A Short Note on a General Framework and Software for Localization of Mining Reserves

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Determining one single model to use in mine planning is difficult. Ordinary Kriging is often considered but the smoothing effect of kriging must be accounted for with implementation 'tricks'. Realizations from simulation algorithms such as sequential Gaussian simulation provide too many models and CPU constraints restrict the use of the realization as an ensemble in mine planning software. The localization approach is appropriate for generating a single model with the correct histogram for mine planning. While the histogram is correct, the small scale spatial variability is not. Planning on a 'localized' model must be done at the appropriate scale to prevent the local artifacts from affecting the mine plan. This correct scale is the panel scale, any optimization on a smaller scale (SMU or point) would be inappropriate. A program LOCSIM is presented for generating localized models from a set of realizations.

Introduction

The mining industry is hesitant to use multiple realizations in mine planning for a number of reasons (1) there can only be one mine plan that must be followed, considering multiple realizations is important for uncertainty evaluation but difficult for mine planning or sequencing (2) mine planning software can be computationally expensive and likely cannot handle multiple high resolution models (3) in general, a single model is preferred by mining engineers.

In the localization technique there are three potential scales of interest, the point, SMU and panel scales (Figure 1). The localization approach (Abzalov 2006; Hardtke et al 2011) is to generate a panel scale distribution and populate SMU blocks within the panel such that the panel distribution is correct. First the distribution for the panel is determined using an appropriate change of support technique or simulation and upscaling (Figure 2). The panel is subdivided into *n* SMU blocks (15 blocks in Figure 2). The panel distribution is also divided into *n* bins of equal width. The *n* SMU blocks are assigned these *n* values. In Hardtke (2011) the assignment of property values is based on an ordinary kriging (OK) model at the SMU scale. The *n* OK estimates are ranked and the values to assign to the SMU scale blocks in the panel are assigned as per the OK ranking. Note that the OK estimates are never used in the model, they are only used in determining the assignment of values (from the panel distribution) to the SMU blocks in the realization.

In the generalization presented here, all distributions are obtained with a set of point scale sequential Gaussian realizations. This removes the requirement to perform indicator kriging (Hardtke et al 2011) or uniform conditioning (Abzalov 2006).

Methodology

The goal is to generate a single realization with the correct distribution of properties to be used in mine planning. This realization would be used for mine planning, rather than a smoothed kriging based model. There are three scales of interest, the panel scale (largest) the SMU scale (intermediate) and the point scale (smallest), represented in Figure 1. The procedure is to determine the proper distribution in a given panel from the distributions in the ensemble of realizations (Figure 2 left). A CDF of all SMU's and all realizations in a panel is generated (Figure 2 center) from the realizations at the SMU scale. Equally spaced (on the probability scale) values are drawn from this cdf (Figure 2 right). These SMU values are assigned to the SMU blocks within the panel of interest in the localized model based on the ranking of the average SMU value in the panel. Thus, the local distribution within the panel is correct as it was derived directly from the SMU distributions in the panel; however, it is important to note that the spatial distribution of the SMU scale blocks within the panel is not correct. Planning based on this model should only consider optimization at the panel scale, planning based on the SMU blocks would not be reasonable. The resulting block distribution of the single localized model is representative of the SMU distributions (Figure 3).

The model generated using this localization methodology tends to under-sample the extreme high and low values depending on the level of discretization of the panel scale distribution. To correct for this, the CDF is sampled using a Latin Hypercube Sampling (LHS) scheme (McKay et al. 1979) where the CDF is binned and random values are drawn within each bin rather than at equal partitions of the CDF. In our experience, this has had better reproduction of the SMU scale distribution (Figure 4) especially for large tail distributions.

Program

LOCSIM can be used to generate the localized model from a set of realizations. The parameter file is described below:

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                  Parameters for LOCSIM
                  *********************

