Khronos Data Format Specification

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Khronos Data Format Specification License Information

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Contents

List of Figures

List of Tables

Abstract

This document describes a data format specification for non-opaque (user-visible) representations of user data to be used by, and shared between, Khronos standards. The intent of this specification is to avoid replication of incompatible format descriptions between standards and to provide a definitive mechanism for describing data that avoids excluding useful information that may be ignored by other standards. Other APIs are expected to map internal formats to this standard scheme, allowing formats to be shared and compared. This document also acts as a reference for the memory layout of a number of common compressed texture formats, and describes conversion between a number of common color spaces.

Part I

Introduction

Chapter 1

Introduction

Many APIs operate on bulk data — buffers, images, volumes, etc. — each composed of many elements with a fixed and often simple representation. Frequently, multiple alternative representations of data are supported: vertices can be represented with different numbers of dimensions, textures may have different bit depths and channel orders, and so on. Sometimes the representation of the data is highly specific to the application, but there are many types of data that are common to multiple APIs — and these can reasonably be described in a portable manner. In this standard, the term *data format* describes the representation of data.

It is typical for each API to define its own enumeration of the data formats on which it can operate. This causes a problem when multiple APIs are in use: the representations are likely to be incompatible, even where the capabilities intersect. When additional format-specific capabilities are added to an API which was designed without them, the description of the data representation often becomes inconsistent and disjoint. Concepts that are unimportant to the core design of an API may be represented simplistically or inaccurately, which can be a problem as the API is enhanced or when data is shared.

Some APIs do not have a strict definition of how to interpret their data. For example, a rendering API may treat all color channels of a texture identically, leaving the interpretation of each channel to the user's choice of convention. This may be true even if color channels are given names that are associated with actual colors — in some APIs, nothing stops the user from storing the blue quantity in the red channel and the red quantity in the blue channel. Without enforcing a single data interpretation on such APIs, it is nonetheless often useful to offer a clear definition of the color interpretation convention that is in force, both for code maintenance and for communication with external APIs which do have a defined interpretation. Should the user wish to use an unconventional interpretation of the data, an appropriate descriptor can be defined that is specific to this choice, in order to simplify automated interpretation of the chosen representation and to provide concise documentation.

Where multiple APIs are in use, relying on an API-specific representation as an intermediary can cause loss of important information. For example, a camera API may associate color space information with a captured image, and a printer API may be able to operate with that color space, but if the data is passed through an intermediate compute API for processing and that API has no concept of a color space, the useful information may be discarded.

The intent of this standard is to provide a common, consistent, machine-readable way to describe those data formats which are amenable to non-proprietary representation. This standard provides a portable means of storing the most common descriptive information associated with data formats, and an extension mechanism that can be used when this common functionality must be supplemented.

While this standard is intended to support the description of many kinds of data, the most common class of bulk data used in Khronos standards represents color information. For this reason, the range of standard color representations used in Khronos standards is diverse, and a significant portion of this specification is devoted to color formats.

Later sections describe some of the common color space conversion operations and provide a description of the memory layout of a number of common texture compression formats.

Part II

The Khronos Data Format Descriptor Block

Chapter 2

Formats and texel access

This document describes a standard layout for a data structure that can be used to define the representation of simple, portable, bulk data. Using such a data structure has the following benefits:

- Ensuring a precise description of the portable data
- Simplifying the writing of generic functionality that acts on many types of data
- Offering portability of data between APIs

The “bulk data” may be, for example:

- Pixel/texel data
- Vertex data
- A buffer of simple type

The layout of proprietary data structures is beyond the remit of this specification, but the large number of ways to describe colors, vertices and other repeated data makes standardization useful. The widest variety of standard representations and the most common expected use of this API is to describe pixels or texels; as such the terms “texel” and “pixel” are used interchangeably in this specification when referring to elements of data, without intending to imply a restriction in use.

The data structure in this specification describes the elements in the bulk data in memory, not the layout of the whole. For example, it may describe the size, location and interpretation of color channels within a pixel, but is not responsible for determining the mapping between spatial coordinates and the location of pixels in memory. That is, two textures which share the same pixel layout can share the same descriptor as defined in this specification, but may have different sizes, line or plane strides, tiling or dimensionality; in common parlance, two images that describe (for example) color data in the same way but which are of different shapes or sizes are still described as having the same “format”.

An example pixel representation is described in Figure 2.1: a single 5:6:5-bit pixel composed of a blue channel in the low 5 bits, a green channel in the next 6 bits, and red channel in the top 5 bits of a 16-bit word as laid out in memory on a little-endian machine (see Table 11.1).

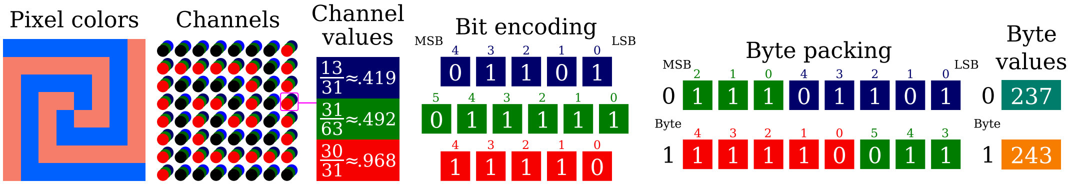


Figure 2.1: A simple one-texel texel block

2.1 1-D texel addressing

In bulk data, each element is interpreted first by addressing it in some form, then by interpreting the addressed values. Texels often represent a color (or other data) as a multi-dimensional set of values, each representing a *channel*. The bulk-data *image* or *buffer* then describes a number of these texels. Taking the simplest case of an array in the C programming language as an example, a developer might define the following structure to represent a color texel:

```
typedef struct _MyRGB {
  unsigned char red;
  unsigned char green;
  unsigned char blue;
} MyRGB;

MyRGB *myRGBarray = (MyRGB *) malloc(100 * sizeof(MyRGB));
```

To determine the location of, for example, the tenth element of `myRGBarray`, the compiler needs to know the base address of the array and `sizeof myRGB`. Extracting the `red`, `green` and `blue` components of `myRGBarray[9]` given its base address is, in a sense, orthogonal to *finding* the base address of `myRGBarray[9]`.

Note also that `sizeof(MyRGB)` will often exceed the total size of `red`, `green` and `blue` due to padding; the difference in address between one `MyRGB` and the next can be described as the *pixel stride* in bytes.

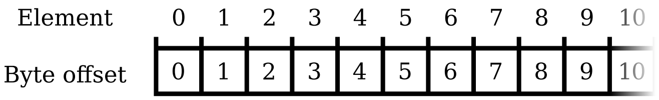


Figure 2.2: (Trivial) 1D address offsets for 1-byte elements, start of buffer

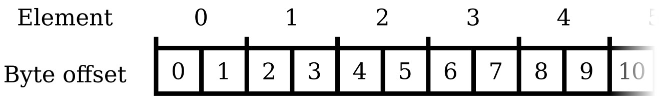


Figure 2.3: 1D address offsets for 2-byte elements, start of buffer

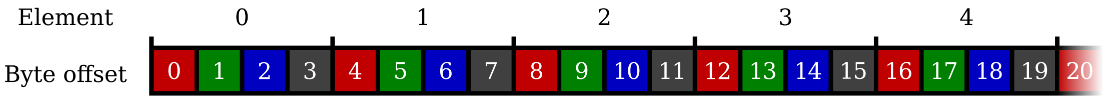


Figure 2.4: 1D address offsets for *R*,*G*,*B* elements (padding in gray), start of buffer

An alternative representation is a “structure of arrays”, distinct from the “array of structures” `myRGBarray`:

```
typedef struct _MyRGBSoA {
  unsigned char *red;
  unsigned char *green;
  unsigned char *blue;
} MyRGBSoA;

MyRGBSoA myRGBSoA;
myRGBSoA.red = (unsigned char *) malloc(100);
myRGBSoA.green = (unsigned char *) malloc(100);
myRGBSoA.blue = (unsigned char *) malloc(100);
```

In this case, accessing a value requires the `sizeof` each channel element. The best approach depends on the operations performed: calculations on one whole `MyRGB` a time likely favor `MyRGB`, those processing multiple values from a single channel may prefer `MyRGBSoA`. A “pixel” need not fill an entire byte — nor need *pixel stride* be a whole number of bytes. For example, a C++ `std::vector<bool>` can be considered to be a 1-D bulk data structure of individual bits.

