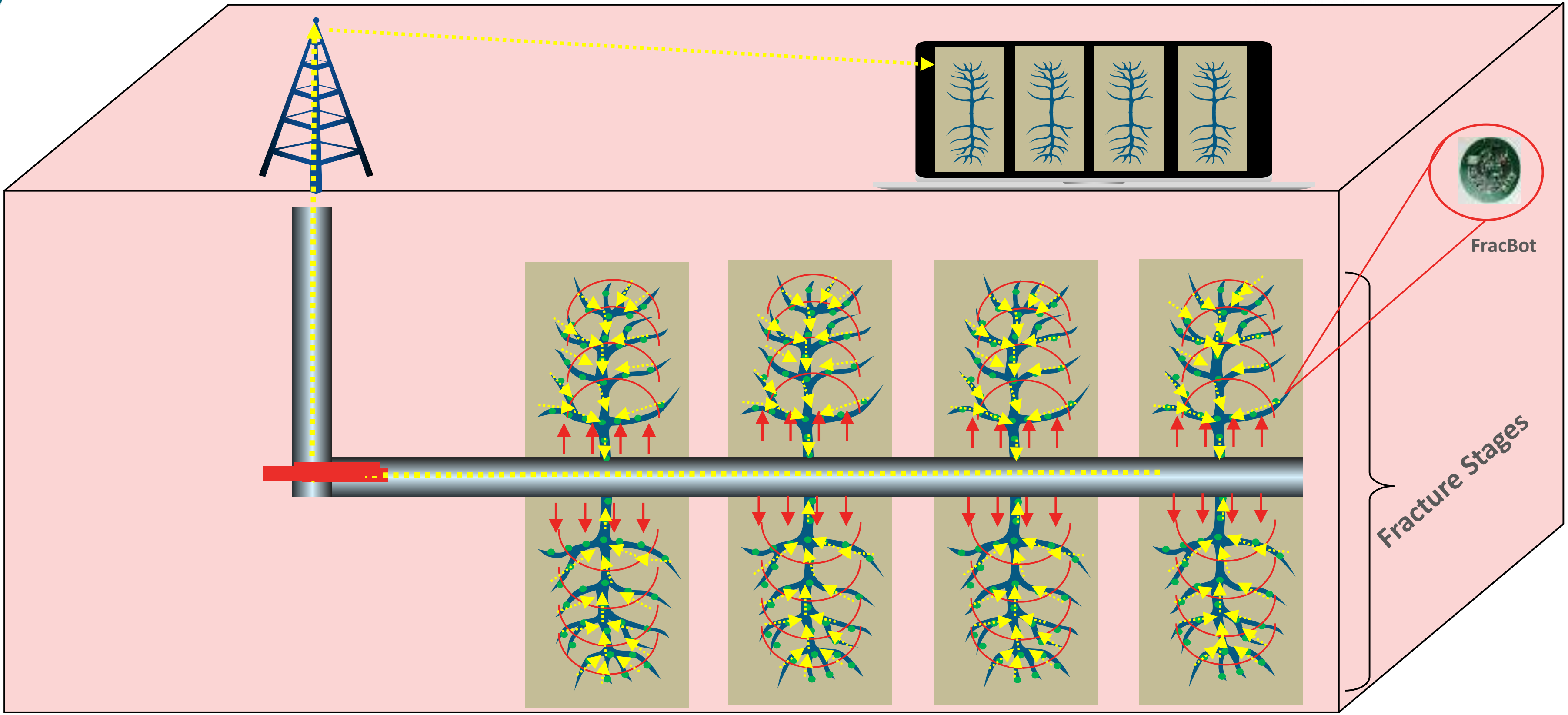
Miniaturized sensor

What are subsurface reservoir sensors?

- In-house out-of-the-box idea
- Tiny devices with wireless communication, and sensing capabilities
- Real-time mapping of fracture networks
- Real-time reservoir information



How FracBots Technology Works



Challenges - Sensing

In-situ reservoir sensing is quintessential with several sensors available to operate in reservoir conditions

