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FFV1 Video Coding Format Version 4
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Abstract

This document defines FFV1, a lossless intra-frame video encoding format. FFV1 is designed to efficiently compress video data in a variety of pixel formats. Compared to uncompressed video, FFV1 offers storage compression, frame fixity, and self-description, which makes FFV1 useful as a preservation or intermediate video format.

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[1.](#) Introduction

This document describes FFV1, a lossless video encoding format. The design of FFV1 considers the storage of image characteristics, data fixity, and the optimized use of encoding time and storage requirements. FFV1 is designed to support a wide range of lossless video applications such as long-term audiovisual preservation, scientific imaging, screen recording, and other video encoding scenarios that seek to avoid the generational loss of lossy video encodings.

This document defines a version 4 of FFV1. Prior versions of FFV1 are defined within [[I-D.ietf-cellar-ffv1](#)].

The latest version of this document is available at
<<https://raw.githubusercontent.com/FFmpeg/FFV1/master/ffv1.md>>

This document assumes familiarity with mathematical and coding concepts such as Range coding [[range-coding](#)] and YCbCr color spaces [[YCbCr](#)].

[2.](#) Notation and Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [[RFC2119](#)].

[2.1.](#) Definitions

"Frame": An encoded representation of a complete static image.

"Slice": A spatial sub-section of a "Frame" that is encoded separately from an other region of the same frame.

"Container": Format that encapsulates "Frames" and (when required) a "Configuration Record" into a bitstream.

"Sample": The smallest addressable representation of a color component or a luma component in a "Frame". Examples of sample are Luma, Blue Chrominance, Red Chrominance, Alpha, Red, Green, and Blue.

"Pixel": The smallest addressable representation of a color in a "Frame". It is composed of 1 or more samples.

"ESC": An ESCape symbol to indicate that the symbol to be stored is too large for normal storage and that an alternate storage method.

"MSB": Most Significant Bit, the bit that can cause the largest change in magnitude of the symbol.

"RCT": Reversible Color Transform, a near linear, exactly reversible integer transform that converts between RGB and YCbCr representations of a Pixel.

"VLC": Variable Length Code, a code that maps source symbols to a variable number of bits.

"RGB": A reference to the method of storing the value of a Pixel by using three numeric values that represent Red, Green, and Blue.

"YCbCr": A reference to the method of storing the value of a Pixel by using three numeric values that represent the luma of the Pixel (Y) and the chrominance of the Pixel (Cb and Cr). YCbCr word is used for historical reasons and currently references any color space relying on 1 luma sample and 2 chrominance samples e.g. YCbCr, YCgCo or ICtCp. Exact meaning of the three numeric values is unspecified.

"TBA": To Be Announced. Used in reference to the development of future iterations of the FFV1 specification.

2.2. Conventions

2.2.1. Pseudo-code

The FFV1 bitstream is described in this document using pseudo-code. Note that the pseudo-code is used for clarity in order to illustrate the structure of FFV1 and not intended to specify any particular implementation. The pseudo-code used is based upon the C programming language [[ISO.9899.1990](#)] and uses its "if/else", "while" and "for" functions as well as functions defined within this document.

2.2.2. Arithmetic Operators

Note: the operators and the order of precedence are the same as used in the C programming language [[ISO.9899.1990](#)].

"a + b" means a plus b.

"a - b" means a minus b.

"-a" means negation of a.

"a * b" means a multiplied by b.

"a / b" means a divided by b.

"a & b" means bit-wise "and" of a and b.

"a | b" means bit-wise "or" of a and b.

"a >> b" means arithmetic right shift of two's complement integer representation of a by b binary digits.

"a << b" means arithmetic left shift of two's complement integer representation of a by b binary digits.

2.2.3. Assignment Operators

"a = b" means a is assigned b.

"a++" is equivalent to a is assigned a + 1.

"a--" is equivalent to a is assigned a - 1.

"a += b" is equivalent to a is assigned a + b.

"a -= b" is equivalent to a is assigned a - b.

"a *= b" is equivalent to a is assigned a * b.

2.2.4. Comparison Operators

"a > b" means a is greater than b.

"a >= b" means a is greater than or equal to b.

"a < b" means a is less than b.

"a <= b" means a is less than or equal b.

"a == b" means a is equal to b.

"a != b" means a is not equal to b.

"a && b" means Boolean logical "and" of a and b.

"a || b" means Boolean logical "or" of a and b.

"!a" means Boolean logical "not" of a.

"a ? b : c" if a is true, then b, otherwise c.

2.2.5. Mathematical Functions

`floor(a)` the largest integer less than or equal to `a`

`ceil(a)` the smallest integer greater than or equal to `a`

`sign(a)` extracts the sign of a number, i.e. if `a < 0` then `-1`, else if `a > 0` then `1`, else `0`

`abs(a)` the absolute value of `a`, i.e. `abs(a) = sign(a)*a`

`log2(a)` the base-two logarithm of `a`

`min(a,b)` the smallest of two values `a` and `b`

`max(a,b)` the largest of two values `a` and `b`

`median(a,b,c)` the numerical middle value in a data set of `a`, `b`, and `c`, i.e. `a+b+c-min(a,b,c)-max(a,b,c)`

`a_{b}` the `b`-th value of a sequence of `a`

`a_{b,c}` the '`b,c`'-th value of a sequence of `a`

2.2.6. Order of Operation Precedence

When order of precedence is not indicated explicitly by use of parentheses, operations are evaluated in the following order (from top to bottom, operations of same precedence being evaluated from left to right). This order of operations is based on the order of operations used in Standard C.

```
a++, a--  
!a, -a  
a * b, a / b, a % b  
a + b, a - b  
a << b, a >> b  
a < b, a <= b, a > b, a >= b  
a == b, a != b  
a & b  
a | b  
a && b  
a || b  
a ? b : c  
a = b, a += b, a -= b, a *= b
```


2.2.7. Range

"a...b" means any value starting from a to b, inclusive.

2.2.8. NumBytes

"NumBytes" is a non-negative integer that expresses the size in 8-bit octets of particular FFV1 "Configuration Record" or "Frame". FFV1 relies on its "Container" to store the "NumBytes" values, see [Section 4.2.3](#).

