Book Review of George Wolberg's *Digital Image Warping*

IEEE Computer Society Press, Los Alamitos, CA, 1990, $60, 318 pp., ISBN 0-8186-8944-7

by Paul Heckbert

George Wolberg has a new book on *Digital Image Warping*: the distortion of one two-dimensional image into another. Image warping is an important subject in a number of applications. In computer graphics, when we use texture mapping in image synthesis, we map a 2-D texture image onto a 3-D surface, then project the scene to create a 2-D screen image. The net effect is a warp from the 2-D texture image to 2-D screen image: an image warp. In image processing, image warps are used to register images when creating mosaics of satellite photos and to correct for camera nonlinearities and geometric distortions from remote sensing images. For special effects in movies, image warps are now used to create fantastic metamorphoses, such as the transformation from ostrich to tiger to woman in *Willow*. And in computer vision, image warps define the disparity between a pair of images when doing stereo matching.

There have been numerous papers on image warping in the technical journals of each of these fields, and it receives passing mention in many books on image processing and computer graphics, but until now there has been no book providing a conceptually unified, interdisciplinary survey of the field.

Wolberg's book consists almost entirely of a survey of previous work. Work in the newer topics such as texture filtering and two-pass warp algorithms is thoroughly surveyed, while older subjects such as 2-D transformation methods and low pass (blurring) filters are necessarily less complete. Unfortunately, Wolberg has not digested the material much for his readers, so the book often reads like an annotated bibliography. The reader is in spline-land in one paragraph, and in computer-vision-land the next. Many readers will find this confusing. Also, he propagates many inconsistencies in terminology. I encountered, for instance, three different names and notations for the box filter in different chapters of the book. Wolberg fails to cite his sources sufficiently; several figures were appropriated from SIGGRAPH papers without credit, and in one case he paraphrases about six pages of a survey paper but does not cite it until the next chapter.

The book suffers from vague terminology in many places. Wolberg's definition of separable transformation, for example, is confused with that of a separable filter. In other cases, the distinction between a transformation and the algorithm used to compute it is lost, weakening a powerful abstraction. The book also contains a number of errors in its equations and a few errors in the pseudocode.

Who is the target audience of this book? In the preface, Wolberg says "This book is intended to be a practical guide for eclectic scientists and engineers who find themselves

Appeared in IEEE Computer Graphics and Applications, Jan. 1991, pp. 114-116. Addendum May 1991, p. 5.

in need of implementing warping algorithms and comprehending the underlying concepts. ... The material in this book is a delicate balance between theory and practice.'' Unfortunately, the beginner will be discouraged by the use of words like ''bandlimited'' and ''texture mapping'' hundreds of pages before their definition, and the expert is left wanting for a theoretical framework. Beginner and expert alike will wish there were more comparisons of the many techniques surveyed. When discussing transformations, filters, or two-pass algorithms, for instance, there are few side-by-side comparisons of the subjective quality of images, quantitative quality of methods (via some error metric), memory cost, time cost, and simplicity of implementation.

In the book's defense, this is the first book on a fast-moving research topic. Any writer on this subject is faced with the difficult job of assembling many sources from disparate fields. Wolberg has assembled a bibliography that is up-to-date and quite complete; a valuable resource in itself. The book contains C code for several of the algorithms described. Finally, the book is readable, though occasionally verbose.

We now summarize the contents of the book. It consists of six main chapters: preliminaries, spatial transformations, sampling theory, image resampling, antialiasing, and scanline algorithms.

The preliminaries chapter is a brief synopsis of digital signal processing followed by a survey of image digitization hardware. The section on digitizers is interesting, but peripheral to the remainder of the book. Wolberg gives only brief summaries of the applications of image warping.

The next chapter covers spatial transformations: transformations of a 2-D source image with coordinates (u,v) into a 2-D destination image with coordinates (x,y). Before computing a warp, one must choose how to define the mapping mathematically. First, borrowing from the computer graphics literature, Wolberg surveys affine, perspective, and bilinear mappings. Next, borrowing from literature on splines, Wolberg makes the analogy between 2-D transformations and the height fields u=U(x,y) and v=V(x,y), which can be defined by scattered data interpolation. A number of local and global spline techniques are discussed. C code is given for one of the (slower) techniques. Then, in a digression into the computer vision literature, Wolberg relates image transformation with visible surface reconstruction: reconstructing a depth image from scattered, noisy samples. Wolberg does not make the case that these vision techniques are relevant to the definition of transformations for image warping, however. Unfortunately, after surveying these fourteen techniques/papers, he does not provide comparative pictures or cost analysis. The chapter concludes ''the reader is encouraged to experiment with the various methods''.

