

This is the Table of Contents for *Digital Video and HD Algorithms and Interfaces*, Second Edition (Burlington, Mass.: Elsevier/Morgan Kaufmann, 2012). Copyright © 2012 Charles Poynton

Contents

List of Figures xxi

List of Tables xxxi

Preface xxxvii

Legacy technology xxxix

Layout and typography xxxix

Formulas xxxix

Spelling xl

Acknowledgments xli

Part 1 – Introduction 1

1 Raster images 3

Aspect ratio 4

Geometry 6

Image capture 7

Digitization 7

Perceptual uniformity 8

Colour 10

Luma and colour difference components 11

Digital image representation 11

SD and HD 13

Square sampling 14

Comparison of aspect ratios 14

Aspect ratio 15

Frame rates 18

2 Image acquisition and presentation 19

Image state 20

EOCF standards 22

Entertainment programming 22

	Acquisition 24
	Consumer origination 24
	Consumer electronics (CE) display 24
3 Linear-light and perceptual uniformity 27	Contrast 28 Contrast ratio 29 Perceptual uniformity 30 The "code 100" problem and nonlinear image coding 31 Linear and nonlinear 36
4 Quantization 37	Linearity 37 Decibels 38 Noise, signal, sensitivity 40 Quantization error 40 Full-swing 41 Studio-swing (footroom and headroom) 42 Interface offset 44 Processing coding 45 Two's complement wrap-around 46
5 Contrast, brightness, CONTRAST, and BRIGHTNESS 47	Perceptual attributes 47 History of display signal processing 48 Digital driving levels 51 Relationship between signal and lightness 51 Algorithm 52 Black level setting 56 Effect of CONTRAST and BRIGHTNESS on contrast and brightness 56 An alternate interpretation 59 BRIGHTNESS and CONTRAST controls in LCDs 62 BRIGHTNESS and CONTRAST controls in PDPs 62 BRIGHTNESS and CONTRAST controls in desktop graphics 62
6 Raster images in computing 65	Symbolic image description 66 Raster images 67 Conversion among types 72 Image files 72 "Resolution" in computer graphics 73
7 Image structure 75	Image reconstruction 76 Sampling aperture 78 Spot profile 80

	Box distribution	80
	Gaussian distribution	81
8 Raster scanning	83	
	Flicker, refresh rate, and frame rate	83
	Introduction to scanning	85
	Scanning parameters	86
	Interlaced format	88
	Twitter	89
	Interlace in analog systems	90
	Interlace and progressive	90
	Scanning notation	92
	Motion portrayal	93
	Segmented-frame (24PsF)	94
	Video system taxonomy	94
	Conversion among systems	95
9 Resolution	97	
	Magnitude frequency response and bandwidth	97
	Visual acuity	99
	Viewing distance and angle	100
	Kell effect	102
	Resolution	103
	Resolution in video	104
	Viewing distance	104
	Interlace revisited	105
10 Constant luminance	107	
	The principle of constant luminance	108
	Compensating for the CRT	109
	Departure from constant luminance	110
	Luma	111
	"Leakage" of luminance into chroma	112
11 Picture rendering	115	
	Surround effect	116
	Tone scale alteration	117
	Incorporation of rendering	117
	Rendering in desktop computing	119
12 Introduction to luma and chroma	121	
	Luma	121
	Sloppy use of the term <i>luminance</i>	122
	Colour difference coding (chroma)	123
	Chroma subsampling	124
	Chroma subsampling notation	125
	Chroma subsampling filters	127
	Chroma in composite NTSC and PAL	128

13	Introduction to component SD 129	Scanning standards 129 Widescreen (16:9) SD 133 Square and nonsquare sampling 133 Resampling 134
14	Introduction to composite NTSC and PAL 135	NTSC and PAL encoding 136 NTSC and PAL decoding 137 S-video interface 137 Frequency interleaving 137 Composite analog SD 139
15	Introduction to HD 141	HD scanning 141 Colour coding for BT.709 HD 144
16	Introduction to video compression 147	Data compression 147 Image compression 148 Lossy compression 148 JPEG 149 Motion-JPEG 150 JPEG 2000 150 Mezzanine compression 151 MPEG 152 Picture coding types (I, P, B) 153 Reordering 156 MPEG-1 157 MPEG-2 157 Other MPEGs 158 MPEG IMX 158 MPEG-4 159 H.264 160 AVC-Intra 160 WM9, WM10, VC-1 codecs 160 Compression for CE acquisition 161 HDV 161 AVCHD 162 Compression for IP transport to consumers 162 VP8 ("WebM") codec 162 Dirac (basic) 162
17	Streams and files 163	Historical overview 164 Physical layer 166 Stream interfaces 166 IEEE 1394 (FireWire, i.LINK) 167 HTTP live streaming (HLS) 168

