

# ***Introduction to 3D Game Programming with DirectX® 10***

***Frank D. Luna***

***Wordware Publishing, Inc.***

# Contents

Acknowledgments . . . . .	xvii
Introduction . . . . .	xix

## ***Part I — Mathematical Prerequisites***

---

<b><i>Chapter 1 Vector Algebra</i></b> . . . . .	<b>3</b>
1.1 Vectors . . . . .	3
1.1.1 Vectors and Coordinate Systems . . . . .	4
1.1.2 Left-Handed Versus Right-Handed Coordinate Systems. . . . .	6
1.1.3 Basic Vector Operations. . . . .	6
1.2 Length and Unit Vectors . . . . .	8
1.3 The Dot Product . . . . .	9
1.4 The Cross Product . . . . .	12
1.5 Points . . . . .	13
1.6 D3DX Vectors. . . . .	14
1.7 Summary . . . . .	18
1.8 Exercises . . . . .	19
<b><i>Chapter 2 Matrix Algebra</i></b> . . . . .	<b>23</b>
2.1 Definition . . . . .	23
2.2 Matrix Multiplication . . . . .	25
2.2.1 Definition . . . . .	25
2.2.2 Vector-Matrix Multiplication. . . . .	27
2.2.3 Associativity . . . . .	27
2.3 The Transpose of a Matrix . . . . .	28
2.4 The Identity Matrix . . . . .	28
2.5 The Inverse of a Matrix. . . . .	29
2.6 D3DX Matrices . . . . .	30
2.7 Summary . . . . .	34
2.8 Exercises . . . . .	35
<b><i>Chapter 3 Transformations</i></b> . . . . .	<b>37</b>
3.1 Basic Transformations . . . . .	38
3.1.1 Scaling . . . . .	39
3.1.2 Rotation . . . . .	40
3.1.3 Translation . . . . .	43
3.2 D3DX Transformation Functions . . . . .	44
3.3 Composition of Transformations . . . . .	45
3.4 Change of Coordinate Transformations. . . . .	46
3.4.1 Vectors . . . . .	47

3.4.2 Points . . . . .	48
3.4.3 Matrix Representation . . . . .	49
3.4.4 Associativity and Change of Coordinate Matrices . . . . .	50
3.4.5 Inverses and Change of Coordinate Matrices . . . . .	51
3.5 Summary . . . . .	52
3.6 Exercises . . . . .	53

## ***Part II — Direct3D Foundations***

---

<b>Chapter 4 Direct3D Initialization . . . . .</b>	<b>57</b>
4.1 Preliminaries . . . . .	58
4.1.1 Direct3D Overview . . . . .	58
4.1.2 COM . . . . .	58
4.1.3 Textures and Data Resource Formats . . . . .	59
4.1.4 The Swap Chain and Page Flipping . . . . .	60
4.1.5 Depth Buffering . . . . .	61
4.1.6 Texture Resource Views . . . . .	64
4.1.7 Multisampling . . . . .	65
4.2 Initializing Direct3D . . . . .	66
4.2.1 Describe the Swap Chain . . . . .	67
4.2.2 Create the Device and Swap Chain . . . . .	68
4.2.3 Create the Render Target View . . . . .	70
4.2.4 Create the Depth/Stencil Buffer and View . . . . .	71
4.2.5 Bind the Views to the Output Merger Stage . . . . .	73
4.2.6 Set the Viewport . . . . .	73
4.3 Timing and Animation . . . . .	75
4.3.1 The Performance Timer . . . . .	75
4.3.2 Game Timer Class . . . . .	76
4.3.3 Time Elapsed between Frames . . . . .	77
4.3.4 Game Time . . . . .	79
4.4 Text Output . . . . .	82
4.5 The Demo Application Framework . . . . .	83
4.5.1 D3DApp . . . . .	84
4.5.2 Non-Framework Methods . . . . .	85
4.5.3 Framework Methods . . . . .	86
4.5.4 Frame Statistics . . . . .	87
4.5.5 The Message Handler . . . . .	89
4.5.6 Going Full Screen . . . . .	91
4.5.7 The Init Direct3D Demo . . . . .	91
4.6 Debugging Direct3D Applications . . . . .	93
4.7 Summary . . . . .	94
4.8 Exercises . . . . .	96
<b>Chapter 5 The Rendering Pipeline . . . . .</b>	<b>99</b>
5.1 The 3D Illusion . . . . .	100
5.2 Model Representation . . . . .	102
5.3 Basic Computer Color . . . . .	104

