

Contents

Foreword by Jim Blinn vii

Foreword by Mark Schubin ix

List of figures xxv

List of tables xxxv

Part 1 – Introduction 1

1 Raster images 3

Imaging 3

Aspect ratio 4

Digitization 5

Pixel array 6

Visual acuity 8

Viewing distance and angle 8

Spatiotemporal domains 10

Lightness terminology 11

Nonlinear image coding 12

Linear and nonlinear 15

Luma and color difference components 16

SDTV/HDTV 16

2 Quantization 17

Decibels 18

Noise, signal, sensitivity 19

Quantization error 20

Linearity 21

Perceptual uniformity 21

Headroom and footroom 22

3 BRIGHTNESS and CONTRAST controls	25	BRIGHTNESS and CONTRAST controls in desktop graphics	27
4 Raster images in computing	31	Symbolic image description	33
		Raster images	34
		Conversion among types	39
		Display modes	40
		Image files	41
		"Resolution" in computer graphics	41
5 Image structure	43	Image reconstruction	43
		Sampling aperture	46
		Spot profile	48
		Box distribution	48
		Gaussian distribution	49
6 Raster scanning	51	Flicker, refresh rate, and frame rate	51
		Introduction to scanning	53
		Scanning parameters	54
		Interlaced scanning	56
		Twitter	57
		Interlace in analog systems	57
		Interlace and progressive	58
		Scanning notation	59
		Interlace artifacts	60
		Motion portrayal	61
		Segmented frame (24PsF)	62
		Video system taxonomy	62
		Conversion among systems	63
7 Resolution	65	Magnitude frequency response and bandwidth	65
		Kell effect	67
		Resolution	68
		Resolution in video	69
		Viewing distance	72
		Interlace revisited	73
8 Constant luminance	75	The principle of constant luminance	76
		Compensating the CRT	77
		Departure from constant luminance	78
		"Leakage" of luminance into chroma	79
9 Rendering intent	81	Surround effect	82
		Tone scale alteration	83

	Incorporation of rendering intent	83
	Rendering intent in desktop computing	86
10	Introduction to luma and chroma	87
	Luma	87
	Sloppy use of the term <i>luminance</i>	88
	Color difference coding (chroma)	89
	Chroma subsampling	90
	Chroma subsampling notation	91
	Chroma subsampling filters	93
	Chroma in composite NTSC and PAL	94
11	Introduction to component SDTV	95
	Scanning standards	95
	Widescreen (16:9) SDTV	99
	Progressive SDTV (480p/483p)	100
	Square and nonsquare sampling	101
	Resampling	102
12	Introduction to composite NTSC and PAL	103
	NTSC and PAL encoding	105
	NTSC and PAL decoding	105
	S-video interface	107
	Frequency interleaving	107
	Composite digital SDTV ($4f_{SC}$)	108
	Composite analog SDTV	109
13	Introduction to HDTV	111
	Comparison of aspect ratios	112
	HDTV scanning	113
	The 1035 <i>i</i> (1125/60) system	116
	Color coding for Rec. 709 HDTV	116
14	Introduction to video compression	117
	Data compression	117
	Image compression	117
	Lossy compression	118
	JPEG	119
	Motion-JPEG	119
	MPEG	120
	Picture coding types (I, P, B)	121
	Reordering	124
	MPEG-1	125
	MPEG-2	126
15	Digital video interfaces	127
	Component digital SDTV interface (Rec. 601, "4:2:2")	127
	Composite digital SDTV ($4f_{SC}$) interface	129
	Serial digital interface (SDI)	130

Component digital HDTV HD-SDI	130
Interfaces for compressed video	131
SDTI	132
DVB ASI and SMPTE SSI	133
IEEE 1394 (FireWire, i.LINK)	133
Switching and mixing	134
Timing in analog facilities	135
Timing in composite analog NTSC and PAL	136
Timing in digital facilities	137

Part 2 – Principles 139

16 Filtering and sampling 141

Sampling theorem	142
Sampling at exactly $0.5f_s$	143
Magnitude frequency response	146
Magnitude frequency response of a boxcar	147
The sinc weighting function	148
Frequency response of point sampling	149
Fourier transform pairs	150
Analog filters	150
Digital filters	150
Impulse response	157
Finite impulse response (FIR) filters	157
Physical realizability of a filter	158
Phase response (group delay)	159
Infinite impulse response (IIR) filters	160
Lowpass filter	162
Digital filter design	163
Reconstruction	167
Reconstruction close to $0.5f_s$	168
(sin x)/x correction	168
Further reading	170

