PREFACE

Digital image warping is a growing branch of image processing that deals with geometric transformation techniques. Early interest in this area dates back to the mid-1960s when it was introduced for geometric correction applications in remote sensing. Since that time it has experienced vigorous growth, finding uses in such fields as medical imaging, computer vision, and computer graphics. Although image warping has traditionally been dominated by results from the remote sensing community, it has recently enjoyed a new surge of interest from the computer graphics field. This is largely due to the growing availability of advanced graphics workstations and increasingly powerful computers that make warping a viable tool for image synthesis and special effects. Work in this area has already led to successful market products such as real-time video effects generators for the television industry and cost-effective warping hardware for geometric correction. Current trends indicate that this area will have growing impact on desktop video, a new technology that promises to revolutionize the video production market in much the same way as desktop publishing has altered the way in which people prepare documents.

Digital image warping has benefited greatly from several fields, ranging from early work in remote sensing to recent developments in computer graphics. The scope of these contributions, however, often varies widely owing to different operating conditions and assumptions. This state is reflected in the image processing literature. Despite the fact that image processing is a well-established subject with many textbooks devoted to its study, image warping is generally treated as a peripheral subject with only sparse coverage. Furthermore, these textbooks rarely present image warping concepts as a single body of knowledge. Since the presentations are usually tailored to some narrow readership, different components of the same conceptual framework are emphasized. This has left a noticeable gap in the literature with respect to a unified treatment of digital image warping in a single text. This book attempts to redress this imbalance.

The purpose of this book is to introduce the fundamental concepts of digital image warping and to lay a foundation that can be used as the basis for further study and research in this field. Emphasis is given to the development of a single coherent

framework. This serves to unify the terminology, motivation, and contributions of many disciplines that have each contributed in significantly different ways. The coherent framework puts the diverse aspects of this subject into proper perspective. In this manner, the needs and goals of a diverse readership are addressed.

This book is intended to be a practical guide for eclectic scientists and engineers who find themselves in need of implementing warping algorithms and comprehending the underlying concepts. It is also geared to students of image processing who wish to apply their knowledge of that subject to a well-defined application. Special effort has been made to keep prerequisites to a minimum in the hope of presenting a self-contained treatment of this field. Consequently, knowledge of elementary image processing is helpful, although not essential. Furthermore, every effort is made to reinforce the discussion with an intuitive understanding. As a result, only those aspects of supporting theory that are directly relevant to the subject are brought to bear. Interested readers may consult the extensive bibliography for suggested readings that delve further into those areas.

This book originally grew out of a survey paper that I had written on geometric transformation techniques for digital images. During the course of preparing that paper, the large number of disparate sources with potential bearing on digital image warping became strikingly apparent. This writing reflects my goal to consolidate these works into a self-contained central repository. Since digital image warping involves many diverse aspects, from implementation considerations to the mathematical abstractions of sampling and filtering theory, I have attempted to chart a middle path by focusing upon those basic concepts, techniques, and problems that characterize the geometric transformation of digital images, given the inevitable limitations of discrete approximations. The material in this book is thus a delicate balance between theory and practice. The practical segment includes algorithms which the reader may implement. The theory segment is comprised of proofs and formulas derived to motivate the algorithms and to establish a standard of comparison among them. In this manner, theory provides a necessary context in which to understand the goals and limitations of the collection of algorithms presented herein.

The organization of this book closely follows the components of the conceptual framework for digital image warping. Chapter 1 discusses the history of this field and presents a brief overview of the subsequent chapters. A review of common terminology, mathematical preliminaries, and digital image acquisition is presented in Chapter 2. As we shall see later, digital image warping consists of two basic operations: a spatial transformation to define the rearrangement of pixels and interpolation to compute their values. Chapter 3 describes various common formulations for spatial transformations, as well as techniques for inferring them when only a set of correspondence points are known. Chapter 4 provides a review of sampling theory, the mathematical framework used to describe the filtering problems that follow. Chapter 5 describes image resampling, including several common interpolation kernels. They are applied in the discussion of antialiasing in Chapter 6. This chapter demonstrates several approaches used to avoid artifacts that manifest themselves to the discrete nature of digital images. Fast warping techniques based on scanline algorithms are presented in Chapter 7. These

results are particularly useful for both hardware and software realizations of geometric transformations. Finally, the main points of the book are recapitulated in Chapter 8. Source code, written in C, is scattered among the chapters and appendices to demonstrate implementation details for various algorithms.

It is often difficult to measure the success of a book. Ultimately, the effectiveness of this text can be judged in two ways. First, the reader should appreciate the difficulties and subtleties in actually warping a digital image. This includes a full understanding of the problems posed due to the discrete nature of digital images, as well as an awareness of the tradeoffs confronting an algorithm designer. There are valuable lessons to be learned in this process. Second, the reader should master the key concepts and techniques that facilitate further research and development. Unlike many other branches of science, students of digital image warping benefit from the direct visual realization of mathematical abstractions and concepts. As a result, readers are fortunate to have images clarify what mathematical notation sometimes obscures. This makes the study of digital image warping a truly fascinating and enjoyable endeavor.

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