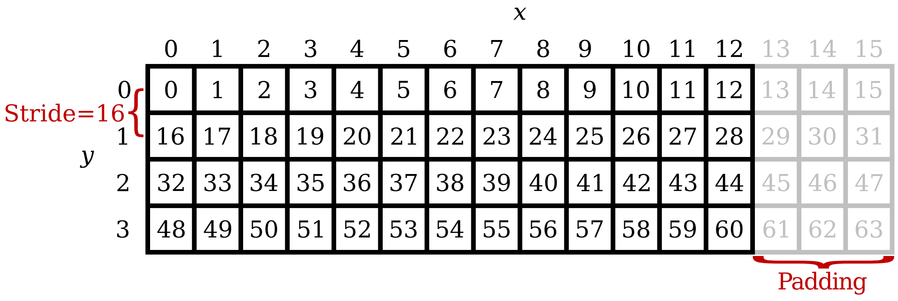
An implementation may choose to combine these approaches — storing more than one channel per plane, but still using multiple planes. This approach is particularly useful for downsampled channels, as discussed below. Whether because different numbers of channels are stored in an array or because the underlying representation of the data requires a different number of bits, the mapping from offsets to addresses will vary per channel, and certainly per array. When the data are stored as separate arrays, note that the offsets between the arrays are not defined by the "format", although there may be a convention that is followed: different representations may place constraints on alignment and padding between texel arrays, or allow free-form allocation, but since any such constraint typically depends on the amount of data it is considered to be outside the conventional definition of a "format".

2.2 Simple 2-D texel addressing

The simplest way to represent two-dimensional data is in consecutive rows, each representing a one-dimensional array — as with a 2-D array in C. There may be padding after each row to achieve the required alignment: in some cases each row should begin at the start of a cache line, or rows may be deliberately offset to different cache lines to ensure that vertically-adjacent values can be cached concurrently. The offset from the start of one horizontal row to the next is a *line stride* or *row stride* (or just *stride* for short), and is necessarily at least the width of the row. If each row holds an whole number of pixels, row stride can be described either in bytes or pixels; it is rare not to start each row on a byte boundary. In a simple 2-D representation, the row stride and the offset from the start of the storage can be described as follows:

$$\begin{aligned}
row\ stride_{pixels} &= width_{pixels} + padding_{pixels} \\
row\ stride_{bytes} &= width_{pixels} \times pixel\ stride_{bytes} + padding_{bytes} \\
offset_{pixels} &= x + (y \times rowstride_{pixels}) \\
address_{bytes} &= base + (x \times pixel\ stride_{bytes}) + (y \times row\ stride_{bytes})
\end{aligned}$$

Figure 2.5 shows example coordinate byte offsets for a 13×4 buffer, padding row stride to a multiple of four elements.

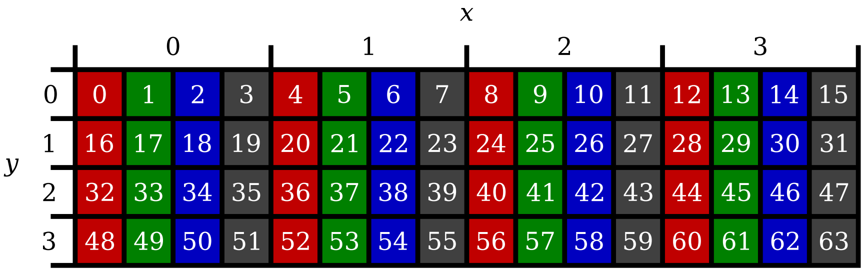


y \ x	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
3	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63

Figure 2.5: 2D linear texel offsets from coordinates

Byte	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Coords	**0,0**	**1,0**	**2,0**	**3,0**	**4,0**	*5,0*	*6,0*	*7,0*	**0,1**	**1,1**	**2,1**	**3,1**	**4,1**	*5,1*	*6,1*	*7,1*	**0,2**	**1,2**	**2,2**	**3,2**	**4,2**	*5,2*	*6,2*	*7,2*

Table 2.1: Order of byte storage in memory for coordinates in a linear 5×3 buffer, padded (italics) to 8×3



y \ x	0				1				2				3			
0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
3	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63

Figure 2.6: 2D *R*,*G*,*B* byte offsets (padding in gray) from coordinates for a 4×4 image

By convention, this “linear” layout is in *y*-major order (with the *x* axis changing most quickly). This does not necessarily imply that an API which accesses the 2D data will do so in this orientation, and there are image layouts which have *x* and *y* swapped. The direction of the axes (particularly *y*) in relation to the image orientation also varies between representations.

Each contiguous region described in this way can be considered as a *plane* of data. In the same way that 1-D data can be described in structure-of-arrays form, two-dimensional data can also be implemented as multiple *planes*, which each may have independent base addresses and strides.

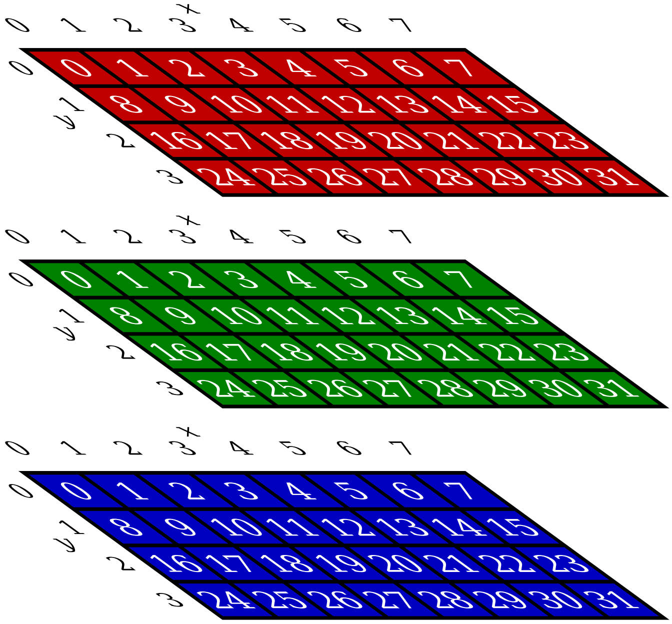


Figure 2.7: 2D *R*,*G*,*B* plane offsets from coordinates for 8×4 texels

In early graphics, planes often contributed individual bits to the pixel. This allowed pixels of less than a byte, reducing bandwidth and storage; combining 1-bit planes allowed, for example, 64-color, 6-bit pixels. Storing six bits per pixel consecutively would make the number of memory bytes holding a pixel vary by alignment; a planar layout needs simpler hardware. This hardware could often process a subset of the planes — scrolling text may require blitting just one plane, and changes to the display controller start location for each plane independently provide cheap parallax effects.

In modern architectures, planes are typically (at least) byte-aligned and contain the entirety of the data corresponding to one or more channels. One motivation of a multi-planar description is the avoidance of padding. Some common hardware can only access powers of two bytes for each pixel: for example, texels of three 1-byte channels may need padding to four bytes for alignment restrictions; separate planes of one byte per texel need no padding. Other benefits are supporting different downsampling of each channel (described below), and more efficient independent processing of each channel: many common operations (such as filtering and image compression) treat channels separately.

As with the 1-D case, the addressing for each plane is, at least in part, independent. In a linear representation, each plane still has its own base address, row stride and pixel stride — and, as discussed in downsampled channels, the coordinate dimensions of each plane may not always be the same. Commonly, but not universally, in a simple linear layout the pixel stride can be deduced from the image format, but line stride and row stride are dependent on the image dimensions and any implementation-imposed alignment limitations which fall outside the “format”. Modern hardware may further complicate the relationship between coordinates and addresses by use of a memory management unit providing a mapping of logical address regions to physical (device) addresses; this is further complicated with the capability of “sparse” memory allocation, in which not all of the address space may be bound to physical addresses.