18	Metadata 171	<ul style="list-style-type: none"> Metadata example 1: CD-DA 172 Metadata example 2: .yuv files 173 Metadata example 3: RFF 174 Metadata example 4: JPEG/JFIF 175 Metadata example 5: Sequence display extension 176 Conclusions 179
19	Stereoscopic ("3-D") video 181	<ul style="list-style-type: none"> Acquisition 181 S3D display 181 Anaglyph 182 Temporal multiplexing 183 Polarization 183 Wavelength multiplexing (Infitec/Dolby) 184 Autostereoscopic displays 185 Parallax barrier display 185 Lenticular display 185 Recording and compression 186 Consumer interface and display 186 Ghosting 187 Vergence and accommodation 188 <p>Part 2 – Theory 189</p>
20	Filtering and sampling 191	<ul style="list-style-type: none"> Sampling theorem 192 Sampling at exactly $0.5f_s$ 193 Magnitude frequency response 196 Magnitude frequency response of a boxcar 197 The sinc weighting function 198 Frequency response of point sampling 199 Fourier transform pairs 200 Analog filters 202 Digital filters 202 Impulse response 207 Finite impulse response (FIR) filters 207 Physical realizability of a filter 208 Phase response (group delay) 209 Infinite impulse response (IIR) filters 210 Lowpass filter 211 Digital filter design 214 Reconstruction 216 Reconstruction close to $0.5f_s$ 217 "(sin x)/x" correction 218 Further reading 220

21	Resampling, interpolation, and decimation 221	<ul style="list-style-type: none"> 2:1 downsampling 224 Oversampling 224 Interpolation 226 Lagrange interpolation 227 Lagrange interpolation as filtering 229 Polyphase interpolators 231 Polyphase taps and phases 232 Implementing polyphase interpolators 233 Decimation 234 Lowpass filtering in decimation 234
22	Image digitization and reconstruction 237	<ul style="list-style-type: none"> Spatial frequency domain 238 Comb filtering 241 Spatial filtering 242 Image presampling filters 242 Image reconstruction filters 243 Spatial (2-D) oversampling 244
23	Perception and visual acuity 247	<ul style="list-style-type: none"> Retina 247 Adaptation 247 Contrast sensitivity 249 Contrast sensitivity function (CSF) 251
24	Luminance and lightness 255	<ul style="list-style-type: none"> Radiance, intensity 255 Luminance 256 Relative luminance 258 Luminance from red, green, and blue 258 Lightness (CIE L^*) 259
25	The CIE system of colorimetry 265	<ul style="list-style-type: none"> Fundamentals of vision 266 Definitions 266 Spectral power distribution (SPD) and tristimulus 267 Spectral constraints 268 CIE XYZ tristimulus 272 CIE [x, y] chromaticity 275 Blackbody radiation 276 Colour temperature 277 White 278 Chromatic adaptation 280 Perceptually uniform colour spaces 280 CIE $L^*u^*v^*$ 281 CIE $L^*a^*b^*$ (CIELAB) 283 CIE $L^*u^*v^*$ and CIE $L^*a^*b^*$ summary 284

	Colour specification and colour image coding	285
	Further reading	285
26	Colour science for video	287
	Additive reproduction (<i>RGB</i>)	288
	Characterization of <i>RGB</i> primaries	290
	BT.709 primaries	290
	Legacy SD primaries	293
	sRGB system	294
	SMPTE Free Scale (FS) primaries	294
	AMPAS ACES primaries	294
	SMPTE/DCI P3 primaries	295
	CMFs and SPDs	296
	Normalization and scaling	299
	Luminance coefficients	306
	Transformations between <i>RGB</i> and CIE XYZ	307
	Noise due to matrixing	308
	Transforms among <i>RGB</i> systems	309
	Camera white reference	310
	Display white reference	310
	Gamut	311
	Wide-gamut reproduction	312
	Free Scale Gamut, Free Scale Log (FS-Gamut, FS-Log)	312
	Further reading	313
27	Gamma	315
	Gamma in CRT physics	316
	The amazing coincidence!	318
	Gamma in video	318
	Opto-electronic conversion functions (OECFs)	320
	BT.709 OECF	320
	SMPTE ST 240M transfer function	322
	sRGB transfer function	323
	Transfer functions in SD	324
	Bit depth requirements	325
	Gamma in modern display devices	326
	Estimating gamma	326
	Gamma in video, CGI, and Macintosh	328
	Gamma in computer graphics	332
	Gamma in pseudocolour	332
	Limitations of 8-bit linear coding	333
	Linear and nonlinear coding in CGI	333
28	Luma and colour differences	335
	Colour acuity	335
	<i>RGB</i> and <i>R'G'B'</i> colour cubes	337