5.3.1 Color Operations . . . . .	105
5.3.2 128-Bit Color . . . . .	106
5.3.3 32-Bit Color . . . . .	107
5.4 Overview of the Rendering Pipeline. . . . .	108
5.5 The Input Assembler Stage . . . . .	109
5.5.1 Vertex Layouts . . . . .	109
5.5.2 Vertex Buffers . . . . .	114
5.5.3 Primitive Topology . . . . .	118
5.5.3.1 Point List . . . . .	119
5.5.3.2 Line Strip . . . . .	119
5.5.3.3 Line List . . . . .	119
5.5.3.4 Triangle Strip . . . . .	119
5.5.3.5 Triangle List . . . . .	120
5.5.3.6 Primitives with Adjacency . . . . .	120
5.5.4 Indices and Index Buffers . . . . .	121
5.6 The Vertex Shader Stage . . . . .	126
5.6.1 Local Space and World Space . . . . .	126
5.6.2 View Space . . . . .	128
5.6.3 Projection and Homogeneous Clip Space . . . . .	131
5.6.3.1 Defining a Frustum . . . . .	132
5.6.3.2 Projecting Vertices . . . . .	134
5.6.3.3 Normalized Device Coordinates (NDC) . . . . .	134
5.6.3.4 Writing the Projection Equations with a Matrix . . . . .	135
5.6.3.5 Normalized Depth Value . . . . .	136
5.6.3.6 D3DXMatrixPerspectiveFovLH . . . . .	138
5.6.4 Example Vertex Shader . . . . .	139
5.6.5 Constant Buffers . . . . .	141
5.7 The Geometry Shader Stage . . . . .	143
5.8 The Clipping Stage . . . . .	143
5.9 The Rasterization Stage . . . . .	145
5.9.1 Viewport Transform . . . . .	145
5.9.2 Backface Culling . . . . .	146
5.9.3 Vertex Attribute Interpolation . . . . .	147
5.10 The Pixel Shader Stage . . . . .	148
5.11 The Output Merger Stage . . . . .	150
5.12 Render States . . . . .	150
5.13 Effects . . . . .	153
5.13.1 Effect Files . . . . .	153
5.13.2 Creating an Effect . . . . .	155
5.13.3 Interfacing with Effects from the C++ Application . . . . .	156
5.13.4 Using Effects to Draw . . . . .	157
5.14 Colored Cube Demo . . . . .	158
5.15 Peaks and Valleys Demo . . . . .	166
5.16 Dynamic Vertex Buffers . . . . .	169
5.17 Summary . . . . .	171
5.18 Exercises . . . . .	173

## Contents

<b>Chapter 6 Lighting . . . . .</b>	<b>177</b>
6.1 Light and Material Interaction . . . . .	178
6.2 Normal Vectors . . . . .	180
6.2.1 Computing Normal Vectors . . . . .	181
6.2.2 Transforming Normal Vectors . . . . .	183
6.3 Lambert's Cosine Law . . . . .	185
6.4 Diffuse Lighting . . . . .	186
6.5 Ambient Lighting . . . . .	187
6.6 Specular Lighting . . . . .	188
6.7 Brief Recap . . . . .	191
6.8 Parallel Lights . . . . .	193
6.9 Point Lights . . . . .	194
6.9.1 Attenuation . . . . .	194
6.9.2 Range . . . . .	195
6.10 Spotlights . . . . .	195
6.11 Implementation . . . . .	197
6.11.1 Lighting Structures . . . . .	197
6.11.2 Implementing Parallel Lights . . . . .	198
6.11.3 Implementing Point Lights . . . . .	198
6.11.4 Implementing Spotlights . . . . .	199
6.12 Lighting Demo . . . . .	200
6.12.1 Effect File . . . . .	200
6.12.2 Structure Packing . . . . .	202
6.12.3 C++ Application Code . . . . .	204
6.12.4 Normal Computation . . . . .	206
6.13 Summary . . . . .	207
6.14 Exercises . . . . .	208
<b>Chapter 7 Texturing . . . . .</b>	<b>211</b>
7.1 Texture and Resource Recap . . . . .	212
7.2 Texture Coordinates . . . . .	214
7.3 Creating and Enabling a Texture . . . . .	216
7.4 Filters . . . . .	218
7.4.1 Magnification . . . . .	218
7.4.2 Minification . . . . .	220
7.4.2.1 Creating Mipmaps . . . . .	221
7.4.3 Anisotropic Filtering . . . . .	221
7.5 Sampling Textures . . . . .	222
7.6 Textures as Materials . . . . .	223
7.7 Crate Demo . . . . .	225
7.7.1 Specifying Texture Coordinates . . . . .	225
7.7.2 Creating the Texture . . . . .	226
7.7.3 Setting the Texture . . . . .	226
7.7.4 Texture Effect . . . . .	227
7.8 Address Modes . . . . .	229
7.9 Transforming Textures . . . . .	232
7.10 Land Tex Demo . . . . .	233
7.10.1 Grid Texture Coordinate Generation . . . . .	234