Challenges → **Solution**

Sensing data quality

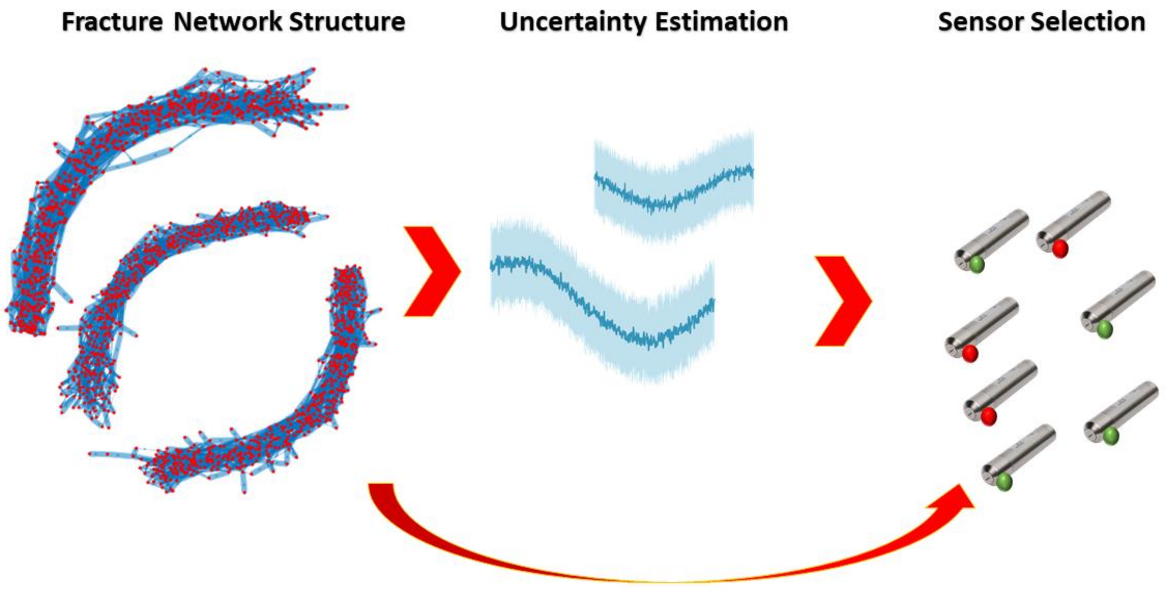
Power requirements

Data transmission quality

Optimally select sensors to maximize coverage while maintaining data quality

Real-time Intelligent Sensor Selection

The framework incorporates a deep learning approach combined with a fast iterative solver for real-time optimization of the sensor selection.

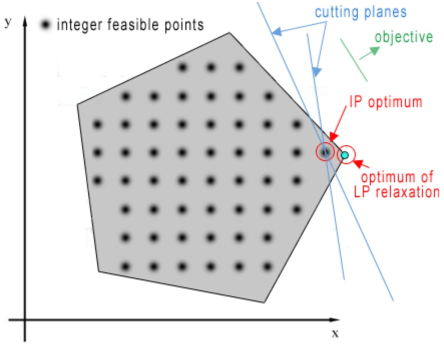


From the fracture network to the uncertainty and selection of sensors.

Sensor Optimization Problem

Problem Statement

Select the minimum numbers of sensors in each step the cost function (which is inversely proportional to the remaining power) subject to maintaining sufficient data quality and ensure that each fracture is covered by a sensor (NP-hard).

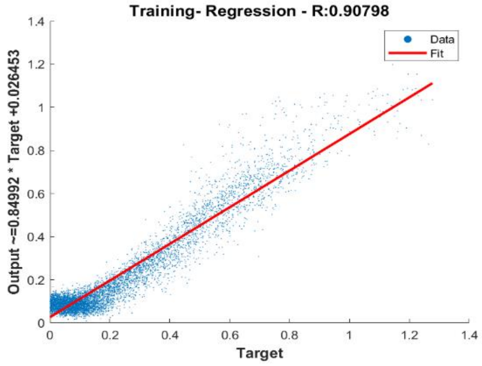


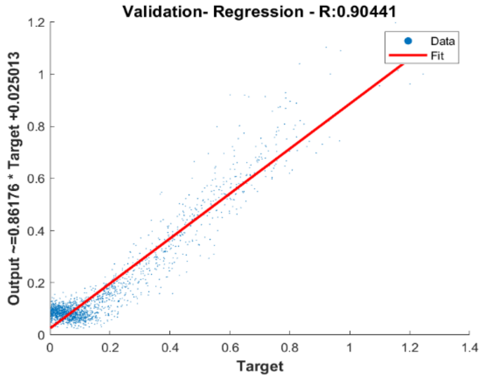
$$\min f'z$$
$$s.t.\ Cz > 0, \forall i \in N$$
$$Uz \leq b_u, \forall i \in N$$
$$z_i \in \{0,1\}, \forall i \in N$$