17 Resampling, interpolation, and decimation 171

2:1 downsampling	174
Oversampling	174
Interpolation	176
Lagrange interpolation	177
Lagrange interpolation as filtering	180
Polyphase interpolators	181
Polyphase taps and phases	182
Implementing polyphase interpolators	183
Decimation	184
Lowpass filtering in decimation	185

18 Image digitization and reconstruction	187	Spatial frequency domain	188
		Comb filtering	190
		Spatial filtering	191
		Image presampling filters	192
		Image reconstruction filters	192
		Spatial (2-D) oversampling	193
19 Perception and visual acuity	195	Retina	195
		Adaptation	196
		Contrast ratio	197
		Contrast sensitivity	198
		Contrast sensitivity function (CSF)	201
20 Luminance and lightness	203	Radiance, intensity	204
		Luminance	205
		Relative luminance	206
		Luminance from red, green, and blue	207
		Lightness (CIE L^*)	208
21 The CIE system of colorimetry	211	Fundamentals of vision	212
		Definitions	212
		Spectral power distribution (SPD) and tristimulus	213
		Scanner spectral constraints	214
		CIE XYZ tristimulus	217
		CIE $[x, y]$ chromaticity	219
		Blackbody radiation	222
		Color temperature	223
		White	223
		Perceptually uniform color spaces	225
		CIE $L^*u^*v^*$	226
		CIE $L^*a^*b^*$	228
		CIE $L^*u^*v^*$ and CIE $L^*a^*b^*$ summary	228
		Color specification	229
		Color image coding	230
		Further reading	231
22 Color science for video	233	Additive reproduction (RGB)	234
		Characterization of RGB primaries	236
		CIE RGB primaries	236
		NTSC primaries (obsolete)	236
		EBU Tech. 3213 primaries	238
		SMPTE RP 145 primaries	239
		Rec. 709/sRGB primaries	239
		CMFs and SPDs	240

	Luminance coefficients	250
	Transformations between <i>RGB</i> and CIE <i>XYZ</i>	251
	Noise due to matrixing	252
	Transforms among <i>RGB</i> systems	252
	Camera white reference	253
	Monitor white reference	254
	Gamut	255
	Wide-gamut reproduction	256
	Further reading	256
23	Gamma	257
	Gamma in CRT physics	258
	The amazing coincidence!	260
	Gamma in video	261
	Optoelectronic transfer functions (OETFs)	262
	Rec. 709 transfer function	263
	SMPTE 240M transfer function	265
	Rec. 1361 transfer function	265
	sRGB transfer function	267
	Transfer functions in SDTV	268
	Bit depth requirements	269
	Gamma in emerging display devices	270
	CRT transfer function details	270
	Gamma in video, CGI, SGI, and Macintosh	273
	Gamma in computer graphics	276
	Gamma in pseudocolor	278
	Limitations of 8-bit linear coding	278
	Linear and nonlinear coding in CGI	279
24	Luma and color differences	281
	Color acuity	281
	<i>RGB</i> and <i>R'G'B'</i> color cubes	283
	Conventional luma/color difference coding	286
	Luminance and luma notation	288
	Nonlinear red, green, blue (<i>R'G'B'</i>)	290
	Rec. 601 luma	291
	Rec. 709 luma	292
	SMPTE 240M-1988 luma	292
	Chroma subsampling, revisited	292
	Luma/color difference summary	293
	SDTV and HDTV luma chaos	296
	Luma/color difference component sets	298
25	Component video color coding for SDTV	301
	<i>B'-Y'</i> , <i>R'-Y'</i> components for SDTV	303
	<i>P_BP_R</i> components for SDTV	303
	<i>C_BC_R</i> components for SDTV	305

