Reflection on Computer Modeling of Concentric Folds

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Abstract
The present work introduces a reflection on the possible application of the representation of geological objects of a certain number of computational methods (solid modeling, computer graphics...), that are commonly used to design and visualize manufactured objects. The geometry of geological objects or bodies, which we are interested in is very different and has many specific points of view (shape of objects and their borders, relations with neighboring objects...) (Cheaito, 1993). A flexible deformation generally induces the folding of continuous surfaces initially flat, also the deformed objects being qualified as folds (Cheaito and Cheaito, 2014). Thus, a fold will be a mineral volume between two folded surfaces nested one on the other (Requicha, 1980). The boundaries of surfaces usually correspond to surfaces of stratification. We focus the reflection on the modeling of geological objects, starting from a simple object (set of layers) which undergoes a deformation represented by a profile simulating the force of deformation that obtains the effect of concentric fold (Amrouch, 2010).

1. Introduction

The present work takes place at the center of the researches on computer modeling of geological objects that are at the origin of the composition of a geological scene. The geologists characterize the geological objects by their geometric form (Suppe and Connors, 2004). Many researches have indicated that the geometric form of the geological objects is strictly related to their history that is they are related to the series of processes during the geological evolution which determines the characteristics of the object (Spraggins and Dunne, 2002). Henceforth, the geometric definition of objects relies on the analysis of successive transformations affected by their original form. Each of the presented objects within the geological scene has a form which usually results from some history: the object, when it first appears (sedimentation layer, injection of granite ...) (Cheaito, 1993) has a certain form that could undergo further changes (folding, dislocation induced by faults, partial digestion by recent intrusive bodies ...). Similarly, the geometric relations between different objects of the scene correspond to a certain "system state", generally different from a number of previous states. Thus there exists a link, which the geologists can easily establish between the forms which are sometimes very complex objects and assemblies, and the sequencing of natural processes under which they were put.

The characteristics of some simple geological processes that induce deformations (Averbuch, Frizon de Lamotte and Kissel, 1992). The geometry of deformed objects will be captured using benchmarks (Requicha, 1977). Thus, a folding may be characterized as the deformation of one or more surfaces from stratification that is initially flat (Ramsay, 1962) (figure 1).

2. The Geological Objects and Computer Science

The earth's crust consists of rocky sets that constitute the geological bodies. These bodies have different properties depending upon their geometric form, their chemical and mineralogical composition, and their mechanical properties. They produce between them a precise relations. The representation of the geometry of geological objects is the origin of many computer softwares (Srivastava and Gairola, 1999). We will be interested in the form of different geological objects seen in the nature and spatial relations that undertaken one with each other. More precisely we will try to describe a « geological scene », consisting of a set of objects spatially structured (Smith, Aubourg, Guezou, Nazari Molinaro, Braud, and Guya, 2005). We will be concerned with the rendering of the individual form of different objects, and with that of their spatial relations together with the vision of the scene. The computer techniques used for this will be developed by the synthesis of the image (Computer Graphics).

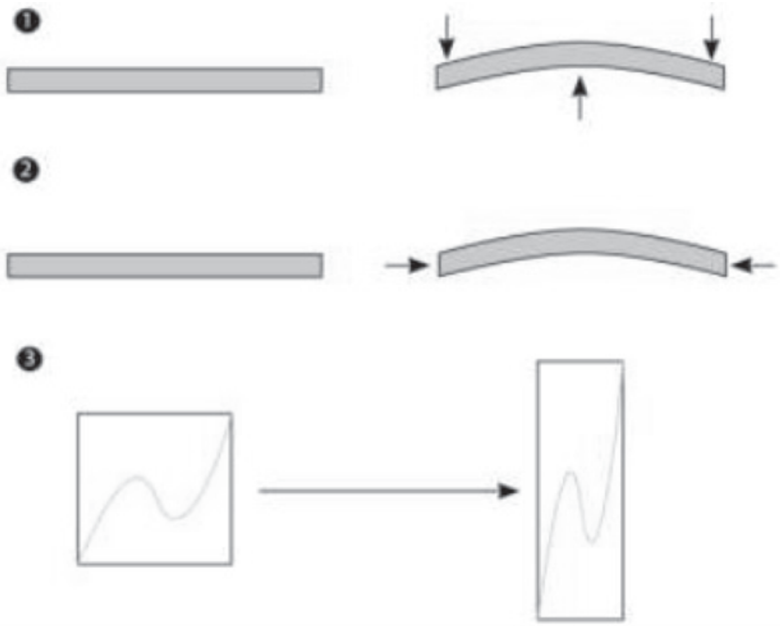

Figure 1: The three principal mechanisms of folding in rocks (Suppe, 1985)