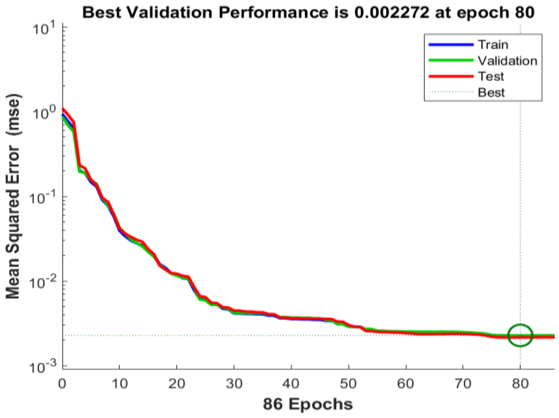
Solver

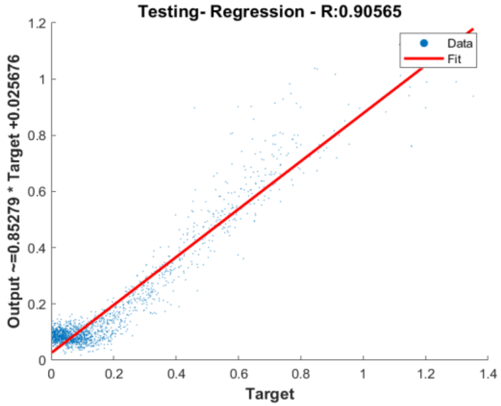
We utilized a fast and efficient branch and bound solver for fast convergent to optimum for the integer optimization problem.