START OF PARAMETERS:
01  pnt_sim.out   - file with realizations
02  1             - column for grade
03  -998 1.0e21   - trimming limits
04  1     69235   - 1=use latin hypercube sampl (0=partition cdf into equal bins), Rand num
05  10            - number of realizations
06  1000 0.5 1    - Input Point size: nx,xmn,xsiz
07  1000 0.5 1    - Input Point size: ny,ymn,ysiz
08  1    0.0 1    - Input Point size: nz,zmn,zsiz
09  panel.out     - file for output
10  200 2.5 5     - SMU size: nx,xmn,xsiz
11  200 2.5 5     - SMU size: ny,ymn,ysiz
12  1   0   1     - SMU size: nz,zmn,zsiz
13  20 25   50    - Pannel size: nx,xmn,xsiz
14  20 25   50    - Pannel size: ny,ymn,ysiz
15  1  0    1     - Pannel size: nz,zmn,zsiz
16  1             - option to write out the block averaged realizations, 1=yes
17  blkavg.out    - SMU realizations
```

Line 1 – input file with the realizations at the point scale
Line 2 – column for the simulation
Line 3 – trimming limits on the point scale realizations
Line 4 – option to use the LHS, otherwise equally divide the distribution into bins and sample
Line 5 – number of realization in the file from Line 1
Line 6-8 – point scale model definition from Line 1 (Figure 1)
Line 9 – file for the final output
Line 10-12 – SMU scale model definition (Figure 1)
Line 13-15 – Panel scale model definition (Figure 1)
Line 16 – can also write out the averaged SMU block realization if needed
Line 17 – file for the averaged SMU block realization

Example

Consider 63 synthetic data in Figure 3. Ten realizations are generated at the point scale (1 unit blocks) (Figure 3). Each realization is block averaged up to the SMU scale (5 unit blocks) (Figure 4). The LOCSIM program calculates the distribution for each panel (50 unit blocks) as the collection of all SMU's within a panel over all 10 realizations. In each realization, each panel is defined by 100 SMU blocks; therefore, each panel distribution in the localized model is defined by 100*10=1000 values. 100 values are sampled from this distribution (Figure 2) using LHS and assigned to the SMU blocks within the panel in the localized model (Figure 5).