Note that, once all the data from any contributing channels have been combined, the interpretation of the resulting values is again orthogonal to addressing the data.

2.3 More complex 2-D texel addressing

In many applications, the simple "linear" layout of memory has disadvantages. The primary concern is that data which is vertically adjacent in two-dimensional space may be widely separated in memory address. Many computer graphics rendering operations involve accessing the frame buffer in an order not aligned with its x-axis; for example, traversing horizontally across the width of a textured triangle while writing to the frame buffer will result in a texture access pattern which depends on the orientation of the texture relative to the triangle and the triangle relative to the frame buffer. If each texel access processed a different cache line, the resulting performance would be heavily compromised. Modern GPUs process multiple texels in parallel, meaning that many nearby texels in different orientations may need to be accessed quickly. Additionally, texture filtering operations typically read a 2×2 quad of texels, inherently requiring access to texels which would be distant in memory in the linear representation.

One solution to this is to divide the image into smaller rectangular tiles of texels (of $tw \times th$) rather than horizontal rows. The texel ordering within the tiles may be treated as though each tile were an independent, smaller image, and the order of tiles in memory may be as in the linear layout:

$$\mathit{If}\ a \mathbin{\%} b = a - \left(b \times \left\lfloor \frac{a}{b} \right\rfloor\right), \qquad \mathit{texel\ offset} = (x \mathbin{\%} tw) + tw \times (y \mathbin{\%} th) + \left\lfloor \frac{x}{tw} \right\rfloor \times th \times tw + \left\lfloor \frac{y}{th} \right\rfloor \times th \times \mathit{line\ stride}$$

This approach can be implemented efficiently in hardware, so long as the tile dimensions are powers of two, by interleaving some bits from the y-coordinate with the bits contributed by the x-coordinate. If `twb` = $\log_2(tw)$ and `thb` = $\log_2(th)$:

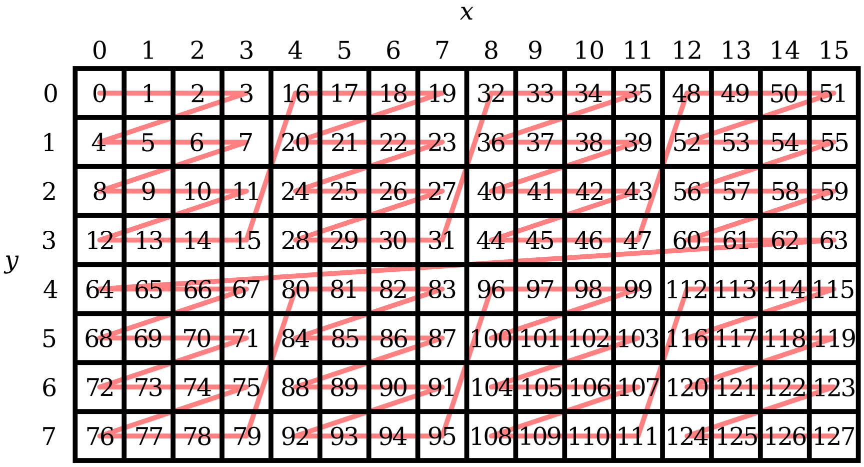
```
pixelOffset = (x & ((1 << twb) - 1)) | ((y & ((1 << thb) - 1)) << twb)
            | ((x & ~((1 << twb) - 1)) << thb) | ((y & ~((1 << thb)-1)) * lineStride);
```

For example, if a linear 16×12 image calculates a pixel offset relative to the start of the buffer as:

```
pixelOffset = x | (y * 16);
```

a 16×12 image comprised of 4×4 tiles may calculate the pixel offset relative to the start of the buffer as:

```
pixelOffset = (x & 3) | ((y & 3) << 2) | ((x & ~3) << 2) | ((y & ~3) * 16);
```



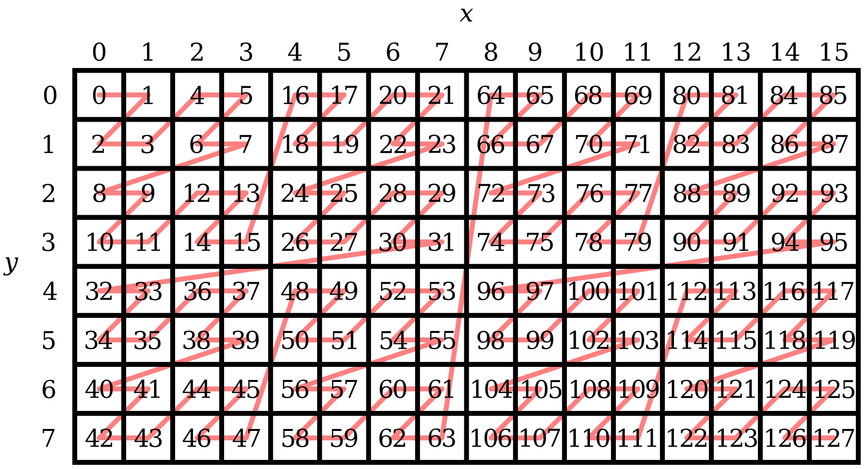
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	16	17	18	19	32	33	34	35	48	49	50	51
1	4	5	6	7	20	21	22	23	36	37	38	39	52	53	54	55
2	8	9	10	11	24	25	26	27	40	41	42	43	56	57	58	59
3	12	13	14	15	28	29	30	31	44	45	46	47	60	61	62	63
4	64	65	66	67	80	81	82	83	96	97	98	99	112	113	114	115
5	68	69	70	71	84	85	86	87	100	101	102	103	116	117	118	119
6	72	73	74	75	88	89	90	91	104	105	106	107	120	121	122	123
7	76	77	78	79	92	93	94	95	108	109	110	111	124	125	126	127

Figure 2.8: 4×4 tiled order texel offsets from coordinates (consecutive values linked in red to show the pattern)

Textures which have dimensions that are not a multiple of the tile size require padding.

For so long as the size of a tile fits into an on-chip cache and can be filled efficiently by the memory subsystem, this approach has the benefit that only one in $\frac{1}{n}$ transitions between vertically-adjacent lines requires accessing outside a tile of height n. The larger the tile, the greater the probability that vertically-adjacent accesses fall inside the same scan line. However, horizontally-adjacent texels that cross a tile boundary are made more distant in memory the larger the tile size, and tile sizes which do not conveniently fit the cache and bus sizes of the memory subsystem have inefficiencies; thus the tile size is an architectural trade-off.

While any nonlinear representation is typically referred to as “tiling”, some hardware implementations actually use a more complex layout in order to provide further locality of reference. One such scheme is Morton order:



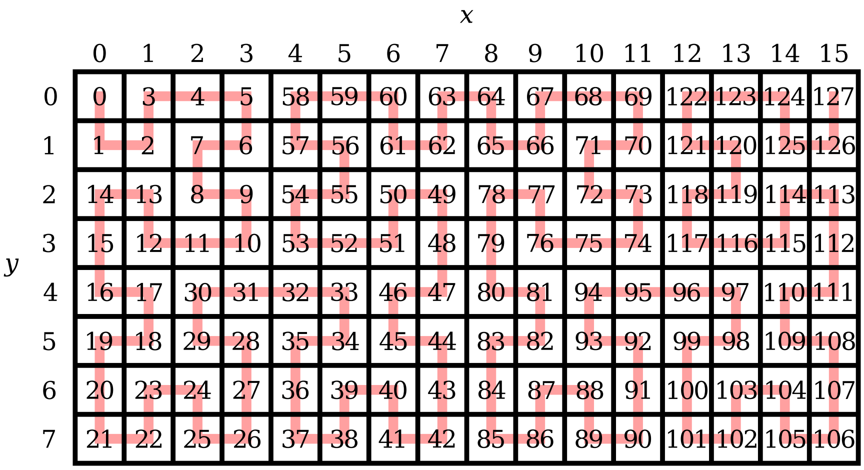
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	4	5	16	17	20	21	64	65	68	69	80	81	84	85
1	2	3	6	7	18	19	22	23	66	67	70	71	82	83	86	87
2	8	9	12	13	24	25	28	29	72	73	76	77	88	89	92	93
3	10	11	14	15	26	27	30	31	74	75	78	79	90	91	94	95
4	32	33	36	37	48	49	52	53	96	97	100	101	112	113	116	117
5	34	35	38	39	50	51	54	55	98	99	102	103	114	115	118	119
6	40	41	44	45	56	57	60	61	104	105	108	109	120	121	124	125
7	42	43	46	47	58	59	62	63	106	107	110	111	122	123	126	127