2.2.9. Bitstream Functions

2.2.9.1. remaining_bits_in_bitstream

"remaining_bits_in_bitstream()" means the count of remaining bits after the pointer in that "Configuration Record" or "Frame". It is computed from the "NumBytes" value multiplied by 8 minus the count of bits of that "Configuration Record" or "Frame" already read by the bitstream parser.

2.2.9.2. byte_aligned

"byte_aligned()" is true if "remaining_bits_in_bitstream(NumBytes)" is a multiple of 8, otherwise false.

2.2.9.3. get_bits

"get_bits(i)" is the action to read the next "i" bits in the bitstream, from most significant bit to least significant bit, and to return the corresponding value. The pointer is increased by "i".

3. General Description

Samples within a plane are coded in raster scan order (left->right, top->bottom). Each sample is predicted by the median predictor from samples in the same plane and the difference is stored see [Section 3.8](#).

3.1. Border

A border is assumed for each coded slice for the purpose of the predictor and context according to the following rules:

- o one column of samples to the left of the coded slice is assumed as identical to the samples of the leftmost column of the coded slice shifted down by one row. The value of the topmost sample of the

column of samples to the left of the coded slice is assumed to be "0"

- o one column of samples to the right of the coded slice is assumed as identical to the samples of the rightmost column of the coded slice
- o an additional column of samples to the left of the coded slice and two rows of samples above the coded slice are assumed to be "0"

The following table depicts a slice of samples "a,b,c,d,e,f,g,h,i" along with its assumed border.

```

+---+---+---+---+---+---+---+---+
| 0 | 0 |   | 0 | 0 | 0 |   | 0 |
+---+---+---+---+---+---+---+---+
| 0 | 0 |   | 0 | 0 | 0 |   | 0 |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
| 0 | 0 |   | a | b | c |   | c |
+---+---+---+---+---+---+---+---+
| 0 | a |   | d | e | f |   | f |
+---+---+---+---+---+---+---+---+
| 0 | d |   | g | h | i |   | i |
+---+---+---+---+---+---+---+---+

```

3.2. Samples

Positions used for context and median predictor are:

```

+---+---+---+---+
|   |   | T |   |
+---+---+---+---+
|   | t1 | t | tr |
+---+---+---+---+
| L | l | X |   |
+---+---+---+---+

```

"X" is the current processed Sample. The identifiers are made of the first letters of the words Top, Left and Right.

3.3. Median Predictor

The prediction for any sample value at position "X" may be computed based upon the relative neighboring values of "l", "t", and "t1" via this equation:


```
"median(l, t, l + t - t1)".
```

Note, this prediction template is also used in [[ISO.14495-1.1999](#)] and [[HuffyUV](#)].

Exception for the media predictor: if "colorspace_type == 0 && bits_per_raw_sample == 16 && (coder_type == 1 || coder_type == 2)", the following media predictor MUST be used:

```
"median(left16s, top16s, left16s + top16s - diag16s)"
```

where:

```
left16s = l  >= 32768 ? ( l  - 65536 ) : l
top16s  = t  >= 32768 ? ( t  - 65536 ) : t
diag16s = t1 >= 32768 ? ( t1 - 65536 ) : t1
```

Background: a two's complement signed 16-bit signed integer was used for storing sample values in all known implementations of FFV1 bitstream. So in some circumstances, the most significant bit was wrongly interpreted (used as a sign bit instead of the 16th bit of an unsigned integer). Note that when the issue is discovered, the only configuration of all known implementations being impacted is 16-bit YCbCr with no Pixel transformation with Range Coder coder, as other potentially impacted configurations (e.g. 15/16-bit JPEG2000-RCT with Range Coder coder, or 16-bit content with Golomb Rice coder) were implemented nowhere [[ISO.15444-1.2016](#)]. In the meanwhile, 16-bit JPEG2000-RCT with Range Coder coder was implemented without this issue in one implementation and validated by one conformance checker. It is expected (to be confirmed) to remove this exception for the media predictor in the next version of the FFV1 bitstream.

[3.4.](#) Context

Relative to any sample "X", the Quantized Sample Differences "L-l", "l-t1", "t1-t", "T-t", and "t-tr" are used as context:

```
context = Q_{0}[l - t1] +
          Q_{1}[t1 - t] +
          Q_{2}[t - tr] +
          Q_{3}[L - l] +
          Q_{4}[T - t]
```

If "context >= 0" then "context" is used and the difference between the sample and its predicted value is encoded as is, else "-context" is used and the difference between the sample and its predicted value is encoded with a flipped sign.

3.5. Quantization Table Sets

The FFV1 bitstream contains 1 or more Quantization Table Sets. Each Quantization Table Set contains exactly 5 Quantization Tables, each Quantization Table corresponding to 1 of the 5 Quantized Sample Differences. For each Quantization Table, both the number of quantization steps and their distribution are stored in the FFV1 bitstream; each Quantization Table has exactly 256 entries, and the 8 least significant bits of the Quantized Sample Difference are used as index:

$$Q_{\{j\}}[k] = \text{quant_tables}[i][j][k \& 255]$$

In this formula, "i" is the Quantization Table Set index, "j" is the Quantized Table index, "k" the Quantized Sample Difference.

3.6. Quantization Table Set Indexes

For each plane of each slice, a Quantization Table Set is selected from an index:

- o For Y plane, "quant_table_set_index [0]" index is used
- o For Cb and Cr planes, "quant_table_set_index [1]" index is used
- o For Alpha plane, "quant_table_set_index [(version <= 3 || chroma_planes) ? 2 : 1]" index is used

Background: in first implementations of FFV1 bitstream, the index for Cb and Cr planes was stored even if it is not used (chroma_planes set to 0), this index is kept for version <= 3 in order to keep compatibility with FFV1 bitstreams in the wild.

3.7. Color spaces

FFV1 supports two color spaces: YCbCr and RGB. Both color spaces allow an optional Alpha plane that can be used to code transparency data.

3.7.1. YCbCr

In YCbCr color space, the Cb and Cr planes are optional, but if used then MUST be used together. Omitting the Cb and Cr planes codes the frames in grayscale without color data. An FFV1 "Frame" using YCbCr MUST use one of the following arrangements:

- o Y

- o Y, Alpha
- o Y, Cb, Cr
- o Y, Cb, Cr, Alpha

The Y plane MUST be coded first. If the Cb and Cr planes are used then they MUST be coded after the Y plane. If an Alpha (transparency) plane is used, then it MUST be coded last.