The geological scene corresponds to the representation of a fraction from the underground. We consider that this fraction consists of a set of well bounded objects. To represent a scene we suppose the following steps:

- Characterize the form of its different objects and as well as their geometric position one relative to the other.
- Create an implicit or explicit geometrical model.
- Give the means of vision.

Many difficulties arising in geology that are referred to the following factors:

- The geological objects are of very variable shapes going from the chain of mountain to a dissymmetrical sample.
- When they have big shape, in general they will not be recognized other than their punctual data, and discontinues usually heterogeneously (dips, cartographic boundary, discrete survey…). These data should be always interpolated.
- The geological scene is susceptible to be very complex: multiple objects, showing irregular forms, active with each other in a complicated manner.

A possible option to represent the geological objects and their relations consists of considering them as ordinary objects. To establish the scene, it is convenient to give the means allowing to determine accurately the forms of different objects, and then assemble them together according to their spatial mechanism. The difficulties arise from the complexity of forms and the complexity of the layout of objects. Another option consists of starting from a character « geological » of objects and their assembly. This assumes that we examine the particularities of these objects and we aim to know their specific character. This is the point of view adopted throughout this work. In this work, we will characterize the geometry of objects and the most common geological assembly (case of concentric folds). We see that the specific characters are strictly related to their history that is to the chain of processes which through the geological evolution have determined the characteristic of the scene that will be represented. Therefore, we examine the possibility of a geometric definition of objects that relies on the analysis of successful transformations due to their original form. Thus, we see that it is usually convenient to define the geological objects starting from the form that they have at a previous stage of their history rather than approaching directly their actual form. We invent a method known as, *the dynamic model*, which aim to define the objects starting from their original forms by simulating them with the aid of convenient operators. The geometric transformations that they have undergone under the effect of geological processes (folding, injection or digestion of rocky materials…). The result from using computer graphics yields in our case not only a modeling tool of processes but less geometric consequences.

3. The Deformation

The flexible deformation of geological objects, usually involves a reduction in a determined direction and an elongation in a perpendicular direction. This deformation doesn't create neither emptiness nor significant discontinuity in the object (Perrin et al., 1993). We symbolize it by a continuous function:

$$\varphi: R^3 \rightarrow R^3$$

Equation 1

The geometry of folds is highly dependent on the behavior of the sides. If the thickness of the sides remains constant, the fold is called concentric fold. This geometry imposes an increasing radius of curvature towards the outside of the fold. A simply folded surface will transform a continuous flat surface S into S' using the function of flexible transformation φ:

$$S' = \varphi(S)$$

Equation 2

φ has the following two characteristics:

1. Bijective.
2. If a segment AB drawn on S, then AB has an image a line CD drawn on S', for any point M situated between A and B on AB, an image M' of M will be situated between C and D.

Many folds can be assimilated in a first approximation to a set of parallel cylindrical surfaces (Ramsay, 1967). Some of the harmonic complex folds can be analyzed as the result of deformation of a set of originally flat layers by a sequence of several simple cylindrical folds (Ramsay, 1962 and Thiessen, 1986) (figure 2).