Figure 2.9: Morton order texel offsets from coordinates (consecutive values linked in red)

```
uint32_t mortonOffset(uint32_t x, uint32_t y,
                      uint32_t width, uint32_t height) {

    const uint32_t minDim = (width <= height) ? width : height;
    uint32_t offset = 0, shift = 0, mask;

    // Tests xy bounds AND that width and height != 0
    assert(x < width && y < height);

    // Smaller size must be a power of 2
    assert((minDim & (minDim - 1)) == 0);

    // Larger size must be a multiple of the smaller
    assert(width % minDim == 0 && height % minDim == 0);

    for (mask = 1; mask < minDim; mask <<= 1) {
        offset |= (((y & mask) << 1) | (x & mask)) << shift;
        shift++;
    }

    // At least one of width and height will have run out of most-significant bits
    offset |= ((x | y) >> shift) << (shift * 2);
    return offset;
}
```

Note that this particular implementation assumes that the smaller of `width` and `height` is a power of two, and the larger is a multiple of the smaller. A practical hardware implementation of the calculation is likely much more efficient than this C code would imply.

Another approach, with even more correlation between locality in *x*,*y* space and memory offset, is Hilbert curve order:



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	3	4	5	58	59	60	63	64	67	68	69	122	123	124	127
1	1	2	7	6	57	56	61	62	65	66	71	70	121	120	125	126
2	14	13	8	9	54	55	50	49	78	77	72	73	118	119	114	113
3	15	12	11	10	53	52	51	48	79	76	75	74	117	116	115	112
4	16	17	30	31	32	33	46	47	80	81	94	95	96	97	110	111
5	19	18	29	28	35	34	45	44	83	82	93	92	99	98	109	108
6	20	23	24	27	36	39	40	43	84	87	88	91	100	103	104	107
7	21	22	25	26	37	38	41	42	85	86	89	90	101	102	105	106

Figure 2.10: Hilbert curve order texel offsets from coordinates (consecutive values linked in red)

```
uint32_t h(uint32_t size, uint32_t x, uint32_t y) {
    const uint32_t z = x ^ y;
    uint32_t offset = 0;

    while (size >>= 1) { // Iterate in decreasing block size order
        // Accumulate preceding blocks of size * size
        offset += size * (((size & x) << 1) + (size & z));
        y = z ^ x; // Transpose x and y
        if (!(size & y)) x = (size & x) ? ~y : y; // Conditionally swap/mirror
    }
    return offset;
}

uint32_t hilbertOffset(uint32_t x, uint32_t y, uint32_t width, uint32_t height) {
    const uint32_t minDim = (width <= height) ? width : height;

    // Tests xy bounds AND that width and height != 0
    assert(x < width && y < height);

    // Smaller size must be a power of 2
    assert((minDim & (minDim - 1)) == 0);

    // Larger size must be a multiple of the smaller
    assert(width % minDim == 0 && height % minDim == 0);

    if (width < height) return (width * width) * (y / width) + h(width, y % width, x);
    else return (height * height) * (x / height) + h(height, x % height, y);
}
```

This code assumes that the smaller of `width` and `height` is a power of two, with the larger a multiple of the smaller.

Some implementations will mix these approaches — for example, having linear tiles arranged in Morton order, or Morton order texels within tiles which are themselves in linear order. Indeed, for non-square areas, the tiling, Morton and Hilbert orderings shown here can be considered as a linear row of square areas with edges of the shorter dimension.

In all these cases, the relationship between coordinates and the memory storage location of the buffer depends on the image size and, other than needing to know the amount of memory occupied by a single texel, is orthogonal to the “format”. Tiling schemes tend to be complemented by proprietary hardware that performs the coordinate-to-address mapping and depends on cache details, so many APIs expose only a linear layout to end-users, keeping the tiled representation opaque. The variety of possible mappings between coordinates and addresses mandates leaving the calculation to the application.

2.4 3-dimensional texel addressing

These storage approaches can be extended to additional dimensions, for example treating a 3-D image as being made up of 2-D “planes”, which are distinct from the concept of storing channels or bits of data in separate planes. In a linear layout, 3-dimensional textures can be accessed as:

$$address_{bytes} = base + (x \times pixel\ stride_{bytes}) + (y \times row\ stride_{bytes}) + (z \times plane\ stride_{bytes})$$

Here, the *plane stride* is the offset between the start of one contiguous 2-D plane of data and the next. The *plane stride* is therefore *height* × *row stride* plus any additional padding. This assumes a regular mapping between the addresses along the third dimension; 3-D texturing can also be implemented as an array of 2-D textures, with each 2-D image having a separate base address. Since the plane stride falls outside the remit of a “format”, being dependent on the image size, this distinction is not otherwise considered in this specification.

Again, nonlinear approaches can be used to increase the correlation between storage address and coordinates, which can be useful especially when filtering samples taken from fractional 3D coordinates.

```
uint32_t tileOffset3D(uint32_t x, uint32_t y, uint32_t z,
                      uint32_t twb, uint32_t thb, uint32_t tdb,
                      uint32_t lineStride, uint32_t planeStride) {
  // twb = tile width bits (log2 of tile width)
  // thb = tile height bits (log2 of tile height)
  // tdb = tile depth bits (log2 of tile depth)
  return (x & ((1 << twb) - 1)) |
         ((y & ((1 << thb) - 1)) << twb) |
         ((z & ((1 << tdb) - 1)) << (twb + thb)) |
         ((x & ~((1 << twb) - 1)) << (thb + tdb)) |
         ((y & ~((1 << thb) - 1)) << tdb) * lineStride |
         ((z & ~((1 << tdb) - 1)) * planeStride);
}
```

```
uint32_t mortonOffset3D(uint32_t x, uint32_t y, uint32_t z,
                        uint32_t width, uint32_t height, uint32_t depth) {
    const uint32_t max = width | height | depth;
    uint32_t offset = 0, shift = 0, mask;
    for (mask = 1; max > mask; mask <<= 1) {
        if (width > mask)  offset |= (x & mask) << shift++;
        if (height > mask) offset |= (y & mask) << shift++;
        if (depth > mask)  offset |= (z & mask) << shift++;
        --shift;
    }
    return offset;
}
```

There are multiple 3D variations on the Hilbert curve; one such is this:

```
uint32_t hilbertOffset3D(uint32_t x, uint32_t y, uint32_t z, uint32_t size) {
    // "Harmonious" 3D Hilbert curve for cube of power-of-two edge "size":
    // http://herman.haverkort.net/recursive_tilings_and_space-filling_curves
    uint32_t offset = 0;
    while (size >>= 1) {
        uint32_t tx = (size & x) > 0, ty = (size & y) > 0, tz = (size & z) > 0;
        switch (tx + 2 * ty + 4 * tz) {
        case 0: tx =  z; ty =  y; tz =  x; break;
        case 1: tx =  x; ty =  z; tz =  y; offset += size * size * size; break;
        case 2: tx = ~y; ty = ~x; tz =  z; offset += size * size * size * 3; break;
        case 3: tx =  z; ty =  x; tz =  y; offset += size * size * size * 2; break;
        case 4: tx = ~z; ty =  y; tz = ~x; offset += size * size * size * 7; break;
        case 5: tx =  x; ty = ~z; tz = ~y; offset += size * size * size * 6; break;
        case 6: tx = ~y; ty = ~x; tz =  z; offset += size * size * size * 4; break;
        case 7: tx = ~z; ty =  x; tz = ~y; offset += size * size * size * 5; break;
        }
        x = tx; y = ty; z = tz;
    }
    return offset;
}
```

A related concept to 3-D texturing is mip maps, in which the same image is stored at different levels of detail to simplify filtering operations. Mip maps are not directly considered as part of a “format” for the purposes of this specification, especially since the details of addressing may be complicated by hardware limitations when it comes to the tails of mip chains; an implementation would typically have to represent each mip level as a separate image, although there are representations which might interleave them in texel blocks, in which case they could be mapped to a third dimension for texel coordinates.