	$Y' C_B C_R$ from studio <i>RGB</i>	309
	$Y' C_B C_R$ from computer <i>RGB</i>	309
	"Full-range" $Y' C_B C_R$	310
	$Y' UV, Y' IQ$ confusion	311
26	Component video color coding for HDTV	313
	$B' - Y', R' - Y'$ components for Rec. 709 HDTV	314
	$P_B P_R$ components for Rec. 709 HDTV	314
	$C_B C_R$ components for Rec. 709 HDTV	316
	$C_B C_R$ components for Rec. 1361 HDTV	318
	$Y' C_B C_R$ from studio <i>RGB</i>	318
	$Y' C_B C_R$ from computer <i>RGB</i>	319
	Conversions between HDTV and SDTV	319
	SMPTE 240M-1988 luma	320
	Color coding standards	321
27	Video signal processing	323
	Transition samples	323
	Edge treatment	323
	Picture lines	324
	Choice of S_{AL} and S_{PW} parameters	325
	Video levels	326
	Setup (pedestal)	327
	Rec. 601 to computing	328
	Enhancement	330
	Median filtering	331
	Coring	331
	Chroma transition improvement (CTI)	332
	Scan-velocity modulation (SVM)	333
	Mixing and keying	333
28	NTSC and PAL chroma modulation	335
	UV components	336
	NTSC chroma modulation	338
	NTSC chroma demodulation	340
	PAL chroma modulation	341
	Subcarrier regeneration	344
	S-video interface	346
	Decoder controls	346
29	NTSC and PAL frequency interleaving	349
	Notch filtering	349
	Frequency interleaving in NTSC	352
	Cross-luma and cross-color	353
	Frequency interleaving in PAL	355
	Spatial frequency spectra of NTSC	357
	Spatial frequency spectra of PAL	360

- One-dimensional frequency spectrum of NTSC 361
 - One-dimensional frequency spectrum of PAL 364
- 30 NTSC Y'IQ system 365**
 - Narrowband Q 366
 - I/Q components 367
 - Y'IQ encoding 368
- 31 Frame, field, line, and sample rates 371**
 - Field rate 371
 - Line rate 372
 - Sound subcarrier 372
 - Addition of composite color 373
 - NTSC color subcarrier 373
 - 576i PAL color subcarrier 375
 - $4f_{SC}$ sampling 375
 - Common sampling rate 376
 - Numerology of HDTV scanning 377
 - Audio rates 379
- 32 Timecode 381**
 - Introduction 381
 - Dropframe timecode 382
 - Editing 384
 - Linear timecode (LTC) 384
 - Vertical interval timecode (VITC) 385
 - Timecode structure 386
 - Further reading 388
- 33 Digital sync, TRS, ancillary data, and interface 389**
 - TRS in 4:2:2 component SDTV 390
 - TRS in HD-SDI 392
 - TRS-ID in $4f_{SC}$ composite video 393
 - Digital to analog timing relationships 394
 - Ancillary data 395
 - SDI coding 396
 - HD-SDI coding 398
 - Summary 398
- 34 Analog SDTV sync, genlock, and interface 399**
 - Analog sync 399
 - Odd/even, first/second, top/bottom 403
 - Sync distribution 404
 - Genlock 405
 - Analog horizontal blanking interval 405
 - Sync separation 406
 - Component analog levels 407
 - Composite analog levels 407
 - Analog electrical interface 408

- Analog mechanical interface 408
- S-video electrical and mechanical interface 409
- 35 Videotape recording 411**
 - Playback in shuttle 413
 - Recording 414
 - Playback 415
 - Editing 416
 - Digital VTRs 417
 - Timebase error 417
 - Channel coding 418
 - Analog VTR signal processing 418
 - Analog videotape formats 419
 - Digital VTR signal processing 420
 - Digital videotape formats 421
 - DV family 422
 - DV recording 424
 - Studio adaptation of DV technology 425
 - HDTV videotape formats 426
 - Consumer bitstream recording – DV ATV, DV DVB 427
 - Further reading 428
- 36 2-3 pulldown 429**
 - Conversion of film to different frame rates 431
 - Native 24 Hz coding 434
 - Conversion to other rates 435
- 37 Deinterlacing 437**
 - Spatial domain 437
 - Vertical-temporal domain 439
 - Motion adaptivity 440
- Part 3 – Video compression 445**
- 38 JPEG and motion-JPEG (M-JPEG) compression 447**
 - JPEG blocks and MCUs 448
 - JPEG block diagram 450
 - Level-shifting 451
 - Discrete cosine transform (DCT) 451
 - JPEG encoding example 452
 - JPEG decoding 456
 - Compression ratio control 457
 - JPEG/JFIF 459
 - Motion-JPEG (M-JPEG) 460
 - Further reading 460
- 39 DV compression 461**
 - DV chroma subsampling 462
 - DV frame/field modes 463

Picture-in-shuttle in DV 464
DV overflow scheme 465
DV quantization 466
Consumer DV variants – SD, LP, SDL, HD 468
Professional DV variants 469
DV digital interface (DIF) 470
Sony Digital Betacam compression 471
Sony Betacam SX compression 471
D-5 HD compression 471
D-11 (HDCAM) compression 471