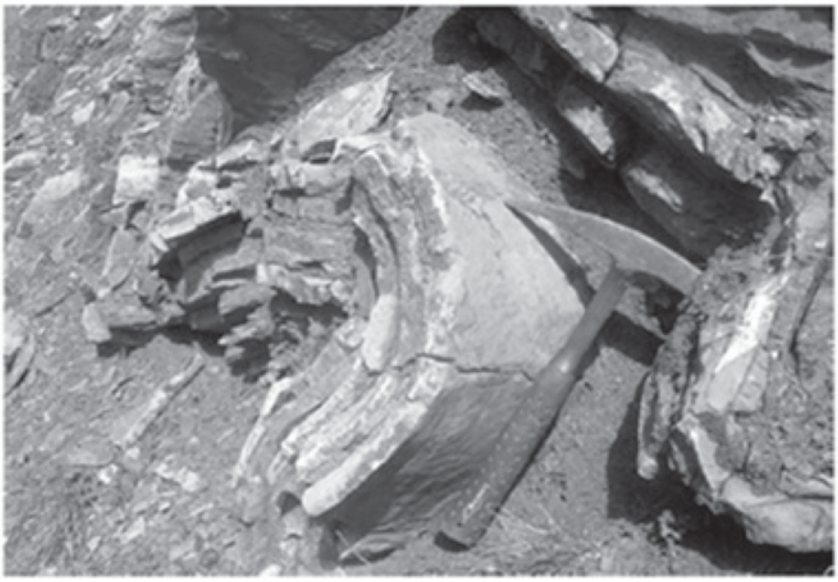

Figure 2: The thickness of the sides of a concentric fold remains constant (Pomerol, Lagabrielle, Renaud, and Guillot, 2011)

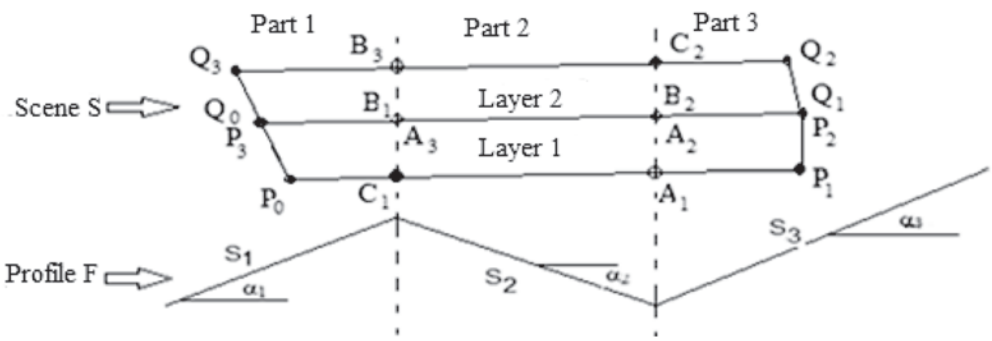

Figure 3: The initial state of a Scene S and a profile F

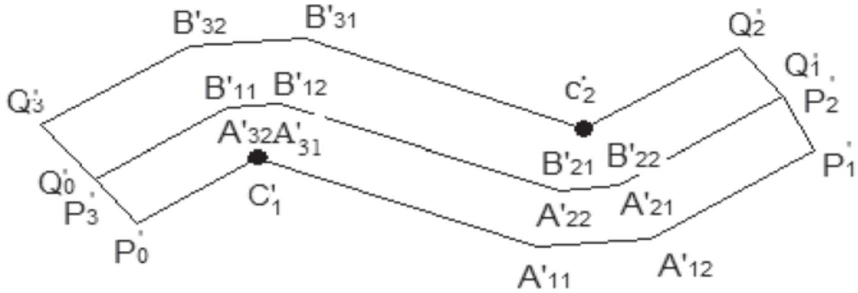

Figure 4: Scene after deformation

4. Method of Concentric Deformation

To achieve the deformation model on a part of a simple object consisting of a set of layers S and a deformation profile F (figure 3). We define at first, the points of contact of the profile peaks with the scene S in our case they are C1 and C2. We have chosen the lowest point C1 starting from S1 towards S2 of the profile F because $\alpha_1 >= \alpha_2$, and we have chosen the highest point C2 and starting from S2 to S3 because $\alpha_2 <= \alpha_3$. Now we rotate the part 1 by an angle α_1 around the point C1 (Figure 4).

