Conditional simulation of realistic meandering channels using 1D multiple-point simulations

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Abstract An important characteristic of many fluvial reservoirs is the presence of sinuous sand-filled channels within a background of floodplain shale. The complex geometry and the heterogeneity of these deposits makes their characterization challenging. We propose a new approach to model channels geometry using continuous variable multiple-point geostatistical method (Direct Sampling, DS). The idea is to simulate the direction taken by the channel along the river axis, discretized as a 1D process. The simulations are based on training images consisting of orientations observed on present-day rivers. The simulated meanders show a high degree of realism, including meanders presenting multiple internal bends and oxbow lakes. Since the simulations are 1D, the computational cost is minimal. Conditioning to observed channels locations is accomplished by subtracting a trend on the simulated meander that is an interpolation of the error to the conditioning data.

Introduction

The study of fluvial deposits has been a relevant topic for petroleum and hydrogeology during the last decades. Reservoirs of fluvial origin are playing a major role in newly proven reserves of hydrocarbons. An important characteristic of many fluvial reservoirs is the presence of sinuous sand-filled channels within a background of floodplain shale. The complex geometry and the heterogeneity of these deposits make their characterization challenging.

A number of approaches have been proposed for stochastic modeling of meandering rivers, which can be broadly classified in two main approaches: stochastic models and physically-based models.

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Physical models generate realistic meanders by resorting to geological knowledge in which sediment transport, erosion, channel cut-off, crevasse and levee formation are based on realist distributions of stream discharge, duration of annual floods, sediment load, etc. Examples of this type of simulation can be found in [1-3].

On the other hand, stochastic models do not explicitly include the geological rules, and instead focus on mimicking the statistical properties of known channels. In Boolean models, the location of a channel centroid is described by (possibly random) parameters describing characteristics such as a principal direction line, the deviation of the channel from its centerline, the channel sinuosity, etc. Examples of this approach can be found for example in [4-6]. Multiple-point geostatistics has constituted an interesting approach [7, 8], but in many cases still has difficulties in preserving the continuity of the generated channels. An interesting stochastic approach was proposed by [9] and extended by [10]. It consists in a representation where, instead of modeling the channel with a limited number of discrete parameters, it is modeled as a random function representing the angle taken by the channel along a curvilinear coordinate axis. However, this random function was modeled as a multiGaussian process, resulting in smooth curves that do not look like realistic meandering channels. Our method is based on a similar principle, but considers non-multiGaussian succession of orientations, resulting in a high degree of realism.

Methodology

We propose a new approach to model realistic channels geometries by simulating the channels orientations as a non- multiGaussian random process. This is accomplished by using continuous variable multiple-point geostatistical method of Direct Sampling (DS) [11] to model the river channel geometry.

The simulations are based on training images consisting of orientations observed on present-day rivers. DS takes as training data the succession of orientation taken by the river axis calculated with a defined step. These angles are simulated using DS in a 1D curvilinear space. This enables the method to mimic the meander shapes without simplifying the geometry and without a great computer expense. The methodology is illustrated in Figure 1.

Conditioning to known channel is done by choosing a point in the river channel that has the minimum distance to the observed point. Then, a trend is applied to adjust the river channel to pass through the observed locations. The conditioning method is illustrated in Figure 2. The simulated channel can present some inconsistencies such as intersections with itself. It is therefore necessary to apply a post processing analysis in order to inspect and possibly correct the simulated and conditioned river.

Once the general geometry of the river is defined, sedimentary deposits from previous and future river stages are generated iteratively following the meander migration process known as translation and expansion, described in [12] and [13].

