Index

Adams, Ansel, 305
Adaptive gain control, Pattanaik, 313–316
Adobe Digital Negative, 87
Adobe RGB color space, 79
Aliasing, 436
Alignment of images
– Kang method, 122
– mean threshold bitmap, 122, 123–136
Ambient occlusion, 370, 466–468
Angular map, 410–411
Appearance correlates, 59
– computation of perceptual, 66–69
Applied Science Fiction, 117
Artificial scenes, 15
Ashikhmin spatially variant operator, 301–305

Background intensity
– image average, 211–212
– local average, 212–215
– multiscale adaptation, 215–219
Baxall, 163
Beer's law, 231
Bent normals, 467
Bidirectional reflection distribution functions (BRDFs), 23, 421–423
Bilateral filtering, 215, 326, 333–340
Bleaching, 197
Blind spots, 387
Blur, Gaussian, 233–235, 278–281
Bradford chromatic adaptation transform, 40–41
Brightness
– adjustments, 8
– defined, 62
– encoding, 73–76
– Miller brightness-ratio preserving operator, 237–241
– Tumblin–Rushmeier brightness preserving, 242–246
Byte per color channel per pixel encoding, 7

Calibration, 225–228
– of sphere reflectivity, 387, 390
Camera response function, deriving, 136
– calibration guidelines, 143–147
– Debevec–Malik technique, 137–139
– image samples for, 142–143
– Mitsunaga–Nayar technique, 140–142
Candela, 27
Cathode ray tubes (CRTs), 6, 176–179
Chiu spatially variant operator, 278–281
Choudhury trilateral filtering, 326, 340–345
Chroma, defined, 62–63
Chromatic adaptation, 39–48, 65–66
CIE (Commission Internationale de l'Eclairage)
– CAM02, 63–69
– CAM97, 63
– CAT02 chromatic adaptation transform, 41–42, 44–46
– D_{55}, D_{65}, and D_{75} illuminants, 36–37, 38
– LAB, 59, 60–61, 62, 63
– LUV, 59–60, 61–62, 63
– 1931 standard observer (XYZ color-matching function), 30–31, 34
– 1964 standard observer, 28
– photopic luminous efficiency curve, 25–26
– xy chromaticity diagram, 32
Cineon, 99

reinhard v.2005/03/22 Prn:15/06/2005; 16:15 F:reinhardsi.tex; VTEX/EA p. 2

Cinepaint, 88
Color appearance, 57–69
– Fairchild iCAM, 286–292
– Pattanaik multiscale observer model, 292–301
Color constancy, 39
Color contrast, simultaneous, 58
Color correction, 48–50
Color gamut, 33
Color images, 228–231
Colorimetry, 28–33
Color manipulation, 8, 11
Color-matching functions, 28–31
Color opponent spaces, 50–57
Color spaces, 33–36
– standard RGB, 76–83
Color temperature, 37
– correlated, 38
Commission Internationale de l'Eclairage. *See* CIE
Compressed image data sets, relighting from, 473–476
Compression, Fattal gradient domain, 352–357
Cone response domains, 39–43
Contrast, 8
– Ward contrast-based scale factor, 246–247
Cube map, 413–415

Debevec–Malik technique, 137–139
Density chart, 169–170
Density representations, 232–233
Difference-of-Gaussian (DoG), 292–296
Differential rendering, 457–458
Digital cinema and video, 88
– displays, 182
Digital Light Processing (DLP) system, 182
Digital Micromirror Device (DMD), 182–183
Digital photography, 87
Digital-to-analog (D/A) converters, 6–7
Display devices, 9–11, 14
– cathode ray tubes (CRTs), 6, 176–179
– hardcopy, 167–176
– liquid crystal displays (LCDs), 7, 176–179
– reflection print, 168–170
– softcopy, 176–185
– still image viewer, 171–176
– Sunnybrook Technologies, 175, 179–182
– transparent media, 170–171
Display gamma, 69–73
Dithering, 94–95, 96
Dodge-and-burn, 117
– Reinhard operator, 305–313
Drago logarithmic mapping, 255–258
Dry developing method, 117
Durand bilateral filtering, 326, 333–340
Dynamic range reduction, 15–17

Edge-detection filters, 123
Encoding
– *See also* Image encodings, HDR
– defined, 85
Energy per unit of area, 20, 23
Energy per unit of time, 20, 23
Energy per unit of time per unit of direction, 20, 23
Environment mapping, 370, 459–465
– mirrored sphere, photographing a, 386–391
Equirectangular mapping, 411
Exclusion bitmap, 128–131
Exponential mappings, 252–255
EXtended Range format (.exr), 97

