Applied Virtual Intelligence in Oil & Gas Industry; Past, Present, & Future

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SPE Annual Technical Conference & Exhibition
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OUTLINE

- Definitions & Overview
  - Virtual Intelligence
  - Neural Networks
  - Genetic Algorithms
  - Fuzzy Logic
- The Early Days
- Recent Applications
- What’s Next
**Virtual Intelligence**

**Precise Rules**
- Laser Gun
- Number of Rules
- Execution

**Objectives**
- Stop before the light
- Do not hit stopped cars

**IF** the car is at a distance of \( d \) ft. AND moving at a speed of \( s \) ft/sec.

**THEN** press the brake with \( p \) psi pressure for \( t \) seconds.
**Virtual Intelligence**

**IF** the car is *very fast AND* the red light is *close*,

**THEN** press the brake *pretty hard*.

**Human Like Decisions**

**Approximate Rules**
- Information needed
  - Approximate Distance
  - Approximate Speed

**Objectives**
- Stop before the light
- Do not hit stopped cars

**Acceptable Solutions at Low Cost**

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Virtual Intelligence

Precise solution becomes impossible
Virtual Intelligence

- WHY can’t we build a computer that thinks?

- WHY can’t we expect machines that can perform 100 mflops to be able to comprehend the meaning of shapes in visual images or even distinguish between different kinds of similar objects?

- WHY can’t machines learn from experience, rather than repeating forever an explicit set of instructions generated by human programmer?
Virtual Intelligence

- Also known as:
  - Computational Intelligence
  - Soft Computing

- Imitating life to solve complex, non-linear and dynamic problems.

- If it can be solved efficiently using conventional methods, don’t use virtual intelligence.
Virtual Intelligence

Conventional Computing
- Bivalent Logic
- Numerical Analysis
- Probability
- Differential Equations
- Functional Analysis
- Mathematical Programming
- Approximation Theory

Virtual Intelligence
- Fuzzy Logic
- Neurocomputing
- Probabilistic Reasoning
- Genetic Algorithms
- Belief Networks
- Chaos
- Rough Sets

Quantitative, Precise, Formal
Qualitative, Imprecise, Informal

Precision and certainty carry a cost

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Neural Networks

- No longer a “new” technology.
- Used on a daily basis by almost everyone.
  - Credit Card Fraud Detection
  - Bank Loan Approval
  - Bomb Sniffing Devices
  - Chemical Plant Process Control
Neural Networks

Definition:

A neural network is a computing system made up of a number of simple, highly interconnected processing elements, which processes information by its dynamic state response to external inputs.

Robert Hecht-Nielsen
Neural Networks

- Major characteristics of Neural Networks
  - Biologically inspired
  - Adaptive Learning
  - Fault Tolerant
  - Parallel, distribute processing of information
A biological neuron (nerve cell) has 3 parts, a “cell body,” an input part “dendrites,” and an output part “axon.” The end of an axon has a set of branching fibers which are connected to dendrites of other neurons. Signals are sent through this route among neurons. These connections are called synapses.
Neural Networks

- Adaptive Learning

Information and knowledge are encoded in form of stable states or mapping embedded in the network.
Neural Networks

- **Adaptive Learning**
  - Neural networks, have an excellent flexibility to learn. They can learn from their surrounding environments and improve their performances.
  - They can handle noisy and incomplete data.
  - Once the neural network is trained, it can cope with noisy inputs and unknown or incomplete data.
Neural Networks

- Fault Tolerant
  - In neural networks, unlike the computer's memory, information is distributed over entire network. Therefore, a small amount of damage in some neurons does not interrupt the behavior of the entire system.
Neural Networks

- Parallel, Distributed Information Processing
  - Case of a wide receiver
    - Tracking the state of dynamic systems
      - Estimated the speed of the football
      - Estimated the trajectory of the football
      - Estimated the angular velocity of the football
      - Estimated the weight of the football
      - Estimated the point of contact with the football & the safety, or corner back
    - React
    - Catch the football
Neural Networks

● Parallel, Distributed Information Processing
  ● Our processor, the brain, is significantly slower than today’s computer, (about 10 million times slower) yet we can evaluate all the components quickly enough to reset and catch the ball. WHY?
Neural Networks

- Parallel, distributed information processing

Pattern Recognition
Neural Networks

- Parallel, distributed information processing

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Pattern Recognition

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Neural Networks

- Parallel, distributed information processing

**Pattern Recognition**

- What did that phrase say?
- Sequential, Point source, information processing.
Neural Networks

