

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	How to Read This Book	1
1.2	A Brief Walk Through the History of Video Coding Standards	2
1.2.1	Advanced Video Coding	5
1.2.2	High Efficiency Video Coding	5
1.3	Evolution of a Specification	6
1.3.1	Formal Procedure for a Standard in ISO/IEC	8
1.3.2	Formal Procedure for a Recommendation in the ITU-T	10
1.4	The Joint Collaborative Team on Video Coding	12
1.4.1	Approval Process	13
1.4.2	Method of Working	14
1.4.3	Deliverables	15
1.4.4	Structure of the JCT-VC	16
	References	19
<b>2</b>	<b>Video Coding Fundamentals</b>	<b>23</b>
2.1	Video Coding Systems	23
2.1.1	Video Acquisition	24
2.1.2	Pre-processing	25
2.1.3	Encoding	25
2.1.4	Transmission	26
2.1.5	Decoding	26
2.1.6	Post-processing	27
2.1.7	Display	27
2.2	Structure of a Video Sequence	28
2.2.1	Pictures, Frames, and Fields	28
2.2.2	Sample Shape	29
2.3	Representation of Color	30

2.3.1	The CIE Standard Observer . . . . .	31
2.3.2	Color Primaries . . . . .	32
2.3.3	Display Transfer Characteristics . . . . .	32
2.3.4	Color Conversion . . . . .	33
2.3.5	Chroma Sub-sampling . . . . .	35
2.4	The Hybrid Video Coding Scheme . . . . .	37
2.4.1	Picture Partitioning . . . . .	39
2.4.2	Intra Prediction . . . . .	40
2.4.3	Inter Prediction . . . . .	41
2.4.4	Motion Estimation . . . . .	43
2.4.5	Residual Coding . . . . .	43
2.4.6	In-loop Filtering . . . . .	53
2.4.7	The Decoded Picture Buffer . . . . .	55
2.4.8	Entropy Coding . . . . .	55
2.5	Encoder Control . . . . .	62
2.5.1	Distortion Measures . . . . .	63
2.5.2	Rate-Distortion Optimization . . . . .	65
2.6	Compression Artifacts . . . . .	66
	References . . . . .	69
<b>3</b>	<b>Design and Specification . . . . .</b>	<b>73</b>
3.1	Specification Fundamentals . . . . .	74
3.1.1	Interoperability . . . . .	74
3.1.2	Specification Scope . . . . .	75
3.1.3	Text Classification . . . . .	75
3.1.4	Editing Perspective . . . . .	76
3.2	Specification Elements . . . . .	77
3.2.1	Syntax and Semantics . . . . .	77
3.2.2	Decoding Process . . . . .	78
3.2.3	Parsing Process . . . . .	78
3.3	Specification Principles . . . . .	79
3.3.1	Loss Robustness . . . . .	79
3.3.2	Independent Parsing . . . . .	80
3.3.3	Bit-Exact Specification . . . . .	81
3.3.4	Parallelization . . . . .	81
3.3.5	Dynamic Range . . . . .	82
3.3.6	Timing . . . . .	83
3.4	Conformance . . . . .	83
3.5	How to Read the Specification Text . . . . .	84
3.5.1	Terminology . . . . .	86
3.5.2	Conventions and Geometric Relations . . . . .	88

3.6	Drafting Methodology . . . . .	91
3.6.1	Measuring the Compression Performance . . . . .	92
3.6.2	Proposal Assessment . . . . .	97
	References . . . . .	99
<b>4</b>	<b>Coding Structures . . . . .</b>	<b>101</b>
4.1	Temporal Coding Structures . . . . .	102
4.1.1	Temporal Layers . . . . .	105
4.1.2	Picture Types . . . . .	106
4.1.3	Splicing of Video Sequences . . . . .	112
4.1.4	Comparison to H.264   AVC . . . . .	113
4.2	Spatial Coding Structures . . . . .	114
4.2.1	Blocks and Units . . . . .	114
4.2.2	Slices and Slice Segments . . . . .	115
4.2.3	Tiles . . . . .	118
4.2.4	Coding Tree Block and Coding Block . . . . .	120
4.2.5	Prediction Block . . . . .	121
4.2.6	Transform Tree and Transform Block . . . . .	122
4.2.7	Comparison to H.264   AVC . . . . .	123
4.3	Reference Pictures . . . . .	124
4.3.1	Reference Picture Sets . . . . .	125
4.3.2	Reference Picture Lists . . . . .	128
4.3.3	Short-Term Reference Picture Set Signaling . . . . .	130
4.3.4	Long-Term Reference Picture Set Signaling . . . . .	130
4.3.5	Comparison to H.264   AVC . . . . .	131
	References . . . . .	132
<b>5</b>	<b>High-Level Syntax . . . . .</b>	<b>133</b>
5.1	Byte Stream Format . . . . .	133
5.2	Network Abstraction Layer . . . . .	134
5.2.1	NAL Unit Structure . . . . .	134
5.2.2	NAL Unit Types . . . . .	136
5.2.3	Access Units . . . . .	139
5.2.4	Decoding Units . . . . .	140
5.3	Parameter Sets . . . . .	140
5.3.1	Video Parameter Set . . . . .	143
5.3.2	Sequence Parameter Set . . . . .	144
5.3.3	Picture Parameter Set . . . . .	144
5.4	Slice Segment Header . . . . .	145
5.4.1	Picture Order Count . . . . .	145
5.5	Supplemental Enhancement Information . . . . .	147