3.7.2. RGB

JPEG2000-RCT is a Reversible Color Transform that codes RGB (red, green, blue) planes losslessly in a modified YCbCr color space [[ISO.15444-1.2016](#)]. Reversible Pixel transformations between YCbCr and RGB use the following formulae.

$$Cb=b-g$$

$$Cr=r-g$$

$$Y=g+(Cb+Cr)>>2$$

$$g=Y-(Cb+Cr)>>2$$

$$r=Cr+g$$

$$b=Cb+g$$

Exception for the JPEG2000-RCT conversion: if `bits_per_raw_sample` is between 9 and 15 inclusive and `alpha_plane` is 0, the following formulae for reversible conversions between YCbCr and RGB MUST be used instead of the ones above:

$$Cb=g-b$$

$$Cr=r-b$$

$$Y=b+(Cb+Cr)>>2$$

$$b=Y-(Cb+Cr)>>2$$

$$r=Cr+b$$

$$g=Cb+b$$

Background: At the time of this writing, in all known implementations of FFV1 bitstream, when `bits_per_raw_sample` was between 9 and 15

inclusive and alpha_plane is 0, GBR planes were used as BGR planes during both encoding and decoding. In the meanwhile, 16-bit JPEG2000-RCT was implemented without this issue in one implementation and validated by one conformance checker. Methods to address this exception for the transform are under consideration for the next version of the FFV1 bitstream.

When FFV1 uses the JPEG2000-RCT, the horizontal lines are interleaved to improve caching efficiency since it is most likely that the RCT will immediately be converted to RGB during decoding. The interleaved coding order is also Y, then Cb, then Cr, and then if used Alpha.

As an example, a "Frame" that is two pixels wide and two pixels high, could be comprised of the following structure:

```
+-----+-----+
| Pixel[1,1]          | Pixel[2,1]          |
| Y[1,1] Cb[1,1] Cr[1,1] | Y[2,1] Cb[2,1] Cr[2,1] |
+-----+-----+
| Pixel[1,2]          | Pixel[2,2]          |
| Y[1,2] Cb[1,2] Cr[1,2] | Y[2,2] Cb[2,2] Cr[2,2] |
+-----+-----+
```

In JPEG2000-RCT, the coding order would be left to right and then top to bottom, with values interleaved by lines and stored in this order:

```
Y[1,1] Y[2,1] Cb[1,1] Cb[2,1] Cr[1,1] Cr[2,1] Y[1,2] Y[2,2] Cb[1,2]
Cb[2,2] Cr[1,2] Cr[2,2]
```

3.8. Coding of the Sample Difference

Instead of coding the $n+1$ bits of the Sample Difference with Huffman or Range coding (or $n+2$ bits, in the case of RCT), only the n (or $n+1$) least significant bits are used, since this is sufficient to recover the original sample. In the equation below, the term "bits" represents `bits_per_raw_sample+1` for RCT or `bits_per_raw_sample` otherwise:

```
coder_input =
    [(sample_difference + 2^(bits-1)) & (2^bits - 1)] - 2^(bits-1)
```

3.8.1. Range Coding Mode

Early experimental versions of FFV1 used the CABAC Arithmetic coder from H.264 as defined in [[ISO.14496-10.2014](#)] but due to the uncertain patent/royalty situation, as well as its slightly worse performance,

CABAC was replaced by a Range coder based on an algorithm defined by G. Nigel and N. Martin in 1979 [[range-coding](#)].

3.8.1.1. Range Binary Values

To encode binary digits efficiently a Range coder is used. "C_i" is the i-th Context. "B_i" is the i-th byte of the bytestream. "b_i" is the i-th Range coded binary value, "S_{0,i}" is the i-th initial state, which is 128. The length of the bytestream encoding n binary symbols is "j_n" bytes.

$$r_{\{i\}} = \text{floor}((R_{\{i\}} * S_{\{i,C_{\{i\}}\}}) / 2^8)$$

$$\begin{aligned} S_{\{i+1,C_{\{i\}}\}} &= \text{zero_state}_{\{S_{\{i,C_{\{i\}}\}}\}} \text{ XOR} \\ l_{\{i\}} &= l_{\{i\}} \text{ XOR} \\ t_{\{i\}} &= R_{\{i\}} - r_{\{i\}} <== \\ b_{\{i\}} &= 0 <==> \\ L_{\{i\}} &< R_{\{i\}} - r_{\{i\}} \end{aligned}$$

$$\begin{aligned} S_{\{i+1,C_{\{i\}}\}} &= \text{one_state}_{\{S_{\{i,C_{\{i\}}\}}\}} \text{ XOR} \\ l_{\{i\}} &= l_{\{i\}} - R_{\{i\}} + r_{\{i\}} \text{ XOR} \\ t_{\{i\}} &= r_{\{i\}} <== \\ b_{\{i\}} &= 1 <==> \\ L_{\{i\}} & \geq R_{\{i\}} - r_{\{i\}} \end{aligned}$$

$$S_{\{i+1,k\}} = S_{\{i,k\}} <== C_{\{i\}} \neq k$$

$$\begin{aligned} R_{\{i+1\}} &= 2^8 * t_{\{i\}} \text{ XOR} \\ L_{\{i+1\}} &= 2^8 * l_{\{i\}} + B_{\{j_{\{i\}}\}} \text{ XOR} \\ j_{\{i+1\}} &= j_{\{i\}} + 1 <== \\ t_{\{i\}} &< 2^8 \end{aligned}$$

$$\begin{aligned} R_{\{i+1\}} &= t_{\{i\}} \text{ XOR} \\ L_{\{i+1\}} &= l_{\{i\}} \text{ XOR} \\ j_{\{i+1\}} &= j_{\{i\}} <== \\ t_{\{i\}} &\geq 2^8 \end{aligned}$$

$$R_{\{0\}} = 65280$$

$$L_{\{0\}} = 2^8 * B_{\{0\}} + B_{\{1\}}$$

$$j_{\{0\}} = 2$$

3.8.1.2. Range Non Binary Values

To encode scalar integers, it would be possible to encode each bit separately and use the past bits as context. However that would mean 255 contexts per 8-bit symbol that is not only a waste of memory but

also requires more past data to reach a reasonably good estimate of the probabilities. Alternatively assuming a Laplacian distribution and only dealing with its variance and mean (as in Huffman coding) would also be possible, however, for maximum flexibility and simplicity, the chosen method uses a single symbol to encode if a number is 0 and if not encodes the number using its exponent, mantissa and sign. The exact contexts used are best described by the following code, followed by some comments.