Facial Reflectance Field Demo, 473
Fairchild iCAM, 286–292
Fattal gradient domain compression, 352–357
Ferwerda model of visual adaptation, 247–252
File formats, 13–14
Film scanning, 118–121
FilmStream Viper, 11
Fisheye lenses, 394–395
Fisheye projection, hemispherical, 172–173
Flare, 116, 121
– lens flare removal, 152–159
Floating-point representation, 75–76
Format
– *See also* Image formats

– defined, 85
Frequency-based operator, Oppenheim, 326–333
Frequency domain operators. *See* Tone reproduction/operators, frequency domain

Gain control function, 208
Gamma encoding, 75, 65
Gamma estimation and display, 69–73
Gamut, color, 33
Gaussian blur, 233–235, 278–281
Ghost removal, 147–152
Global illumination, 87
– computation, 415–423
Global tone reproduction/operators. *See* Tone reproduction/operators, global
Gradient domain operators. *See* Tone reproduction/operators, gradient domain
Grating light valve (GLV), 183–184
Gray cards, 62
Gretag–MacBeth ColorChecker chart, 403

Halos, 278–281
Hat function, 119, 120
HDR environment maps, 368
HDR format, 91–93
HDTV, 79
Hemispherical fisheye projection, 172–173
High dynamic range (HDR) imaging
– *See also* Image-based lighting (IBL)
– advantages of, 7–9
– compared with conventional imaging, 2–6
Histograms, use of, 225–228
– Ward histogram adjustment, 266–272
Homomorphic filtering, 231–233, 331
Horn lightness computation, 231, 346–352
Hue
– angles, 62
– defined, 62
Human-referred encodings, 86
Human vision, 6
– adaptation, 191–193
– photopigment depletion and regeneration, 196–197
– photoreceptor mechanisms, 197–205
– pupil, 193
– rod and cone systems, 193–196
Hunt–Pointer–Estevez color space, 66

iCAM (color appearance model), 39, 40, 69
– Fairchild, 286–292
Illuminance, 27
Illuminants, 36–48
Image-based lighting (IBL), 14, 87
– applications, 468–476
– approximations, 459–468
– basics, 370–385
– capturing light probe images, 368, 371–373, 385–407
– defined, 367–370
– global computation, 415–423
– omnidirectional image mappings, 407–415
– sampling incident illumination, 423–452
– shadows and scene-object inter-reflection, simulating, 452–459
Image capturing, 11
– camera response function, deriving, 136–147
– direct, 159–164
– film scanning, 118–121
– ghost removal, 147–152
– lens flare removal, 152–159
– mean threshold bitmap alignment technique, 122, 123–136
– multiple exposures and, 117–118
– photography and light measurement, 115–117
– registration and alignment of images, 122
Image editing, 88
Image encodings, HDR
– applications, 87–89
– benefits, 111–114
– LDR versus, 85–86
Image formats, 89–90
– Cineon, 99
– comparison of, 106–111

reinhard v.2005/03/22 Prn:15/06/2005; 16:15 F:reinhardsi.tex; VTEX/EA p. 4

– emerging lossy HDR, 99–106
– HDR, 91–93
– LogLuv, 90, 93–97
– OpenEXR, 97–98
– Pixar log, 98–99
Tagged Image File Format (TIFF) float, 93–97
Image mappings, omnidirectional
– angular map, 410–411
– cube map, 413–415
– ideal mirrored sphere, 407–409
– latitude-longitude, 411–413
Importance sampling, 445–452
Industrial Light and Magic (ILM), 97, 98
International Electrotechnical Commission (IEC), 77, 99
Irradiance, 20, 21
– environment map, 462
ITU (International Telecommunication Union)
– Recommendation BT.709, 33, 35
JPEG, sub-band encoding, 99–103
Just noticeable difference (JND), 192, 210–211, 247

Kodak Film Processing Station, 117
Kodak organic light-emitting diode (OLED) displays, 185