**40 MPEG-2 video
compression 473**

MPEG-2 profiles and levels 474
Picture structure 477
Frame rate and 2-3 pulldown in MPEG 478
Luma and chroma sampling structures 479
Macroblocks 480
Picture coding types – I, P, B 480
Prediction 481
Motion vectors (MVs) 484
Coding of a block 485
Frame and field DCT types 486
Zigzag and VLE 487
Refresh 488
Motion estimation 490
Rate control and buffer management 491
Bitstream syntax 493
Transport 495
Further reading 496

Part 4 – Studio standards 497

**41 480i component
video 499**

Frame rate 499
Interlace 499
Line sync 501
Field/frame sync 502
RGB primary components 504
Nonlinear transfer function 504
Luma (Y') 504
Picture center, aspect ratio, and blanking 505
Halfline blanking 506
Component digital 4:2:2 interface 506
Component analog R'G'B' interface 507

Component analog $Y'P_B P_R$ interface, EBU N10 508

Component analog $Y'P_B P_R$ interface, industry standard 509

42 480i NTSC composite video 511

Subcarrier 511

NTSC two-frame sequence 512

NTSC burst 512

Color differences (U, V) 513

Color difference filtering 513

Chroma (C) 513

Setup 514

S-video-525 ($Y'/C3.58$) 515

Composite NTSC encoding 515

Composite digital NTSC interface ($4f_{SC}$) 516

Composite analog NTSC interface 517

43 576i component video 519

Frame rate 519

Interlace 519

Line sync 521

Analog field/frame sync 521

RGB primary components 524

Nonlinear transfer function 524

Luma (Y') 524

Picture center, aspect ratio, and blanking 525

Component digital 4:2:2 interface 525

Component analog $R'G'B'$ interface 526

Component analog $Y'P_B P_R$ interface 527

44 576i PAL composite video 529

Subcarrier 529

PAL four-frame sequence 529

PAL burst 530

Color difference components (U, V) 530

Color difference filtering 531

Chroma (C) 531

S-video-625 ($Y'/C4.43$) 531

Composite PAL encoding 532

Composite digital PAL interface ($4f_{SC}$) 532

Composite analog PAL interface 534

45 SDTV test signals 535

Colorbars 535

Colorbar notation 539

Frequency response 539

Differential gain (DG) 539

Differential phase (DP) 541

	Pulse signals	542
	Modulated 12.5T, 20T pulses	544
46	1280×720 HDTV	547
	Scanning	547
	Analog sync	549
	Picture center, aspect ratio, and blanking	549
	RGB primary components	551
	Nonlinear transfer function	551
	Luma (Y')	551
	Component digital 4:2:2 interface	552
	Component analog R'G'B' interface	552
	Component analog Y'P _B P _R interface	552
	Pre- and postfiltering characteristics	553
47	1920×1080 HDTV	557
	Scanning	558
	Analog sync	560
	Picture center, aspect ratio, and blanking	563
	Relationship to SMPTE 240M (1035i) scanning	563
	RGB primary components	565
	Nonlinear transfer function	565
	Luma (Y')	565
	Component digital 4:2:2 interface	566
	Component analog R'G'B' interface	566
	Component analog Y'P _B P _R interface	566
	Pre- and postfiltering characteristics	567
	Part 5 – Broadcast and consumer standards	569
48	Analog NTSC and PAL broadcast standards	571
	ITU-R (former CCIR)	572
	ITU-R scanning nomenclature	572
	M/NTSC (NTSC)	573
	Audio in NTSC	573
	B,G,H,I/PAL (PAL)	574
	Audio in PAL	575
	PAL-M, PAL-N	575
	SECAM	576
	Multiplexed analog components (MAC)	577
	Summary of parameters	578
49	Consumer analog NTSC and PAL	579
	Multistandard consumer equipment	579
	Degenerate analog NTSC and PAL	581
	Coherent subcarrier	581
	Incoherent subcarrier	582
	Nonstandard scanning	582

- SCART interface 583
- Heterodyne (color-under) recording 583
- VHS trick mode playback 585
- Timebase correction (TBC) 585
- 50 Digital television broadcast standards 587**
 - Japan 588
 - United States 588
 - ATSC modulation 589
 - Europe 591
 - Further reading 592

Appendices 593

A YUV and luminance considered harmful 595

- Cement vs. concrete 595
- True CIE luminance 596
- The misinterpretation of luminance 596
- The enshrining of luma 598
- Color difference scale factors 599
- Conclusion: A plea 600

B Introduction to radiometry and photometry 601

- Radiometry 602
- Photometry 603
- Image science 606
- Units 606
- Further reading 607

Glossary of video signal terms 609

Index 653