Multiscale Ranking for Improved Characterization

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Ranking is common practice in reservoir modeling. Ranking provides a practical alternative to processing all realizations (typically 100 or more) through flow simulation. A large number of realizations are generated to account for variability and the consequent uncertainty. Ranking selects a few realizations for detailed analysis. Processing the selected realizations provides an understanding of the performance of the set of realizations. The choice of a ranking index varies depending on the application and the complexity of the process. There are many engineering decisions including the precise placement of the wells that will affect the predicted performance of a realization. Therefore, the ranking selection of realizations becomes very specific to well placement. At times, reservoir post processing and decision making requires knowledge of the performance of reservoir in different local areas as well as the entire global area simultaneously. In other words, multiple scales of interest exist in the study (e.g., there may be the option of having multiple well pairs within a drainage area). Different realizations would be selected for a specific quantile, say the P50, for the entire area and different subareas. Nevertheless, there may be a desire to have one realization that approximately represents the target quantile for multiple scales simultaneously. We may want a "P50" realization that is close to the P50 for the entire drainage area, while being close to the P50 for each well pair that constitutes the drainage area. An optimization process is developed in this paper to select a realization that ranks the closest to the required quantile for all ranking areas.

Background

Simulation has been developed and popularized due to its ability to characterize the inevitable geological heterogeneity and improve uncertainty assessment. Simulation results in number of realizations honoring available data and characterizing the heterogeneity. The importance of generating multiple realizations goes back to the fact that there exists a large number of realizations honoring the data equally while performing differently (Deutsch and Srinivasan, 1996). Understanding this fact and addressing it is essential to the final recovery of the reservoir. Although multiple realizations are required to understand the uncertainty in a reservoir, processing all of them through detailed flow simulation is not practically possible.

Reducing the number of realizations is always a desired key step in the assessment of a reservoir. The objectivity and precision of realization selection improves the uncertainty assessment and recovery plans. To select realizations, the most popular and practical approach to date is a form of quantile-preserving ranking originally proposed by Ballin et al. (1992). Ranking techniques select the low, median and high realizations according to a specific (desired) measurement. These ranked realizations are the ones that will undergo further processing. In practice, one low, median and high realizations representing the P10, P50 and P90 models of the reservoir are typically selected. These three models are utilized to manage the recovery and reservoir production.

In the past decades, a number of workers have studied ranking (Deutsch and Srinivasan, 1996), (Hird and Dubrule, 1998), and (Saad et al., 1996). While different criteria have been introduced in the literature, the most objective, reliable measurement is the one that can evaluate the connectivity in terms of flow while considering the net distribution in the reservoir. This implies that well-placement is crucial to the measurement of connectivity and ranking realizations.

Problem Definition

The measurements of net connectivity in the reservoir depends strongly on where injectors and producers are placed. The connectivity varies as the well placement varies due to the non-uniform distribution of net/non-net reservoir. Having said that, in SAGD projects, recovery is planned at different scales and different areas; many different well pairs are considered. This paper addresses the interest in many locations simultaneously and demonstrates the challenge relative to the ranking process and realization selection when different scales of interest exist. Despite the large uncertainty represented by many realizations, decisions are made based on a few selected models (typically low, median and high models). The challenge increases in difficulty when different recovery windows and well placement results in different ranking (see Figure 1). To achieve a good reservoir assessment, it is essential to rank the realizations in a way that the low ranked model remains low in all other possible connectivity (drainage) measurements and so on.

The ranking (quantile-preserving) result would definitely be different for different scales of drainage. Note that the ranking criteria (connected hydrocarbon volume) should be kept the same for recovery at any scale. Areas closer to the well placement at overall drainage have higher ranking correlation as expected.

Multi-Scale Ranking

Typically the drainage in the recovery area happens at a number of well-pairs. The net-connected area is not distributed uniformly so that drainage at different areas is not similar. However, in practice, one model for every quantiles of e.g., P10, P50 and P90 is required to describe the heterogeneity for all the drainage. Therefore, the final models should be as close as possible to the ranked models of different drainage set up. This is challenging since a low-ranked model could be actually a high-ranked one in another setting depending on the distribution of connected hydrocarbon volume. However, it is equally crucial to the well-placement and final recovery.

