Autopoiesis and Image Processing II: Autopoietic–agents for Texture Analysis

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March 15, 2000

Abstract

The theory of Autopoiesis attempts to give an integrated characterization of the nature of the living systems. This article explores the use of autopoietic concepts in the field of Image Processing. Two different approaches can be used. The first approach, explored in the related article *Autopoiesis and Image Processing I: Detection of image structures by using auto-projective operators*, assumes that the organization of an image is represented only by its grayvalue distribution. In order to identify autopoietic organization inside an images' pixel distribution, the steady state Xor-operation is identified as the only valid approach for an autopoietic processing of images. The second approach, presented in this article, makes use of a second space, the *A*–space, as an autopoietic processing–domain. This allows the formulation of adaptable recognition tasks. Based on this second approach, the concept of autopoiesis as a tool for the analysis of textures is explored. As a concrete example, a Texture Retrieval System based on the use of an autopoietic–agent is presented.

1 Introduction

Texture perception plays an important role in human vision. It is used to detect and distinguish objects, to infer surface orientation and perspective, and to determine shape in 3D scenes. Even though texture is an intuitive concept, there is no universally accepted definition for it. Despite this fact we can say that textures are homogeneous visual patterns that we perceive in natural or synthetic images. They are made of local micropatterns, repeated somehow, producing the sensation of uniformity. It is important to point out, that textures can not be characterized only by their structure because the same texture, viewed under different conditions, is perceived as having different structures.

In the framework of the theory of autopoiesis (see the related article *Autopoiesis and Image Processing I*) , Maturana and Varela make a complementary definition of the concepts of organization and structure of a system. The organization of a system defines its identity as a unity, while the structure determines only an instance of the system organization. In other words, the organization of a system defines its invariant characteristics. The concept of autopoiesis captures the key idea that living systems are systems that self maintain their organization. In the context of texture analysis, the systems to be analysed are the textures. As it was established, the concept of organization must be used to characterize a system and in our case to characterize a texture. For this reason, in this section the concept of autopoiesis is explored as a tool for texture identification, which corresponds to an important task in the field of texture analysis. The analogy between the process of autopoietic organization in a chemical medium (i.e. life) and the process of texture identification is used.

Before to apply the concept of autopoiesis as a tool for texture identification a computational model of autopoiesis must be defined. Varela *et al.* developed the first computer model that was capable of supporting autopoietic organization [1]. Recently, McMullin developed the SCL model that corresponds to an improvement of the model presented by Varela [2] [3]. The SCL model from McMullin is modified in this article to allow the identification of textures.

This article is organized as follows. In section 2 the SCL Model from McMullin is presented. The modified SCL model and its use as a tool for the analysis of textures is described in section 3. As a concrete example, a Texture Retrieval System based on the use of an autopoietic–agent is presented in section 4. Finally, in section 5 some conclusions are given.

2 The SCL Model

SCL involves three different chemical elements (or particles): Substrate (S), Catalyst (K) and Link (L). These particles move in random walks in a discrete, two dimensional space. In this space, each position is occupied by a single particle, or is empty. Empty positions are managed by introducing a fourth class of particles: a Hole (H). SCL supports six distinct reactions among particles [3]:

1. Production:

   K+S+S $\longrightarrow$ K+L+H

2. Disintegration:

   L $\longrightarrow$ S+S

3. Bonding:

   Adjacent L particles bond into indefinitely long chains

4. Bond decay:

   Individual bonds can decay, breaking a chain

5. Absorption:

   L+S $\longrightarrow$ L*

6. Emission:

   L* $\longrightarrow$ L+S

The autopoietic organization is produced, when a chain of L-elements forms a boundary, which defines a concrete unity in the space. Of course, this boundary must be continuously regenerated (see the related article *Autopoiesis and Image Processing I*). The L-elements are produced only in the presence of a catalyst (*Production* reaction). For this reason, we can say that in this model, an autopoietic organization is produced only in the presence of a catalyst.

3 The modified SCL Model

The original SCL model was modified to allow the identification of textures, by introducing the idea of a texture-dependent catalyst. That means, a catalyst that is tuned with a defined texture and that produced an autopoietic organization only in this texture. To implement this idea an autopoietic image $A(i, j)$ is defined for each texture image $T(i, j)$. Each pixel of $A(i, j)$ has a corresponding position in $T(i, j)$ and is represented by 2 bits (enough for representing four particles). A T-Space is associated with the texture images $T(i, j)$ and an A-Space is associated with the autopoietic images $A(i, j)$ (see figure 1). The reactions defined by the SCL model, i.e. the possible autopoietic organization, take place in the A-Space, but by taking into account information from the T-Space (textures).

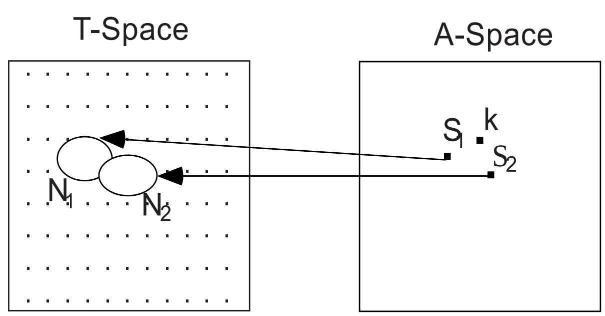

Figure 1: The A–Space, where the autopoietic organization is created, and the T–Space, where convolution between the texture and the GABOR-Filter is performed, are shown.