We obtain:

For layer 1 the obtained vertices are: P'$_0$, C'$_1$, A'$_{32}$, P'$_3$

For layer 2 the obtained vertices are: Q'$_0$, B'$_{11}$, B'$_{32}$, Q'$_3$

A'$_{32}$=Rotation of A_3 by an angle α_1 around the point C_1

A'$_{31}$=Rotation of A_3 by an angle α_2 around the point C_1

B'$_{11}$= Rotation of B_1 by an angle α_1 around the point C_1

B'$_{12}$=Rotation of B_1 by an angle α_2 around the point C_1

B'$_{32}$= Rotation of B_3 by an angle α_1 around the point C_1

B'$_{31}$=Rotation of B_3 by an angle α_2 around the point C_1

A'$_{22}$=Rotation of A_2 by an angle α_2 around the point C_1

A'$_{21}$=Rotation of A_2 by an angle α_3 around the point C_2

B'$_{21}$= Rotation of B_2 by an angle α_2 around the point C_1

B'$_{22}$=Rotation of B_2 by an angle α_3 around the point C_2

A'$_{11}$= Rotation of A_1 by an angle α_2 around the point C_1

A'$_{12}$=Rotation of A_1 by an angle α_3 around the point C_2

P'$_1$, P'$_2$, Q'$_1$, and Q'2: are the respective rotations of P_1, P_2, Q_1, and Q2 by an angle α_3 around the point C_2

P'$_0$, P'$_3$, Q'$_0$, and Q'3: are the respective rotations of P_0, P_3, Q_0, and Q3 by an angle α_1 around the point C_1

Note that the point C2 undergoes a rotation by an angle α_2 around the point C_1

We obtain the point C'$_{21}$, and since the part 2 of S and the part 3 remain in contact with point C_2 thus we translate the parts 1 and 2 of a vector (we call collage vector at the point C2) such that C'$_{21}$ sticks to the point C_2 in order to get the point C'$_2$.

Finally:

Layer 1 is represented by: P'$_0$, C'$_1$, A'$_{11}$, A'$_{12}$, P'$_1$, P'$_2$, A'$_{21}$, A'$_{22}$, A'$_{31}$, A'32, and P'$_3$

Layer 2 is represented by: Q'$_0$, B'$_{11}$, B'$_{12}$, B'21, B'$_{22}$, Q'$_1$, Q'$_2$, C'$_2$, B'$_{31}$, B'$_{32}$, and Q'3

In the general case, we repeat the effect of segments of the profile F in order to achieve the final object. Remarkable case: In the case where layer 2 is weaker than the layer 1 (figure 5) and for layer 2 remains stuck to layer 1, then the translations of the collage vectors of the points C2 and C3 should be applied to the layer 2.

5. The Content of the Scene

To model the content of the scene, we use the structure of binary partition type of the space based on the recursive use of flat separators dividing a given space into two spaces (Naylor, 1990, Lysenko, DeSouza, and Shene, 2008, Naylor and Thibault, 1986 and Chrysanthou and Slater, 1992) (figure 6).

6. Algorithm of Construction of the BSP Tree

To construct the BSP tree nodes (Wang and Manocha, 2013), we insert a segment S in the tree as seen in figure 7 (Fuchs et al., 1980 and Fuchs, 1983).