LadyBug spherical video camera, 163–164
Large Expanse Extra Perspective (LEEP), 172
Latitude-longitude mapping, 411–413
Layer averaging, 316–323
Lens flare removal, 152–159
Light, 11
– measurement, 115–117
– photometry and measuring, 24–28
– radiometry and measuring, 19–24
– reflection, 23
Light-emitting diode (LED) display, 181–182, 184–185
LightGen, 443–445
Lightness, defined, 62
Lightness computation, Horn, 231, 346–352
Light probe images, capturing, 368, 371–373, 385
– environments with very bright sources, 397–407
– fisheye lenses, 394–395
– mirrored sphere, photographing a, 386–391
– scanning panoramic cameras, 395–397
– tiled photographs, 392–394
Light sources
– constellation, 436–445
– identifying, 428–435
Linear transformations, 34–36
Liquid crystal displays (LCDs), 7, 176–179
LMS color space, 39–40
Local scene, rendering into a nondiffuse, 458–459
Logarithmic and exponential mappings, 252–255
– Drago, 255–258
Log encoding, 73–75, 76
LogLuv, 90, 93–97
Low dynamic range (LDR) imaging, 5–6, 11
– reflection print, 168–170
– versus HDR encodings, 85–86
Luminance, 27
– computing, 35–36
– world versus display, 229
Luminance levels, common ambient, 6
Luminous energy, 27
Luminous exitance, 27
Luminous intensity, 26–27
Luminous power/flux, 26–27

Mean threshold bitmap (MTB) alignment technique, 122, 123–136
Measuring
– equation, 23
– light, 19–29
Median threshold bitmap, 125
Metamerism, 33
Michaelis–Menten equation, 198–199, 220
Microelectromechanical systems (MEMS), 182

reinhard v.2005/03/22 Prn:15/06/2005; 16:15 F:reinhardsi.tex; VTEX/EA p. 5

Miller brightness-ratio preserving operator, 237–241
Millions of colors, 1
Mirrored sphere, photographing a
– blind spots, 387
– framing and focus, 386
– image resolution, 391
– reflectance, nonspecular, 390–391
– reflectance, polarized, 391
– sphere reflectivity, calibrating, 387, 390
Mirrored sphere mapping, 407–409
Mitsunaga–Nayar
– camera response function, 140–142
– weighting function, 119–121
MPEG, HDR extension to, 103–106
Multiscale observer model, 39
– Pattanaik, 292–301

Naka–Rushton equation, 198–199
National Television System Committee (NTSC) color space, 83
Noise, threshold, 128–131
Nonlinear response compression, 66

Omnidirectional image mappings, 407–415
OpenEXR, 97–98
Oppenheim frequency-based operator, 326–333
Organic light-emitting diode (OLED) displays, 185
Output-referred standards, 76, 85, 86

PAL (Phase Alternating Line), 83
Panoscan, 395, 397
Pattanaik adaptive gain control, 313–316
Pattanaik multiscale observer model, 292–301
Perceptual encodings, 86
Performance, 357–362
Photogenics, 88
Photographic tone-mapping function, 210
Photographic tone reproduction, Reinhard, 305–313
Photography
– digital, 87
– light measurement, 115–117
Photometry, 24–28
Photons, 23
Photopigment depletion and regeneration, 196–197
Photoreceptor adaptation model, for tone mapping, 207–210
– Reinhard–Devlin model, 258–266
Photoreceptor mechanisms, 197–205
Physically-based rendering, 87
Pixar, 97, 98–99
Pixim, 162–163
PIZ, 98
Point Grey Research, 163–164
Point spread function (PSF), 152–159
Power law function, 69–70
Primaries, imaginary versus real, 31
Principal components analysis (PCA), 52–53
Printing
– film, 116–117
– presses, 167–168
– reflection, 168–170
Probe mapping, 416
Project-based display, 179–181
Pyramids, use of image, 126–128

QuickTime VR, 392

RADIANCE light simulation system, 371–385, 415
Radiance maps, 7, 117
Radiance picture format, 91
Radiant energy, 19, 20
Radiant exitance, 20, 21
Radiant intensity, 20, 22
Radiant power/flux, 20
Radiometry, 19–24
Radiosity, 368
Rahman retinex, 281–286
Rational quantization function, 208
Raw image formats (RAW), 13, 87
Ray tracing, 370, 415
Real subjects, lighting, 468–473
Reflectance, 19
– function, 473

reinhard v.2005/03/22 Prn:15/06/2005; 16:15 F:reinhardsi.tex; VTEX/EA p. 6

– standards, 402–403
Reflection occlusion, 462
Reflection print, 168–170
Reinhard–Devlin photoreceptor model, 258–266
Reinhard photographic tone reproduction, 305–313
Relighting, 473–476
Remote sensing, 87
Rendering equation, 370
Rendering with Natural Light (RNL), 370–385
Response-threshold relation, 201–205
Retinex theory, 281–286
RGB color cube, 33
– converting from XYZ to, 34–35
RGB color spaces, standard, 76–83