Obviously 3-D texturing can be extended to additional dimensions. The basic representation in this specification directly supports 4-D texel blocks, which may for example represent an animated 3-D texture. Further dimensions are not uncommon for tensor representations, and these can be supported by extension, although it may be common for the texel blocks themselves to be unit-sized in some of the dimensions.

2.5 Downsampled channels

The examples provided so far have assumed that a unique value from each color channel is present at each access coordinate. However, some common representations break this assumption.

One reason for this variation comes from representing the image in the $Y'C_BC_R$ color model, described in Section 15.1; in this description, the Y' channel represents the intensity of light, with C_B and C_R channels describing how the color differs from a gray value of the same intensity in the blue and red axes. Since the human eye is more sensitive to high spatial frequencies in brightness than in the hue of a color, the C_B and C_R channels can be recorded at lower spatial resolution than the Y' channel with little loss in visual quality, saving storage space and bandwidth.

In one common representation known colloquially as *YUV* 4:2:2, each horizontal pair of Y' values has a single C_B and C_R value shared for the pair. For example, Figure 2.11 shows a 6-element 1-D buffer with one Y' value for each element, but as shown in Figure 2.12 the C_B and C_R values are shared across pairs of elements.

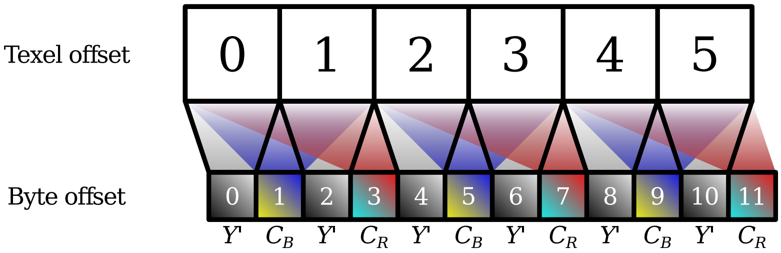


Figure 2.11: 1-D $Y'C_BC_R$ 4:2:2 buffer, texels associated with Y' values

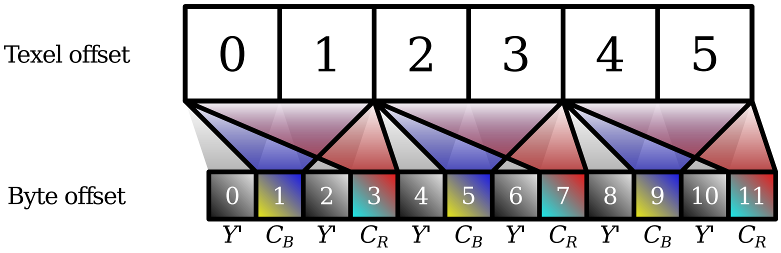


Figure 2.12: 1-D $Y'C_BC_R$ 4:2:2 buffer, texels associated with C_B and C_R values

In this case, we can say that the 2×1 coordinate region forms a *texel block* which contains two Y' values, one C_B value and one C_R value; our bulk-data buffer or image is composed of a repeating pattern of these texel blocks.

Note that this representation raises a question: while we have assumed so far that accessing a value at texel coordinates will provide the value contained in the texel, how should the shared C_B and C_R values relate to the coordinates of the Y' channel? Each texel coordinate represents a value in the coordinate space of the image or buffer, which can be considered as a *sample* of the value of a continuous surface at that position. The preferred means of reconstructing this surface is left to the application: since this specification only defines the values in the image and not how they are used, it is concerned with the sample values rather than the reconstruction algorithm or means of access. For example, in graphics APIs the coordinates used to access a 2-D texture may offset the sample positions of a texture by half a coordinate relative to the origin of sample space, and filtering between samples is typically used to implement antialiasing. However, to interpret the data correctly, any application still needs to know the theoretical position associated with the samples, so that information is within the remit of this specification.

Our Y' samples should fall naturally on our native coordinates. However, the C_B and C_R sample positions (which are typically at the same position as each other) could be considered as located coincident with one or other of the Y' values as shown in Figure 2.13, or could be defined as falling at the mid-point between them as in Figure 2.14. Different representations have chosen either of these alternatives — in some cases, choosing a different option for each coordinate axis. The application can choose how to treat these sample positions: in some cases it may suffice to duplicate C_B and C_R across the pair of Y' values, in others bilinear or bicubic filtering may be more appropriate.

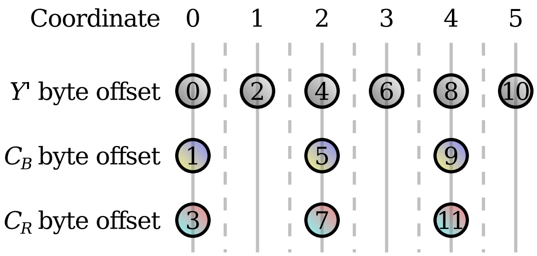


Figure 2.13: 1-D $Y'C_BC_R$ 4:2:2 buffer, C_B and C_R cosited with even Y' values

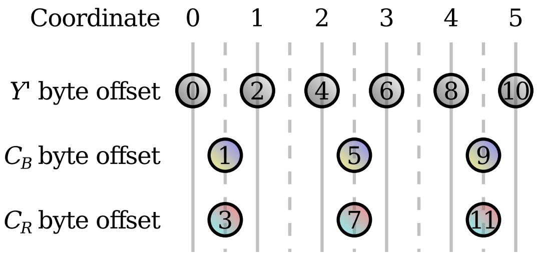


Figure 2.14: 1-D $Y'C_BC_R$ 4:2:2 buffer, C_B and C_R midpoint between Y' values

Traditional APIs have described the C_B and C_R as having 2×1 *downsampling* in this format (there are half as many samples available in the horizontal axis for these channels).

This concept can be extended to more dimensions. Commonly, a two-dimensional image stored in $Y'C_BC_R$ format may store the C_B and C_R channels downsampled by a factor of two in each dimension ("2×2 downsampling", also known for historical reasons as "4:2:0"). This approach is used in, for example, many JPEG images and MPEG video streams.

Because there are twice as many rows of Y' data as there are C_B and C_R data, it is convenient to record the channels as separate planes as shown in Figure 2.15 (with 2×2 texel blocks outlined in red); in addition, image compression schemes often work with the channels independently, which is amenable to planar storage.