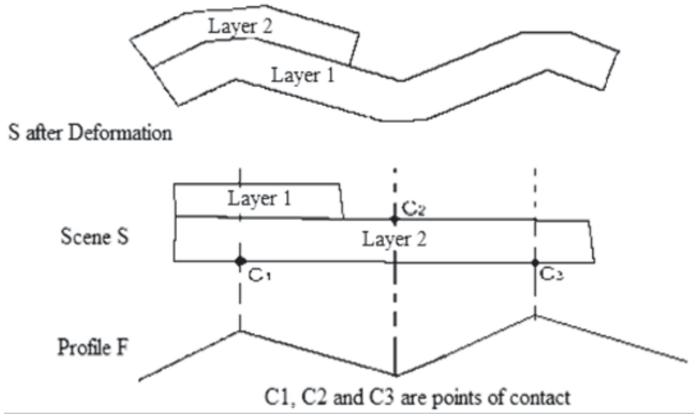

Figure 5: Realization of collages of two layers

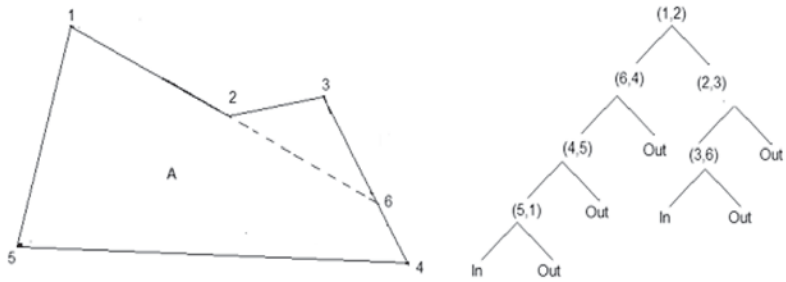

Figure 6: Representation of the polygon tree

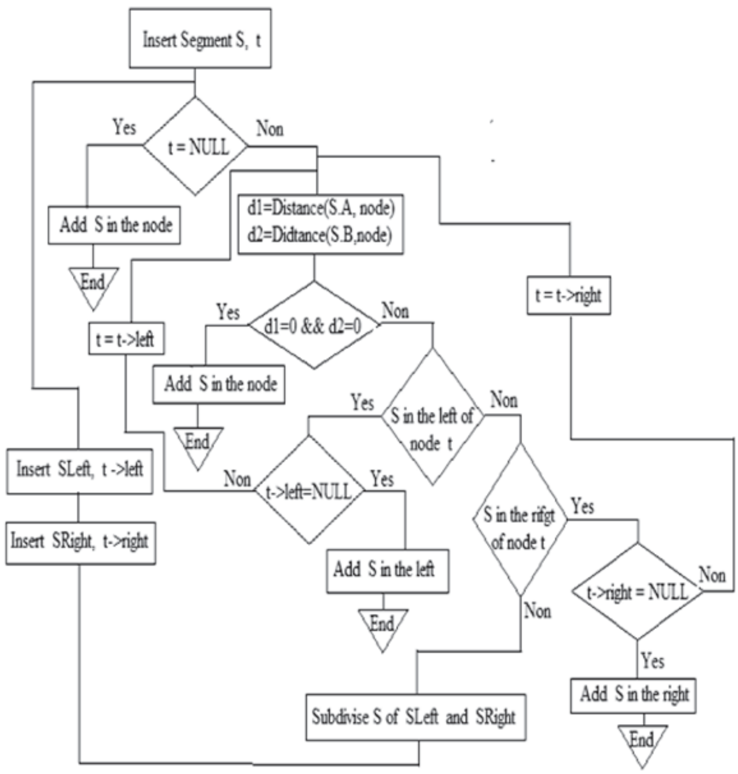

Figure 7: Inserting a segment in the tree

7. Some Technical Results

The following figures are the technical results taken from software PCheGeol (Cheaito, 2013) of an initial scene and by application of any phases of concentric deformation.