pseudo-code	type
-----	-----
void put_symbol(RangeCoder *c, uint8_t *state, int v, int \	
is_signed) {	
int i;	
put_rac(c, state+0, !v);	
if (v) {	
int a= abs(v);	
int e= log2(a);	
for (i=0; i<e; i++)	
put_rac(c, state+1+min(i,9), 1); //1..10	
put_rac(c, state+1+min(i,9), 0);	
for (i=e-1; i>=0; i--)	
put_rac(c, state+22+min(i,9), (a>>i)&1); //22..31	
if (is_signed)	
put_rac(c, state+11 + min(e, 10), v < 0); //11..21	
}	
}	

[3.8.1.3.](#) Initial Values for the Context Model

At keyframes all Range coder state variables are set to their initial state.

[3.8.1.4.](#) State Transition Table

```

one_state_{i} =
    default_state_transition_{i} + state_transition_delta_{i}

zero_state_{i} = 256 - one_state_{256-i}

```

[3.8.1.5.](#) default_state_transition

0, 0, 0, 0, 0, 0, 0, 0, 20, 21, 22, 23, 24, 25, 26, 27,
28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 37, 38, 39, 40, 41, 42,
43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 56, 57,
58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73,
74, 75, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88,
89, 90, 91, 92, 93, 94, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103,
104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 114, 115, 116, 117, 118,
119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 133,
134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149,
150, 151, 152, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164,
165, 166, 167, 168, 169, 170, 171, 171, 172, 173, 174, 175, 176, 177, 178, 179,
180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 190, 191, 192, 194, 194,
195, 196, 197, 198, 199, 200, 201, 202, 202, 204, 205, 206, 207, 208, 209, 209,
210, 211, 212, 213, 215, 215, 216, 217, 218, 219, 220, 220, 222, 223, 224, 225,
226, 227, 227, 229, 229, 230, 231, 232, 234, 234, 235, 236, 237, 238, 239, 240,
241, 242, 243, 244, 245, 246, 247, 248, 248, 0, 0, 0, 0, 0, 0, 0,

3.8.1.6. Alternative State Transition Table

The alternative state transition table has been built using iterative minimization of frame sizes and generally performs better than the default. To use it, the `coder_type` MUST be set to 2 and the difference to the default MUST be stored in the "Parameters", see [Section 4.1](#). The reference implementation of FFV1 in FFmpeg uses this table by default at the time of this writing when Range coding is used.

0, 10, 10, 10, 10, 16, 16, 16, 28, 16, 16, 29, 42, 49, 20, 49,
59, 25, 26, 26, 27, 31, 33, 33, 33, 34, 34, 37, 67, 38, 39, 39,
40, 40, 41, 79, 43, 44, 45, 45, 48, 48, 64, 50, 51, 52, 88, 52,
53, 74, 55, 57, 58, 58, 74, 60, 101, 61, 62, 84, 66, 66, 68, 69,
87, 82, 71, 97, 73, 73, 82, 75, 111, 77, 94, 78, 87, 81, 83, 97,
85, 83, 94, 86, 99, 89, 90, 99, 111, 92, 93, 134, 95, 98, 105, 98,
105, 110, 102, 108, 102, 118, 103, 106, 106, 113, 109, 112, 114, 112, 116, 125,
115, 116, 117, 117, 126, 119, 125, 121, 121, 123, 145, 124, 126, 131, 127, 129,
165, 130, 132, 138, 133, 135, 145, 136, 137, 139, 146, 141, 143, 142, 144, 148,
147, 155, 151, 149, 151, 150, 152, 157, 153, 154, 156, 168, 158, 162, 161, 160,
172, 163, 169, 164, 166, 184, 167, 170, 177, 174, 171, 173, 182, 176, 180, 178,
175, 189, 179, 181, 186, 183, 192, 185, 200, 187, 191, 188, 190, 197, 193, 196,
197, 194, 195, 196, 198, 202, 199, 201, 210, 203, 207, 204, 205, 206, 208, 214,
209, 211, 221, 212, 213, 215, 224, 216, 217, 218, 219, 220, 222, 228, 223, 225,
226, 224, 227, 229, 240, 230, 231, 232, 233, 234, 235, 236, 238, 239, 237, 242,
241, 243, 242, 244, 245, 246, 247, 248, 249, 250, 251, 252, 252, 253, 254, 255,

3.8.2. Golomb Rice Mode

This coding mode uses Golomb Rice codes. The VLC is split into 2 parts, the prefix stores the most significant bits and the suffix stores the k least significant bits or stores the whole number in the ESC case. The end of the bitstream of the "Frame" is filled with 0-bits until that the bitstream contains a multiple of 8 bits.

3.8.2.1. Prefix

bits	value
1	0
01	1
...	...
0000 0000 0001	11
0000 0000 0000	ESC

3.8.2.2. Suffix

non	the k least significant bits MSB first
ESC	
ESC	the value - 11, in MSB first order, ESC may only be used
	if the value cannot be coded as non ESC

3.8.2.3. Examples

k	bits	value
0	"1"	0
0	"001"	2
2	"1 00"	0
2	"1 10"	2
2	"01 01"	5
any	"000000000000 10000000"	139

3.8.2.4. Run Mode

Run mode is entered when the context is 0 and left as soon as a non-0 difference is found. The level is identical to the predicted one. The run and the first different level are coded.