To select the specific ranked (quantile-preserved) models, (1) is defined as the objective function. The function is defined to minimize the distance between the overall drainage ranks and the target ranks as well as minimizing the difference between scale's ranks and the target ranks simultaneously. Every realization represents an actual rank in different scales. The realization which its actual rank in all scales is closer to the interested quantile will be selected as the representative of that quantile. This realization is basically the one which result in the least penalty of (1).

$$O_l = \frac{w_0}{2} \left\| r_{l_{overall}} - r_{target} \right\|^2 + \frac{w_1}{2} \frac{1}{n_{set}} \left\| r_{l_{set}} - r_{target} \right\|^2 \quad (1)$$

Minimizing (1) leads to the following relations:

$$\left\| r_{l_{overall}} - r_{target} \right\| = 0; \quad (2)$$

$$\left\| r_{l_{set}} - r_{target} \right\| = 0; \quad (3)$$

which results in $r_{l_{overall}} = r_{l_{set}} = r_{target}$. Our approach to this minimization is to evaluate the penalty associated with every realization using their actual ranks in the objective model. The challenge is how to select the weights associated with every scale of drainage. Our experiments on different number of well-pairs show that as the number of well-pairs increases the weight associated with the overall drainage decreases; the recovery at every scale is confined to a specific window while still getting advantage from the line of sight (averaging over the large number of them is a closer approximation of the entire deposit drainage area).

Implementation

Our ranking measurement is based on the program called CHV. CHV stands for connected hydrocarbon volume and calculates the connectivity of the hydrocarbons throughout the specified recovery window size around the well pair as expected. The measurement depends on the well placement and the window size that the recovery takes place. This measurements is more complicated (precise) than net to non-net volume due to flow consideration. To achieve ranking at different scales, the SAGD well pair is placed at various depths with different window size of recovery. After sorting the obtained CHV ranks for different scales of same area (no overlapping of areas), the proper realization should be selected to represent the ranking of all areas at the specific quantiles. The goal is to optimize the realization selection so that P10, P50 and P90 quantiles be the best representation of the area of interest at different scales.

A program called ``MultiScaleRanking'' is developed to do the realization selection based on optimization explained earlier. The program gets the input file which includes the ranking of the realizations. CHV is one of the ranking measurements. Other measurements could be used as well, and the file is just required to be input to this program. The parameter file comes before the end of the section.

Our approach is to consider the overall drainage ranking as the ranking reference. Therefore, every realization represents different ranking number at different scales. This implies that the realization representing P10 in the overall drainage might represents another rank at the smaller scales which we refer to it as actual rank. The next section discusses the challenge of selecting one model of low, medium and high ranks when the number of recovery well pair increases.

