

Non-parametric synthesis of laminar volumetric textures from a 2D sample

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Motivation

Many tools in image processing and computer graphics involve texture analysis and synthesis. The field of texture synthesis is particularly dynamic with notable applications in image compression, inpainting, extrapolation or texture mapping. This research field has led to the development of many 2D synthesis techniques, but their extension to the 3D environment remains unstable proving itself as a very complex and computational issue. 3D textures are mainly used for texturing volumetric objects trying to increase the realism of 3D scenarios, but they can also be observed in 3D vision when exploring for instance material structure or seismic data.

In this article, we are interested in non-parametric algorithms that achieve 3D texture synthesis from a single 2D sample. In particular, we investigate their capability to produce laminar textures, i.e. textures made of anisotropic sheets stacked along a given direction. The algorithms under study are variants of the original algorithm proposed by Wei and Levoy [1]. In spite of its versatility and its good computational properties, this algorithm is also known to produce output textures that are more regular than the examples they try to mimic. Several authors have proposed variants of these algorithms that intend to better reproduce, in the output texture, the diversity learned in the input sample. How do these algorithms perform on laminar textures with strong anisotropy? How are their properties modified when inferring 3D from 2D? That is what we intend to investigate in this work.

Algorithms under study

The first algorithm we implemented is a 2D/3D extension of Wei and Levoy's algorithm [1] that uses only a single 2D image as source of synthesis. Based on a Markov field hypothesis [4], the method relies on texture locality and texture stationarity. Starting from a random initialization, we synthesize voxel by voxel, examining the 2D neighbourhoods of the current voxel from two orthogonal views of the 3D block. This phase implies a search of the best match for each of these two neighbourhoods in the same input image. The output voxel value is updated with the average of the two found voxels and we reiterate until reaching the same neighbourhoods after two consecutive iterations.

Next we turned our attention to the approach proposed by Kopf et al. [2]. It aims at an optimal combination of information from the front view and the side view as suggested by Kwatra et al. [5] and, in the same time, at adding a colour histogram matching mechanism in the texture optimization procedure. But the results are, more or less, affected by blurring or missing textural patterns.

To improve these results, we addressed the algorithm of Chen and Wang [6]. Their optimization procedure, constrained by two new kinds of matching histograms – position and index histograms, indirectly achieves colour histogram matching while preserving the input texture by distributing uniformly the input pixels in the output block.

Whatever the method, a problematic issue remains the choice of the neighbourhood system. The causality of the neighbourhood is strongly related to the scan type used for synthesis. Alternative to the random walk – that allows the synthesis of a pixel by freeing itself from its past, or the lexicographical walk – making the synthesis of a pixel dependent on previous pixels, we propose new scan types, namely the 3D extensions of space filling curves (e.g. Hilbert Curve in Fig. 1).

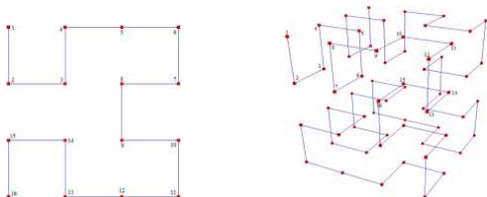


Figure 1: Illustration of a fractal scan type: on the left, the Hilbert curve in 2-dimensions and on the right, its extension to 3-dimensions.

Experimental benchmark and application

Experimental evaluation is performed on laminar textures of dense carbons observed by High Resolution Transmission Electronic Microscopy (HRTEM) and we present some results in Fig. 2.

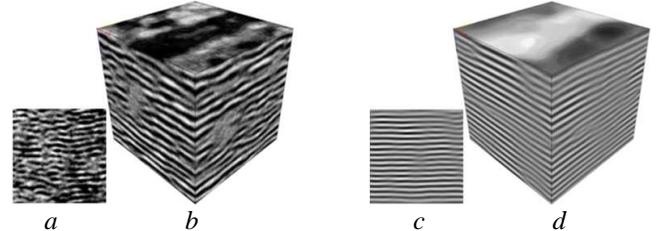


Figure 2: Volumetric results: *b* - the 3D view of the solid texture obtained from the raw HRTEM sample in *a*; and *d* is the volumetric texture obtained by synthesizing the filter HRTEM sample from *c*.

Beyond the traditional subjective evaluation of the synthesized textures as in [1-5], we propose a genuine quantitative benchmark for the analysis of the synthesized textures which consists in comparing input and output image characteristics. Both grey level statistics and pattern morphology are studied. Precisely, this original study focuses on the one hand, on grey level dynamics (1st order statistics) and spatial statistics (autocorrelations), and on the other hand on morphological properties (fringe lengths, tortuosity and orientation).

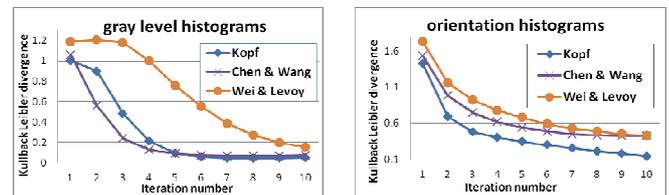


Figure 3: Indicators of the objective comparison of the 3D textures: comparing the gray level or orientation histograms of the sample and the ones obtained after a multi-2D blocks analysis.

Our objective comparison of the evolution of the 3D blocks statistics towards the ones of the 2D sample strengthens the visual assumptions relative to the improvements brought by the histogram matching, while Wei and Levoy's algorithm is not able to conserve the contrast. In terms of preserving texture structure, our study reveals the 3D textures tendency towards the same structure observed on the 2D sample. Computationally, using Kopf's approach with a fractal scan type to reduce the convergence time proves to be the most efficient method.

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