- Parallel, distributed information processing

Pattern Recognition

_ P_NN_ S_V_D

_S _

P_NN_ ___RN_D
 Neural Networks

- Computational capabilities of some biological networks

<table>
<thead>
<tr>
<th>ANIMAL</th>
<th>Interconnections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leech</td>
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<td>Worm</td>
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<td>80 Million</td>
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<td>Cockroach</td>
<td>1 Billion</td>
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<tr>
<td>Bee</td>
<td>5 Billion</td>
</tr>
<tr>
<td>Man</td>
<td>10 Trillion</td>
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</tbody>
</table>
OUTLINE

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  - Genetic Algorithms
  - Fuzzy Logic
- The Early Days
- Recent Applications
- What’s Next
Genetic Algorithms

- **Definition**
  - A class of general purpose (domain independent) search mechanism which strike a remarkable balance between exploration and exploitation of the search space.
Genetic Algorithms

- The metaphor underlying Genetic Algorithm is that of natural evolution.
- In evolution the problem each species face is one of searching for beneficial adaptations to a complicated and changing environment.
- The “knowledge” that each species has gained is embodied in the makeup of the chromosomes of its member.
Genetic Algorithms

- Biological Genetics
  - All living objects are composed of cells with nuclei and each nucleus contains DNA

Inside the nucleus, there are pairs of complex double stranded chromosomes which hold the genes in their specific places called “Locus.”

Genes are made of DNA, which is the actual information that's inherited, for example color of eyes, color of skin, height, etc.
Genetic Algorithms

- GA derives its behavior from a metaphor of evolution in nature by the creation of a POPULATION of individuals represented by chromosomes (a set of coded character strings).
- GA tries to model and simplify the complex double stranded chromosomes into 1-dimensional chromosomes.
Genetic Algorithms

- Genetic Algorithms is based on four processes:
  - Initialization
  - Fitness evaluation
  - Genetic Operation
    - Mating (cross-over)
    - Mutation
Genetic Algorithms

- Initialization
  - GA starts by choosing a set of possible solutions. They are generated in a random for each independent variable.
## Genetic Algorithms

<table>
<thead>
<tr>
<th>Parameter 1</th>
<th>Parameter 2</th>
<th>Parameter 3</th>
<th>Parameter 4</th>
<th>Parameter 5</th>
<th>Parameter 6</th>
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<td>0 0 0 0 1</td>
<td>0 0 1 1 1</td>
<td>1 0 1 1 1</td>
</tr>
</tbody>
</table>

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Genetic Algorithms

- Fitness Evaluation
  - This stage involves checking the solutions against some standards to see how good they are.
Genetic Algorithms

```
0 1 1 0 1 0 0 1 1 0 1 1 0 1 0 1 0 0 1 0 1 1 0 1 0 0 0 1 1
0 1 0 0 0 0 1 1 0 0 1 0 0 0 1 1 1 0 1 0 1 0 0 0 1 0 1
0 1 1 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 0 0 0 1 0 1 1 0 0 1
0 0 0 0 1 1 0 1 1 0 1 1 0 0 1 1 1 1 1 1 0 0 1 0 1 0 1
0 1 0 1 1 1 1 0 0 0 0 0 0 0 0 0 1 0 1 0 0 1 1 1 0 0 1
1 0 0 0 1 0 1 0 1 1 0 1 0 1 0 1 0 0 1 0 1 1 0 1 0 0 0
0 0 0 1 0 0 0 1 0 0 1 0 1 0 0 1 1 1 0 1 0 1 0 0 1 1 0 1
0 1 0 1 1 0 1 0 1 1 0 1 1 1 1 1 0 0 0 0 0 1 0 1 1 0 0 1
0 1 0 1 1 1 1 1 0 1 1 0 1 0 0 1 1 1 1 1 0 0 1 0 1 0 1 0
0 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1 1 1 0 1 0 1
```

FITNESS FUNCTION

\[ X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_5 \quad X_6 \quad X_7 \quad X_8 \quad X_9 \quad X_{10} \]
Genetic Algorithms

- Genetic Operations
  - **MATING**
  - The most important stage in genetic algorithm
  - There are two key components to mating:
    - Selection
    - Crossover
Genetic Algorithms

- Genetic Operations
  - MATING
    - SLECTION
  - Selection occurs when the algorithm decides which individual solutions should mate in order to form the next generation.
  - Fitter individuals are more likely to be selected for mating.
Genetic Algorithms

- Genetic Operations
  - MATING
    - Crossover
  - Selected individuals are crossed - i.e. combined, to form new individuals.
  - This means that the algorithm takes a part of chromosomes (i.e. the solution) from each individual and makes a new solution.
  - For example, a problem having four independent variables might take two variables from the first parent and two variables from the second parent.
Genetic Algorithms

- Genetic Operations
  - MATING
  - CROSSOVER

![Diagram showing genetic operations with parent 1 and parent 2 overlapping in the middle to form an offspring.](image-url)
Genetic Algorithms

- Genetic Operations
  - MUTATION
  - Mutation allows a solution to change in a random manner.
Genetic Algorithms

- Genetic Algorithms are “intelligent” search and optimization techniques that continuously “explore” and “exploit” the search space in order to achieve their objectives.
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- Today’s Applications
- What’s Next
Fuzzy Logic

As complexity rises, precise statement lose meaning and meaningful statements lose precision

Lotfi A. Zadeh
Fuzzy Logic

- Human reasoning uses features which successfully process ambiguous information and then use approximate reasoning methods to produce a relatively clear answer.