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Parameters for MULTISCALERANKING
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START OF PARAMETERS:
chv1PADEntire.out        - rankOverall data file
4                        - column number for ranking measure
3                        - How many sets of ranking exist?
chv1PAD1.out             - rankSet data file
4                        - column number for ranking measure
chv1PAD2.out             - rankSet data file
4                        - column number for ranking measure
chv1PAD3.out             - rankSet data file
4                        - column number for ranking measure
100                      - number of realizations
varparameters.out        - multi ranking in output file
```

Two, Four and Eight Well Pair Ranking

The non-uniform distribution of net reservoir enforces the generated realizations to perform differently as if the drainage set up varies. The net reservoir connected to the well pair has a large influence on the recovery. The purpose is to make sure the model which has been ranked as low (high) stays as low (high) rank in different well placement and drainage set up. Therefore, to select the models for low, median and high quantiles, it is important to take all recovery information (different scales) into account and select the model which represents more or less the same quantile (in a fairly small interval) in every different recovery plan. It is important to realize how the model of entire drainage should take weight in the final results.

The program minimizes the penalty by not just actual rank distance calculations but the weight that the overall drainage and smaller scales are taken. Running the program alone and finding the minimum penalty would not give very accurate results. One good observation is to check the final low, median and high quantiles for all different drainage results and make sure it doesn't rank odd in any one of them. Figure 2 demonstrates the ranking improvement by optimization for the different well pair drainage. Table 1 and2 shows the selected realization and optimization performance

Table 1: Selected realization for low, median and high quantiles after performing optimization.

	Two well-pair	Four well-pair	Eight well-pair
P10 Realization	48	52	86
P50 Realization	67	2	9
P90 Realization	67	2	9

Table 2: Ranking Spread before and after optimization.

	Two well-pair	Four well-pair	Eight well-pair
P10 Initial	0.22%	0.21%	0.32%
P10 Optimized	0.15%	0.21%	0.32%
P50 Initial	0.13%	0.37%	0.46%
P50 Optimized	0.13%	0.09%	0.27%
P90 Initial	0.13%	0.76%	0.82%
P90 Optimized	0.08%	0.05%	0.16%

Large Nugget Effect

If the nugget effect is high, the overall estimation suffers from large uncertainty and sometimes ranking deficiency. For example, in the example worked out here, having a large nugget effect of 0.45, the three well pair ranking results give exactly opposite realization for P10 and P90. Realization number 42 turns out to be close to P80 for the case when there exists high nugget effect whereas it is in fact P10 for the case where the estimation is more reliable. Also, for example realization number 13 turns out to be about P70 in the reliable estimation while it represents P10 in the estimation with high nugget effect.