Conventional luma/colour difference coding 341
 Luminance and luma notation 342
 Nonlinear red, green, blue ($R'G'B'$) 345
 BT.601 luma 346
 BT.709 luma 346
 Chroma subsampling, revisited 347
 Luma/colour difference summary 347
 SD and HD luma chaos 350
 Luma/colour difference component sets 352

Part 3 – Practical matters 355

- 29 Component video colour coding for SD 357 $B'-Y'$, $R'-Y'$ components for SD 359
 $P_B P_R$ components for SD 359
 $C_B C_R$ components for SD 361
 $Y' C_B C_R$ from studio RGB 364
 $Y' C_B C_R$ from computer RGB 365
 "Full-swing" $Y' C_B C_R$ 365
 $Y'UV$, $Y'IQ$ confusion 367
- 30 Component video colour coding for HD 369 $B'-Y'$, $R'-Y'$ components for BT.709 HD 369
 $P_B P_R$ components for BT.709 HD 370
 $C_B C_R$ components for BT.709 HD 371
 $C_B C_R$ components for xvYCC 373
 $Y' C_B C_R$ from studio RGB 374
 $Y' C_B C_R$ from computer RGB 374
 Conversions between HD and SD 375
 Colour coding standards 376
- 31 Video signal processing 377 Edge treatment 377
 Transition samples 378
 Picture lines 379
 Choice of S_{AL} and S_{PW} parameters 380
 Video levels 381
 Setup (pedestal) 381
 BT.601 to computing 383
 Enhancement 383
 Median filtering 385
 Coring 385
 Chroma transition improvement (CTI) 387
 Mixing and keying 387
- 32 Frame, field, line, and sample rates 389 Field rate 389
 Line rate 390

	Sound subcarrier 391
	Addition of composite colour 391
	NTSC colour subcarrier 391
	576i PAL colour subcarrier 393
	$4f_{SC}$ sampling 393
	Common sampling rate 394
	Numerology of HD scanning 395
	Audio rates 398
33	Timecode 399
	Introduction 399
	Dropframe timecode 400
	Editing 401
	Linear timecode (LTC) 402
	Vertical interval timecode (VITC) 402
	Timecode structure 402
	Further reading 404
34	2-3 pulldown 405
	2-3-3-2 pulldown 407
	Conversion of film to different frame rates 408
	Native 24 Hz coding 411
	Conversion to other rates 412
35	Deinterlacing 413
	Spatial domain 413
	Vertical-temporal domain 415
	Motion adaptivity 416
	Further reading 418
36	Colourbars 419
	SD colourbars 419
	SD colourbar notation 421
	PLUGE element 421
	Composite decoder adjustment using colourbars 422
	-I, +Q, and PLUGE elements in SD colourbars 423
	HD colourbars 423
	Part 4 – Studio standards 425
37	Reference display and viewing conditions 427
	References 428
38	SDI and HD-SDI interfaces 429
	Component digital SD interface (BT.601) 430
	Serial digital interface (SDI) 432
	Component digital HD-SDI 432
	SDI and HD-SDI sync, TRS, and ancillary data 433
	TRS in 4:2:2 SD-SDI 434