- Human uses features like:
  - Intuition
  - Experience
  - Tricks
Fuzzy Logic

- Fuzzy reasoning uses membership function to describe the human's reasoning process.
Fuzzy Logic

● A Binary Example:

Knowledge:
  IF the room temperature is less than 20°C, THEN turn on the heater

Fact:
  The present temperature is 15°C

Conclusion:
  Turn on the heater

Knowledge:
  IF “A” THEN “B” (precise rule)

Fact:
  “A” (precise matching: binary truth-value estimation)

Conclusion:
  “B” (precise conclusion)
Fuzzy Logic

A Fuzzy Example:

Knowledge:
IF the room is cold, THEN turn on the heater

Fact:
The room is a little bit cold

Conclusion:
Turn the heater a little bit

Knowledge:
IF "A" THEN "B" (fuzzy rule)

Fact:
"A~" (Approximate matching: multivalue truth-value estimation)

Conclusion:
"B~" (Ambiguous conclusion)
A Fuzzy Example:

Let's review the example using a rule-based fuzzy reasoning method.

Knowledge: IF the room is cold, THEN open the heater

Fact: The room is a little bit cold

Conclusion:
Paradox in modern math
Fuzzy Logic

2 people answering the following question?
Are you satisfied with your job?

1 = Totally satisfied
0 = Totally unsatisfied
## Fuzzy Logic

<table>
<thead>
<tr>
<th>Bivalent Logic</th>
<th>Fuzzy Logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aristotle</td>
<td>Buddha</td>
</tr>
<tr>
<td>A or Not A</td>
<td>A and Not A</td>
</tr>
<tr>
<td>Exact</td>
<td>Partial</td>
</tr>
<tr>
<td>All or None</td>
<td>Some Degree</td>
</tr>
<tr>
<td>0 or 1</td>
<td>Continuum between 0 &amp; 1</td>
</tr>
<tr>
<td>Digital Computer</td>
<td>Brain</td>
</tr>
<tr>
<td>Fortran</td>
<td>Natural Language (English)</td>
</tr>
<tr>
<td>Bits</td>
<td>Fits</td>
</tr>
</tbody>
</table>
Virtual intelligence

- **When to use them:**
  - To capture associations or discover patterns.
  - Very large volumes of data.
  - Large number of variables.
  - When the relationships between variables are not understood, or vaguely understood.
  - When the relationships can not be described or are very difficult to describe using conventional approaches (mathematically).
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The Early Days

- Application of virtual intelligence in oil & gas industry has 13 years of history.
- First applications appeared in 1989.
- Early days start with rule-based expert systems and are dominated by neural network applications.
The Early Days

- Three SPE papers appeared in 1989
  - Inst. Francais du Petrole, Expert Systems
    - Intelligent Reservoir Simulator Interface
  - Exxon Production Research Co., Neural Networks
    - Drill Bit Diagnosis Using Neural Networks
  - Halliburton Logging Services, Neural Networks
    - Well Log Interpretation
The Early Days

![Bar chart showing the number of SPE papers from 1989 to 1995 for different technologies including Expert Systems, Neural Networks, Genetic Algorithms, and Fuzzy Logic.]
The Early Days

- Topics of the early applications included:
  - Interface development for simulators
  - Well log interpretation
  - Drill bit diagnosis
  - Pump operation diagnosis
  - Well test model selection & interpretation
  - Hydraulic fracturing analysis
  - Gas-lift optimization
  - Reservoir Characterization PVT correlations
  - EOR project risk analysis
  - Fluid flow in pipes
The Early Days

- Characteristics of the early days application
  - Single technique, no hybridization
  - Solving not highly complicated problems
  - Testing the water
  - Academic interest
  - Industry’s skepticism & resistance
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Recent Applications

- Starting in 1996 hybrid systems surface in the oil & gas industry.
- Hybrid systems combine more than one virtual intelligence paradigm to solve a problem.
- In the First (oil & gas industry related) hybrid system application neural network was combined with genetic algorithms to optimize hydraulic fracture design.
- Different virtual intelligence paradigms complement each other, they do not compete.
Recent Applications

- We started realizing that the real potential of these paradigms are unleashed once they are used in concert.
- Most of today’s applications that address complex problems, use several intelligent paradigms including neural networks, genetic algorithms, and fuzzy logic augmented by conventional techniques.
Recent Applications

![Bar chart showing the number of SPE papers from 1996 to 2002, categorized by Expert Systems, Neural Networks, Genetic Algorithms, Fuzzy Logic, and Hybrid Systems.]

