

Virtual Reality ExCursions

WITH PROGRAMS IN C

Christopher Watkins
Stephen R. Marenka



Bring your PC to life!

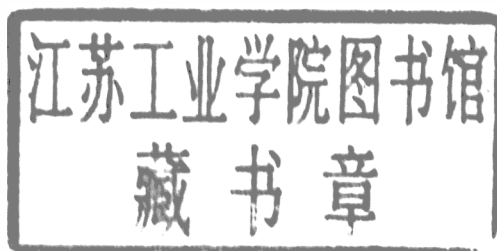


Virtual Reality ExCursions

WITH PROGRAMS IN C

Christopher D. Watkins

Stephen R. Marenka



AP PROFESSIONAL

Boston San Diego New York
London Sydney Tokyo Toronto

This book is printed on acid-free paper. ∞

Copyright © 1994 by Academic Press, Inc.

Copyright © 1994 by Christopher D. Watkins and Stephen R. Marenka

All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

All brand names and product names mentioned in this book are trademarks or registered trademarks of their respective copyright owners.

AP PROFESSIONAL

955 Massachusetts Avenue, Cambridge, MA 02139

An imprint of ACADEMIC PRESS, INC.

A Division of HARCOURT BRACE & COMPANY

United Kingdom Edition published by

ACADEMIC PRESS LIMITED

24-28 Oval Road, London NW1 7DX

ISBN 0-12-737865-0

Printed in the United States of America.

94 95 96 97 98 ML 9 8 7 6 5 4 3 2 1

Virtual Reality ExCursions

WITH PROGRAMS IN C

LIMITED WARRANTY AND DISCLAIMER OF LIABILITY

ACADEMIC PRESS, INC. ("AP") AND ANYONE ELSE WHO HAS BEEN INVOLVED IN THE CREATION OR PRODUCTION OF THE ACCOMPANYING CODE ("THE PRODUCT") CANNOT AND DO NOT WARRANT THE PERFORMANCE OR RESULTS THAT MAY BE OBTAINED BY USING THE PRODUCT. THE PRODUCT IS SOLD "AS IS" WITHOUT WARRANTY OF ANY KIND (EXCEPT AS HEREAFTER DESCRIBED), EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY WARRANTY OF PERFORMANCE OR ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. AP WARRANTS ONLY THAT THE MAGNETIC DISKETTE(S) ON WHICH THE CODE IS RECORDED IS FREE FROM DEFECTS IN MATERIAL AND FAULTY WORKMANSHIP UNDER THE NORMAL USE AND SERVICE FOR A PERIOD OF NINETY (90) DAYS FROM THE DATE THE PRODUCT IS DELIVERED. THE PURCHASER'S SOLE AND EXCLUSIVE REMEDY IN THE EVENT OF A DEFECT IS EXPRESSLY LIMITED TO EITHER REPLACEMENT OF THE DISKETTE(S) OR REFUND OF THE PURCHASE PRICE, AT AP'S SOLE DISCRETION.

IN NO EVENT, WHETHER AS A RESULT OF BREACH OF CONTRACT, WARRANTY OR TORT (INCLUDING NEGLIGENCE), WILL AP OR ANYONE WHO HAS BEEN INVOLVED IN THE CREATION OR PRODUCTION OF THE PRODUCT BE LIABLE TO PURCHASER FOR ANY DAMAGES, INCLUDING ANY LOST PROFITS, LOST SAVINGS OR OTHER INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PRODUCT OR ANY MODIFICATIONS THEREOF, OR DUE TO THE CONTENTS OF THE CODE, EVEN IF AP HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, OR FOR ANY CLAIM BY ANY OTHER PARTY.

Any request for replacement of a defective diskette must be postage prepaid and must be accompanied by the original defective diskette, your mailing address and telephone number, and proof of date of purchase and purchase price. Send such requests, stating the nature of the problem, to Academic Press Customer Service, 6277 Sea Harbor Drive, Orlando, FL 32887, 1-800-321-5068. APP shall have no obligation to refund the purchase price or to replace a diskette based on claims of defects in the nature or operation of the Product.

Some states do not allow limitation on how long an implied warranty lasts, nor exclusions or limitations of incidental or consequential damage, so the above limitations and exclusions may not apply to you. This Warranty gives you specific legal rights, and you may also have other rights which vary from jurisdiction to jurisdiction.