7.10.2 Texture Tiling . . . . .	235
7.10.3 Texture Animation . . . . .	235
7.11 Compressed Texture Formats . . . . .	236
7.12 Summary . . . . .	238
7.13 Exercises . . . . .	239
<b>Chapter 8 Blending . . . . .</b>	<b>241</b>
8.1 The Blending Equation . . . . .	242
8.2 Blend Operations . . . . .	243
8.3 Blend Factors . . . . .	243
8.4 Blend State. . . . .	244
8.5 Examples. . . . .	247
8.5.1 No Color Write . . . . .	247
8.5.2 Adding/Subtracting . . . . .	248
8.5.3 Multiplying . . . . .	248
8.5.4 Transparency . . . . .	249
8.5.5 Blending and the Depth Buffer. . . . .	250
8.6 Alpha Channels . . . . .	251
8.7 Transparent Water Demo . . . . .	253
8.8 Clipping Pixels. . . . .	255
8.9 Fog . . . . .	256
8.10 Summary . . . . .	260
8.11 Exercises . . . . .	261
<b>Chapter 9 Stenciling . . . . .</b>	<b>263</b>
9.1 Depth/Stencil Formats and Clearing. . . . .	264
9.2 The Stencil Test . . . . .	265
9.3 The Depth/Stencil State Block . . . . .	266
9.3.1 Depth Settings . . . . .	266
9.3.2 Stencil Settings. . . . .	267
9.3.3 Creating and Binding a Depth/Stencil State . . . . .	269
9.3.4 Depth/Stencil States in Effect Files . . . . .	269
9.4 Mirror Demo. . . . .	270
9.4.1 Overview . . . . .	271
9.4.2 Defining the Depth/Stencil States . . . . .	272
9.4.3 Blending the Reflection. . . . .	273
9.4.4 Drawing the Scene . . . . .	274
9.5 Summary. . . . .	276
9.6 Exercises. . . . .	277
<b>Chapter 10 The Geometry Shader. . . . .</b>	<b>281</b>
10.1 Programming Geometry Shaders . . . . .	282
10.2 Tree Billboards Demo . . . . .	286
10.2.1 Overview . . . . .	286
10.2.2 Vertex Structure . . . . .	288
10.2.3 Effect File . . . . .	289
10.2.4 SV_PrimitiveID . . . . .	292
10.3 Texture Arrays . . . . .	293

10.3.1 Overview . . . . .	293
10.3.2 Sampling a Texture Array . . . . .	294
10.3.3 Loading Texture Arrays . . . . .	295
10.3.4 Texture Subresources . . . . .	297
10.4 Summary . . . . .	298
10.5 Exercises . . . . .	300

