

**THE MORGAN KAUFMANN SERIES
IN COMPUTER GRAPHICS**

HIGH DYNAMIC RANGE IMAGING

ACQUISITION, DISPLAY, AND IMAGE-BASED LIGHTING

**ERIK REINHARD
GREG WARD**

**SUMANTA PATTANAİK
PAUL DEBEVEC**



ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG
LONDON • NEW YORK • OXFORD
PARIS • SAN DIEGO • SAN FRANCISCO
SINGAPORE • SYDNEY • TOKYO

Morgan Kaufmann is an imprint of Elsevier



MORGAN KAUFMANN PUBLISHER

Contents

	FOREWORD	XV
	PREFACE	XVII
01	INTRODUCTION	1
02	LIGHT AND COLOR	19
	2.1 Radiometry	19
	2.2 Photometry	24
	2.3 Colorimetry	28
	2.4 Color Spaces	33
	2.5 White Point and Illuminants	36
	2.6 Color Correction	48
	2.7 Color Opponent Spaces	50
	2.8 Color Appearance	57
	2.9 Display Gamma	69
	2.10 Brightness Encoding	73
	2.11 Standard RGB Color Spaces	76
03	HDR IMAGE ENCODINGS	85
	3.1 LDR Versus HDR Encodings	85
	3.2 Applications of HDR Images	87
	3.3 HDR Image Formats	89
	3.3.1 The HDR Format	91

3.3.2	The TIFF Float and LogLuv Formats	93
3.3.3	The OpenEXR Format	97
3.3.4	Other Encodings	98
3.3.5	Emerging “Lossy” HDR Formats	99
3.4	HDR Encoding Comparison	106
3.5	Conclusions	111
04	HDR IMAGE CAPTURE	115
4.1	Photography and Light Measurement	115
4.2	HDR Image Capture from Multiple Exposures	117
4.3	Film Scanning	118
4.4	Image Registration and Alignment	122
4.5	The Mean Threshold Bitmap Alignment Technique	123
4.5.1	Threshold Noise	128
4.5.2	Overall Algorithm	131
4.5.3	Efficiency Considerations	134
4.5.4	Results	135
4.6	Deriving the Camera Response Function	136
4.6.1	Debevec and Malik Technique	137
4.6.2	Mitsunaga and Nayar Technique	140
4.6.3	Choosing Image Samples for Response Recovery	142
4.6.4	Caveats and Calibration	143
4.7	Ghost Removal	147
4.8	Lens Flare Removal	152
4.8.1	The Point Spread Function	152
4.8.2	Estimating the PSF	155
4.8.3	Removing the PSF	159
4.9	Direct Capture of HDR Imagery	159
4.9.1	Viper FilmStream	160
4.9.2	SMaL	161
4.9.3	Pixim	162
4.9.4	SpheronVR	163

4.9.5	Point Grey Research	163
4.10	Conclusions	164
05	DISPLAY DEVICES	167
5.1	Hardcopy Devices	167
5.1.1	The Reflection Print	168
5.1.2	Transparent Media	170
5.1.3	HDR Still Image Viewer	171
5.2	Softcopy Devices	176
5.2.1	Cathode-ray Tubes and Liquid Crystal Displays	176
5.2.2	Sunnybrook Technologies' HDR Displays	179
5.2.3	Other Display Technologies	182
06	THE HUMAN VISUAL SYSTEM AND HDR TONE MAPPING	187
6.1	Tone-mapping Problem	187
6.2	Human Visual Adaptation	191
6.2.1	The Pupil	193
6.2.2	The Rod and Cone Systems	193
6.2.3	Photo-pigment Depletion and Regeneration	196
6.2.4	Photoreceptor Mechanisms	197
6.3	Visual Adaptation Models for HDR Tone Mapping	206
6.3.1	Photoreceptor Adaptation Model for Tone Mapping	207
6.3.2	Threshold Versus Intensity Model for Tone Mapping	210
6.4	Background Intensity in Complex Images	211
6.4.1	Image Average As I_b	211
6.4.2	Local Average As I_b	212
6.4.3	Multiscale Adaptation	215
6.5	Dynamics of Visual Adaptation	219
6.6	Summary	221
07	SPATIAL TONE REPRODUCTION	223
7.1	Preliminaries	224