THE RE-EXPORT OF UNITED STATES ORIGIN SOFTWARE IS SUBJECT TO THE UNITED STATES LAWS UNDER THE EXPORT ADMINISTRATION ACT OF 1969 AS AMENDED. ANY FURTHER SALE OF THE PRODUCT SHALL BE IN COMPLIANCE WITH THE UNITED STATES DEPARTMENT OF COMMERCE ADMINISTRATION REGULATIONS. COMPLIANCE WITH SUCH REGULATIONS IS YOUR RESPONSIBILITY AND NOT THE RESPONSIBILITY OF AP.

Acknowledgments

The outline for this book was generated by Christopher D. Watkins and Stephen R. Marenka. The technical text and figures were written and created by Christopher D. Watkins, while the vast writing of the general text was done by Stephen R. Marenka. Vincent Mallette of the Georgia Institute of Technology made gross contributions to the human perception chapter of this book, with the research assistance of Alice Merta and Cassandra Jeffries. Christopher D. Watkins is totally responsible for the labour of birth for all of the software found with this book. Some proofing of the manuscript, as well as compilation of profiles for companies and universities involved in virtual reality products and research, was done by Christina N. Noland.

All of the software in this book was written in C using Borland C++ version 3.1. The Borland C++ software was furnished by Borland International, 1800 Green Hills Road, Scotts Valley, CA 95066.

Thanks also to WATCOM of 415 Phillip Street, Ontario, Canada, N2L 3X2 for supplying the WATCOM compiler version 9.5.

Thanks go to director Michael Sinclair of the Georgia Institute of Technology Multimedia Technology Laboratory for supplying images of the Eye Surgery Simulator, of the Motion Interactive System for sports, and of the three-dimensional scanner output.

Thanks go to Paul Kingston and Schelly Weedman of IVEX Corporation for information and images regarding the IVEX Visual System for Flight Simulation. IVEX Corporation designs, manufactures, and markets a series of high-performance visual simulation systems for use in civil and military training markets. Their systems distinguish themselves from others in that the overall reality of the visual scene is greater. This "reality" is primarily achieved using fractal texturing methods and high polygon counts for detail. IVEX Corporation is located at 4355 International Blvd., Norcross, GA 30093.

Thanks go to director James D. Foley, Larry Hodges, and Tom Meyer of the Georgia Institute of Technology College of Computing Graphics, Visualization & Usability (GVU) Center for the remainder of the images found throughout the book and for their contributions regarding virtual reality research.

Thanks go to Thomas Morley of Georgia Institute of Technology for supplying information on mass-spring systems.

Thanks to John Poulton and Linda Houseman of the University of North Carolina at Chapel Hill for their contributions regarding their research into virtual reality.

Thanks go to Ken Welton and Michael Glaser of Lavista Systems, Inc., Tucker, Georgia for supplying equipment necessary for the completion of this book.

Thanks to Jordan Hargrave for supplying us with the BGI graphics drivers found along with the software. The drivers are copyright Jordan Hargrave.

Thanks to Jack Brady of Southeastern Digital Images, Inc. and C/Food Software, Atlanta, for acting as a sounding board for ideas.

Thanks go to Jack Tumblin for his brainstorming regarding three-dimensional computer graphics techniques.

Thanks go to Stephen B. Coy for his help in obtaining information on algorithms for polygon filling and for his brainstorming on three-dimensional computer graphics techniques.

Thanks go to Adam Schiffman of The Graphics Alternative for production of his copyrighted image "silver surfers" found on the front cover of this book. The Graphics Alternative consults for 3D Animation, 2D Imaging, and Video. The Graphics Alternative is located at 190 El Cerrito Plaza #107, EL Cerrito, CA 94530, and TGA can also be contacted by voice at 510-528-1652 or BBS at 510-524-2780.

Thanks go to Mitch Kolbe of 34 W. Orange Street, Tarpon Springs, Florida for providing the photorealistic paintings used as texture maps. Mr. Kolbe has worked on such projects as one of America's largest murals, The Cyclorama, which depicts the Civil War in Atlanta in 1864. Several projects followed the completion of The Cyclorama; these included museum background murals, which required molding, casting, and fiberglass sculpture, as well as work for the U.S. Fish and Wildlife Service, Epcot Center, and Disney World. Since 1985 Mr. Kolbe has been fully dedicated to the creation of fine art oil paintings. He presently resides in the original studio of the famous artist George Innes Jr. in Tarpon Springs, Florida.