3.8.2.5. Run Length Coding

The run value is encoded in 2 parts, the prefix part stores the more significant part of the run as well as adjusting the run_index that determines the number of bits in the less significant part of the run. The 2nd part of the value stores the less significant part of the run as it is. The run_index is reset for each plane and slice to 0.

pseudo-code	type
-----	-----
log2_run[41]={ 0, 0, 0, 0, 1, 1, 1, 1, 2, 2, 2, 2, 3, 3, 3, 3, 4, 4, 5, 5, 6, 6, 7, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, };	
if (run_count == 0 && run_mode == 1) { if (get_bits(1)) { run_count = 1 << log2_run[run_index]; if (x + run_count <= w) run_index++; } else { if (log2_run[run_index]) run_count = get_bits(log2_run[run_index]); else run_count = 0; if (run_index) run_index--; run_mode = 2; } }	

The log2_run function is also used within [[ISO.14495-1.1999](#)].

3.8.2.6. Level Coding

Level coding is identical to the normal difference coding with the exception that the 0 value is removed as it cannot occur:

```
if (diff>0) diff--;
encode(diff);
```

Note, this is different from JPEG-LS, which doesn't use prediction in run mode and uses a different encoding and context model for the last difference. On a small set of test samples the use of prediction slightly improved the compression rate.

4. Bitstream

Symbol		Definition
u(n)		unsigned big endian integer using n bits
sg		Golomb Rice coded signed scalar symbol coded with the method described in Section 3.8.2
br		Range coded Boolean (1-bit) symbol with the method described in Section 3.8.1.1
ur		Range coded unsigned scalar symbol coded with the method described in Section 3.8.1.2
sr		Range coded signed scalar symbol coded with the method described in Section 3.8.1.2

The same context that is initialized to 128 is used for all fields in the header.

The following MUST be provided by external means during initialization of the decoder:

"frame_pixel_width" is defined as "Frame" width in pixels.

"frame_pixel_height" is defined as "Frame" height in pixels.

Default values at the decoder initialization phase:

"ConfigurationRecordIsPresent" is set to 0.

[4.1.](#) Parameters

The "Parameters" section contains significant characteristics used for all instances of "Frame". The pseudo-code below describes the contents of the bitstream.

pseudo-code	type
-----	----
Parameters() {	
version	ur
if (version >= 3)	
micro_version	ur
coder_type	ur
if (coder_type > 1)	
for (i = 1; i < 256; i++)	
state_transition_delta[i]	sr
colorspace_type	ur
if (version >= 1)	
bits_per_raw_sample	ur
chroma_planes	br
log2_h_chroma_subsample	ur
log2_v_chroma_subsample	ur
alpha_plane	br
if (version >= 3) {	
num_h_slices - 1	ur
num_v_slices - 1	ur
quant_table_set_count	ur
}	
for(i = 0; i < quant_table_set_count; i++)	
QuantizationTableSet(i)	
if (version >= 3) {	
for(i = 0; i < quant_table_set_count; i++) {	
states_coded	br
if (states_coded)	
for(j = 0; j < context_count[i]; j++)	
for(k = 0; k < CONTEXT_SIZE; k++)	
initial_state_delta[i][j][k]	sr
}	
ec	ur
intra	ur
}	
}	

[4.1.1.1.](#) version

"version" specifies the version of the FFV1 bitstream.

Each version is incompatible with others versions: decoders SHOULD reject a file due to unknown version.

Decoders SHOULD reject a file with version <= 1 &&

ConfigurationRecordIsPresent == 1.

Decoders SHOULD reject a file with version >= 3 &&

ConfigurationRecordIsPresent == 0.

value	version
0	FFV1 version 0
1	FFV1 version 1
2	reserved*
3	FFV1 version 3
4	FFV1 version 4
Other	reserved for future use

* Version 2 was never enabled in the encoder thus version 2 files SHOULD NOT exist, and this document does not describe them to keep the text simpler.

[4.1.2.](#) micro_version

"micro_version" specifies the micro-version of the FFV1 bitstream. After a version is considered stable (a micro-version value is assigned to be the first stable variant of a specific version), each new micro-version after this first stable variant is compatible with the previous micro-version: decoders SHOULD NOT reject a file due to an unknown micro-version equal or above the micro-version considered as stable.

Meaning of micro_version for version 3:

value	micro_version
0...3	reserved*
4	first stable variant
Other	reserved for future use

* development versions may be incompatible with the stable variants.

Meaning of micro_version for version 4 (note: at the time of writing of this specification, version 4 is not considered stable so the first stable version value is to be announced in the future):

value	micro_version
0...TBA	reserved*
TBA	first stable variant
Other	reserved for future use

* development versions which may be incompatible with the stable variants.

4.1.3. `coder_type`

"`coder_type`" specifies the coder used.

value	coder used
0	Golomb Rice
1	Range Coder with default state transition table
2	Range Coder with custom state transition table
Other	reserved for future use

4.1.4. `state_transition_delta`

"`state_transition_delta`" specifies the Range coder custom state transition table.

If `state_transition_delta` is not present in the FFV1 bitstream, all Range coder custom state transition table elements are assumed to be 0.

4.1.5. `colorspace_type`

"`colorspace_type`" specifies color space losslessly encoded, Pixel transformation used by the encoder, as well as interleave method.

value	color space losslessly encoded	transformation	interleave method
0	YCbCr	No Pixel transformation	plane then line
1	RGB	JPEG2000-RCT	line then plane
Other	reserved for future use	reserved for future use	reserved for future use

Restrictions:

If "`colorspace_type`" is 1, then "`chroma_planes`" MUST be 1, "`log2_h_chroma_subsample`" MUST be 0, and "`log2_v_chroma_subsample`" MUST be 0.

4.1.6. chroma_planes

"chroma_planes" indicates if chroma (color) planes are present.

value	presence
0	chroma planes are not present
1	chroma planes are present

4.1.7. bits_per_raw_sample

"bits_per_raw_sample" indicates the number of bits for each sample.
Inferred to be 8 if not present.

value	bits for each sample
0	reserved*
Other	the actual bits for each sample

* Encoders MUST NOT store bits_per_raw_sample = 0 Decoders SHOULD accept and interpret bits_per_raw_sample = 0 as 8.

4.1.8. log2_h_chroma_subsample

"log2_h_chroma_subsample" indicates the subsample factor, stored in powers to which the number 2 must be raised, between luma and chroma width ("chroma_width = 2^(-log2_h_chroma_subsample) * luma_width").

4.1.9. log2_v_chroma_subsample

"log2_v_chroma_subsample" indicates the subsample factor, stored in powers to which the number 2 must be raised, between luma and chroma height ("chroma_height=2^(-log2_v_chroma_subsample) * luma_height").

