Synthesis Lectures on Computer Graphics and Animation

SYNTHESIS
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Ron Goldman

Rethinking Quaternions

Theory and Computation

Springer

Rethinking Quaternions Ron Goldman

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Rethinking Quaternions Ron Goldman,2010-05-05 Quaternion multiplication can be used to rotate vectors in three dimensions Therefore in computer graphics quaternions have three principal applications to increase speed and reduce storage for calculations involving rotations to avoid distortions arising from numerical inaccuracies caused by floating point computations with rotations and to interpolate between two rotations for key frame animation Yet while the formal algebra of quaternions is well known in the graphics community the derivations of the formulas for this algebra and the geometric principles underlying this algebra are not well understood The goals of this monograph are to provide a fresh geometric interpretation for quaternions appropriate for contemporary computer graphics based on mass points to present better ways to visualize quaternions and the effect of quaternion multiplication on points and vectors in three dimensions using insights from the algebra and geometry of multiplication in the complex plane to derive the formula for quaternion multiplication from first principles to develop simple intuitive proofs of the sandwiching formulas for rotation and reflection to show how to apply sandwiching to compute perspective projections In addition to these theoretical issues we also address some computational questions We develop straightforward formulas for converting back and forth between quaternion and matrix representations for rotations reflections and perspective projections and we discuss the relative advantages and disadvantages of the quaternion and matrix representations for these transformations Moreover we show how to avoid distortions due to floating point computations with rotations by using unit quaternions to represent rotations We also derive the formula for spherical linear interpolation and we explain how to apply this formula to interpolate between two rotations for key frame animation Finally we explain the role of quaternions in low dimensional Clifford algebras and we show how to apply the Clifford algebra for R3 to model rotations reflections and perspective projections To help the reader understand the concepts and formulas presented here we have incorporated many exercises in order to clarify and elaborate some of the key points in the text Table of Contents Preface Theory Computation Rethinking Quaternions and Clif ford Algebras References Further Reading Author Biography *Rethinking Quaternions* Ron Goldman,2022-05-31 Quaternion multiplication can be used to rotate vectors in three dimensions Therefore in computer graphics quaternions have three principal applications to increase speed and reduce storage for calculations involving rotations to avoid distortions arising from numerical inaccuracies caused by floating point computations with rotations and to interpolate between two rotations for key frame animation Yet while the formal algebra of quaternions is well known in the graphics community the derivations of the formulas for this algebra and the geometric principles underlying this algebra are not well understood The goals of this monograph are to provide a fresh geometric interpretation for quaternions appropriate for contemporary computer graphics based on mass points to present better ways to visualize quaternions and the effect of quaternion multiplication on points and vectors in three dimensions using insights from the algebra and geometry of multiplication in the complex plane to derive the

formula for quaternion multiplication from first principles to develop simple intuitive proofs of the sandwiching formulas for rotation and reflection to show how to apply sandwiching to compute perspective projections In addition to these theoretical issues we also address some computational questions We develop straightforward formulas for converting back and forth between quaternion and matrix representations for rotations reflections and perspective projections and we discuss the relative advantages and disadvantages of the quaternion and matrix representations for these transformations Moreover we show how to avoid distortions due to floating point computations with rotations by using unit quaternions to represent rotations We also derive the formula for spherical linear interpolation and we explain how to apply this formula to interpolate between two rotations for key frame animation Finally we explain the role of quaternions in low dimensional Clifford algebras and we show how to apply the Clifford algebra for R3 to model rotations reflections and perspective projections To help the reader understand the concepts and formulas presented here we have incorporated many exercises in order to clarify and elaborate some of the key points in the text Table of Contents Preface Theory Computation Rethinking Quaternions and Clif ford Algebras References Further Reading Author Biography **Dual Quaternions and Their Associated Clifford Algebras** Ronald Goldman,2023-09-29 Clifford algebra for dual quaternions has emerged recently as an alternative to standard matrix algebra as a computational framework for computer graphics This book presents dual quaternions and their associated Clifford algebras in a new light accessible to and geared toward the computer graphics community Collecting all the associated formulas and theorems in one place this book provides an extensive and rigorous treatment of dual quaternions as well as showing how two models of Clifford algebra emerge naturally from the theory of dual quaternions Each section comes complete with a set of exercises to help readers sharpen and practice their understanding This book is accessible to anyone with a basic knowledge of quaternion algebra and is of particular use to forward thinking members of the computer graphics community Dual Quaternions and Their Associated Clifford Algebras Ronald Goldman,2023-09-29 Clifford algebra for dual quaternions has emerged recently as an alternative to standard matrix algebra as a computational framework for computer graphics This book presents dual quaternions and their associated Clifford algebras in a new light accessible to and geared toward the computer graphics community Collecting all the associated formulas and theorems in one place this book provides an extensive and rigorous treatment of dual quaternions as well as showing how two models of Clifford algebra emerge naturally from the theory of dual quaternions Each section comes complete with a set of exercises to help readers sharpen and practice their understanding This book is accessible to anyone with a basic knowledge of quaternion algebra and is of particular use to forward thinking members of the computer graphics community Essential Mathematics for Games and Interactive Applications James M. Van Verth,Lars M. Bishop,2015-09-15 Expert Guidance on the Math Needed for 3D Game ProgrammingDeveloped from the authors popular Game Developers Conference GDC tutorial Essential Mathematics for Games and Interactive Applications Third Edition illustrates the importance of mathematics in 3D