Algorithm, Inc. of 3776 Lavista Road, Suite 100A, Atlanta, GA 30084 produces tools for ray tracing, volume rendering, 3-D modeling and VR, animation, image processing, and interactive image warping and morphing. Contact us at the above address or call/fax (404) 634-0920 for more information regarding our products.

And special thanks again go to our parents, wives, and friends for their love and patience with us during this project.

And, as always, much thanks again to the Coca-Cola Company and to the Jolt Cola Company for providing Cola and to Snapple for providing tea to keep us awake long enough to complete this project.

Biographies

Christopher D. Watkins is founder and president of *Algorithm, Inc.*, an Atlanta-based scientific research and engineering company that produces software for medical imaging and visualization, photorealistic rendering, virtual reality, and animation. He is an electrical engineer, an experienced programmer, and coauthor of *Photorealism and Ray Tracing* (M&T Books, 1992) and *Modern Image Processing: Warping, Morphing and Classical Techniques* (Academic Press, 1993). He received his degrees from The Georgia Institute of Technology and is a member of the IEEE and of the ACM/SIGGRAPH.

Stephen R. Marenka is an electrical engineer from the Georgia Institute of Technology, specializing in intelligent control, data reduction techniques, and human-computer interfaces for multiplatform computing (VAX/VMS, Unix, Macintosh, and PC systems). He is working on his MS in electrical engineering control systems. He is also a coauthor of *Modern Image Processing: Warping, Morphing and Classical Techniques* (Academic Press, 1993) and is a member of the IEEE Control Systems and Computer Societies.

It's All in the Name

You will be encountering some unusual words and terms which surround virtual reality research and development, some of which follow.

display—a device (as a cathode-ray tube) that gives information in visual form in communications

The term display as used in the virtual environments field of research is applied more generally, such as:

display—a device that gives information in communications

Now we may use the term display in reference to a visual display—a computer screen, an auditory display—a stereo or other sound source, and a haptic display—motion, tactile, or force-feedback equipment.

haptic—relating to or based on the sense of touch

The term haptic includes all displays that present information to the loosely defined sense of touch, including tactile, texture, force-feedback, motion, and pressure.

Virtual environments research in modern times is often traced to Ivan Sutherland's 1965 paper "The Ultimate Display," presented to the triennial conference of the International Processing Societies. Sutherland described "a program of research in computer graphics which has challenged and guided the field ever since." Sutherland said that one must look at a computer display screen as a window through which one beholds a *virtual world*. "The challenge to computer graphics is to make the window look real, sound real, and the objects act real. Indeed, in the ultimate display, one will not look at that world through a window, but will be immersed in it, will change viewpoint by natural motions of head and body, and will interact directly and naturally with the object in the world, hearing and feeling them, as well as seeing them." Such research has proceeded under a variety of names, including *virtual environments*, *virtual reality*, *artificial reality*, and *synthetic experience*. (Fuchs and Fisher)

virtual—being in effect but not in actual fact

environment—the conditions, circumstances, and influences surrounding and affecting an organism.

reality—of or relating to practical or everyday concerns or activities

Many of the top researchers in the field, including Frederick Brooks at the University of North Carolina in Chapel Hill and Scott Fisher, formerly of NASA Ames Research Center and now of Telepresence Research, prefer the usage of the term *virtual environments* to describe the field. Jaron Lanier, formerly of VPL Research, coined and prefers the term *virtual reality*. Myron Krueger coined and prefers the term *artificial reality*, which refers to a specific subset of research defined in his book *Artificial Reality*.

This book uses the terms virtual environment and virtual reality indiscriminately. Also, we specifically include parallel lines of research which may not be wholly immersive in nature (since very few systems, if any, can totally immerse all of the senses at this point in time anyway).

The term DataGlove is VPL Research's trademark name for a hand-based input device, further defined in the glossary. You will soon encounter other terms which may be unfamiliar to you; please refer to the glossary in the appendix for definitions of these and other important relevant concepts.