4.1.10. alpha_plane

"alpha_plane" indicates if a transparency plane is present.

value	presence
0	transparency plane is not present
1	transparency plane is present

value	error detection/correction type
0	32-bit CRC on the global header
1	32-bit CRC per slice and the global header
Other	reserved for future use

4.1.17. intra

"intra" indicates the relationship between the instances of "Frame". Inferred to be 0 if not present.

value	relationship
0	Frames are independent or dependent (keyframes and non keyframes)
1	Frames are independent (keyframes only)
Other	reserved for future use

4.2. Configuration Record

In the case of a FFV1 bitstream with "version >= 3", a "Configuration Record" is stored in the underlying "Container", at the track header level. It contains the "Parameters" used for all instances of "Frame". The size of the "Configuration Record", "NumBytes", is supplied by the underlying "Container".

pseudo-code	type
ConfigurationRecord(NumBytes) {	
ConfigurationRecordIsPresent = 1	
Parameters()	
while(remaining_bits_in_bitstream(NumBytes) > 32)	
reserved_for_future_use	u(1)
configuration_record_crc_parity	u(32)
}	

4.2.1. reserved_for_future_use

"reserved_for_future_use" has semantics that are reserved for future use.

Encoders conforming to this version of this specification SHALL NOT write this value.

Decoders conforming to this version of this specification SHALL ignore its value.

4.2.2. configuration_record_crc_parity

"configuration_record_crc_parity" 32 bits that are chosen so that the "Configuration Record" as a whole has a crc remainder of 0.

This is equivalent to storing the crc remainder in the 32-bit parity. The CRC generator polynomial used is the standard IEEE CRC polynomial (0x104C11DB7) with initial value 0.

4.2.3. Mapping FFV1 into Containers

This "Configuration Record" can be placed in any file format supporting "Configuration Records", fitting as much as possible with how the file format uses to store "Configuration Records". The "Configuration Record" storage place and "NumBytes" are currently defined and supported by this version of this specification for the following formats:

4.2.3.1. AVI File Format

The "Configuration Record" extends the stream format chunk ("AVI ", "hdlr", "strl", "strf") with the ConfigurationRecord bitstream. See [\[AVI\]](#) for more information about chunks.

"NumBytes" is defined as the size, in bytes, of the strf chunk indicated in the chunk header minus the size of the stream format structure.

4.2.3.2. ISO Base Media File Format

The "Configuration Record" extends the sample description box ("moov", "trak", "mdia", "minf", "stbl", "stsd") with a "glbl" box that contains the ConfigurationRecord bitstream. See [\[ISO.14496-12.2015\]](#) for more information about boxes.

"NumBytes" is defined as the size, in bytes, of the "glbl" box indicated in the box header minus the size of the box header.

4.2.3.3. NUT File Format

The codec_specific_data element (in "stream_header" packet) contains the ConfigurationRecord bitstream. See [\[NUT\]](#) for more information about elements.

"NumBytes" is defined as the size, in bytes, of the codec_specific_data element as indicated in the "length" field of codec_specific_data

4.2.3.4. Matroska File Format

FFV1 SHOULD use "V_FFV1" as the Matroska "Codec ID". For FFV1 versions 2 or less, the Matroska "CodecPrivate" Element SHOULD NOT be used. For FFV1 versions 3 or greater, the Matroska "CodecPrivate" Element MUST contain the FFV1 "Configuration Record" structure and no other data. See [[Matroska](#)] for more information about elements.

"NumBytes" is defined as the "Element Data Size" of the "CodecPrivate" Element.

4.3. Frame

A "Frame" consists of the keyframe field, "Parameters" (if version <=1), and a sequence of independent slices.

pseudo-code	type
-----	-----
Frame(NumBytes) {	
keyframe	br
if (keyframe && !ConfigurationRecordIsPresent	
Parameters()	
while (remaining_bits_in_bitstream(NumBytes))	
Slice()	
}	

Architecture overview of slices in a "Frame":

+-----+
first slice header
first slice content
first slice footer

second slice header
second slice content
second slice footer

...

last slice header
last slice content
last slice footer
+-----+

4.4. Slice

pseudo-code	type
-----	----
Slice() {	
if (version >= 3)	
SliceHeader()	
SliceContent()	
if (coder_type == 0)	
while (!byte_aligned())	
padding	u(1)
if (version <= 1) {	
while (remaining_bits_in_bitstream(NumBytes) != 0)	
reserved	u(1)
}	
if (version >= 3)	
SliceFooter()	
}	

"padding" specifies a bit without any significance and used only for byte alignment. MUST be 0.

"reserved" specifies a bit without any significance in this revision of the specification and may have a significance in a later revision of this specification.

Encoders SHOULD NOT fill these bits.

Decoders SHOULD ignore these bits.

Note in case these bits are used in a later revision of this specification: any revision of this specification SHOULD care about avoiding to add 40 bits of content after "SliceContent" for version 0 and 1 of the bitstream. Background: due to some non conforming encoders, some bitstreams were found with 40 extra bits corresponding to "error_status" and "slice_crc_parity", a decoder conforming to the revised specification could not do the difference between a revised bitstream and a buggy bitstream.

4.5. Slice Header

pseudo-code	type
-----	----
SliceHeader() {	
slice_x	ur
slice_y	ur
slice_width - 1	ur
slice_height - 1	ur
for(i = 0; i < quant_table_set_index_count; i++)	
quant_table_set_index [i]	ur
picture_structure	ur
sar_num	ur
sar_den	ur
if (version >= 4) {	
reset_contexts	br
slice_coding_mode	ur
}	
}	

[4.5.1.](#) slice_x

"slice_x" indicates the x position on the slice raster formed by num_h_slices.

Inferred to be 0 if not present.

[4.5.2.](#) slice_y

"slice_y" indicates the y position on the slice raster formed by num_v_slices.

Inferred to be 0 if not present.

[4.5.3.](#) slice_width

"slice_width" indicates the width on the slice raster formed by num_h_slices.

Inferred to be 1 if not present.

[4.5.4.](#) slice_height

"slice_height" indicates the height on the slice raster formed by num_v_slices.

Inferred to be 1 if not present.