Network Estimation Performance



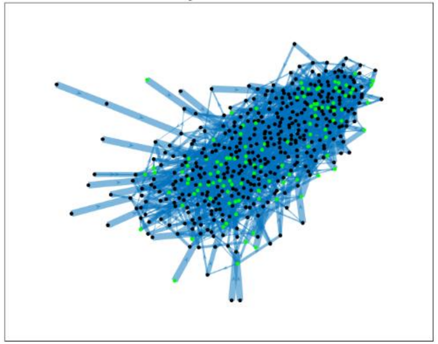




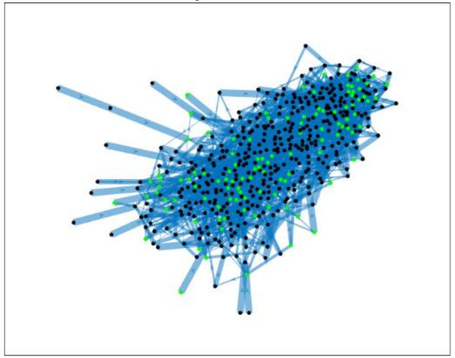


Sensor optimization

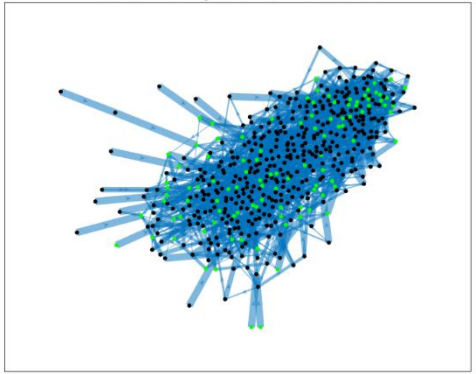
Sensor Activity Overview -2019-04-01



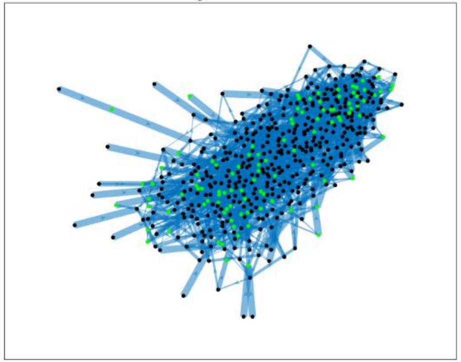
Sensor Activity Overview -2019-06-15



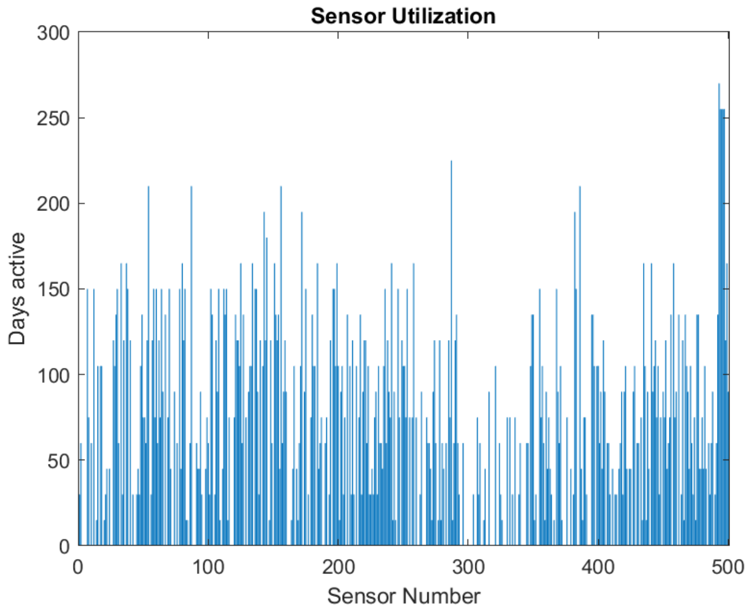
Sensor Activity Overview -2019-09-28

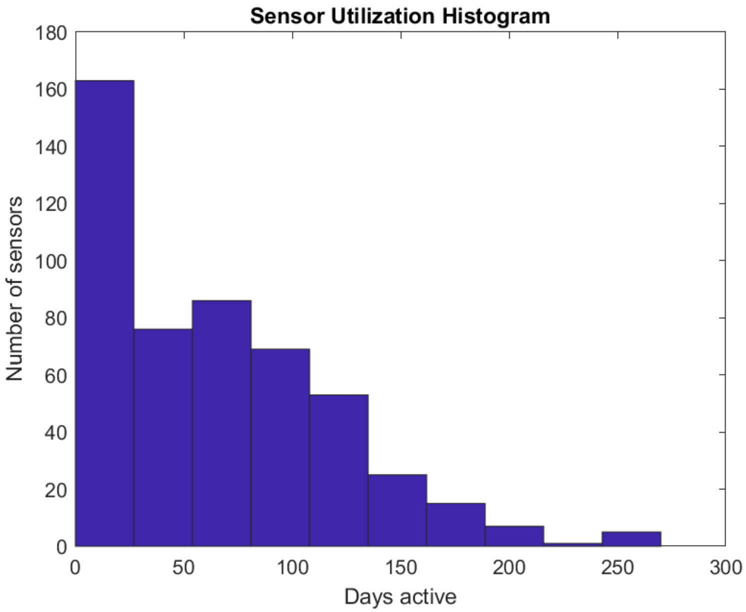


Sensor Activity Overview -2020-01-11



Sensor Activity Overview





Summary

- Optimum selection of sensors essential for long-term reservoir monitoring
- Good reservoir coverage and accurate measurements by the sensors
- Longevity of operation depends on reservoir fracture network structure

A novel deep reinforcement sensor placement method for waterfront tracking

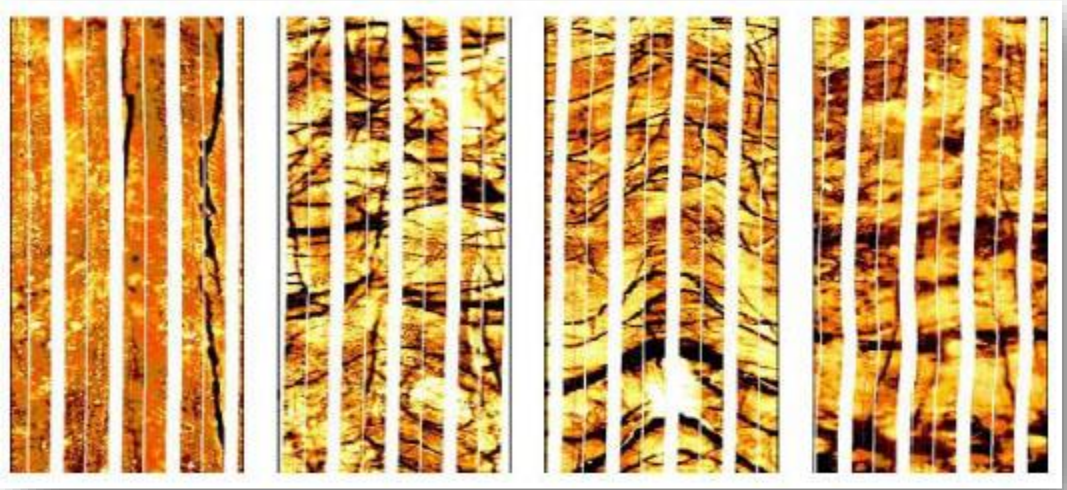
1. Introduction
2. Fracture Networks in Carbonate Reservoirs
3. Deep Reinforcement Learning
4. AI Model
5. Results
6. Conclusions

Introduction

- Water movement primarily occurs in fractures of the carbonate reservoirs
- The fracture channels are conventionally 5 mm in size
- Tracking the waterfronts in fractures challenging without in-situ tracking
- In-situ reservoir monitoring possible with miniaturized sensors

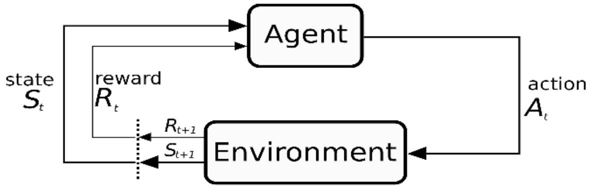
Fracture Networks in Carbonate Reservoirs