programming It shows you how to properly animate simulate and render scenes and discus **An Introduction to Verification of Visualization Techniques** Tiago Etiene,Robert M. Kirby,Cláudio T. Silva,2022-06-01 As we increase our reliance on computer generated information often using it as part of our decision making process we must devise tools to assess the correctness of that information Consider for example software embedded on vehicles used for simulating aircraft performance or used in medical imaging In those cases software correctness is of paramount importance as there s little room for error Software verification is one of the tools available to attain such goals Verification is a well known and widely studied subfield of computer science and computational science and the goal is to help us increase confidence in the software implementation by verifying that the software does what it is supposed to do The goal of this book is to introduce the reader to software verification in the context of visualization In the same way we became more dependent on commercial software we have also increased our reliance on visualization software The reason is simple visualization is the lens through which users can understand complex data and as such it must be verified The explosion in our ability to amass data requires tools not only to store and analyze data but also to visualize it This book is comprised of six chapters After an introduction to the goals of the book we present a brief description of both worlds of visualization Chapter 2 and verification Chapter 3 We then proceed to illustrate the main steps of the verification pipeline for visualization algorithms We focus on two classic volume visualization techniques namely Isosurface Extraction Chapter 4 and Direct Volume Rendering Chapter 5 We explain how to verify implementations of those techniques and report the latest results in the field of verification of visualization techniques The last chapter concludes the book and highlights new research topics for the future **Virtual Crowds** Mubbasir Kapadia,Nuria Pelechano,Jan Allbeck,Norm Badler,2022-05-31 This volume presents novel computational models for representing digital humans and their interactions with other virtual characters and meaningful environments In this context we describe efficient algorithms to animate control and author human like agents having their own set of unique capabilities personalities and desires We begin with the lowest level of footstep determination to steer agents in collision free paths Steering choices are controlled by navigation in complex environments including multi domain planning with dynamically changing situations Virtual agents are given perceptual capabilities analogous to those of real people including sound perception multi sense attention and understanding of environment semantics which affect their behavior choices The roles and impacts of individual attributes such as memory and personality are explored The animation challenges of integrating a number of simultaneous behavior and movement demands on an agent are addressed through an open source software system Finally the creation of stories and narratives with groups of agents subject to planning and environmental constraints culminates the presentation *Efficient Quadrature Rules for Illumination Integrals* Ricardo Marques,Christian Bouville,Luís Paulo Santos,Kadi Bouatouch,2022-06-01 Rendering photorealistic images is a costly process which can take up to several days in the case of high quality images In most cases the task of sampling the incident radiance function to