Initialization

Welcome to a magical land where anything is possible and the physical laws of the real world no longer apply, the land of virtual reality. In this book we make an excursion into this realm to learn about its history, the defining boundaries of the land, and all the fascinating things happening within its borders. In the first chapter we explore the current applications in the vast field of virtual reality. The second chapter presents a brief history of the field and its founders. Chapter 3 comprises human perception and how it works. We cover some interesting notes and much of the hot debate in the field in Chapter four. The fifth chapter describes many of the complexities involved in implementing virtual environments on real equipment. There is lots of good stuff in the appendix; we highly recommend that you take a look. Enjoy the ride!

If we perceive our role aright, we then see more clearly the proper criterion for success: a toolmaker succeeds as, and only as, the *users* of his

tool succeed with his aid. However shining the blade, however jeweled the hilt, however perfect the heft, a sword is tested only by cutting. That swordsmith is successful whose clients die of old age.

—F. Brooks, "Grasping Reality Through Illusion: Interactive Graphics Serving Science"

Contents

List of Illustrations.....	xv
Acknowledgments.....	xviii
Biographies	xxi
It's All in the Name.....	xxii
Initialization.....	xxiii
Chapter 1—Virtual Reality Applications	1
Introduction.....	1
Section 1—Architectural Walkthroughs and Computer-Aided Design	2
Section 2—Augmentation and Decision Support	11
Section 3—Telecommunications and Virtual Interfaces	13
Molecular Studies.....	14
Teleoperation and Telepresence—Remote and Hazardous Workplaces.....	16
Section 4—Training	18
Section 5—Scientific Research.....	20
Section 6—Entertainment.....	22
Section 7—Medical Applications Using Virtual Reality	25
Computer-Aided Designed Treatment.....	25
Virtual Treatments and Rehabilitation.....	26
Therapy with Digital Puppets	29
Augmentation	32
Helping the Physician.....	32
Helping the Handicapped.....	33
Sign Language.....	34

Virtual Surgery	35
Interfaces	35
Remote Workplaces	37
Training	38
Application Notes	41
Chapter 2—From Whence Virtual Reality—A Brief and Incomplete History	43
Introduction.....	43
Section 1—Classical History	44
In the Oral Tradition, Theater and the Dramatic Arts	44
In the Manner of Records and Writing	47
The Beginning of Electronic Communication	47
Morton Heilig and the Experience Theater	49
Section 2—The Age of Information Technology and the Dawn of Cyberspace.....	52
ARPA and the ARC	52
Douglas Engelbart and Intelligence Augmentation.....	54
Sketchpad—“The Most Important Program Ever Written”	55
Ivan and the Sword of Damocles.....	58
ARPAnet and the Internet	60
Xerox PARC	60
Myron Krueger and Responsive Environments	62
MIT’s Arch-Mac and the Media Lab	66
The Aspen Movie Map and Surrogate Travel	67
Atari Research	69
NASA Ames Human Factors Research Division	70
Jaron Lanier and VPL	73
Frederick Brooks and UNC Chapel Hill.....	76
Brooks and Intelligence Amplification	76
Molecular Docking.....	78
The Architectural Walkthrough.....	80
Medical Imaging and Three-Dimensional Interactive Graphics.....	81
More History Related to VR	82
Flight Simulation.....	83
Evans and Sutherland	85
Military HMDs	86
So What’s the History of VR?	87

Chapter 3—From the Point of View	89
Introduction	89
Section 1—Of Sight	90
Section 2—Of Sound	116
Section 3—On Haptics	119
Perception	121
Chapter 4—Virtual Considerations	125
Introduction	125
Section 1—Desktop versus Immersion (What's the View?)	125
The World through a Window	126
Boom-Mounted Displays	127
Immersion in a Room	128
Gloves and Goggles	128
Section 2—Future Possibilities	129
Architectural Walkthroughs and Computer-Aided Design	129
Augmentation	130
Augmenting the Handicapped	131
Telecommunications	132
Remote and Hazardous Workplaces	133
Computer Interfaces	133
The Metamedium	134
Agents and Animation	134
Training	135
Scientific Exploration	136
Entertainment	136
Section 3—Virtual Reality and Society	137
The Internet (and the Matrix)	138
Virtual Identities	139
Virtual Community	140
NetLaw	141
Section 4—Wireheads—Living in a Virtual Environment	142
Living in Virtual Environments	142
VR as the Ultimate Drug	143
Reality Check	143
Section 5—Teledildonics (Cybersex) and Home Entertainment	143