[4.5.5.](#) quant_table_set_index_count

"quant_table_set_index_count" is defined as "1 + ((chroma_planes || version \<= 3) ? 1 : 0) + (alpha_plane ? 1 : 0)".

4.5.6. quant_table_set_index

"quant_table_set_index" indicates the Quantization Table Set index to select the Quantization Table Set and the initial states for the slice.

Inferred to be 0 if not present.

4.5.7. picture_structure

"picture_structure" specifies the temporal and spatial relationship of each line of the "Frame".

Inferred to be 0 if not present.

value	picture structure used
0	unknown
1	top field first
2	bottom field first
3	progressive
Other	reserved for future use

4.5.8. sar_num

"sar_num" specifies the sample aspect ratio numerator.

Inferred to be 0 if not present.

MUST be 0 if sample aspect ratio is unknown.

4.5.9. sar_den

"sar_den" specifies the sample aspect ratio denominator.

Inferred to be 0 if not present.

MUST be 0 if sample aspect ratio is unknown.

4.5.10. reset_contexts

"reset_contexts" indicates if slice contexts must be reset.

Inferred to be 0 if not present.

4.5.11. slice_coding_mode

"slice_coding_mode" indicates the slice coding mode.

Inferred to be 0 if not present.

+-----+-----+-----+-----+-----+													
value	slice coding mode												
+-----+-----+-----+-----+-----+													
0	Range Coding or Golomb Rice												
1	raw PCM												
Other	reserved for future use												
+-----+-----+-----+-----+-----+													

4.6. Slice Content

pseudo-code	type
-----	-----
SliceContent() {	
if (colorspace_type == 0) {	
for(p = 0; p < primary_color_count; p++)	
for(y = 0; y < plane_pixel_height[p]; y++)	
Line(p, y)	
} else if (colorspace_type == 1) {	
for(y = 0; y < slice_pixel_height; y++)	
for(p = 0; p < primary_color_count; p++)	
Line(p, y)	
}	
}	

4.6.1. primary_color_count

"primary_color_count" is defined as "1 + (chroma_planes ? 2 : 0) + (alpha_plane ? 1 : 0)".

4.6.2. plane_pixel_height

"plane_pixel_height[p]" is the height in pixels of plane p of the slice.

"plane_pixel_height[0]" and "plane_pixel_height[1 + (chroma_planes ? 2 : 0)]" value is "slice_pixel_height".

If "chroma_planes" is set to 1, "plane_pixel_height[1]" and "plane_pixel_height[2]" value is "ceil(slice_pixel_height / log2_v_chroma_subsample)".

4.6.3. slice_pixel_height

"slice_pixel_height" is the height in pixels of the slice.

Its value is "floor((slice_y + slice_height) * slice_pixel_height / num_v_slices) - slice_pixel_y".

4.6.4. slice_pixel_y

"slice_pixel_y" is the slice vertical position in pixels.
Its value is "floor(slice_y * frame_pixel_height / num_v_slices)".

4.7. Line

pseudo-code	type
-----	-----
Line(p, y) {	
if (colorspace_type == 0) {	
for(x = 0; x < plane_pixel_width[p]; x++)	
sample_difference[p][y][x]	
} else if (colorspace_type == 1) {	
for(x = 0; x < slice_pixel_width; x++)	
sample_difference[p][y][x]	
}	
}	

4.7.1. plane_pixel_width

"plane_pixel_width[p]" is the width in pixels of plane p of the slice.
"plane_pixel_width[0]" and "plane_pixel_width[1 + (chroma_planes ? 2 : 0)]" value is "slice_pixel_width".
If "chroma_planes" is set to 1, "plane_pixel_width[1]" and "plane_pixel_width[2]" value is "ceil(slice_pixel_width / (1 << log2_h_chroma_subsample))".

4.7.2. slice_pixel_width

"slice_pixel_width" is the width in pixels of the slice.
Its value is "floor((slice_x + slice_width) * slice_pixel_width / num_h_slices) - slice_pixel_x".

4.7.3. slice_pixel_x

"slice_pixel_x" is the slice horizontal position in pixels.
Its value is "floor(slice_x * frame_pixel_width / num_h_slices)".

4.7.4. sample_difference

"sample_difference[p][y][x]" is the sample difference for sample at plane "p", y position "y", and x position "x". The sample value is computed based on prediction and context described in [Section 3.2](#).

4.8. Slice Footer

Note: slice footer is always byte aligned.

pseudo-code	type
-----	-----
SliceFooter() {	
slice_size	u(24)
if (ec) {	
error_status	u(8)
slice_crc_parity	u(32)
}	
}	

4.8.1. slice_size

"slice_size" indicates the size of the slice in bytes.

Note: this allows finding the start of slices before previous slices have been fully decoded, and allows parallel decoding as well as error resilience.

4.8.2. error_status

"error_status" specifies the error status.

+-----+	+-----+	+-----+
value	error status	
+-----+	+-----+	+-----+
0	no error	
1	slice contains a correctable error	
2	slice contains a uncorrectable error	
Other	reserved for future use	
+-----+	+-----+	+-----+

4.8.3. slice_crc_parity

"slice_crc_parity" 32 bits that are chosen so that the slice as a whole has a crc remainder of 0.

This is equivalent to storing the crc remainder in the 32-bit parity. The CRC generator polynomial used is the standard IEEE CRC polynomial (0x104C11DB7) with initial value 0.