evaluate the illumination integral is responsible for an important share of the computation time Therefore to reach acceptable rendering times the illumination integral must be evaluated using a limited set of samples Such a restriction raises the question of how to obtain the most accurate approximation possible with such a limited set of samples One must thus ensure that sampling produces the highest amount of information possible by carefully placing and weighting the limited set of samples Furthermore the integral evaluation should take into account not only the information brought by sampling but also possible information available prior to sampling such as the integrand smoothness This idea of sparse information and the need to fully exploit the little information available is present throughout this book The presented methods correspond to the state of the art solutions in computer graphics and take into account information which had so far been underexploited or even neglected by the previous approaches The intended audiences are Ph D students and researchers in the field of realistic image synthesis or global illumination algorithms or any person with a solid background in graphics and numerical techniques **Cloth Simulation for Computer Graphics** Tuur Stuyck,2022-06-01 Physics based animation is commonplace in animated feature films and even special effects for live action movies Think about a recent movie and there will be some sort of special effects such as explosions or virtual worlds Cloth simulation is no different and is ubiquitous because most virtual characters hopefully wear some sort of clothing The focus of this book is physics based cloth simulation We start by providing background information and discuss a range of applications This book provides explanations of multiple cloth simulation techniques More specifically we start with the most simple explicitly integrated mass spring model and gradually work our way up to more complex and commonly used implicitly integrated continuum techniques in state of the art implementations We give an intuitive explanation of the techniques and give additional information on how to efficiently implement them on a computer This book discusses explicit and implicit integration schemes for cloth simulation modeled with mass spring systems In addition to this simple model we explain the more advanced continuum inspired cloth model introduced in the seminal work of Baraff and Witkin 1998 This method is commonly used in industry We also explain recent work by Liu et al 2013 that provides a technique to obtain fast simulations In addition to these simulation approaches we discuss how cloth simulations can be art directed for stylized animations based on the work of Wojan et al 2016 Controllability is an essential component of a feature animation film production pipeline We conclude by pointing the reader to more advanced techniques **Stochastic Partial Differential Equations for Computer Vision with Uncertain Data** Tobias Preusser,Robert M. Kirby,Torben Pätz,2022-06-01 In image processing and computer vision applications such as medical or scientific image data analysis as well as in industrial scenarios images are used as input measurement data It is good scientific practice that proper measurements must be equipped with error and uncertainty estimates For many applications not only the measured values but also their errors and uncertainties should be and more and more frequently are taken into account for further processing This error and uncertainty propagation must be done for every processing step

such that the final result comes with a reliable precision estimate The goal of this book is to introduce the reader to the recent advances from the field of uncertainty quantification and error propagation for computer vision image processing and image analysis that are based on partial differential equations PDEs It presents a concept with which error propagation and sensitivity analysis can be formulated with a set of basic operations The approach discussed in this book has the potential for application in all areas of quantitative computer vision image processing and image analysis In particular it might help medical imaging finally become a scientific discipline that is characterized by the classical paradigms of observation measurement and error awareness This book is comprised of eight chapters After an introduction to the goals of the book Chapter 1 we present a brief review of PDEs and their numerical treatment Chapter 2 PDE based image processing Chapter 3 and the numerics of stochastic PDEs Chapter 4 We then proceed to define the concept of stochastic images Chapter 5 describe how to accomplish image processing and computer vision with stochastic images Chapter 6 and demonstrate the use of these principles for accomplishing sensitivity analysis Chapter 7 Chapter 8 concludes the book and highlights new research topics for the future **Geometric and Discrete Path Planning for Interactive Virtual Worlds** Marcelo Kallmann,Mubbasir Kapadia,2022-05-31 Path planning and navigation are indispensable components for controlling autonomous agents in interactive virtual worlds Given the growing demands on the size and complexity of modern virtual worlds a number of new techniques have been developed for achieving intelligent navigation for the next generation of interactive multi agent simulations This book reviews the evolution of several related techniques starting from classical planning and computational geometry techniques and then gradually moving toward more advanced topics with focus on recent developments from the work of the authors The covered topics range from discrete search and geometric representations to planning under different types of constraints and harnessing the power of graphics hardware in order to address Euclidean shortest paths and discrete search for multiple agents under limited time budgets The use of planning algorithms beyond path planning is also discussed in the areas of crowd animation and whole body motion planning for virtual characters **Sound Synthesis, Propagation, and Rendering** Shiguang Liu,Dinesh Manocha,2022-03-24 This book gives a broad overview of research on sound simulation driven by a variety of applications Vibrating objects produce sound which then propagates through a medium such as air or water before finally being heard by a listener As a crucial sensory channel sound plays a vital role in many applications There is a well established research community in acoustics that has studied the problems related to sound simulation for six decades Some of the earliest work was motivated by the design of concert halls theaters or lecture rooms with good acoustic characteristics These problems also have been investigated in other applications including noise control and sound design for urban planning building construction and automotive applications Moreover plausible or realistic sound effects can improve the sense of presence in a virtual environment or a game In these applications sound can provide important clues such as source directionality and spatial size

The book first surveys various sound synthesis methods including harmonic synthesis texture synthesis spectral analysis and physics based synthesis Next it provides an overview of sound propagation techniques including wave based methods geometric based methods and hybrid methods The book also summarizes various techniques for sound rendering Finally it surveys some recent trends including the use of machine learning methods to accelerate sound simulation and the use of sound simulation techniques for other applications such as speech recognition source localization and computer aided design