Section 6—Simulator Sickness.....	144
Section 7—The Contributions of Science Fiction	145
The Classics.....	145
Cyberpunks.....	146
Final Considerations	147
Chapter 5—Technical Considerations for Virtual Reality Systems	149
Section 1—The Concept of a Virtual Reality System	149
A Brief, Yet Premature Overview of a VR system	150
Section 2—The Mathematics of Three-dimensional Computer	
Graphics (Geometry, Matrix Algebra, and Trigonometry)	153
A Discussion on Data Types and Structures.....	154
General Types.....	154
Point and Vector Types	155
Polygon Types.....	156
Three-dimensional Graphics World Types.....	157
Control Types	157
Basic Mathematics Functions and Macros.....	158
Comparison Functions and Macros	159
Swapping Functions and Macros	160
Power Functions.....	160
Pseudo-Random Number Generation Functions.....	160
Two-dimensional Vector Functions and Macros.....	161
Three-dimensional Vector Functions and Macros	162
3 x 3 Matrix Functions for Two-Dimensional Manipulations	164
4 x 4 Matrix Functions for Three-Dimensional Manipulations	165
How the Functions Work.....	166
Functions Involving Radians and Degrees	166
The ALG_COSD and ALG_SIND Functions	168
The ALG_POWER and ALG_POWER_INT Functions.....	168
The ALG_LOG Function.....	168
The ALG_EXP10 Function.....	169
The ALG_SIGN Function	169
The ALG_MIN, ALG_MIN3, ALG_MIN4, ALG_MAX,	
ALG_MAX3, ALG_MAX4 Functions	169
Vector and Matrix Functions	169
The ALG_VEC2_MAKE and ALG_VEC3_MAKE Functions ...	171
The ALG_VEC2_COMPONENTS and	
ALG_VEC3_COMPONENTS Functions.....	171
The ALG_VEC2_AVERAGE and ALG_VEC3_AVERAGE	
Functions.....	171

The ALG_VEC2_NEGATE and ALG_VEC3_NEGATE Functions	171
The ALG_VEC2_DOT and ALG_VEC3_DOT Functions	172
The ALG_VEC2_LENGTH and ALG_VEC3_LENGTH Functions	173
The ALG_VEC2_NORMALIZE and ALG_VEC3_NORMALIZE Functions	174
The ALG_VEC2_MINIMUM and ALG_VEC3_MINIMUM Functions	175
The ALG_VEC2_MAXIMUM and ALG_VEC3_MAXIMUM Functions	175
The ALG_VEC2_COMPARE and ALG_VEC3_COMPARE Functions	176
The ALG_VEC2_COPY and ALG_VEC3_COPY Functions	176
The ALG_VEC2_ADD and ALG_VEC3_ADD Functions	176
The ALG_VEC2_SUB and ALG_VEC3_SUB Functions	178
The ALG_VEC2_LIN_COMB and ALG_VEC3_LIN_COMB Functions	178
The ALG_VEC2_SCAL_MULT and ALG_VEC3_SCAL_MULT Functions	178
ALG_VEC3_ADD_SCAL_MULT Functions	179
The ALG_VEC2_MUL and ALG_VEC3_MUL Functions	179
The ALG_VEC2_DETERMINANT Function	180
The ALG_VEC3_CROSS Function	180
The ALG_VEC2_ZERO and ALG_VEC3_ZERO Functions	181
Affine Transformation Routines	181
The alg_copy_4x4_matrix Function	182
The alg_multiply_4x4_matrix Function	182
The alg_zero_4x4_matrix Function	183
The alg_identity_4x4_matrix Function	183
The alg_scale_4x4_matrix Function	183
The alg_rotate_4x4_matrix Function	184
The alg_translate_4x4_matrix Function	185
The alg_transform_4x4_matrix Function	186
Pseudo-Random Number Generation	187
The ALG_RAND Function	188
The ALG_RAND_INT Function	188
On to the Program Listings	188
PROGRAM LISTINGS	188
Section 3—Database Hierarchy and Bubba	218
World Order	218
The Features of an Ideal Database Modeler	220
Primitive Support and Manipulation	220
Object Support and Manipulation	221