7.1.1	Calibration	225
7.1.2	Color Images	228
7.1.3	Homomorphic Filtering	231
7.1.4	Gaussian Blur	233
7.1.5	Validation	235
7.2	Global Operators	237
7.2.1	Miller Brightness-ratio-preserving Operator	237
7.2.2	Tumblin–Rushmeier Brightness-preserving Operator	242
7.2.3	Ward Contrast-based Scale Factor	246
7.2.4	Ferwerda Model of Visual Adaptation	247
7.2.5	Logarithmic and Exponential Mappings	252
7.2.6	Drago Logarithmic Mapping	255
7.2.7	Reinhard and Devlin Photoreceptor Model	258
7.2.8	Ward Histogram Adjustment	266
7.2.9	Schlick Uniform Rational Quantization	273
7.3	Local Operators	277
7.3.1	Chiu Spatially Variant Operator	278
7.3.2	Rahman Retinex	281
7.3.3	Fairchild iCAM	286
7.3.4	Pattanaik Multiscale Observer Model	292
7.3.5	Ashikhmin Spatially Variant Operator	301
7.3.6	Reinhard et al. Photographic Tone Reproduction	305
7.3.7	Pattanaik Adaptive Gain Control	313
7.3.8	Yee Segmentation-based Approach	316
7.4	Summary	323
08	FREQUENCY DOMAIN AND GRADIENT DOMAIN TONE REPRODUCTION	325
8.1	Frequency Domain Operators	325
8.1.1	Oppenheim Frequency-based Operator	326
8.1.2	Durand Bilateral Filtering	333

8.1.3	Choudhury Trilateral Filtering	340
8.2	Gradient Domain Operators	345
8.2.1	Horn Lightness Computation	346
8.2.2	Fattal Gradient Domain Compression	352
8.3	Performance	357
8.3.1	Local and Global Operators	359
8.3.2	Gradient and Frequency Domain Operators	360
8.4	Discussion	362
09	IMAGE-BASED LIGHTING	367
9.1	Introduction	367
9.2	Basic Image-based Lighting	370
9.2.1	Acquire and Assemble the Light Probe Image	370
9.2.2	Model the Geometry and Reflectance of the Scene	372
9.2.3	Map the Light Probe to an Emissive Surface Surrounding the Scene	373
9.2.4	Render the Scene as Illuminated by the IBL Environment	374
9.2.5	Postprocess the Renderings	376
9.3	Capturing Light Probe Images	381
9.3.1	Photographing a Mirrored Sphere	382
9.3.2	Tiled Photographs	387
9.3.3	Fish-eye Lenses	389
9.3.4	Scanning Panoramic Cameras	390
9.3.5	Capturing Environments with Very Bright Sources	392
9.4	Omnidirectional Image Mappings	401
9.4.1	Ideal Mirrored Sphere	402
9.4.2	Angular Map	404
9.4.3	Latitude-Longitude	405
9.4.4	Cube Map	407
9.5	How a Global Illumination Renderer Computes IBL Images	409
9.5.1	Sampling Other Surface Reflectance Types	414

9.6	Sampling Incident Illumination Efficiently	416
9.6.1	Identifying Light Sources	420
9.6.2	Converting a Light Probe into a Constellation of Light Sources	428
9.6.3	Importance Sampling	436
9.7	Simulating Shadows and Scene-Object Interreflection	439
9.7.1	Differential Rendering	444
9.7.2	Rendering into a Nondiffuse Local Scene	445
9.8	Useful IBL Approximations	446
9.8.1	Environment Mapping	447
9.8.2	Ambient Occlusion	452
9.9	Image-based Lighting for Real Objects and People	454
9.9.1	A Technique for Lighting Real Subjects	454
9.9.2	Relighting from Compressed Image Data Sets	456
9.10	Conclusions	461
LIST OF SYMBOLS		463
REFERENCES		467
INDEX		489
ABOUT THE DVD-ROM		497