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Recent Applications

- Topics of recent applications include:
  - Formation damage analysis
  - Pseudo logs generation
  - Reservoir characterization
  - Hydraulic fracture design & optimization
  - Oil production optimization
  - Enhance recovery management
  - Well test analysis
  - Drilling operation optimization
  - Best practices identification
Recent Applications

- Characteristics of recent applications
  - Smarter, more intelligent applications.
  - Solving more complex problems.
  - Increased efficiency
  - Lets us use “all” available data
  - Gaining oil & gas industry’s acceptance and respect.
  - Management has started to believe that it can help the bottom line.
Recent Applications

- Besides the increasing number of papers, an effort has been started in SPE to look at this technology more seriously. Examples:
  - This panel discussion in the annual meeting
  - First SPE Advance Technical Workshop on VI being held in Houston, February 24-25, 2003
  - Consideration for a SPE forum on the subject in the near future.
  - Potential dedicated conference on VI applications in oil & gas industry.
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What’s Next

- The future of intelligent systems in the oil & gas industry can not be much different from its future in other industries.
  - DATA MINING
  - KNOWLEDGE DISCOVERY
  - DATA-KNOWLEDGE FUSION

- The general trend is toward development of smarter & more complex software solutions & more activities toward hardware implementation.
What’s Next

- Development of corporate memory. Retention of corporate knowledge by separating it from individual employees.
- Mining the huge data resources in the corporation that has been gathered through many years.
- Extracting knowledge from the existing data banks and warehouses to help management make better, more informed decision.
What’s Next

- Intelligent automation and real-time optimization of the entire production process from the well head to the refinery.
- A new paradigm for reservoir simulation and modeling in order to address the uncertainties and ambiguities of geological, petrophysical and other information at the grid block level, while increasing the speed of simulation process by orders of magnitude.
- Fully automatic and real-time hydraulic fracture design, implementation, and trouble shooting.
Our only limitation will be our imagination.
The Big Picture

Year

No. of SPE Papers with Keywords in the Title


3 2 3 3 7 15 13 5 8 14 19 15 24 5

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The Big Picture

No. of SPE Papers with Keyword in the Title

- Expert Systems: 5
- Neural Networks: 92
- Genetic Algorithm Keyword: 5
- Fuzzy Logic: 13
- Hybrid Systems: 19
The Big Picture

Source of Research & Development

- Service Company: 12
- University: 63
- Joint: 17
- Major Oil Company: 8
- National Oil Company: 15
- Research Institutes: 9
- Vendor: 12
The Big Picture

Including the Joint Papers

Source of Research & Development

No. of SPE Papers
The Big Picture

![Bar chart showing SPE Papers by University and Technology Type]

- WVU: 18 (12 Expert Systems, 6 Neural Networks)
- TAMU: 8 (2 Genetic Algorithms, 6 Neural Networks)
- Kuwait U: 6
- UNSW: 4

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The Big Picture
Neural Networks

- Biologically Inspired

Visual Cortex of a 2-year Old Child
Genetic Algorithms

History of Genetic Algorithms

1957  First computer simulation of Genetic Systems
Fraser, A.S., “Simulation of Genetic Systems by Automatic Digital Computers,”

1966  First introduction of Evolution Programming (EP)

1967  First announcement of Genetic Algorithm (GA) concept by John Holland

1975  John Holland published a book which became a bible for GA users.
Holland, J.H., “Adaptation in Natural and Artificial Systems,” Ann Arbor, MI:

1985  First International Conference on Genetic Algorithm
International Conference on Genetic Algorithm (ICGA), Carnegie Mellon University
Many papers related to genetic algorithms and artificial life introduced.
History of Genetic Algorithms

1989 David Goldberg (a previous Holland's student) successfully applied the idea of GA in the control of gas-pipeline transmission.

1990 Genetic Programming (GP) concept was introduced by John Koza (a previous Holland's student).

Since 1990
Many papers, books, journals, and software have been released on GA, GP, EP, etc.
GAs are becoming the subject of many different research communities and linguistics, immunology, biology engineering, and computer science.
Fuzzy Logic

So far as the laws of mathematics refer to reality, they are not certain. And so far as they are certain they do not refer to reality.

Albert Einstein

Geometry & Experience