The importance of this study to make sure that the selected realization would be in the desired ranking position in any kind of drainage plan. As was mentioned before, in every reservoir study three models for P10, P50 and P90 is achieved regardless of the number of well pairs would be applied in the area. In the presence of heterogeneity and non-uniform distribution of barriers, it is possible that a model for the smaller window drainage has a very low recovery while the same model considering bigger window results in a good recovery.

We have addressed multiscale ranking in this paper with an exhaustive search approach to select the realization which can stay in a more or less close quantile at all possible drainage scales (windows and coordinates).

Correlation Coefficient

The similarity between the rank of the subset and the target rank have been evaluated using (4) or (5).

$$C_l = 1 - \| \frac{X_l Y_l}{Y_l^2} \| \tag{4}$$

or,

$$\sqrt{\frac{(X_l - Y_l)^2}{Y_l^2}}. \tag{5}$$

Since the ranking at different sets show a monotonic relationship, spearman rank correlation which is as follows

$$1 - \frac{6 \sum d^2}{n(n^2 - 1)},$$

could be utilized to quantify the relationship between the set's ranking and actual ranking.

Table 3: The correlation coefficients for some quantiles of four well pair ranking.

	Set1	Set2	Set3	Set4
P10	8.00	1.20	0.00	3.50
P30	0.70	0.76	0.30	0.70
P50	0.16	0.00	0.10	0.02
P70	0.35	0.01	0.30	0.94
P90	0.04	0.16	0.17	0.64

Conclusion and Discussion

Multiple realizations should be considered simultaneously to assess the geological uncertainty. Ranking has been practiced as a reliable approach to limit the number of realizations required to understand the uncertainty for recovery purposes. In SAGD, however, depending on the recovery plan or geological heterogeneity, various scales of drainage can take