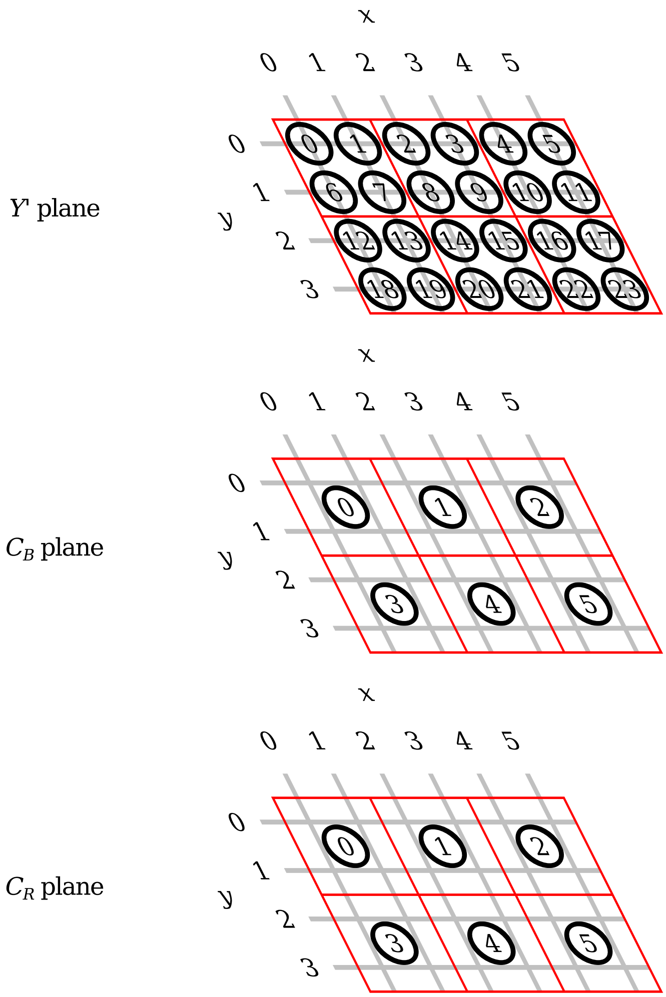


Figure 2.15: 2-D $Y'C_BC_R$ 4:2:0 planes, downsampled C_B and C_R at midpoint between Y' values

In this case, the C_B and C_R planes are half the width and half the height of the Y' plane, and also have half the line stride. Therefore if we store one byte per channel, the offsets for each plane in a linear representation can be calculated as:

$$Y'_{address} = Y'_{base} + x + (y \times row\ stride_{bytes})$$

$$C_{B\,address} = C_{B\,base} + \left\lfloor \frac{x}{2} \right\rfloor + \left(\left\lfloor \frac{y}{2} \right\rfloor \times \frac{row\ stride_{bytes}}{2} \right)$$

$$C_{R\,address} = C_{R\,base} + \left\lfloor \frac{x}{2} \right\rfloor + \left(\left\lfloor \frac{y}{2} \right\rfloor \times \frac{row\ stride_{bytes}}{2} \right)$$

A description based on downsampling factors is sufficient in the case of common $Y'C_BC_R$ layouts, but does not extend conveniently to all representations. For example, one common representation used in camera sensors is a *Bayer pattern*, in which there is only one of the red, green and blue channels at each sample position: one red and blue value per 2×2 texel block, and two green values offset diagonally, as in Figure 2.16.

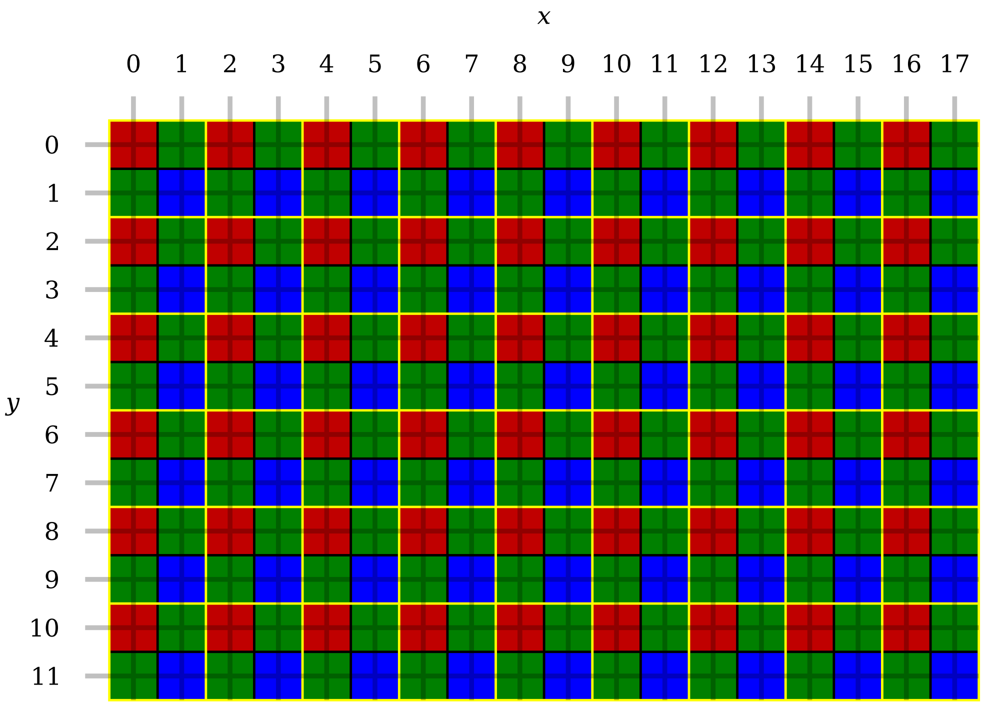


Figure 2.16: An 18×12 $^{RG}/_{GB}$ Bayer filter pattern (repeating pattern outlined in yellow)

A Bayer pattern can then be used to sample an image, as shown in Figure 2.17, and this sampled version can later be used to reconstruct the original image by relying on heuristic correlations between the channels. Technology for image processing continues to develop, so in many cases it is valuable to record the “raw” sensor data for later processing, and to pass the raw data unmodified to a range of algorithms; the choice of algorithm for reconstructing an image from samples is beyond the remit of this specification.

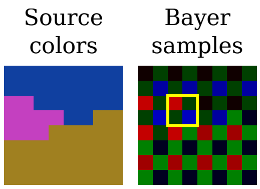


Figure 2.17: A Bayer-sampled image with a repeating 2×2 $^{RG}/_{GB}$ texel block (outlined in yellow)

In the Bayer representation, the red and blue channels can be considered to be downsampled by a factor of two in each dimension. The two green channels per 2×2 repeating block mean that the “downsampling factor” for the green channel is effectively $\sqrt{2}$ in each direction.

More complex layouts are not uncommon. For example, the X-Trans sample arrangement developed by Fujifilm for their digital camera range, shown in Figure 2.18, consists of 6×6 texel blocks, with each sample, as in Bayer, corresponding to a single channel. In X-Trans, each block contains eight red, eight blue and twenty green samples; red and blue are “downsampled” by $\sqrt{\frac{3}{2}}$ and green is “downsampled” by $\frac{3}{\sqrt{5}}$.

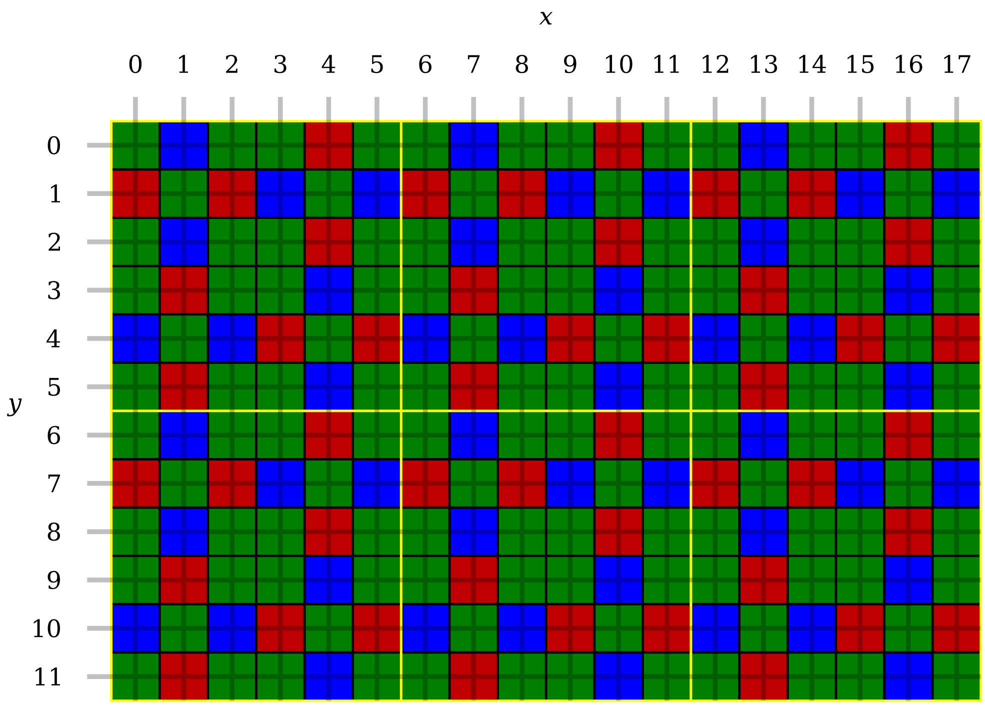


Figure 2.18: An 18×12 X-Trans image (repeating 6×6 pattern outlined in yellow)

Allowing for possible alternative orientations of the samples (such as whether the Bayer pattern starts with a row containing red or blue samples, and whether the first sample is green or red/blue), trying to encode these sample patterns implicitly is difficult.

