MATHEMATICS MATTERS

An Energy Evolution

As oil supplies become harder and more expensive to reach, it's essential that we maximise the yield from available reservoirs in any way possible. Mathematicians are contributing with a tool inspired by biological evolution that seeks out the best way to extract the oil.

Oil is one of the most valuable commodities on the planet, and even though use of renewable sources is increasing, it still provides a large proportion of the world's energy. Our dependency on oil looks set to continue in the near future, but the past 150 years of oil drilling have left many reservoirs depleted and gaining access to those that remain is becoming increasingly difficult. Thankfully, mathematicians are helping to keep the oil flowing with models that map these buried reservoirs and techniques for boosting efficiency that are inspired by biological evolution.

Most oil reservoirs are found thousands of metres below the surface, making it impossible to observe or influence them directly, so mathematicians such as Jonathan Carter at Imperial College London have developed methods to describe reservoir structures and the flow of oil within them, allowing oil companies to produce the maximum yield possible.

Carter begins by constructing a three dimensional model of the reservoir based on data from seismic surveys. This model is then divided into a grid of cells, each of which holds values representing various properties of the reservoir, such as the ratio of water to oil, the capillary pressure or the permeability of the rock.

A typical reservoir model might contain 10 million cells, each describing the average properties of a piece of rock around the size of a large cargo container. While this is fine for describing the geological properties of a reservoir, the additional complexity of calculating oil flow means this level of detail is too high, and the grid has to be further averaged in a process known as upscaling. This creates a grid of 100,000 cells, each 100 times larger than in the previous grid. The model then calculates how oil and water flow in and out of each cell to build up a dynamic description of the entire reservoir.

> "Genetic algorithms can produce varied and sometimes surprising oil well configurations."

At this broad level of detail, many important processes are not captured, but improvements can be made by using smaller cells for particularly complex regions of the reservoir and larger cells for areas that do not require as much detail. Building a multi-sized grid is a difficult task though, because of the large variety in reservoir rocks - some sections of rock might be pure sandstone, while others might include a complex mix of materials. Identifying the best way to deal with these mixed rocks is an active area of mathematical research.

Another issue is that simply running a single model does not account for any uncertainty in its predictions. Exploring a range of scenarios by repeatedly running the model with slightly different parameters helps to quantify the risks involved, but model complexity is again an issue. Advanced models can provide more information about a reservoir but take too long to run multiple times, while simpler models can be run repeatedly but do not capture all of the details. Finding methods to increase the speed that computers solve the mathematical equations is essential to improving both the accuracy and reliability of models.

Once a reservoir has been accurately modelled, the next task is to decide where to place oil producers and water injectors in order to extract the maximum amount of oil. There are a number of methods employed to solve this optimisation problem; Carter uses a tool inspired by biological evolution called a genetic algorithm, since it follows the rule of "survival of the fittest". It works by generating a range of possible solutions, each with their own arrangement of producers and injectors, then randomly "breeding" a new solution by mixing their parameters together. The resulting "child" solution is kept if it produces

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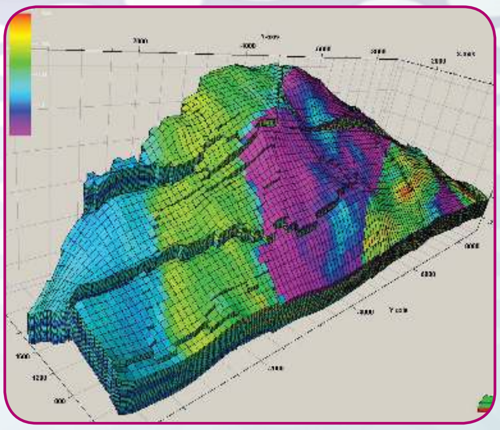
more oil than its "parents", but otherwise it is rejected.

This process runs for many generations, seeking out the most effective evolutionary niches in the same way that living organisms become adapted to their habitat over time, and it can result in surprising and novel solutions. While other optimisation methods might simply develop small improvements on a petroleum engineer's educated guess, genetic algorithms can produce more varied and sometimes surprising well configurations.

For example, in a typical reservoir the water injectors are at the bottom and push the oil towards producers at the top, but this may not be suitable for every situation. In one particular reservoir model, Carter found that the current well configuration was only producing about 30% of the expected level of oil. Running a genetic algorithm on the problem suggested a water injector should be placed at the top of the reservoir. This is a highly unusual configuration and would probably not be suggested by an engineer, but in this case it doubled the predicted oil production from the previous best answer.

Genetic algorithms are just one example of how advanced mathematics is helping to provide the oil that powers our society, and there is a wide range of expertise in the UK that has built up over the years to extract oil from the North Sea. Even though this local source of oil is starting to be exhausted, the mathematical skills developed in this country now contribute to oil drilling and production projects across the globe. It is essential that we continue to support the development of new mathematical techniques for oil extraction, securing the UK's position as a world leader in the field.



TECHNICAL SUPPLEMENT

Genetic algorithms

A typical genetic algorithm begins by randomly generating solutions to the given problem. These random solutions will most likely give poor results, but over time they evolve into better answers through natural selection. Just as natural selection in biological organisms is driven by changes in genetic code, with beneficial combinations and mutations being passed on to the next generation, solutions evolve through changes in their "genes". These are actually just numeric values for a selection of model parameters - in the case of oil well configurations, these parameters might include the number of wells, their location or the rate at which they operate.

The initial population of solutions forms the first generation, from which new "child" solutions are generated by randomly selecting from the two "parent" solutions, and randomly combining their genetic information to create the "child". The algorithm can also introduce "mutations" by changing the values of some of the genetic information. The child solutions are then evaluated for their fitness, to see if they produce a better answer to the problem – e.g., a greater yield of oil. Solutions which perform well are passed into the next generation, while the others are discarded, and the process begins again until the desired level of performance is reached.

Sometimes this process will produce a novel solution that an engineer might not have thought of, as in the case with a water injector at the top of the well. To test whether this was a modelling anomaly, Carter removed the rogue water injector and replaced it with a more orthodox oil producer, but this caused production levels to drop back down again. It turned out that this particular reservoir contained faults that were preventing fluid from flowing, and the water pumped in by the injector at the top served to maintain the pressure, allowing oil to flow more smoothly.

Solutions such as this illustrate the power of genetic algorithms, but one issue is the length of time they take to reach an answer. Each solution has to be individually evaluated for fitness and in the case of complex oil reservoir simulation this can take anything from a few minutes to a few days. The random nature of the process also means that many thousands of simulations have to be evaluated, so running a genetic algorithm can take a number of weeks. Carter's research involves developing methods to speed up the process, such as adapting the genetic algorithm to take advantage of parallel computing.

References

Carter, J. N. & Matthews, J. D. (2008) Optimization of a reservoir development plan using a parallel genetic algorithm. ***Petroleum Geoscience,*** 14(1), 85-90. DOI: 10.1144/1354-079307-788

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