Note that the discontinuities seen in the localized model are correct. The spatial continuity between panels is not maintained. This provides a good reminder to the user that mine planning should not be attempted at the SMU scale even though the resolution of the localized model is at the SMU scale. The correct spatial continuity is only maintained at the panel scale.

Conclusion

Generating one single model for mine planning is difficult. Kriging is attractive as it provides one model and is the 'best' estimate under certain conditions; however, the smoothing effect of kriging leads to the use of restricted searches to honor the data variability. Localization can be used to generate a single model that has the correct histogram; the drawback is that the local SMU values do not have the correct spatial variability. Using a localized model during mine planning is appropriate if planning is optimized on panels, it would not be appropriate to generate a mine plan on a scale smaller than a panel. This is not a strict constraint as computational restrictions on mine planning software often force the model scale used in planning to be larger than the SMU scale.

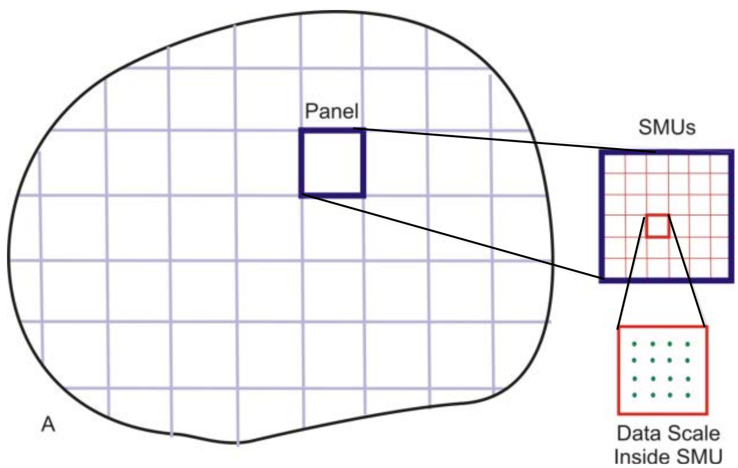

Figure 1: Scales of interest with the localization methodology.

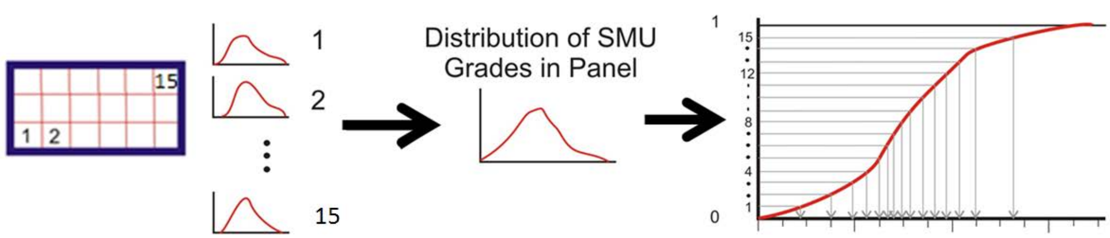

Figure 2: Within one panel (left) there are 15 SMU distributions that are combined to generate the SMU distribution within the panel (right).

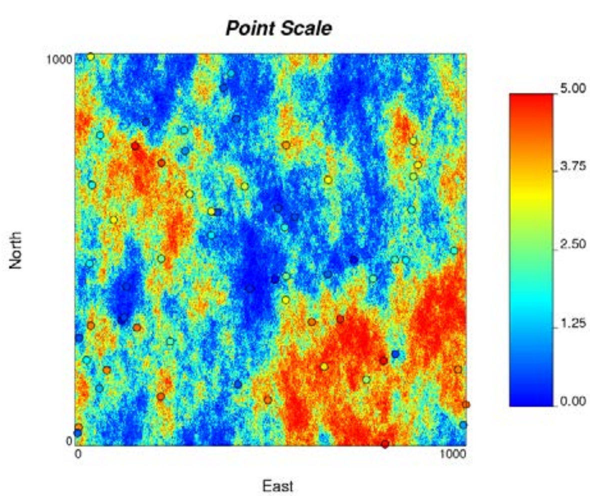

Figure 3: 63 synthetic data. Point scale realization, block size = 1x1 units.

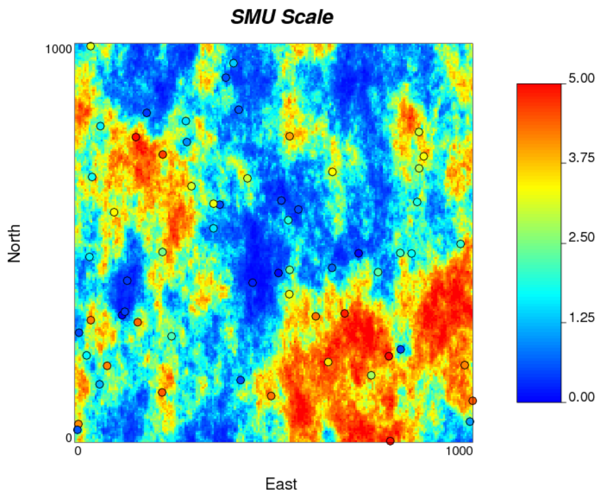

Figure 4: SMU scale realization, block size = 5x5 units.

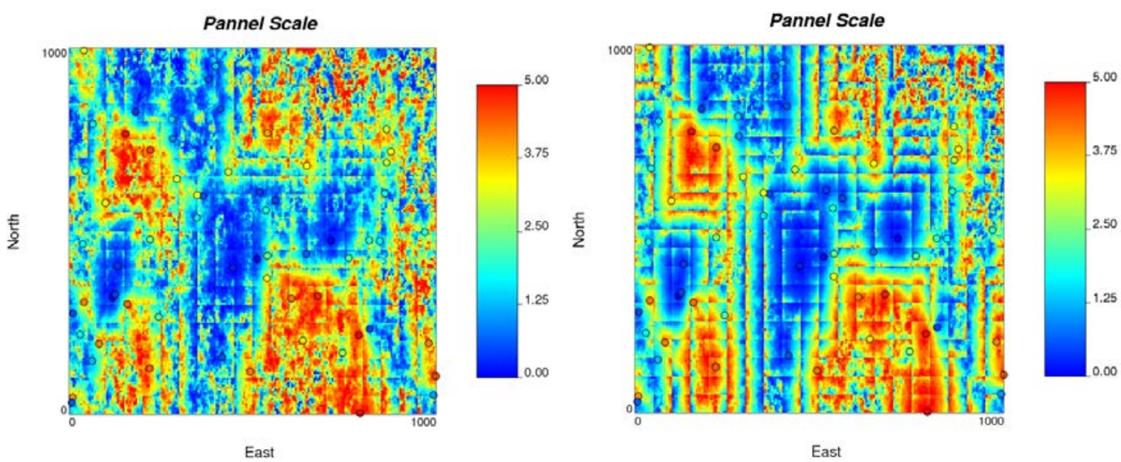

Figure 5: Left: panel scale realization, panel size = 50x50 units with 10 realizations. Right: panel scale realization, block size = 50x50 units with 100 realizations.

References

Abzalov M (2006) Localised Uniform Conditioning: a new approach for direct modeling of small blocks, Mathematical Geology 38(4):393-411.

Hardtke W, Allen L and Douglas I (2011) Localised Indicator Kriging. 35th APCOM symposium, Wollongong 141-147.

McKay, M.D., Beckman, R.J. and Conover, W.J. (1979) A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code, Technometrics, 21, 239-245