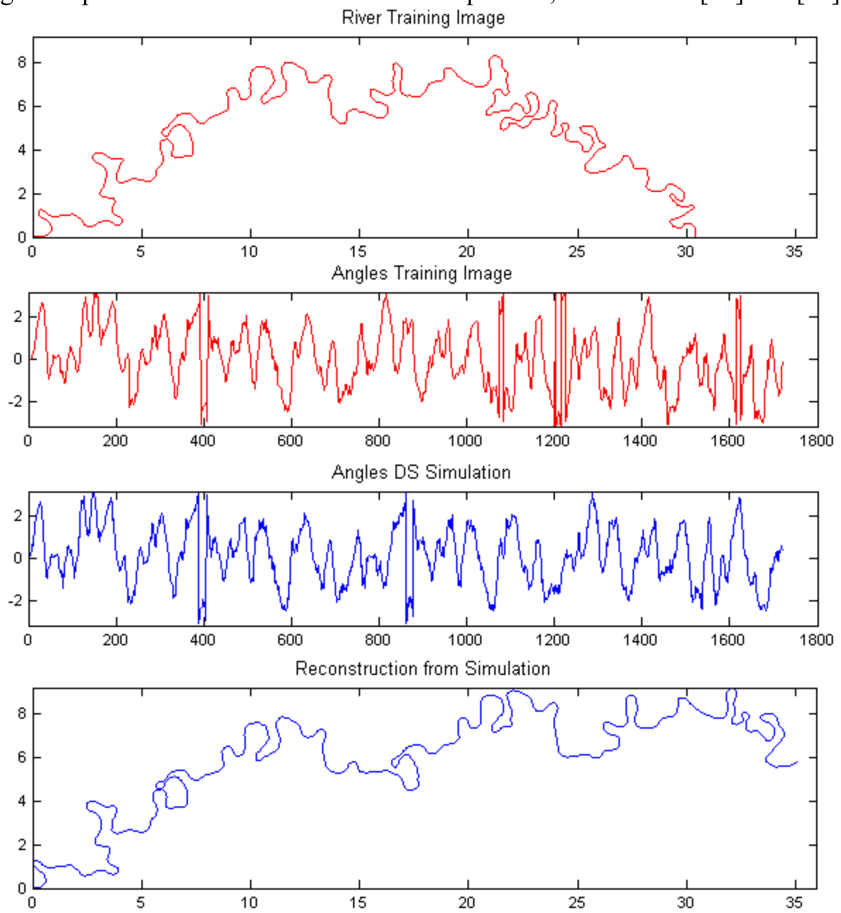

Figure 1 Training data set and simulation

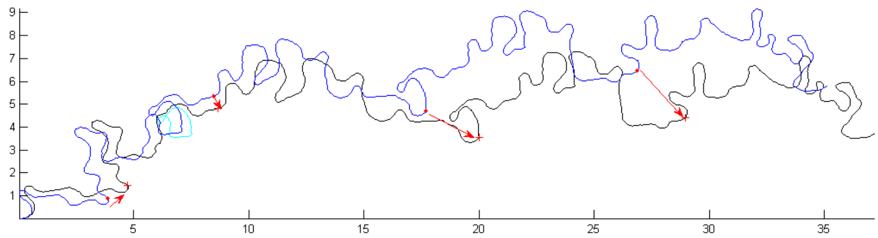

Figure 2 The conditioning procedure. Simulated channel meander (blue) and the simulated channel conditioned to observed locations (black). Red crosses indicate the observed locations and red points indicate the minimum distance point that is corrected to match the observed location. Cyan color indicates self-intersecting loops occuring during the simulation process.

Results and conclusion

The methodology has been tested in a variety of contexts. We illustrate it with a case study based on a highly sinuous meandering river located in the Bolivian Amazon basin. The simulated meanders show a high degree of realism, including meanders presenting multiple internal bends. Oxbow lakes do occur in the simulation, which are thereafter modeled as separate sedimentary bodies. Since the simulations are 1D, the computational cost is minimal, the simulation of a meander taking less than one second. Figure 3 shows the superposition of several meandering channels, all conditioned to the same four data points.

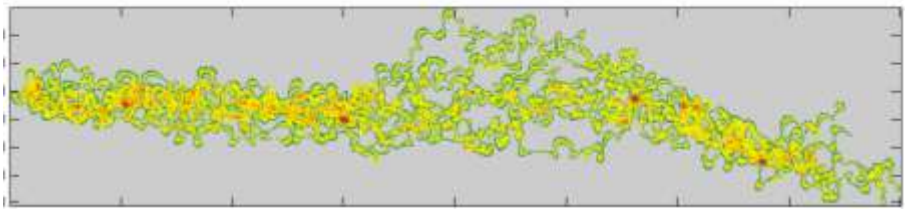

Figure 3 Several superimposed conditional meanders realizations, with sedimentary deposits generated via translation and expansion mechanisms.

Conditioning to observed channels locations is satisfying when a small number of conditioning data is used. However, the conditioning method can produce artifacts when a large number of conditioning data are present, resulting in a loss of realism. In such cases, we propose conditioning through an inverse procedure that is guaranteed to honor the channel orientations observed in the training image.

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