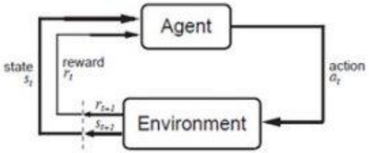
- Fracture networks in carbonates may differ significantly
- Fracture network connection determination is essential in order to accurately determine the water saturation in the reservoir

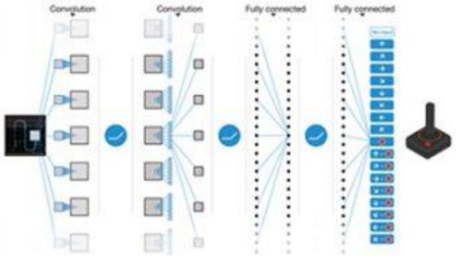


Deep Reinforcement Learning

- Combines reinforcement learning and deep learning
- Reinforcement learning focuses on the problem of computational agent learning to make decisions utilizing trial and error
- Deep RL can utilize very large inputs efficient
- Widely used in robotics, video games and NLP

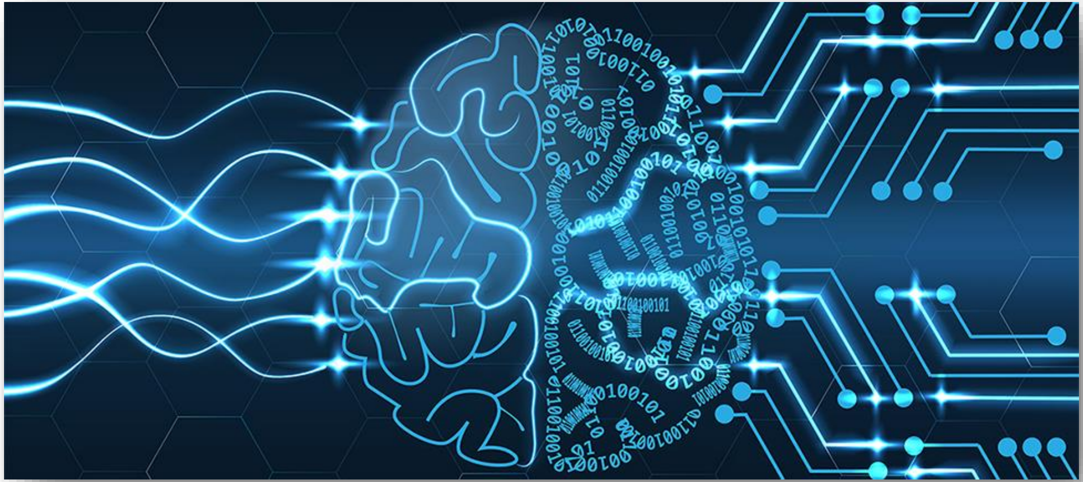






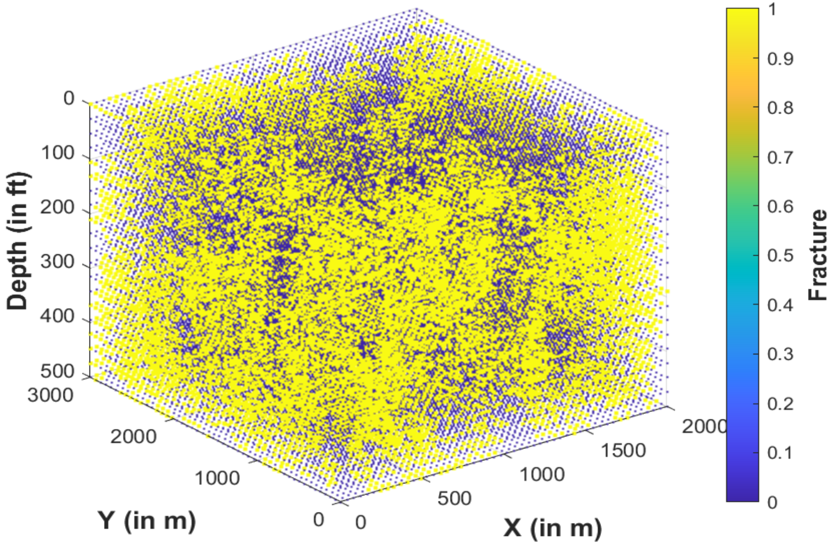
Deep Reinforcement Model

- Focus is to minimize the number of sensors utilized to track waterfronts in a fractured carbonate reservoir
- Training of the deep learning network was performed on a large number of sensors measurement data



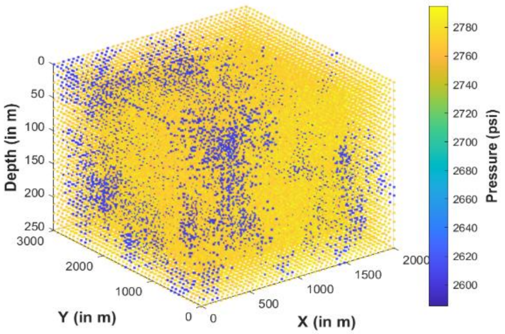
Reservoir model test

- Framework was examined on a box reservoir with a complex fracture network.
- Fracture distribution (yellow) is rather complex and heterogeneous.

