Geostatistical Simulation – Part I

Geostatistical simulation refers to a family of methods that can serve a wide range of purposes. In the past, computationally intensive simulations took a long time to implement, but that has changed in recent times as computers have become more powerful and as more efficient algorithms have been designed. Geostatistical simulation is probably the most under-utilised of the methods offered by the science of geostatistics with respect to mining, but can be a very valuable and powerful tool to aid decision-making.

What is Geostatistical Simulation?

Geostatistical Simulation is able to produce a number of different but equiprobable ‘realisations’, or outcomes, for one or more variables. Random variability is introduced during the simulation process in order to provide a set of differing scenarios. Simulation generally requires, as inputs, the probability distribution of the variable/s as well as the spatial model (ie. variogram) for the variable/s. Although the multiple realisations produced by the simulation are different, they will still all comply closely with the input distribution and input variogram (Figure 1). This implies an important difference between estimation algorithms and simulation – estimation will ‘average’ and therefore smooth the values while simulations retain the variability of the input data.

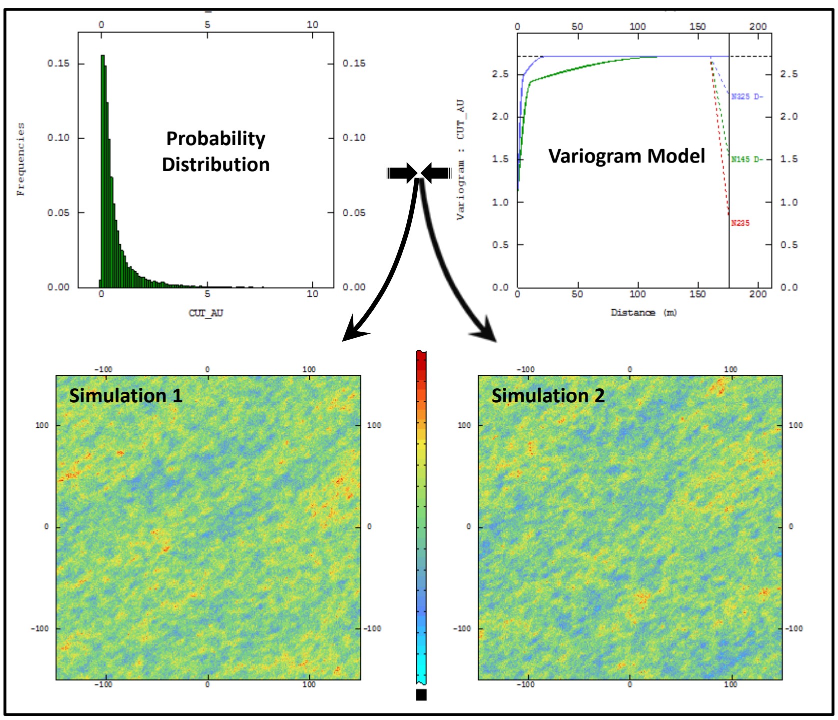

Figure 1: Two simulated realisations which have reproduced the same input distribution and input variogram.

Non-Conditional versus Conditional Simulation

The two simulations shown in Figure 1 are examples of non-conditional simulation. This means that no data have been used to constrain the simulated outcome, hence we see that even though the two results have the same distribution and variogram, areas of like value do not coincide. Conditional simulation, on the other hand, will be constrained by sample data, usually the data you used to define the input distribution and variogram models in the first place.

Different realisations of a Conditional Simulation will therefore take on exactly the same value at the conditioning data points, but will diverge from each other at locations other than the data point locations. The further away you go from the data, the more the individual realisations of Conditional Simulation will differ, until they become completely Non-Conditional at distances greater than the range of the input variogram model.

Types of Simulation

There are three classes of geostatistical simulation:

1. Continuous Variables – in mining such variables would include grade, density, thickness etc.;
2. Categorical/Discrete Variables – for example the simulation of lithofacies, and
3. Object Simulation – the simulation of entities whose morphology is captured as a whole – for example the simulation of rock fractures.

Simulation types 1 and 2 are by far the most commonly used in the mining industry. Let us list and briefly discuss some of the specific methods that are most frequently used for mining studies:

Sequential Gaussian Simulation (SGS)

SGS is a relatively simple simulation method that relies on the transformation of the input data to standard Gaussian space (ie. a Normal Distribution with mean=0 and variance=1), which is suited to continuous variables. The variogram model is also based on the Gaussian transformed data. The simulation thus runs in Gaussian space, and the results are back-transformed to real space after the simulation is complete. There are considerable mathematical advantages to undertaking the simulations in Gaussian space, one of which is the ability to condition the simulation to the data using the Simple Kriging algorithm. The random or non-conditional component of the result is based on the use of the kriging variance multiplied by a random Gaussian value.

Turning Bands Simulation (TBS)

TBS is another simulation method suited to continuous variables, which also operates in Gaussian space. However, it uses a different method for achieving the 'randomness' that characterises the non-conditional part of the algorithm. A spectral method, known as the Turning Bands process, is used.

Sequential Indicator Simulation (SIS)

SIS is designed to simulate categorical variables. For instance, we could code a number of facies with discrete values such as 1, 2, 3, etc., model variograms for each of the facies and then the simulation will produce realisations of the spatial distribution of those facies. SIS is relatively easy to implement.

Truncated Gaussian Simulation (TGS)

TGS is for the simulation of categorical variables;its design was initially driven by the need to simulate facies in the petroleum industry. TGS is a significantly more complicated method to implement than SIS, but has the advantage of being more flexible. For instance, overlapping facies with different continuity orientations can be modelled with TGS, which is not the case for SIS.

Direct Block Simulation (DBS)

DBS is a more recent development in the field of simulations. With the methods described above, the results of the simulation typically reflect the distribution and variogram model of samples, for example downhole assays. However, we often want to obtain the simulation for mineable blocks, which are significantly larger than the samples. The block values will have a distribution which has a much lower variance and more continuous variogram than the samples. This used to be dealt with by simulating at a number of nodes within each block and then averaging the values of those nodes to obtain a block value. However, this can take a long time to compute, because you may have to simulate at 50 or more nodes within a single block to get stable results for the average.

DBS gets around this problem by being able to simulate the block value directly, thus circumventing the need for multiple simulation calculations within each block. The advent of DBS has meant that even fairly large simulations can now be run in a relatively short space of time. DBS can currently be implemented for continuous variables.

What Next?

In the second instalment on geostatistical simulation, we will have a look at some of the practical uses of this family of methods, specifically within a mining context. We will see how a range of solutions, related mainly to the quantification of risk, can be obtained.

Cube's Experience and Capabilities

Cube Consulting has extensive experience and skills in advanced geostatistical solutions Cube's Geostatisticians frequently apply the simulation methods described here for a range of purposes.

Further Reading

Chilès J.P. and Delfiner, P., 1999. Geostatistics: Modeling Spatial Uncertainty. John Wiley & Sons, 695 pp.
Goovaerts, P., 1997. Geostatistic for Natural Resources Evaluation. Oxford University Press, 483 pp.
Isaaks, E.H. and Srivastava, R.M., 1989. Applied Geostatistics. Oxford University Press, 561 pp.
Lantuéjoul, C., 202. Geostatistical Simulation – Models and Algorithms, Springer, 265 pp.