	TRS in HD-SDI	436
	Analog sync and digital/analog timing relationships	437
	Ancillary data	437
	SDI coding	439
	HD-SDI coding	440
	Interfaces for compressed video	441
	SDTI	441
	Switching and mixing	442
	Timing in digital facilities	442
	ASI	443
	Summary of digital interfaces	443
39	480<i>i</i> component video	
	445	
	Frame rate	445
	Interlace	445
	Line sync	447
	Field/frame sync	447
	<i>R'G'B'</i> EOCF and primaries	448
	Luma (<i>Y'</i>)	450
	Picture center, aspect ratio, and blanking	450
	Halfline blanking	451
	Component digital 4:2:2 interface	452
	Component analog <i>R'G'B'</i> interface	452
	Component analog <i>Y'P_BP_R</i> interface, EBU N10	453
	Component analog <i>Y'P_BP_R</i> interface, industry standard	455
40	576<i>i</i> component video	
	457	
	Frame rate	457
	Interlace	457
	Line sync	459
	Analog field/frame sync	459
	<i>R'G'B'</i> EOCF and primaries	460
	Luma (<i>Y'</i>)	462
	Picture center, aspect ratio, and blanking	462
	Component digital 4:2:2 interface	463
	Component analog 576 <i>i</i> interface	464
41	1280×720 HD	467
	Scanning	467
	Analog sync	468
	Picture center, aspect ratio, and blanking	469
	<i>R'G'B'</i> EOCF and primaries	469
	Luma (<i>Y'</i>)	471
	Component digital 4:2:2 interface	471

- 42 1920×1080 HD 473
 - Scanning 473
 - Analog sync 475
 - Picture center, aspect ratio, and blanking 478
 - R'G'B'* EOCF and primaries 478
 - Luma (*Y'*) 480
 - Component digital 4:2:2 interface 480

- 43 HD videotape 481
 - D-5 HD (HD-D5, D-15) 482
 - D-6 482
 - HDCAM (D-11) 482
 - DVCPRO HD (D-12) 482
 - HDCAM SR (D-16) 483

- 44 Component analog HD interface 485
 - Pre- and postfiltering characteristics 487

- Part 5 – Video compression 489**

- 45 JPEG and motion-JPEG (M-JPEG) compression 491
 - JPEG blocks and MCUs 492
 - JPEG block diagram 494
 - Level shifting 495
 - Discrete cosine transform (DCT) 495
 - JPEG encoding example 496
 - JPEG decoding 500
 - Compression ratio control 501
 - JPEG/JFIF 502
 - Motion-JPEG (M-JPEG) 503
 - Further reading 504

- 46 DV compression 505
 - DV chroma subsampling 506
 - DV frame/field modes 507
 - Picture-in-shuttle in DV 508
 - DV overflow scheme 508
 - DV quantization 510
 - DV digital interface (DIF) 511
 - Consumer DV recording 512
 - Professional DV variants 512

- 47 MPEG-2 video compression 513
 - MPEG-2 profiles and levels 514
 - Picture structure 517
 - Frame rate and 2-3 pulldown in MPEG 518
 - Luma and chroma sampling structures 519
 - Macroblocks 520
 - Picture coding types – I, P, B 520

	Prediction 521
	Motion vectors (MVs) 524
	Coding of a block 525
	Frame and field DCT types 525
	Zigzag and VLE 527
	Refresh 528
	Motion estimation 528
	Rate control and buffer management 531
	Bitstream syntax 533
	Transport 535
	Further reading 535
48 H.264 video compression 537	Algorithmic features, profiles, and levels 538
	Baseline and extended profiles 540
	High profiles 541
	Hierarchy 541
	Multiple reference pictures 541
	Slices 542
	Spatial intra prediction 542
	Flexible motion compensation 542
	Quarter-pel motion-compensated interpolation 543
	Weighting and offsetting of MC prediction 543
	16-bit integer transform 543
	Quantizer 544
	Variable-length coding 544
	Context adaptivity 546
	CABAC 546
	Deblocking filter 546
	Buffer control 547
	Scalable video coding (SVC) 547
	Multiview video coding (MVC) 548
	AVC-Intra 548
	Further reading 548
49 VP8 compression 549	Algorithmic features 550
	Further reading 552
	Part 6 – Distribution standards 553
50 MPEG-2 storage and transport 555	Elementary stream (ES) 556
	Packetized elementary stream (PES) 556
	MPEG-2 program stream 556
	MPEG-2 transport stream 556

	System clock	557
	Further reading	558
51	Digital television broadcasting	559
	Japan	560
	United States	560
	ATSC modulation	561
	Europe	563
	Further reading	563
	Appendices	565
A	<i>YUV and luminance</i> considered harmful	567
	Cement vs. concrete	567
	True CIE luminance	568
	The misinterpretation of luminance	568
	The enshrining of luma	570
	Colour difference scale factors	571
	Conclusion: A plea	572
B	Introduction to radiometry and photometry	573
	Radiometry	574
	Photometry	575
	Light level examples	578
	Image science	578
	Units	579
	Further reading	580
	Glossary	581
	Index	669