5.6	Hypothetical Reference Decoder. . . . .	149
5.6.1	Coded Picture Buffer . . . . .	150
5.6.2	Decoded Picture Buffer. . . . .	152
5.6.3	Sub-picture Operation . . . . .	152
5.6.4	Operation Points. . . . .	153
5.6.5	Conformance Points . . . . .	153
5.6.6	Signaling HRD Parameters in the VPS and SPS. . . . .	154
5.7	Video Usability Information. . . . .	154
5.7.1	Geometrical Relations. . . . .	154
5.7.2	Video Signal Type and Color Information. . . . .	155
5.7.3	Frame/Field Indication . . . . .	155
5.7.4	Default Display Window . . . . .	156
5.7.5	Timing Information . . . . .	156
5.7.6	Bitstream Restrictions . . . . .	157
5.8	Comparison to H.264   AVC. . . . .	158
	References . . . . .	159
<b>6</b>	<b>Intra Prediction . . . . .</b>	<b>161</b>
6.1	Prediction Mode and Prediction Block . . . . .	162
6.2	Reference Samples for Intra Prediction . . . . .	163
6.2.1	Reference Construction . . . . .	163
6.2.2	Lowpass Smoothing . . . . .	165
6.2.3	Strong Smoothing for $32 \times 32$ Luma Reference Samples . . . . .	166
6.3	Planar Intra Prediction. . . . .	166
6.4	DC Intra Prediction. . . . .	167
6.5	Angular Intra Prediction . . . . .	168
6.5.1	One-Dimensional Prediction Reference . . . . .	168
6.5.2	Interpolated Prediction . . . . .	169
6.5.3	Horizontal and Vertical Intra Prediction . . . . .	170
6.6	Signaling and Predictive Coding of Intra Prediction Modes . . .	172
6.6.1	Luma Intra Prediction Mode . . . . .	172
6.6.2	Derivation of the Chroma Intra Prediction Mode . . . .	174
6.7	Intra Coding Example . . . . .	175
6.8	Comparison to H.264   AVC. . . . .	176
	References . . . . .	177
<b>7</b>	<b>Inter Prediction . . . . .</b>	<b>179</b>
7.1	Motion Compensated Prediction. . . . .	179
7.1.1	Uni-prediction and Bi-prediction . . . . .	180
7.1.2	Coding Block Partitioning into Prediction Blocks. . . .	181
7.1.3	Weighted Prediction . . . . .	183