## ***Part III — Direct3D Topics***

---

<b><i>Chapter 11 Cube Mapping . . . . .</i></b>	<b>305</b>
11.1 Cube Mapping . . . . .	305
11.2 Environment Maps . . . . .	307
11.2.1 Loading and Using Cube Maps in Direct3D . . . . .	310
11.3 Texturing a Sky . . . . .	311
11.4 Modeling Reflections . . . . .	313
11.5 New Application Code . . . . .	316
11.5.1 Texture Manager . . . . .	316
11.5.2 Global Effects and Input Layouts . . . . .	316
11.5.3 New 3D Object Classes . . . . .	317
11.6 Summary . . . . .	319
11.7 Exercises . . . . .	319
<b><i>Chapter 12 Normal Mapping . . . . .</i></b>	<b>321</b>
12.1 Motivation . . . . .	321
12.2 Normal Maps . . . . .	323
12.3 Texture/Tangent Space . . . . .	325
12.4 Vertex Tangent Space . . . . .	327
12.5 Transforming between Tangent Space and Object Space . . . . .	328
12.6 Shader Code . . . . .	329
12.7 Summary . . . . .	332
12.8 Exercises . . . . .	333
<b><i>Chapter 13 Shadow Mapping . . . . .</i></b>	<b>335</b>
13.1 Render to Texture . . . . .	335
13.1.1 Constructor/Destructor/Accessors . . . . .	337
13.1.2 DrawableTex2D::init . . . . .	337
13.1.3 DrawableTex2D::buildDepthMap . . . . .	338
13.1.4 DrawableTex2D::buildColorMap . . . . .	339
13.1.5 DrawableTex2D::begin . . . . .	340
13.1.6 DrawableTex2D::end . . . . .	341
13.2 Orthographic Projections . . . . .	342
13.3 Projective Texture Coordinates . . . . .	344
13.3.1 Code Implementation . . . . .	346
13.3.2 Points Outside the Frustum . . . . .	346
13.3.3 Orthographic Projections . . . . .	347
13.4 Shadow Mapping . . . . .	348
13.4.1 Algorithm Description . . . . .	348

13.4.2 Building the Shadow Map . . . . .	349
13.4.3 Restore Rendering to the Back Buffer . . . . .	351
13.4.4 The Shadow Factor . . . . .	352
13.4.5 The Shadow Map Test . . . . .	353
13.4.6 Filtering and the Shadow Map Test . . . . .	356
13.4.7 Rendering the Shadow Map . . . . .	358
13.5 Summary . . . . .	359
13.6 Exercises . . . . .	360
<b>Chapter 14 Meshes . . . . .</b>	<b>361</b>
14.1 ID3DX10MeshBuffer . . . . .	361
14.2 Geometry Info . . . . .	362
14.3 Subsets and the Attribute Buffer . . . . .	365
14.4 Drawing . . . . .	367
14.5 Adjacency Information . . . . .	368
14.6 Optimizing . . . . .	369
14.7 The Attribute Table . . . . .	370
14.8 Cloning . . . . .	372
14.9 Commit to Device . . . . .	374
14.10 Creating a Mesh . . . . .	374
14.11 Mesh Viewer Demo . . . . .	376
14.12 Summary . . . . .	377
14.13 Exercises . . . . .	378
<b>Chapter 15 Picking . . . . .</b>	<b>379</b>
15.1 Screen to Projection Window Transform . . . . .	381
15.2 World/Local Space Picking Ray . . . . .	384
15.3 Ray/Mesh Intersection . . . . .	385
15.4 Bounding Volumes . . . . .	387
15.4.1 Computing an Axis-Aligned Bounding Box . . . . .	388
15.4.2 Rotations and Axis-Aligned Bounding Boxes . . . . .	389
15.4.3 Computing a Bounding Sphere . . . . .	391
15.4.4 Scaling and Bounding Spheres . . . . .	391
15.5 Demo Application . . . . .	391
15.6 Summary . . . . .	392
15.7 Exercises . . . . .	392
<b>Chapter 16 Terrain Rendering . . . . .</b>	<b>395</b>
16.1 Heightmaps . . . . .	396
16.1.1 Creating a Heightmap . . . . .	397
16.1.2 Loading a RAW File . . . . .	398
16.1.3 Smoothing . . . . .	400
16.2 Texturing . . . . .	402
16.3 Lighting . . . . .	405
16.4 Terrain FX . . . . .	406
16.5 Terrain Height . . . . .	408
16.6 Summary . . . . .	411
16.7 Exercises . . . . .	412