Finite Element Method Simulation of 3D Deformable Solids Eftychios Sifakis,Jernej Barbič,2022-06-01 This book serves as a practical guide to simulation of 3D deformable solids using the Finite Element Method FEM It reviews a number of topics related to the theory and implementation of FEM approaches measures of deformation constitutive laws of nonlinear materials tetrahedral discretizations and model reduction techniques for real time simulation Simulations of deformable solids are important in many applications in computer graphics including film special effects computer games and virtual surgery The Finite Element Method has become a popular tool in many such applications Variants of FEM catering to both offline and real time simulation have had a mature presence in computer graphics literature This book is designed for readers familiar with numerical simulation in computer graphics who would like to obtain a cohesive picture of the various FEM simulation methods available their strengths and weaknesses and their applicability in various simulation scenarios The book is also a practical implementation guide for the visual effects developer offering a lean yet adequate synopsis of the underlying mathematical theory Chapter 1 introduces the quantitative descriptions used to capture the deformation of elastic solids the concept of strain energy and discusses how force and stress result as a response to deformation Chapter 2 reviews a number of constitutive models i e analytical laws linking deformation to the resulting force that has successfully been used in various graphics oriented simulation tasks Chapter 3 summarizes how deformation and force can be computed discretely on a tetrahedral mesh and how an implicit integrator can be structured around this discretization Finally chapter 4 presents the state of the art in model reduction techniques for real time FEM solid simulation and discusses which techniques are suitable for which applications Topics discussed in this chapter include linear modal analysis modal warping subspace simulation and domain decomposition *Geometric Continuity of Curves and Surfaces* Przemysław Kiciak,2022-05-31 This book is written for students CAD system users and software developers who are interested in geometric continuity a notion needed in everyday practice of Computer Aided Design and also a hot subject of research It contains a description of the classical geometric spline curves and a solid theoretical basis for various constructions of smooth surfaces Textbooks on computer graphics usually cover the most basic and necessary information about spline curves and surfaces in order to explain simple algorithms In textbooks on geometric design one can find more details more algorithms and more theory This book teaches how various parts of the theory can be gathered together and turned into constructions of smooth curves and smooth surfaces of arbitrary topology The mathematical background needed to understand this book is similar to what is

necessary to read other textbooks on geometric design most of it is basic linear algebra and analysis More advanced mathematical material is introduced using elementary explanations Reading Geometric Continuity of Curves and Surfaces provides an excellent opportunity to recall and exercise necessary mathematical notions and it may be your next step towards better practice and higher understanding of design principles **GPU Ray Tracing in Non-Euclidean Spaces** Tiago Novello,Vinícius da Silva,Luiz Velho,2022-05-31 This book explores the visualization of three dimensional non Euclidean spaces using ray tracing techniques in Graphics Processing Unit GPU This is a trending topic in mathematical visualization that combines the mathematics areas of geometry and topology with visualization concepts of computer graphics Several conditions made this a special moment for such topic On one hand the development of mathematical research computer graphics and algorithms have provided the necessary theoretical framework On the other hand the evolution of the technologies and media allows us to be immersed in three dimensional spaces using Virtual Reality The content of this book serves both experts in the areas and students Although this is a short book it is self contained since it considers all the ideas motivations references and intuitive explanations of the required fundamental concepts **Mathematical Basics of Motion and Deformation in Computer Graphics** Ken Anjyo,Hiroyuki Ochiai,2014-10-22 This synthesis lecture presents an intuitive introduction to the mathematics of motion and deformation in computer graphics Starting with familiar concepts in graphics such as Euler angles quaternions and affine transformations we illustrate that a mathematical theory behind these concepts enables us to develop the techniques for efficient effective creation of computer animation This book therefore serves as a good guidepost to mathematics differential geometry and Lie theory for students of geometric modeling and animation in computer graphics Experienced developers and researchers will also benefit from this book since it gives a comprehensive overview of mathematical approaches that are particularly useful in character modeling deformation and animation Table of Contents Preface Symbols and Notations Introduction Rigid Transformation Affine Transformation Exponential and Logarithm of Matrices 2D Affine Transformation between Two Triangles Global 2D Shape Interpolation Parametrizing 3D Positive Affine Transformations Further Readings Bibliography Authors Biographies **Information Theory Tools for Image Processing** Miquel Feixas,Anton Bardera,Jaume Rigau,Qing Xu,2022-06-01 Information Theory IT tools widely used in many scientific fields such as engineering physics genetics neuroscience and many others are also useful transversal tools in image processing In this book we present the basic concepts of IT and how they have been used in the image processing areas of registration segmentation video processing and computational aesthetics Some of the approaches presented such as the application of mutual information to registration are the state of the art in the field All techniques presented in this book have been previously published in peer reviewed conference proceedings or international journals We have stressed here their common aspects and presented them in an unified way so to make clear to the reader which problems IT tools can help to solve which specific tools to use and how to apply them The IT basics are presented so as to be