place. In the ranking approach described here, three models of low, median and high are selected as the ones to consider more thoroughly. The realizations that should be selected as the low, median and high models depends on the location and scale of interest. As the barrier distribution in the reservoir are never uniform, the connected hydrocarbon volume for different windows of drainage will definitely change at different scales. Also, it is possible that one realization in one drainage setup is ranked low while it is ranked high at another scale of drainage. This paper presented an approach that considers these possibilities and selects realizations that have more stable ranks for multiple areas.

References

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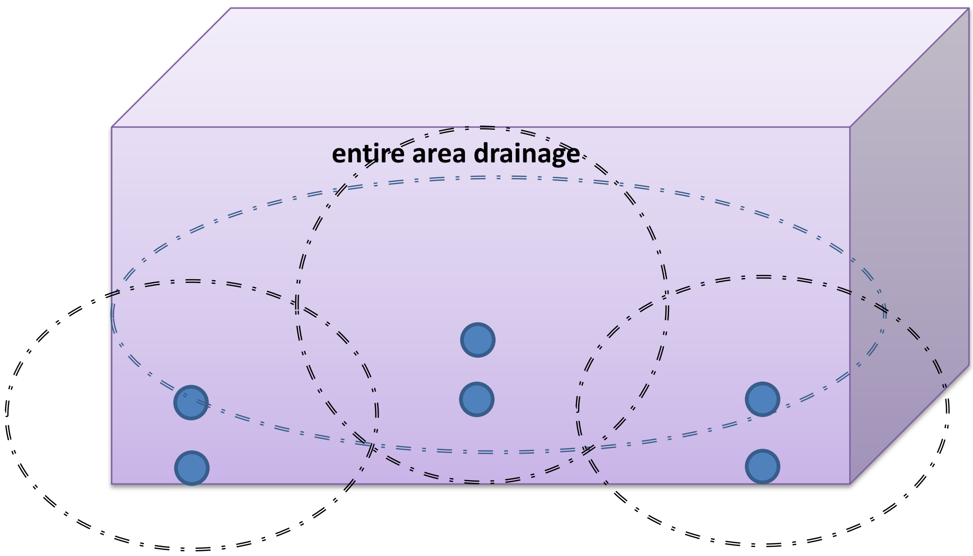

Figure 1: Illustrates multiscale drainage. The well pairs could placed differently and the drainage window would not necessarily be the same.

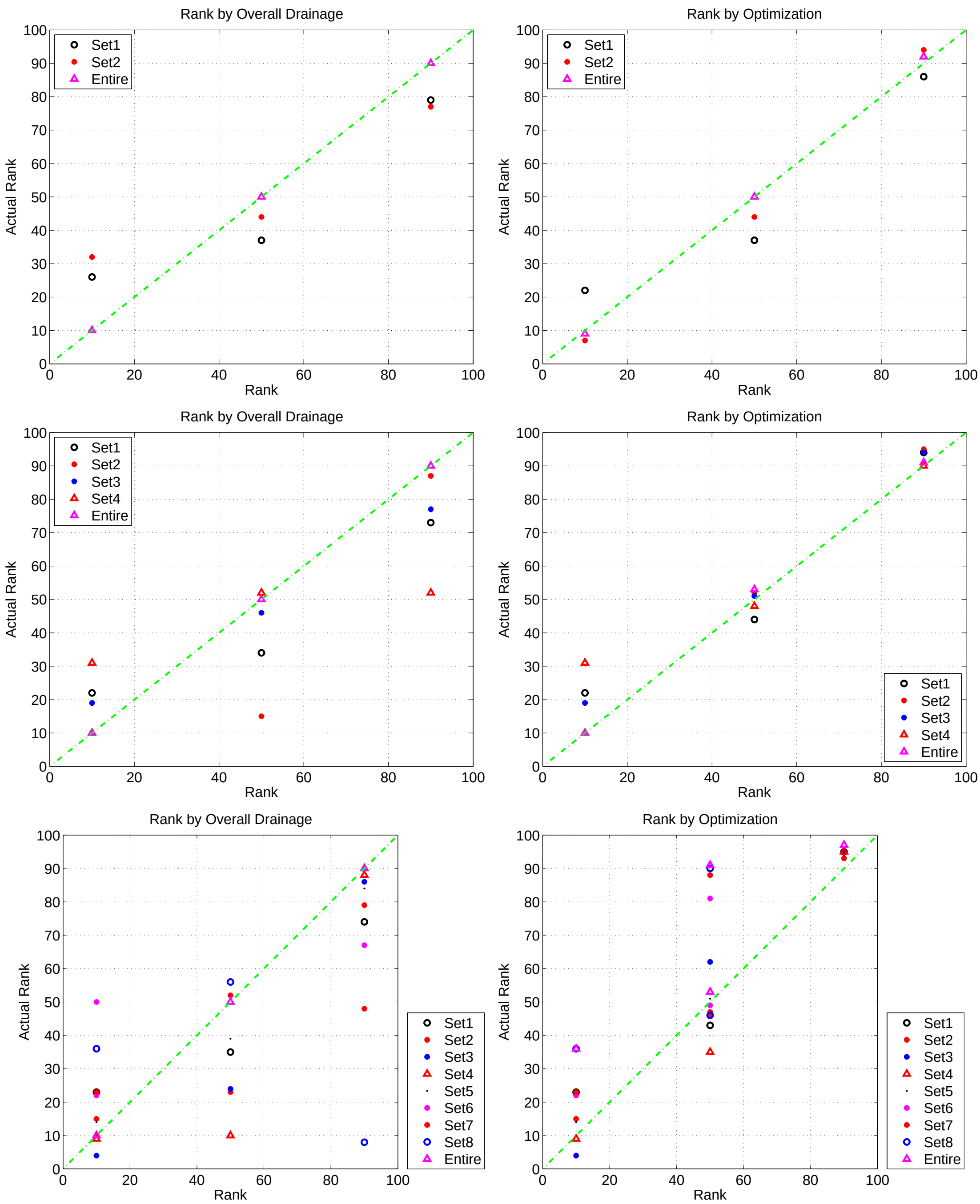

Figure 2: First row represents the ranking for two well pair, second row for four well pair and third for 8 well pair ranking. It can be seen that as the number of well pair increases, selecting the realization becomes harder.

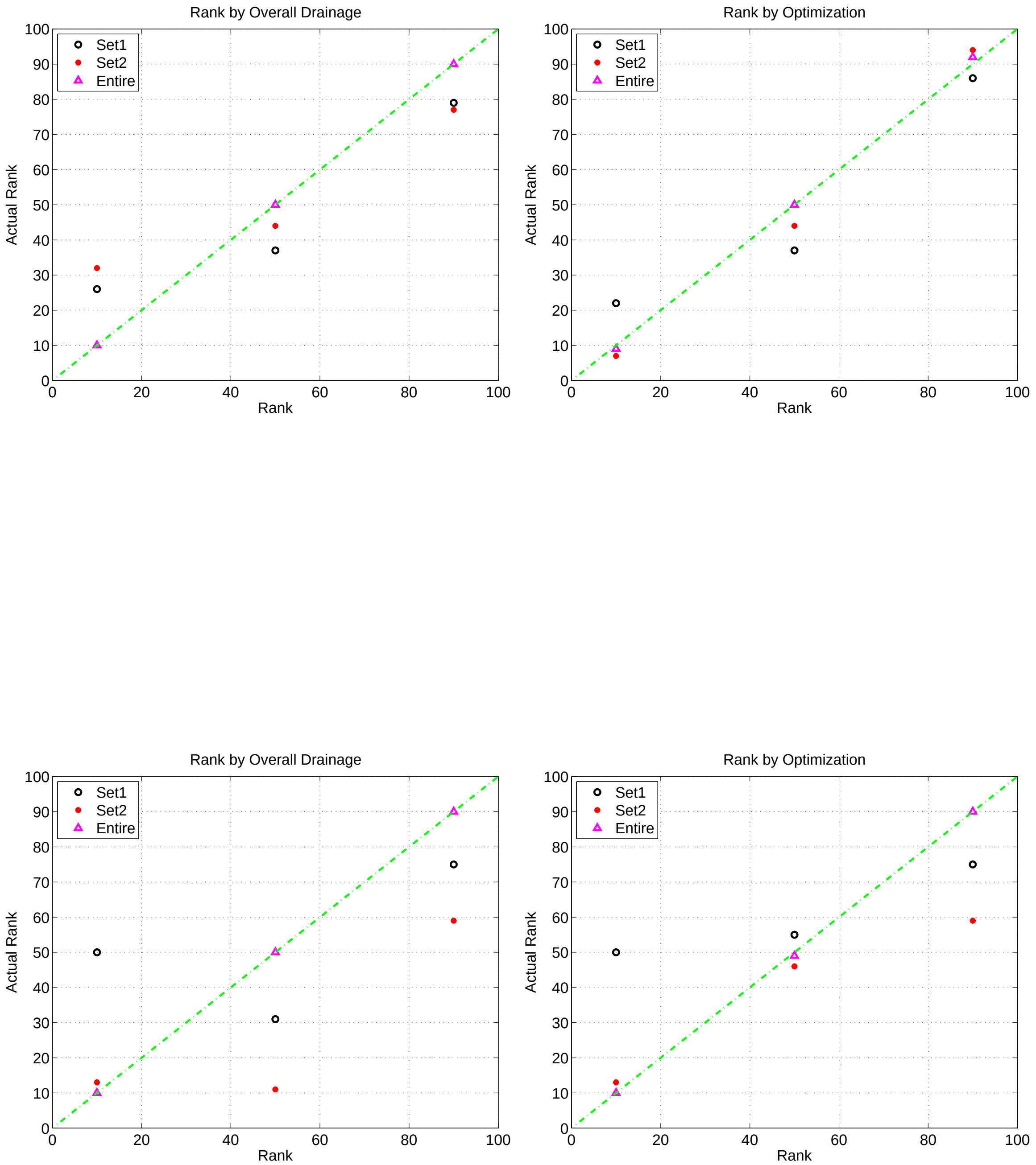

Figure 3: Illustrates the ranking improvement using optimization for the case when the realizations have very large nugget effect (random). The plots show that the optimization for the random case is not working as well as if the reservoir estimation is relatively precise.

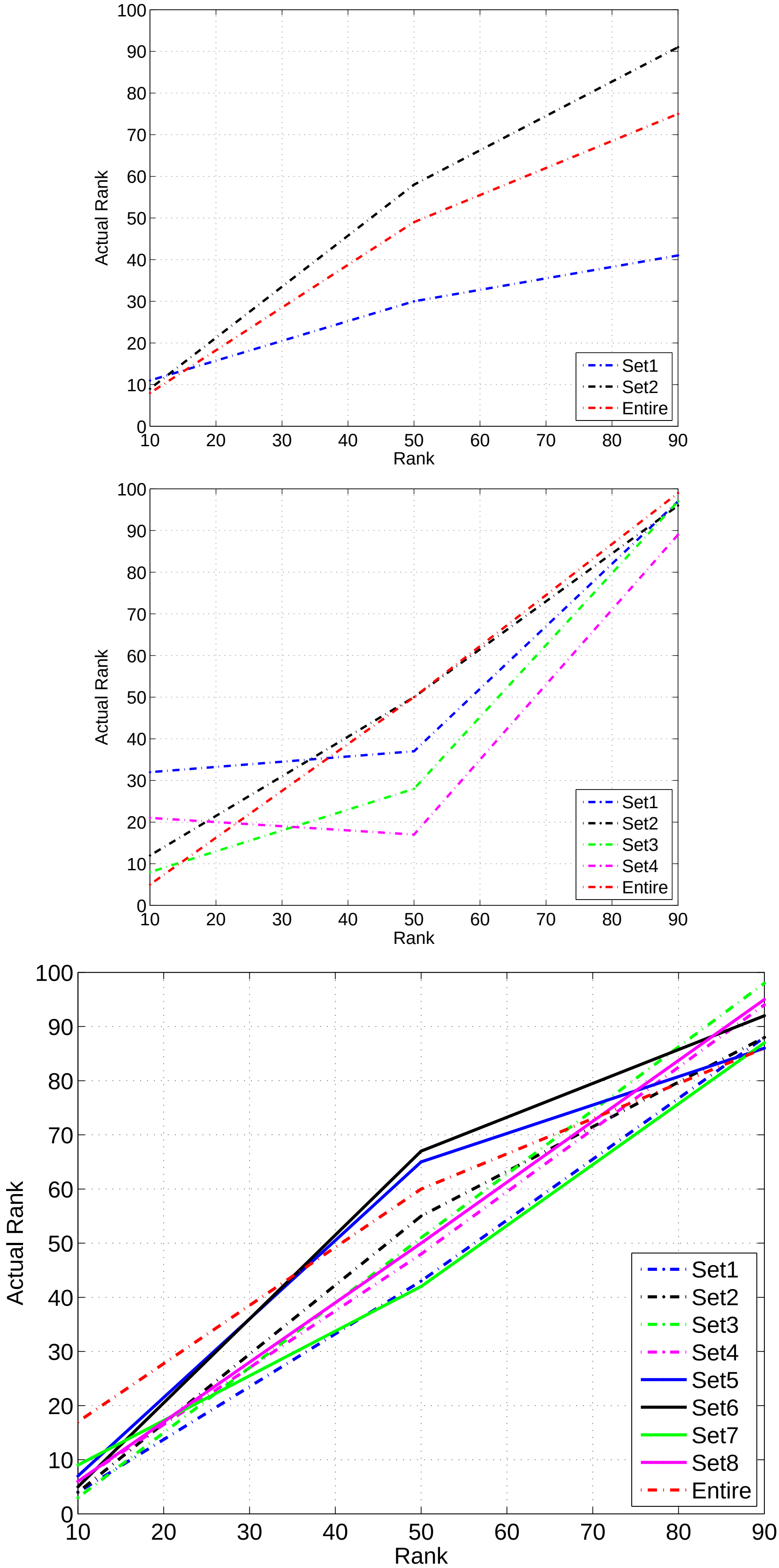

Figure 4: Represents the actual ranking of the selected realization in multi scale set (two, four, and eight well pair respectively).