GABOR-Filters are able to characterize textures by decomposing them into different orientations and frequencies (scales) [4]. In the proposed model, a GABOR-Filter is associated with the catalyst, to allow it (the catalyst) to be tuned with a particular texture. The GABOR-Filter interacts directly with the textures in the T-Space (convolution operation) and the result of this interaction is used to modulate the reactions in the A-Space.

From all the reactions defined by the SCL model only the *Production* reaction was modified, because it is the only one where the catalyst operates and the L-elements are created. The new *Production* reaction is defined by:

Production:

$$
\begin{array}{l}
K + S_1 + S_2 \longrightarrow K + L + H \\
C_1 = N_1 * G_k \\
C_2 = N_2 * G_k \\
\mathrm{if}(C_1 > TH \text{ and } C_2 > TH)\{ \\
\quad \mathrm{if}(C_1 > C_2)\{ \\
\quad\quad S_1 \longrightarrow L \\
\quad\quad S_2 \longrightarrow H \\
\quad \} \\
\quad \mathrm{else}\ \{ \\
\quad\quad S_1 \longrightarrow H \\
\quad\quad S_2 \longrightarrow L \\
\quad \} \\
\}
\end{array}
$$

where G_k is the GABOR-Filter associated with the catalyst K; N_1 and N_2 are the neighborhood in the T-Space of S_1 and S_2, respectively (see figure 1); C_1 and C_2 are the results of the convolution (performed in the T-Space); and TH is a threshold value.

If in the *A*-Space of a given texture a chain of elements forms a boundary, after an interaction time, then the catalyst K has identified the texture (in its T-Space) as corresponding to the class of textures characterized by the GABOR-Filter G_k.

4 An autopoietic–agent for Texture Retrieval

To illustrate the idea of texture identification by using a computational model of autopoiesis, a system for retrieval of textures in image databases is proposed (see figure 2). The system is based in the use of an autopoietic-agent (the texture–dependent catalyst described in section 3), which is generated by using the texture description contained in the query. The autopoietic–agent is tuned with only this texture description, which means it can interact (to produce autopoietic organization) only with the texture that corresponds to this description. The autopoietic agent is sent to every texture of the database and allowed to interact with the substrate particles of the *A*-Space of those textures. After an interaction time, the texture, where an autopoietic organization was produced (in its *A*-Space), is retrieved.

5 Conclusions

The use of autopoietic concepts in the field of Image Processing was explored. Two different approaches were presented. The first approach, presented in the related article *Autopoiesis and Image Processing I*, assumes that the organization of an image is represented only by its grayvalue distribution. The second approach, presented in this article, makes use of a second space, the *A*–space, as autopoietic processing

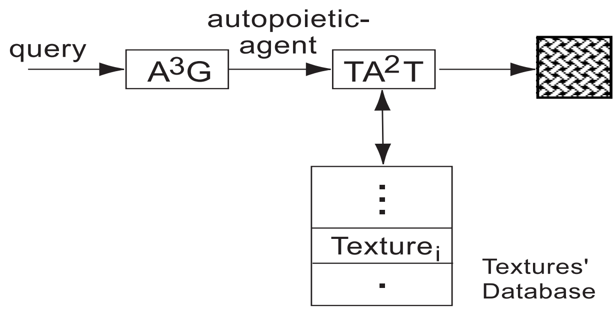

Figure 2: Proposed Texture Retrieval System (A^3G: Automatic Autopoietic–Agent Generator; TA^2T: Textural Autopoietic–Agent Tester).

domain. This allows the formulation of adaptable recognition tasks. Based on this second approach, the concept of autopoiesis as a tool for the analysis of textures was explored. The SCL model, a computational model of autopoiesis, was modified to allow the identification of textures, by introducing the idea of a texture–dependent catalyst. As a demonstrating example, a Texture Retrieval System based on the use of an autopoietic–agent, the texture–dependent catalyst, was presented. Further research must be performed to apply this concept in the solution of real-world problems.

Acknowledgment

The research presented in this paper was partially supported by *Fundacion Andes* (Chile) and by *Deutsche Forschungsgemeinschaft* (Germany).

References

[1] Varela, F.J., Maturana, H.R., and Uribe, R. (1974), *Autopoiesis: The organization of living systems, its characterization and a model*, BioSystems 5: 187-196.

[2] McMullin, B. (1997a), *Computational Autopoiesis: The original algorithm*, Working Paper 97-01-001, Santa Fe Institute, Santa Fe, NM 87501, USA. http://www.santafe.edu/sfi/publications/Working-Papers/97-01-001/

[3] McMullin, B. (1997b), *SCL: An artificial chemistry in Swarm*, Working Paper 97-01-002, Santa Fe Institute, Santa Fe, NM 87501, USA. http://www.santafe.edu/-sfi/publications/Working-Papers/97-01-002/

[4] Ruiz-del-Solar, J. (1997), *TEXSOM: A new Architecture for Texture Segmentation*, Proc. of the Workshop on Self-Organizing Maps - WSOM 97, pp. 227-232, June 4-6, Espoo, Finland.