4.9. Quantization Table Set

The Quantization Table Sets are stored by storing the number of equal entries -1 of the first half of the table (represented as "len - 1" in the pseudo-code below) using the method described in [Section 3.8.1.2](#). The second half doesn't need to be stored as it is

identical to the first with flipped sign. "scale" and "len_count[i][j]" are temporary values used for the computing of "context_count[i]" and are not used outside Quantization Table Set pseudo-code.

example:

Table: 0 0 1 1 1 1 2 2 -2 -2 -2 -1 -1 -1 -1 0

Stored values: 1, 3, 1

pseudo-code	type
<hr style="border-top: 1px dashed black;"/>	
QuantizationTableSet(i) {	
scale = 1	
for(j = 0; j < MAX_CONTEXT_INPUTS; j++) {	
QuantizationTable(i, j, scale)	
scale *= 2 * len_count[i][j] - 1	
}	
context_count[i] = ceil (scale / 2)	
}	

MAX_CONTEXT_INPUTS is 5.

pseudo-code	type
<hr style="border-top: 1px dashed black;"/>	
QuantizationTable(i, j, scale) {	
v = 0	
for(k = 0; k < 128;) {	
len = 1	ur
for(a = 0; a < len; a++) {	
quant_tables[i][j][k] = scale* v	
k++	
}	
v++	
}	
for(k = 1; k < 128; k++) {	
quant_tables[i][j][256 - k] = \	
-quant_tables[i][j][k]	
}	
quant_tables[i][j][128] = \	
-quant_tables[i][j][127]	
len_count[i][j] = v	
}	

4.9.1. quant_tables

"quant_tables[i][j][k]" indicates the quantification table value of the Quantized Sample Difference "k" of the Quantization Table "j" of the Set Quantization Table Set "i".

4.9.2. context_count

"context_count[i]" indicates the count of contexts for Quantization Table Set "i".

5. Restrictions

To ensure that fast multithreaded decoding is possible, starting version 3 and if `frame_pixel_width * frame_pixel_height` is more than 101376, `slice_width * slice_height` MUST be less or equal to `num_h_slices * num_v_slices / 4`. Note: 101376 is the frame size in pixels of a 352x288 frame also known as CIF ("Common Intermediate Format") frame size format.

For each "Frame", each position in the slice raster MUST be filled by one and only one slice of the "Frame" (no missing slice position, no slice overlapping).

For each "Frame" with keyframe value of 0, each slice MUST have the same value of `slice_x`, `slice_y`, `slice_width`, `slice_height` as a slice in the previous "Frame", except if `reset_contexts` is 1.

6. Security Considerations

Like any other codec, (such as [\[RFC6716\]](#)), FFV1 should not be used with insecure ciphers or cipher-modes that are vulnerable to known plaintext attacks. Some of the header bits as well as the padding are easily predictable.

Implementations of the FFV1 codec need to take appropriate security considerations into account, as outlined in [\[RFC4732\]](#). It is extremely important for the decoder to be robust against malicious payloads. Malicious payloads must not cause the decoder to overrun its allocated memory or to take an excessive amount of resources to decode. Although problems in encoders are typically rarer, the same applies to the encoder. Malicious video streams must not cause the encoder to misbehave because this would allow an attacker to attack transcoding gateways. A frequent security problem in image and video codecs is also to not check for integer overflows in Pixel count computations, that is to allocate `width * height` without considering that the multiplication result may have overflowed the arithmetic types range.

The reference implementation [[REFIMPL](#)] contains no known buffer overflow or cases where a specially crafted packet or video segment could cause a significant increase in CPU load.

The reference implementation [[REFIMPL](#)] was validated in the following conditions:

- o Sending the decoder valid packets generated by the reference encoder and verifying that the decoder's output matches the encoder's input.
- o Sending the decoder packets generated by the reference encoder and then subjected to random corruption.
- o Sending the decoder random packets that are not FFV1.

In all of the conditions above, the decoder and encoder was run inside the [[VALGRIND](#)] memory debugger as well as clangs address sanitizer [[Address-Sanitizer](#)], which track reads and writes to invalid memory regions as well as the use of uninitialized memory. There were no errors reported on any of the tested conditions.

7. Media Type Definition

This registration is done using the template defined in [[RFC6838](#)] and following [[RFC4855](#)].

Type name: video

Subtype name: FFV1

Required parameters: None.

Optional parameters:

This parameter is used to signal the capabilities of a receiver implementation. This parameter MUST NOT be used for any other purpose.

version: The version of the FFV1 encoding as defined by [Section 4.1.1](#).

micro_version: The micro_version of the FFV1 encoding as defined by [Section 4.1.2](#).

coder_type: The coder_type of the FFV1 encoding as defined by [Section 4.1.3](#).

colorspace_type: The colorspace_type of the FFV1 encoding as defined by [Section 4.1.5](#).

bits_per_raw_sample: The version of the FFV1 encoding as defined by [Section 4.1.7](#).

max-slices: The value of max-slices is an integer indicating the maximum count of slices with a frames of the FFV1 encoding.

Encoding considerations:

This media type is defined for encapsulation in several audiovisual container formats and contains binary data; see [Section 4.2.3](#). This media type is framed binary data [Section 4.8 of \[RFC4288\]](#).

Security considerations:

See [Section 6](#) of this document.

Interoperability considerations: None.

Published specification:

[I-D.ietf-cellar-ffv1] and RFC XXXX.

[RFC Editor: Upon publication as an RFC, please replace "XXXX" with the number assigned to this document and remove this note.]

Applications which use this media type:

Any application that requires the transport of lossless video can use this media type. Some examples are, but not limited to screen recording, scientific imaging, and digital video preservation.

Fragment identifier considerations: N/A.

Additional information: None.

Person & email address to contact for further information: Michael Niedermayer <<mailto:michael@niedermayer.cc>>

Intended usage: COMMON

Restrictions on usage: None.

Author: Dave Rice <<mailto:dave@dericed.com>>

Change controller: IETF cellar working group delegated from the IESG.

8. IANA Considerations

The IANA is requested to register the following values:

- o Media type registration as described in [Section 7](#).

9. Appendixes

9.1. Decoder implementation suggestions

9.1.1. Multi-threading Support and Independence of Slices

The FFV1 bitstream is parsable in two ways: in sequential order as described in this document or with the pre-analysis of the footer of each slice. Each slice footer contains a `slice_size` field so the boundary of each slice is computable without having to parse the slice content. That allows multi-threading as well as independence of slice content (a bitstream error in a slice header or slice content has no impact on the decoding of the other slices).

After having checked keyframe field, a decoder SHOULD parse `slice_size` fields, from `slice_size` of the last slice at the end of the "Frame" up to `slice_size` of the first slice at the beginning of the "Frame", before parsing slices, in order to have slices boundaries. A decoder MAY fallback on sequential order e.g. in case of a corrupted "Frame" (frame size unknown, `slice_size` of slices not coherent...) or if there is no possibility of seek into the stream.

10. Changelog

See <<https://github.com/FFmpeg/FFV1/commits/master>>

11. References

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