Chapter 3

The Khronos Data Format Descriptor overview

The data structure defined in this specification is termed a *data format descriptor*. This is an extensible block of contiguous memory, with a defined layout. The size of the data format descriptor depends on its content, but is also stored in a field at the start of the descriptor, making it possible to copy the data structure without needing to interpret all possible contents.

The data format descriptor is divided into one or more *descriptor blocks*, each also consisting of contiguous data, as shown in Table 3.1. These descriptor blocks may, themselves, be of different sizes, depending on the data contained within. The size of a descriptor block is stored as part of its data structure, allowing an application to process a data format descriptor while skipping contained descriptor blocks that it does not need to understand. The data format descriptor mechanism is extensible by the addition of new descriptor blocks.

Data format descriptor
Descriptor block 1
Descriptor block 2
:

Table 3.1: Data format descriptor and descriptor blocks

The diversity of possible data makes a concise description that can support every possible format impractical. This document describes one type of descriptor block, a *basic descriptor block*, that is expected to be the first descriptor block inside the data format descriptor where present, and which is sufficient for a large number of common formats, particularly for pixels. Formats which cannot be described within this scheme can use additional descriptor blocks of other types as necessary.

Later sections of this specification describe several common color spaces, and provide a description of the in-memory representation of a number of common compressed texture formats.

3.1 *Texel blocks* in the Khronos Data Format Descriptor

Instead of an implicit representation, the descriptor specifies a *texel block*, which is described in terms of its finite extent in each of four dimensions, and which identifies the position of each sample within that region. The *texel block* is therefore a self-contained, repeating, axis-aligned pattern in the coordinate space of the image. This description conveniently corresponds to the concept of *compressed texel blocks* used in common block-based texture compression schemes, which similarly divide the image into (typically) small rectangular regions which are encoded collectively. The bounds of the texel block are chosen to be aligned to integer coordinates.

Although it is most common to consider one- and two-dimensional textures and texel blocks, it can be convenient to record additional dimensions; for example, the ASTC compressed texture format described in Chapter 23 can support compressed texel blocks with three dimensions. For convenience of encoding, this specification uses a four-dimensional space to define sample positions within a texel block — there is no meaning imposed on how those dimensions should be interpreted.

In many formats, all color channels refer to the same position, and the *texel block* defines a 1×1×1×1 region — that is, a single texel.

Note
Tiling schemes for texel addressing can also be seen to break the image into rectangular (or higher-dimensional) sub-regions, and in many schemes these sub-regions are repeating and axis-aligned. Within reason, it is possible to define some coordinate-to-texel mapping in terms of a texel block; for example, instead of a simple tiled layout of 4×4 texels, it would be possible to describe the image in terms of a linear pattern of texel blocks, each of which contain 4×4 samples. In general, this is not a useful approach: it is very verbose to list each sample individually, it does not extend well to larger block sizes (or to infinite ranges in approaches such as Morton order), it does not handle special cases well (such as the “tail” of a mip chain), and encodings such as Hilbert order do not have a repeating mapping. In most contexts where these concepts exist, tiling is not considered to be part of a “format”.

3.2 *Planes* in the Khronos Data Format Specification

The description above has shown that the data contributing to a texel may be stored in separate locations in memory; for example, R, G and B stored in separate planes may need to be combined to produce a single texel. For the purposes of this specification, a *plane* is defined to be **a contiguous region of bytes in memory that contributes to a single texel block**.

This interpretation contradicts the traditional interpretation of downsampled channels: if two rows of Y' data correspond to a single row of C_B and C_R (in a linear, non-tiled memory layout), the Y' channel contribution to the texel block is *not* “a contiguous region of bytes”. Instead, each row of Y' contributing to a texel block can be treated as a separate “plane”.

In linear layout, this can be represented by offsetting rows of Y' data with odd y coordinates by the row stride of the original Y' plane; each new Y' plane’s stride is then double that of the original Y' plane, as in Figure 3.1 (c.f. Figure 2.15). If the planes of a 6×4 $Y'C_BC_R$ 4:2:0 texture are stored consecutively in memory with no padding, which might be described in a traditional API as Table 3.2, the representation used by this specification would be that shown in Table 3.3.

Plane	Byte offset	Byte stride	Downsample factor
Y'	0	6	1×1
C_B	24	3	2×2
C_R	30	3	2×2

Table 3.2: Plane descriptors of a 6×4 $Y'C_BC_R$-format buffer in a conventional API

Plane	Byte offset	Byte stride	Bytes per plane
Y' plane 1	0	12	2
Y' plane 2	6	12	2
C_B	24	3	1
C_R	30	3	1

Table 3.3: Plane descriptors of a 6×4 $Y'C_BC_R$-format buffer using this standard

Note

There is no expectation that an API must actually use this representation in accessing the data: it is simple for an API with explicit support for the special case of integer chroma downsampling to detect interleaved planes and to deduce that they should be treated as a single plane of double vertical resolution. Many APIs will not support the full flexibility of formats supported by this specification, and will map to a more restrictive internal representation.

The Khronos Basic Descriptor Block indicates a number of bytes contributing to the texel block from each of up to eight planes — if more than eight planes are required, an extension is needed. Eight planes are enough to encode, for example:

- 8-bit data stored as individual bit planes
- Stereo planar R, G, B, A data
- 4× vertically-downsampled $Y'C_BC_R$ data, as might be produced by rotating a (relatively common) 4× horizontally-downsampled $Y'C_BC_R$ (4:1:1) video frame
- A 2×2×2×2 4-D texel block in a linear layout
- Interlaced $Y'C_BC_R$ 4:2:0 data with each field stored separately

If a plane contributes less than a byte to a texel (or a non-integer number of bytes), the texel block size should be expanded to cover more texels until a whole number of bytes are covered — q.v. Table 11.4.

Note

Interlaced $Y'C_BC_R$ data may associate chroma channels with Y' samples only from the same field, not the frame as a whole. This distinction is not made explicit, in part because a number of interlacing schemes exist. One suggested convention for interlaced data is that the field of a sample be encoded in the fourth sample coordinate (the first field as ***samplePosition3*** = 0, the second field as ***samplePosition3*** = 1, etc.) This interpretation is not mandated to allow other reasons for encoding four-dimensional texels, although it is consistent with the fourth dimension representing “time”.