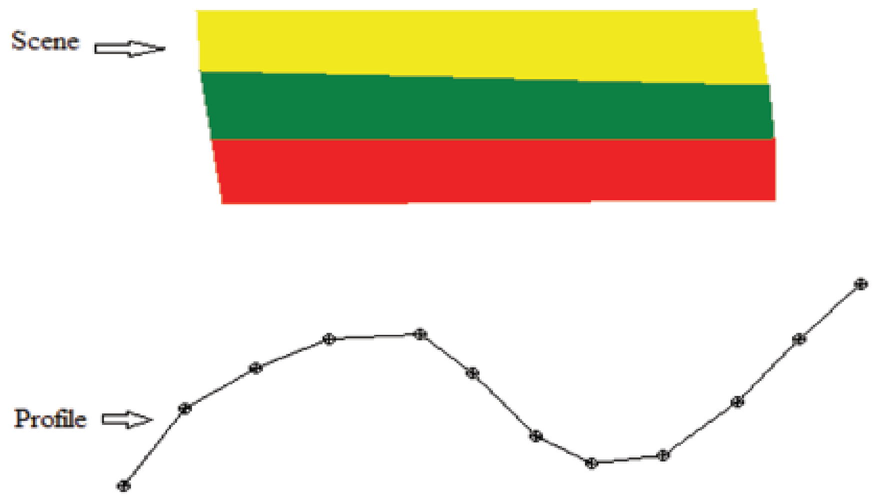

Figure 8: The scene and the Profile in their initial state

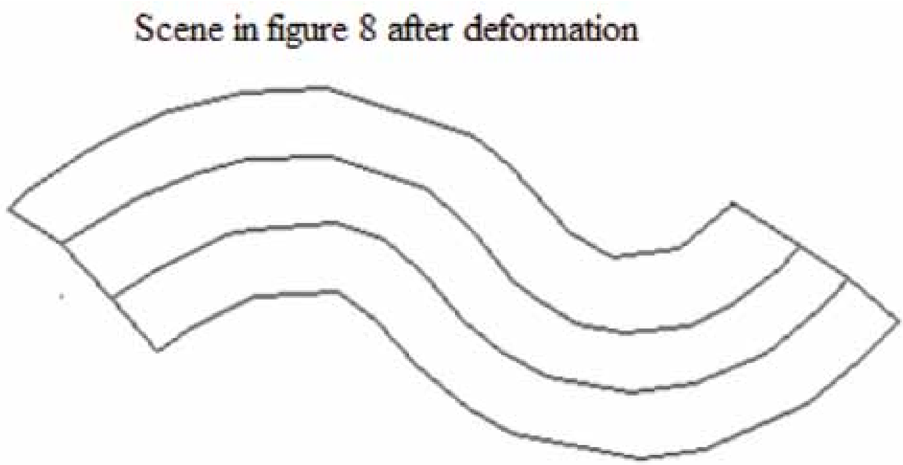

Figure 9: Deformation of the scene through one phase of concentric deformation

Figure 10: Coloring of the scene using the BSP tree algorithm

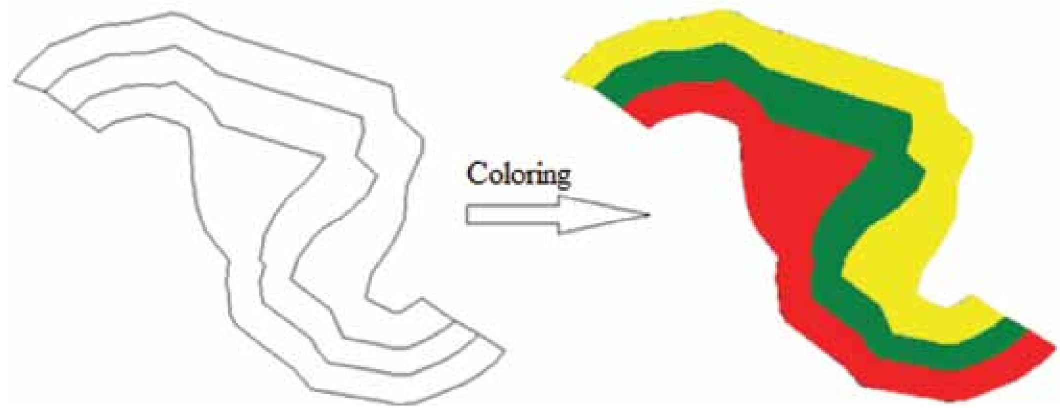

Figure 11 Deformation and coloring of the scene after two phases of concentric deformation

8. Conclusion

The approach of computer modeling by describing the geological processes which played through the history of a geological object, starting from a simple object (a set of layers) to a complex object was the basis of the realization of the software POLYPLI (Perrin et al., 1987). The concentric folds are widely spread than similar folds, and their models are more difficult especially when conserving the property that there is no gap between the objects of the geological scene (Requicha, 1980). The use of object-oriented programming allows us to develop and realize the software PCheGeol, from which we obtain the models of concentric folds (Cheaito, 2013 and Cheaito and Cheaito, 2014)). This modelization opens the road towards the realization of the modelization of the three dimension scene to combine in the future the concentric folds and the similar folds and faults. The use of BSP algorithm that describes the interior of the object is a choice, allowing to recognize the richness and to study the structures in the interior of a geological scene.

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