## Contents

<i>Chapter 17 Particle Systems and Stream Output</i> . . . . .	413
17.1 Particle Representation. . . . .	413
17.2 Particle Motion . . . . .	415
17.3 Randomness . . . . .	417
17.4 Blending and Particle Systems . . . . .	419
17.5 Stream Output . . . . .	421
17.5.1 Creating a Geometry Shader for Stream Output . . . . .	421
17.5.2 Stream Output Only. . . . .	422
17.5.3 Creating a Vertex Buffer for Stream Output . . . . .	423
17.5.4 Binding to the SO Stage. . . . .	424
17.5.5 Unbinding from the Stream Output Stage . . . . .	424
17.5.6 Auto Draw. . . . .	425
17.5.7 Ping-Ponging Vertex Buffers . . . . .	425
17.6 GPU-Based Particle System . . . . .	425
17.6.1 Particle Effects . . . . .	426
17.6.2 The Particle System Class . . . . .	426
17.6.3 Emitter Particles . . . . .	428
17.6.4 The Initialization Vertex Buffer. . . . .	428
17.6.5 The Update/Draw Method . . . . .	429
17.7 Fire . . . . .	431
17.8 Rain. . . . .	436
17.9 Summary . . . . .	442
17.10 Exercises . . . . .	443

## Appendices

---

<i>Appendix A Introduction to Windows Programming</i> . . . . .	445
A.1 Overview . . . . .	446
A.1.1 Resources . . . . .	446
A.1.2 Events, the Message Queue, Messages, and the Message Loop . . . . .	447
A.1.3 GUI. . . . .	448
A.1.4 Unicode. . . . .	449
A.2 Basic Windows Application . . . . .	450
A.3 Explaining the Basic Windows Application . . . . .	454
A.3.1 Includes, Global Variables, and Prototypes . . . . .	454
A.3.2 WinMain . . . . .	454
A.3.3 WNDCLASS and Registration . . . . .	455
A.3.4 Creating and Displaying the Window . . . . .	457
A.3.5 The Message Loop. . . . .	459
A.3.6 The Window Procedure . . . . .	460
A.3.7 The MessageBox Function . . . . .	462
A.4 A Better Message Loop . . . . .	462
A.5 Summary . . . . .	463
A.6 Exercises . . . . .	464

<i>Appendix B High-Level Shading Language Reference</i>	<b>465</b>
B.1 Variable Types . . . . .	465
B.1.1 Scalar Types . . . . .	465
B.1.2 Vector Types . . . . .	465
B.1.2.1 Swizzles . . . . .	466
B.1.3 Matrix Types . . . . .	467
B.1.4 Arrays . . . . .	468
B.1.5 Structures . . . . .	468
B.1.6 The <code>typedef</code> Keyword . . . . .	468
B.1.7 Variable Prefixes . . . . .	469
B.1.8 Casting . . . . .	469
B.2 Keywords and Operators . . . . .	470
B.2.1 Keywords. . . . .	470
B.2.2 Operators. . . . .	470
B.3 Program Flow . . . . .	472
B.4 Functions . . . . .	473
B.4.1 User-Defined Functions . . . . .	473
B.4.2 Built-in Functions . . . . .	475
<i>Appendix C Some Analytic Geometry</i>	<b>479</b>
C.1 Rays, Lines, and Segments . . . . .	479
C.2 Parallelograms. . . . .	480
C.3 Triangles. . . . .	481
C.4 Planes . . . . .	481
C.4.1 D3DXPlane. . . . .	483
C.4.2 Point/Plane Spatial Relation . . . . .	483
C.4.3 Construction . . . . .	484
C.4.4 Normalizing a Plane . . . . .	485
C.4.5 Transforming a Plane. . . . .	486
C.4.6 Finding the Nearest Point on a Plane to a Given Point . . . . .	486
C.4.7 Ray/Plane Intersection. . . . .	487
C.4.8 Reflecting Vectors . . . . .	487
C.4.9 Reflecting Points . . . . .	488
C.4.10 Reflection Matrix . . . . .	488
C.5 Exercises . . . . .	490
Bibliography and Further Reading. . . . .	491
Index . . . . .	495