Multiresolution Maximum Intensity Volume Rendering by Morphological Pyramids

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Abstract We propose a multiresolution representation for maximum intensity projection (MIP) volume rendering, based on morphological pyramids which allow progressive refinement and have the property of perfect reconstruction. The pyramidal analysis and synthesis operators are composed of morphological erosion and dilation, combined with dyadic downsampling for analysis and dyadic upsampling for synthesis. The structure of the multiresolution MIP representation is very similar to wavelet splatting, the main differences being that (i) linear summation of voxel values is replaced by maximum computation, and (ii) linear wavelet filters are replaced by (nonlinear) morphological filters.

1 Introduction

Interactive rendering and transfer of volume data is still a demanding problem due to the sizes of the data sets. For this purpose multiresolution models are developed, which can be used to visualize data incrementally (‘progressive refinement’). An extensively studied class of such multiresolution models is based on wavelets [4, 12, 18]. Recent methods for X-ray rendering include wavelet splatting [7, 8], which extends splatting [19] by using wavelets as reconstruction filters, and Fourier-wavelet volume rendering [14, 17], which extends standard Fourier volume rendering [10], and uses a frequency domain implementation of the wavelet transform.

The goal of this paper is to propose a multiresolution representation for Maximum Intensity Projection (MIP) volume rendering, where one computes not the (opacity-weighted) integral, but the maximum along the line of sight. Because of its computational simplicity, this algorithm is widely used in the display of magnetic resonance angiography (MRA) and ultrasound data. Our approach makes use of the concept of morphological pyramids, following recent work of Goutsias and Heijmans [3, 6], who present a general framework for multiresolution signal decomposition, which includes linear wavelet analysis as a special case. Even though the morphological operators are nonlinear and non-invertible, the pyramid scheme does allow perfect reconstruction as well as progressive refinement, just as in the linear wavelet case. We restrict ourselves here to the so-called flat pyramids, where minima and maxima are computed in a local neighbourhood of each voxel, requiring only integer computations. Flatness in particular means that no new grey values are introduced in the analysis of a signal. Also, flat
pyramids allow global error control, since they have the property that the approximation error decreases monotonically as we add detail signals. Note also that the morphological pyramids used in this paper are not auxiliary data, but an exact representation of the initial data. After the pyramid has been constructed, the original volume data can be discarded, since the pyramid allows perfect reconstruction of the data.

Morphological methods have a well-established mathematical basis and are widely used in image processing for filtering, segmentation, and shape analysis [5,15]. Applications of morphological methods in visualization have so far mostly been restricted to preprocessing of volume data, but this is beginning to change. For example, Lürlig and Ertl [9] used multiscale morphological operators as an alternative to transfer functions in traditional colour-opacity volume rendering. Visualization of solids defined by morphological operators was considered in [13].

Morphological pyramids are useful in the context of MIP for several reasons. First, from a mathematical point of view, the morphological operations of erosion and dilation (involving minimum and maximum computation) are exactly the right ones for the case of MIP, which involves maximum computation, just as linear wavelet representations are the right tool for the case of linear X-ray rendering. Second, the feature extraction capabilities of morphological operators can be incorporated within the volume rendering process. This allows processing based on geometric information, not just on grey value properties, as usually is the case. For example, when processing angiographic data, the multiresolution scheme will systematically remove small veins when going higher up in the pyramid, while keeping larger ones. Whether or not this is a desired property can only be answered in the context of the concrete medical application. Finally, pyramids are one of many possibilities for accelerating MIP. Many methods already exist for that purpose, including distance encoding [20], splatting in sheared object space [2], or MIP at warp speed [11], which preprocesses the data to remove non-contributing voxels from the volume.

We stress that in this paper the main issue is the presentation of a new multiresolution MIP representation. Computational efficiency is a separate issue: any existing fast MIP implementation can in principle be used for computing the maximum projections which are required to render different levels of the pyramid, as long as such an implementation can work directly on the data structures used to represent the pyramid. In the examples below we will use the voxel projection method of Mroz et al. [11]. A detailed study of computational aspects will be presented in future work.

The organization of this paper is as follows. Section 2 gives a few preliminaries on morphological operators, and summarizes the work of Goutsias and Heijmans [3,6] on morphological pyramids. Section 3 contains the new material, i.e. the derivation of a multiresolution MIP rendering algorithm (MMIP) allowing progressive refinement. An example is given in section 4. Section 5 contains a discussion of future work.

2 Morphological pyramids

Before we consider multiresolution signal decomposition, first some elementary morphological operators are introduced.