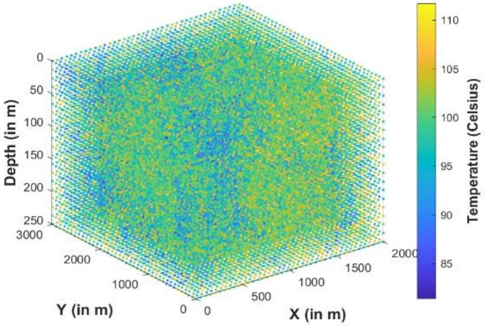


Reservoir Model - Data

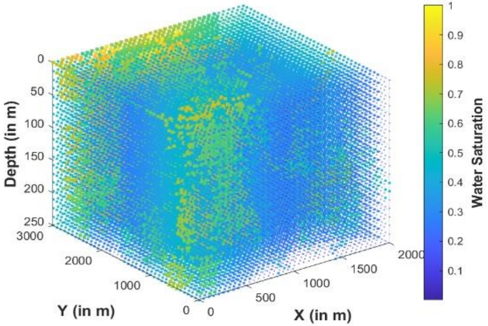
Pressure



Temperature



Water Saturation



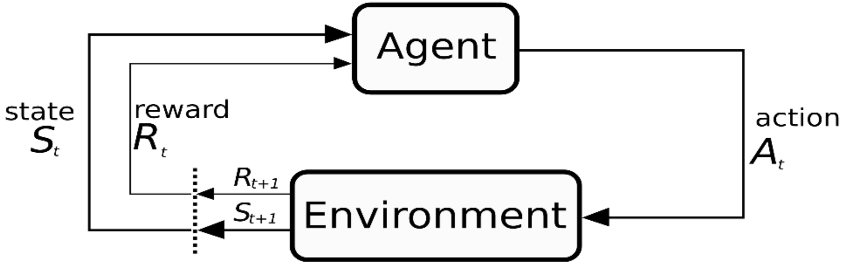
Deep Reinforcement Learning Results

- Q-Learning Framework performs significantly better as compared to best random selection
- The minimum number of sensors needed was more than halved.

	Best Random Selection	Q-Learning Framework
Minimum number of sensors	420	190
Maximum overall reward	-0.12	1.5

Summary

- Advanced AI-OMP framework enables reconstruction of subsurface fracture networks with a sparse amount of data
- Framework allows for the reconstruction of sparse fracture networks in reservoirs

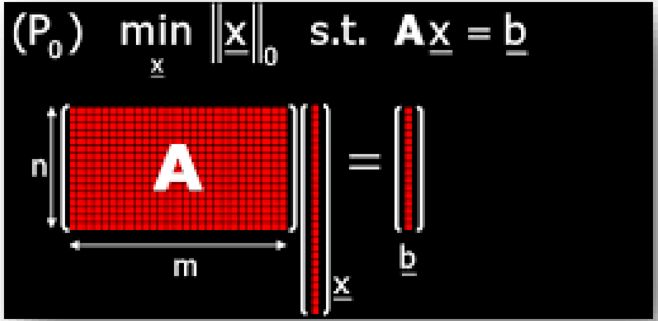


Sparse water fracture channel detection from subsurface sensors via a smart orthogonal matching pursuit

1. Introduction
2. Fracture networks in carbonate reservoirs
3. Orthogonal matching pursuit
4. AI-OMP
5. Results
6. Conclusions

Orthogonal Matching Pursuit

- Sparse approximation algorithm for sparse feature reconstruction
- Extensively used in signal processing for retrieving sparse signals
- Orthogonal matching pursuit requires that reconstruction basis is orthogonal
- OMP has improved stability and performance guarantees although computationally more costly



Algorithm Orthogonal Matching Pursuit

$\Lambda_0 = \emptyset,\ \overline{\Lambda_0} = \{1, 2, \ldots, N\},\ l = 0,\ \mathbf{r}_0 = \mathbf{y}$

repeat

$l = l + 1$

$\lambda_l = \underset{n}{\operatorname{argmax}} \sum_{j \in index_{col}(n)} |\mathbf{A}_j^H \mathbf{r}_{l-1}|$ with $n \in \overline{\Lambda_{l-1}}$