self contained in the book The intended audiences are students and practitioners of image processing and related areas such as computer graphics and visualization In addition students and practitioners of IT will be interested in knowing about these applications Table of Contents Preface Acknowledgments Information Theory Basics Image Registration Image Segmentation Video Key Frame Selection Informational Aesthetics Measures Bibliography Authors Biographies **Mathematical Tools for Shape Analysis and Description** Silvia Biasotti,Bianca Falcidieno,Daniela Giorgi,Michela Spagnuolo,2022-06-01 This book is a guide for researchers and practitioners to the new frontiers of 3D shape analysis and the complex mathematical tools most methods rely on The target reader includes students researchers and professionals with an undergraduate mathematics background who wish to understand the mathematics behind shape analysis The authors begin with a quick review of basic concepts in geometry topology differential geometry and proceed to advanced notions of algebraic topology always keeping an eye on the application of the theory through examples of shape analysis methods such as 3D segmentation correspondence and retrieval A number of research solutions in the field come from advances in pure and applied mathematics as well as from the re reading of classical theories and their adaptation to the discrete setting In a world where disciplines fortunately have blurred boundaries the authors believe that this guide will help to bridge the distance between theory and practice Table of Contents Acknowledgments Figure Credits About this Book 3D Shape Analysis in a Nutshell Geometry Topology and Shape Representation Differential Geometry and Shape Analysis Spectral Methods for Shape Analysis Maps and Distances between Spaces Algebraic Topology and Topology Invariants Differential Topology and Shape Analysis Reeb Graphs Morse and Morse Smale Complexes Topological Persistence Beyond Geometry and Topology Resources Bibliography Authors Biographies **Numerical Methods for Linear Complementarity Problems in Physics-Based Animation** Sarah Niebe,Kenny Erleben,2022-05-31 Linear complementarity problems LCPs have for many years been used in physics based animation to model contact forces between rigid bodies in contact More recently LCPs have found their way into the realm of fluid dynamics Here LCPs are used to model boundary conditions with fluid wall contacts LCPs have also started to appear in deformable models and granular simulations There is an increasing need for numerical methods to solve the resulting LCPs with all these new applications This book provides a numerical foundation for such methods especially suited for use in computer graphics This book is mainly intended for a researcher Ph D student post doc professor who wants to study the algorithms and do more work research in this area Programmers might have to invest some time brushing up on math skills for this we refer to Appendices A and B The reader should be familiar with linear algebra and differential calculus We provide pseudo code for all the numerical methods which should be comprehensible by any computer scientist with rudimentary programming skills The reader can find an online supplementary code repository containing Matlab implementations of many of the core methods covered in these notes as well as a few Python implementations Erleben 2011 Table of Contents Introduction Numerical Methods Guide for Software and Selecting Methods Bibliography Authors

Biographies **Heterogeneous Spatial Data** Giuseppe Patanè,Michela Spagnuolo,2022-05-31 New data acquisition techniques are emerging and are providing fast and efficient means for multidimensional spatial data collection Airborne LIDAR surveys SAR satellites stereo photogrammetry and mobile mapping systems are increasingly used for the digital reconstruction of the environment All these systems provide extremely high volumes of raw data often enriched with other sensor data e g beam intensity Improving methods to process and visually analyze this massive amount of geospatial and user generated data is crucial to increase the efficiency of organizations and to better manage societal challenges Within this context this book proposes an up to date view of computational methods and tools for spatio temporal data fusion multivariate surface generation and feature extraction along with their main applications for surface approximation and rainfall analysis The book is intended to attract interest from different fields such as computer vision computer graphics geomatics and remote sensing working on the common goal of processing 3D data To this end it presents and compares methods that process and analyze the massive amount of geospatial data in order to support better management of societal challenges through more timely and better decision making independent of a specific data modeling paradigm e g 2D vector data regular grids or 3D point clouds We also show how current research is developing from the traditional layered approach adopted by most GIS softwares to intelligent methods for integrating existing data sets that might contain important information on a geographical area and environmental phenomenon These services combine traditional map oriented visualization with fully 3D visual decision support methods and exploit semantics oriented information e g a priori knowledge annotations segmentations when processing merging and integrating big pre existing data sets

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Rethinking Quaternions Ron Goldman Introduction

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