Sampling incident illumination, 423–452
Sampling problem, 427
Saturation, defined, 63
Scale factor, Ward contrast-based, 246–247
Scaling images, 189
Scanning panoramic cameras, 395–397
Scene-referred standard, 76–77, 85–86
Schlick uniform rational quantization, 273–276
S-CIELAB, 69
SECAM (Systeme Electronique Couleur Avec Memoire), 83
Security cameras, 12–13, 163
Segmentation, Yee, 316–323
Shadows and scene-object inter-reflection, simulating, 452–459
SIGGRAPH 99 Electronic Theater animation *Fiat Lux*, 433–435
Signal theory, 119
Silicon Light Machines, 183–184
SMaL Camera Technologies, 12, 161–162
Smartvue, 163
SMPTE-C color space, 83
SMPTE-240M color space, 79
Sony, 185
Spatially variant operator, Ashikhmin, 301–305
Spatial tone reproduction/operators. *See* Tone reproduction/operators, spatial
Spectral sharpening, 47
SpheroCam HDR panoramic camera, 163
SpheronVR, 163, 395
sRGB color space, 77–79
S-shaped curve, 209
Steradian, 20
Still image viewer, 171–176
Storing images. *See* File formats
Sub-band encoding, 99–103
Sun intensity, use of, 401–407
Sunnybrook Technologies, 175, 179–182

Tagged Image File Format (TIFF) float, 93–97
Television, 10–11
10-degree color-matching function, 28, 29
Texas Instruments, 182–183
Thomson Grass Valley, Viper FilmStream camera, 160–161
3-by-3 matrix transformation, 34
Threshold noise, 128–131
Threshold versus intensity (TVI), 192–193, 201, 205, 210–211
Tiled photographs, 392–394
Tumblin–Rushmeier brightness preserving operator, 242–246
Tone mapping, 17, 77, 86, 116, 168
– background intensity, 211–219
– problem, 187–191
– visual adaptation models for, 206–211
Tone reproduction/operators, 17, 39, 100
– calibration, 225–228
– color images, 228–231
– Gaussian blur, 233–235
– homomorphic filtering, 231–233
– performance, 357–362
– validation studies, 235–237
Tone reproduction/operators, frequency domain, 325
– Choudhury trilateral filtering, 326, 340–345
– Durand bilateral filtering, 326, 333–340

– Oppenheim frequency-based, 326–333
– performance, 358, 360–362
Tone reproduction/operators, global, 223–224
– Drago logarithmic mapping, 255–258
– Ferwerda model of visual adaptation, 247–252
– logarithmic and exponential mappings, 252–255
– Miller brightness-ratio preserving, 237–241
– performance, 358, 359–360
– Reinhard–Devlin photoreceptor model, 258–266
– Schlick uniform rational quantization, 273–276
– Tumblin–Rushmeier brightness preserving, 242–246
– Ward contrast-based scale factor, 246–247
– Ward histogram adjustment, 266–272
Tone reproduction/operators, gradient domain, 345
– Fattal compression, 352–357
– Horn lightness computation, 231, 346–352
– performance, 358, 360–362
Tone reproduction/operators, local, 223, 277
– Ashikhmin spatially variant, 301–305
– Chiu spatially variant, 278–281
– Fairchild iCAM, 286–292
– Pattanaik adaptive gain control, 313–316
– Pattanaik multiscale observer model, 292–301
– performance, 358, 359–360
– Rahman retinex, 281–286
– Reinhard photographic, 305–313
– Yee segmentation, 316–323
Tone reproduction/operators, spatial
– global, 223–224, 237–276
– local, 223, 277–323
Transparent media, 170–171
Trilateral filtering, 326, 340–345
Tristimulus value, 29, 31

Uniform rational quantization, Schlick, 273–276

$V(\lambda)$ (vee-lambda) curve, 25–26
Viper FilmStream camera, 160–161
Virtual reality, 88
Visible differences predictor (VDP), 102
Visual adaptation
– dynamics of, 219–221
– Ferwerda model of, 247–252
– models for tone mapping, 206–211
Visual threshold, 192
von Kries chromatic adaptation transform, 39–40

Ward contrast-based scale factor, 246–247
Ward HDR transparency viewer, 175
Ward histogram adjustment, 266–272
Ward tone-mapping algorithm, 210–211
Weber's law, 193, 205
Weighted variance, 147
Weighting function, 118–121
White balancing, 37
Whitening filter, 327
White point, 34, 35, 36–48
Wide gamut color space, 83

XYZ
– color-matching function, 30–31
– color space, 34
– converting to RGB, 34–35
– scaling, 46

Yee segmentation, 316–323