$\Lambda_l = \Lambda_{l-1} \cup \{\lambda_l\};\ \overline{\Lambda_l} = \overline{\Lambda_{l-1}} - \{\lambda_l\}$

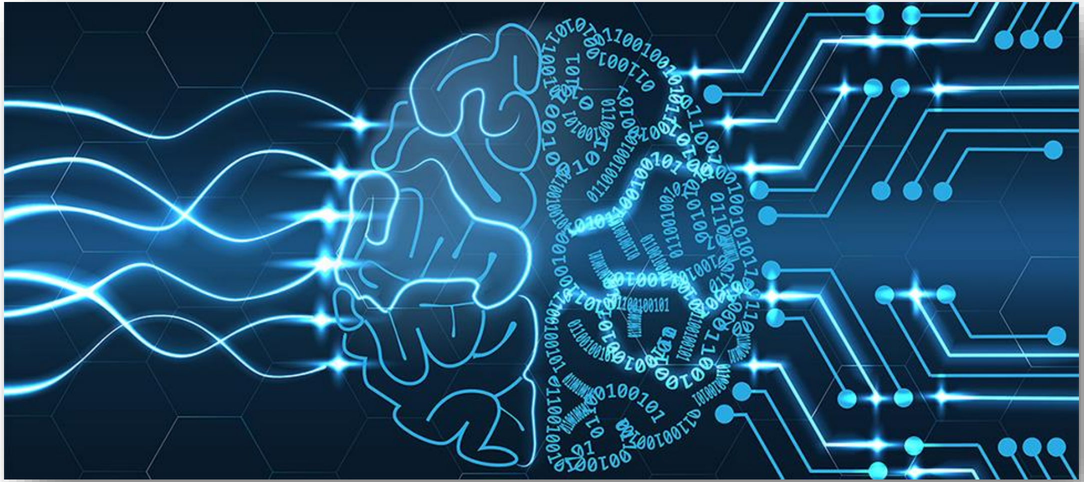
$\mathbf{x}_l = \mathbf{A}^{\dagger}_{index_{col}(\Lambda_l)} \mathbf{y}$

$\mathbf{r}_l = \mathbf{y} - \mathbf{A}\mathbf{x}_l$

until $l = \max < criteria_{stop},\ N >$

AI-OMP

- Integration of the orthogonal matching pursuit together with a deep learning framework for the estimation of the sensor measurements
- Training of the deep learning network was performed on a large number of sensors measurement data



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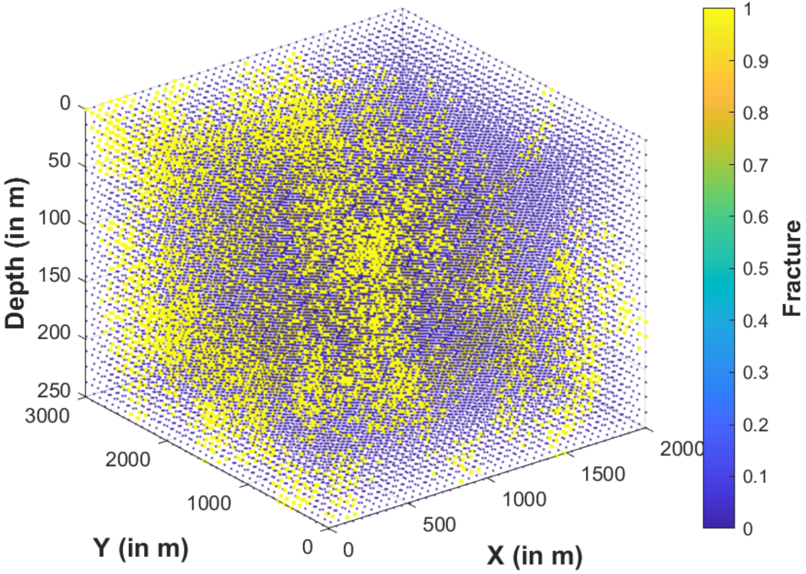
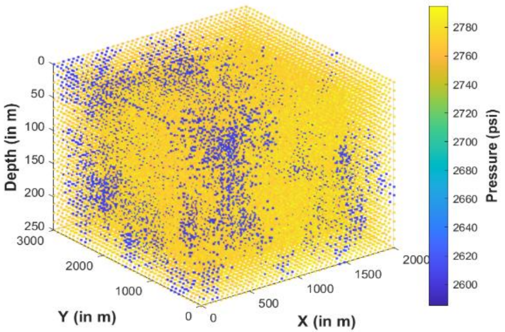
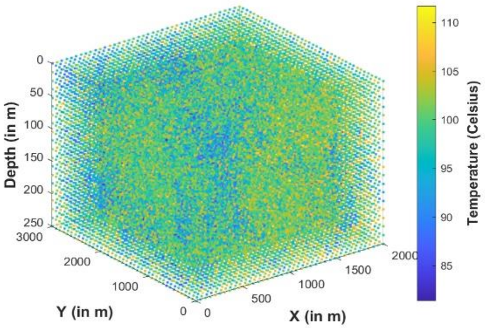