7.2	Motion Vector Representation . . . . .	184
7.2.1	Motion Data Storage Reduction . . . . .	184
7.2.2	Merging Motion Vectors . . . . .	185
7.2.3	Predictive Motion Vector Coding . . . . .	188
7.2.4	Signaling . . . . .	190
7.3	Sub-Sample Interpolation. . . . .	191
7.3.1	Luma Sub-Sample Interpolation Filtering . . . . .	191
7.3.2	Chroma Sub-Sample Interpolation Filtering . . . . .	192
7.3.3	Derivation of the Interpolation Filter Coefficients. . . . .	194
7.4	Inter Coding Examples . . . . .	197
7.5	Comparison to H.264   AVC. . . . .	198
7.5.1	Motion Vector Representation . . . . .	198
7.5.2	Sub-Sample Interpolation . . . . .	200
	References . . . . .	202
<b>8</b>	<b>Residual Coding . . . . .</b>	<b>205</b>
8.1	Transforms and Quantization . . . . .	206
8.1.1	Integer DCTs . . . . .	206
8.1.2	Integer $4 \times 4$ DST . . . . .	210
8.1.3	Dynamic Range and Transform Normalization. . . . .	211
8.1.4	Quantizer Design . . . . .	213
8.1.5	Quantizer Weighting Matrix . . . . .	216
8.1.6	Decoder-Side Weighting and Level Scaling Operation. . . . .	218
8.1.7	Signaling of the Quantization Parameter . . . . .	218
8.2	Coded Representation of Transform Blocks . . . . .	219
8.2.1	Transform Sub-Blocks. . . . .	219
8.2.2	Last Significant Coefficient Position. . . . .	220
8.2.3	Transform Block Coefficient Coding . . . . .	221
8.2.4	Sign Data Hiding . . . . .	223
8.3	Transform Skip . . . . .	224
8.4	Transform and Quantization Bypass . . . . .	224
8.5	PCM Coding . . . . .	225
8.6	Comparison to H.264   AVC. . . . .	225
	References . . . . .	226
<b>9</b>	<b>In-Loop Filtering . . . . .</b>	<b>229</b>
9.1	Deblocking Filter . . . . .	229
9.1.1	Determination of Edges. . . . .	230
9.1.2	Determination of the Deblocking Filter Strength Parameter . . . . .	231
9.1.3	Deblocking Filtering . . . . .	233
9.1.4	Deblocking Filter Example . . . . .	240

9.2	Sample Adaptive Offset . . . . .	241
9.2.1	Edge Offset . . . . .	242
9.2.2	Band Offset . . . . .	243
9.2.3	Signaling of SAO Parameters. . . . .	244
9.2.4	SAO Filter Example . . . . .	245
9.2.5	Encoder-Side Derivation of Sample Adaptive Offset Parameters . . . . .	245
9.3	Comparison to H.264   AVC. . . . .	249
	References . . . . .	250
<b>10</b>	<b>Entropy Coding . . . . .</b>	<b>251</b>
10.1	Fixed- and Variable-Length Coding . . . . .	252
10.1.1	Fixed-Length Codes . . . . .	252
10.1.2	Exp-Golomb Codes. . . . .	253
10.2	CABAC—Context-Based Adaptive Binary Arithmetic Coding . . . . .	253
10.2.1	Process Overview. . . . .	254
10.2.2	Binary Arithmetic Coding . . . . .	255
10.2.3	Binarization . . . . .	266
10.2.4	Context Initialization. . . . .	274
10.2.5	Context Selection . . . . .	275
10.3	Comparison to H.264   AVC. . . . .	281
	References . . . . .	282
<b>11</b>	<b>Profiles, Tiers, and Levels. . . . .</b>	<b>283</b>
11.1	Profiles . . . . .	284
11.1.1	Main Profile . . . . .	285
11.1.2	Main 10 Profile . . . . .	285
11.1.3	Main Still Picture Profile. . . . .	286
11.2	Tiers and Levels. . . . .	286
11.3	Syntax Structure. . . . .	287
	References . . . . .	289
<b>12</b>	<b>Extensions to HEVC. . . . .</b>	<b>291</b>
12.1	Range Extensions . . . . .	292
12.1.1	Proposed RExt Profiles . . . . .	292
12.1.2	Proposed RExt Tools . . . . .	293
12.1.3	Comparison to H.264   AVC. . . . .	295
12.2	Common Specification Structure for Multi-Layer Video Coding Extensions . . . . .	295
12.2.1	Definition of Layers . . . . .	296
12.2.2	Proposed Joint Tools. . . . .	297

12.3	Multiview Coding . . . . .	299
12.3.1	Proposed Multiview Profile . . . . .	300
12.3.2	Comparison to H.264   AVC. . . . .	300
12.4	Scalable Extension . . . . .	301
12.4.1	Proposed SHVC Profile. . . . .	301
12.4.2	Proposed SHVC Tools . . . . .	301
12.4.3	Comparison to H.264   AVC. . . . .	304
12.5	3D Video Coding . . . . .	305
	References . . . . .	306
	<b>Index . . . . .</b>	<b>309</b>

High Efficiency Video Coding  
Coding Tools and Specification

Wien, M.

2015, XXIV, 314 p. 127 illus., 22 illus. in color.,

Hardcover

ISBN: 978-3-662-44275-3