The brief chapter on sampling theory is perhaps the best. It is surprisingly difficult to find a good tutorial on sampling and aliasing in the signal processing and computer graphics literature. The chapter in the new edition of Foley-van Dam-Feiner-Hughes is a welcome exception, as is this chapter. Important concepts such as reconstruction and overlapping spectra are illustrated nicely here. The best figures in this chapter also appear in Foley et al, however.

The chapter on image resampling begins with the derivation of unified filters for resampling. They are explained as a combination of the ''reconstruction filter'' that should be used to smooth any discrete image during access, the warp, and the ''prefilter'' (also known as an antialiasing filter) that is used to blur an image appropriately before it is sampled. Unfortunately, Wolberg omits one of the main points of that work, which is that the prefilter is dominant when an image is being zoomed down (decimated), while the reconstruction filter is dominant when an image is being zoomed up (interpolated). In the remainder of the chapter, curiously, Wolberg largely neglects the decimation case, treating only interpolation.

Next, nine different families of low pass filters are discussed. This section describes simple polynomial filters of finite support (splines with local control) plus natural cubic spline techniques. Wolberg is so focused on the details of the spline methods he surveys, however, that he fails to point out the equivalence of two of them. Windowed sinc filters are next discussed. After seeing all of these options, one would hope for a comparison discussing the speed/quality tradeoff, but no such summary is given. Sadly, the figure comparing reconstruction filters was printed with poor color separations, so it is difficult to judge the filter quality visually. Perhaps this error will be amended in future printings of the book. Also, Wolberg does not explain how one would use a general filter for practical resampling. The chapter concludes with a detailed description of three 1-D signal resampling algorithms.

The next chapter, on antialiasing, is curiously out of place, coming as it does after the resampling section, where it is needed. This chapter is a mixed survey of texture filtering work and stochastic sampling techniques from ray tracing. The stochastic sampling material is extraneous, however: no reference is made to it elsewhere in the book. And the explanation of antialiasing is not as general as it might be, because it is mixed up with irrelevant concepts from texture filtering. The section on texture filtering is a survey of eight previous methods that differ in speed and quality. These are quite relevant to image warping, but very little use is made of them elsewhere in the book, perhaps because most of Wolberg's own work employs two-pass warping algorithms, which require only 1-D resampling techniques.

The final, and largest, chapter in the book discusses scanline algorithms. To warp an image one can scan systematically in the source, writing to the destination (source scanning); scan systematically in the destination, reading from the source (destination scanning); or employ one of several multi-pass algorithms that transform only rows or columns of the image in each pass. This chapter covers three topics: destination scanning algorithms for perspective transformations, various algorithms for image rotation, and two-pass algorithms.

The two-pass section is the best. It begins by summarizing the simplest two-pass algorithms, which can be used to perform affine, perspective, and bilinear warps. Next, in perhaps the most novel and interesting section of the book, Wolberg summarizes the unpublished algorithm developed by Douglas Smythe that was used by Lucasfilm to create the metamorphosis effect for *Willow* mentioned earlier. He describes the goals and techniques used by the algorithm, relating them to techniques previously discussed in the book, provides C code for the core of the program, and illustrates it with photographs of the user interface and the beautiful results that were created at ILM. Smythe's technique defines the warp by a rectangular mesh of control points, and computes it with two passes of cubic resampling. Unfortunately, Wolberg does not critically analyze the capabilities and limitations of this algorithm. The remainder of the chapter is a re-publication of Wolberg's generalization of the two-pass warping algorithm. Unfortunately, the chapter does not discuss the memory costs or filter quality of two-pass algorithms: topics that deserve attention.

The book concludes with appendices on the FFT algorithm, natural cubic splines, and foward differencing.

All things considered, I cannot recommend this book for most readers; there is neither a conceptual framework to glue the surveyed techniques together, nor significant new material. Instead, Wolberg has extracted the equations and algorithms from a number of sources, and he has not been selective in this survey: he summarizes the bad alongside the good. Also, in many cases he has not included their conclusions and comparisons. The reader is left to form his or her own synthesis of the ideas. Most readers expect more from a book.

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