Reservoir Model - Data

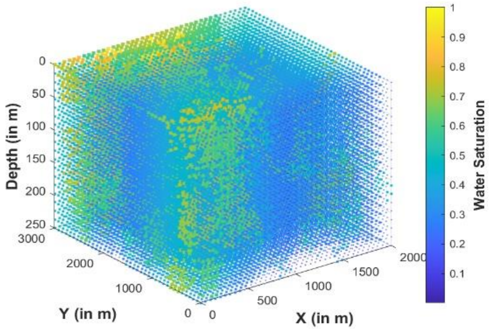
Pressure



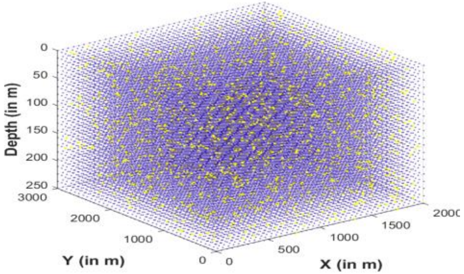
Temperature



Water Saturation

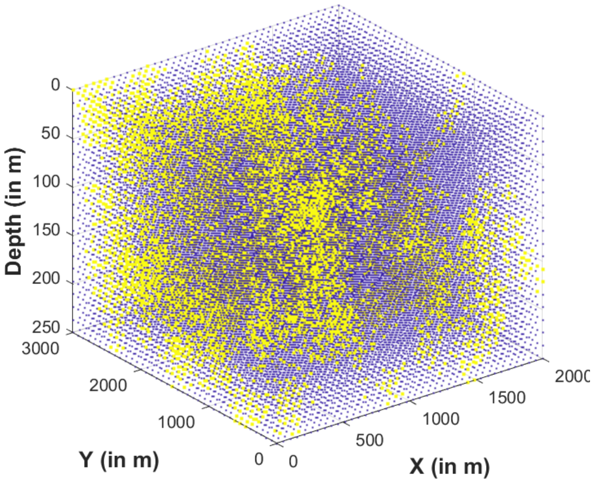


Sensor Location

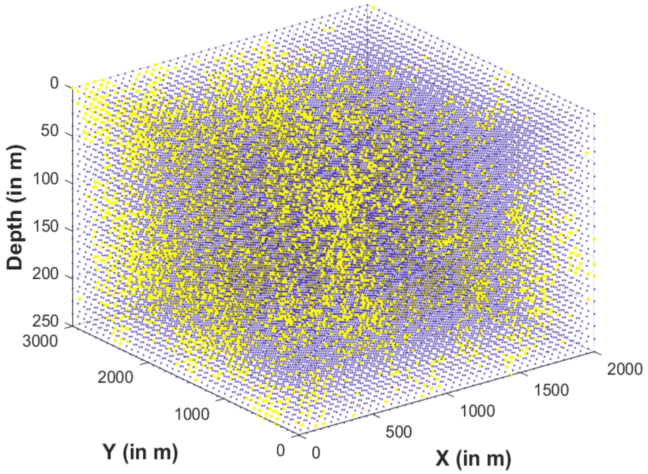


OMP Results – Fracture reconstruction

True Fracture Channel



Recovered Fracture Channel



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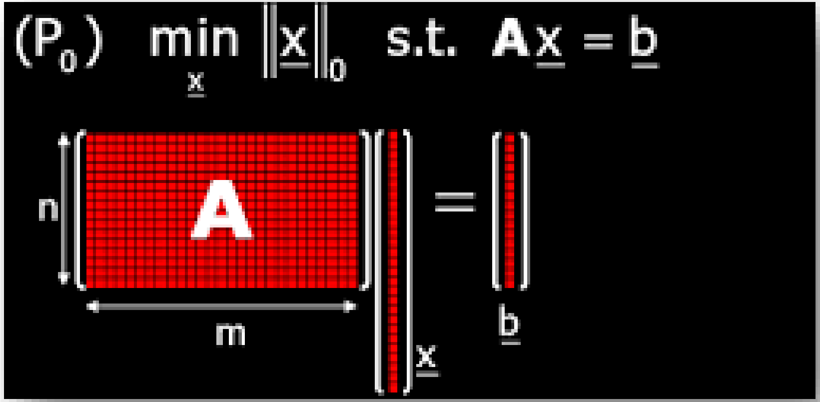

Thank you