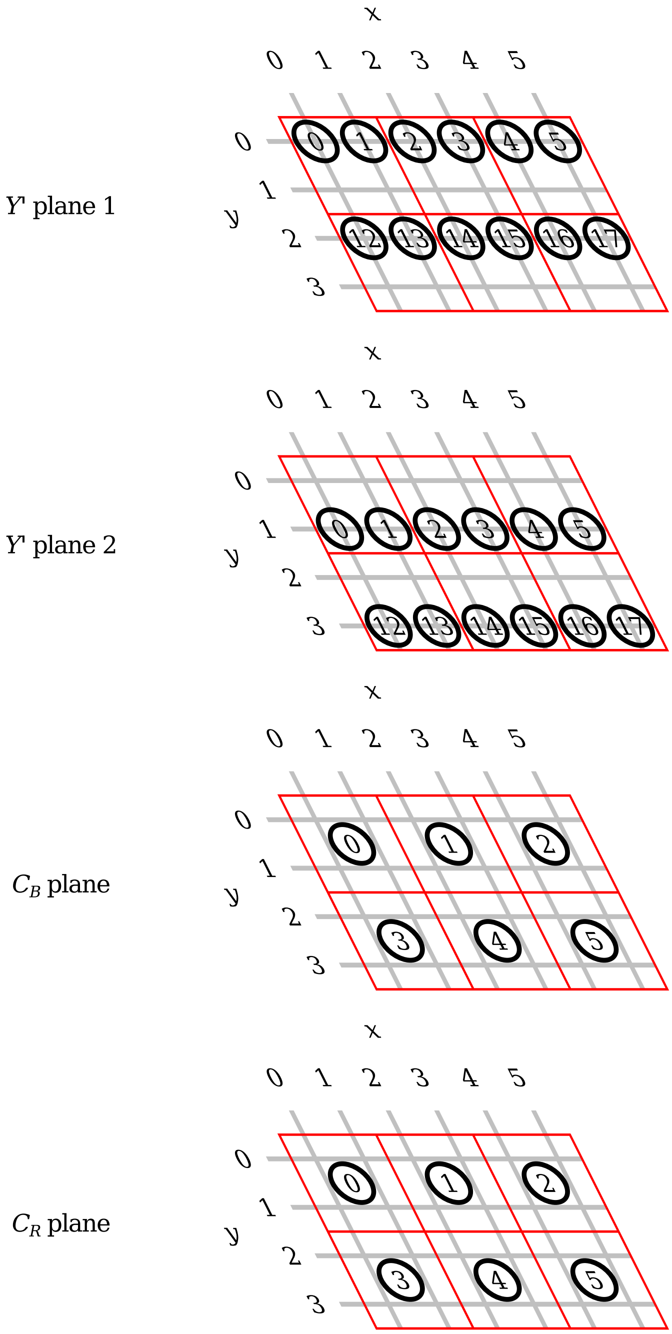


Figure 3.1: 2-D $Y'C_BC_R$ 4:2:0 planes, with separate even and odd Y' planes

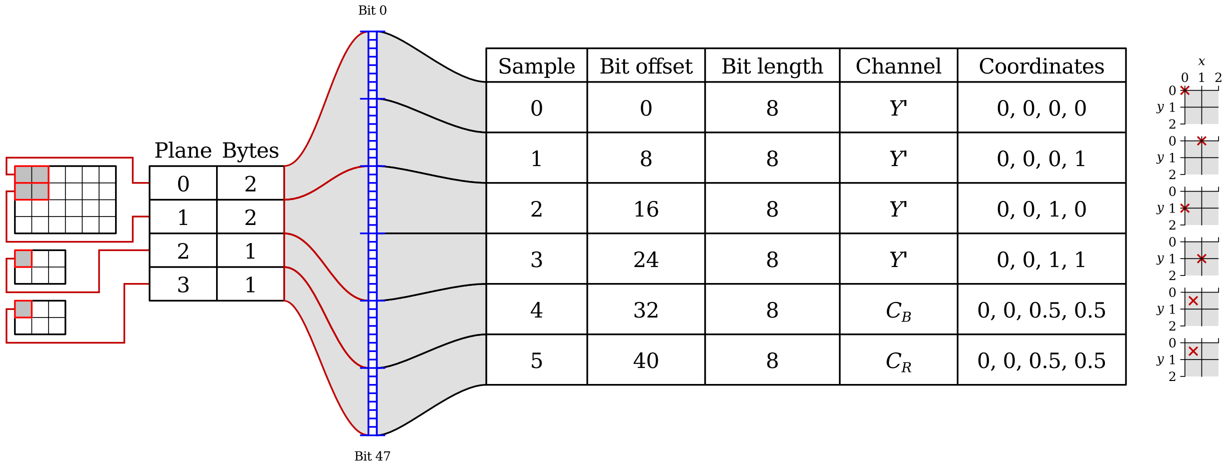
3.3 Bit pattern interpretation and *samples*

For the purposes of description, the bytes contributed by each plane are considered to be concatenated into a single contiguous *logical bit stream*. This "concatenation" of bits is purely conceptual for the purposes of determining the interpretation of the bits that contribute to the texel block, and is not expected to be the way that actual decoders would process the data.

That is, if planes zero and one contribute two bytes of data each and planes two and three contribute one byte of data each, this bit stream would consist of the two bytes from plane zero followed by the two bytes from plane one, then the byte from plane two, then the byte from plane three.

The data format descriptor then describes a series of *samples* that are contained within the texel block. Each sample represents a series of contiguous bits from the bit stream, interpreted in little-endian order, and is associated with a single channel and four-dimensional coordinate offset within the texel block; in formats for which only a single texel is being described, this coordinate offset will always be 0,0,0,0.

The descriptor block for a $Y'C_BC_R$ 4:2:0 layout is shown in Table 11.9. Figure 3.2 shows this representation graphically: the three disjoint regions for each channels and the texel block covering them are shown on the left, represented in this specification as four planes of contiguous bytes. These are concatenated into a 48-bit logical bit stream (shown in blue, in top-to-bottom order); these *samples* then describe the contributions from these logical bits, with geometric position of the sample at the right.



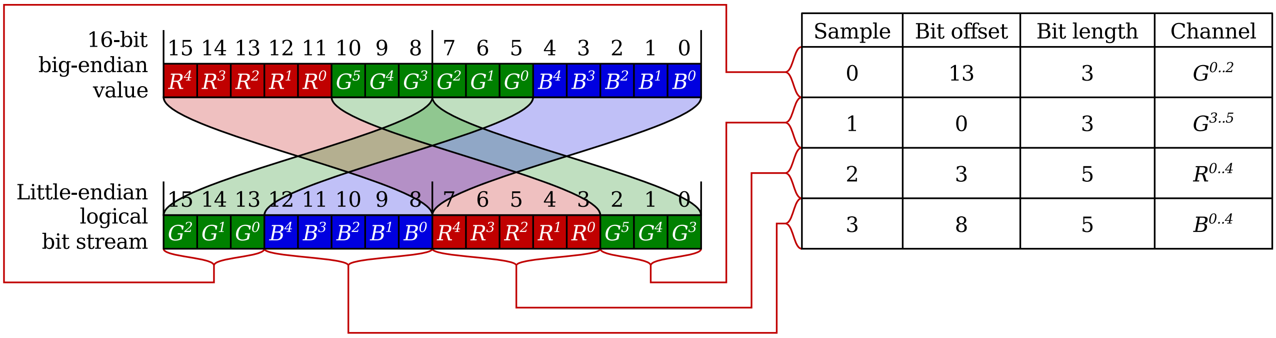
Plane	Bytes
0	2
1	2
2	1
3	1

Sample	Bit offset	Bit length	Channel	Coordinates
0	0	8	Y'	0, 0, 0, 0
1	8	8	Y'	0, 0, 0, 1
2	16	8	Y'	0, 0, 1, 0
3	24	8	Y'	0, 0, 1, 1
4	32	8	C_B	0, 0, 0.5, 0.5
5	40	8	C_R	0, 0, 0.5, 0.5

Figure 3.2: $Y'C_BC_R$ 4:2:0 described in six samples

Consecutive samples with the same channel, position and flags may describe additional bits that contribute to the same final value, and appear in increasing order. For example, a 16-bit big-endian word in memory can be described by one sample describing bits 0..7, coming from the higher byte address, followed by one sample describing bits 8..15, coming from the lower address. These samples comprise a single *virtual sample*, of 16 bits.

Figure 3.3 shows how multiple contributions to single value can be used to represent a channel which, due to a big-endian native word type (high bits stored in lower byte addresses), is not contiguous in a little-endian representation (low bits stored in lower byte addresses). Here, channels are comprised of consecutive bits from a 16-bit big-endian word; the bits of each channel cease to be contiguous when the memory bytes are interpreted in little-endian order for the logical bit stream. The bit contributions to each channel from each bit location are shown in superscript, as later in this specification; the channel contributions start at bit 0 with the first sample contributing to the value, and are deduced implicitly from the number of bits each sample contributes. This example assumes that we are describing a single texel, with the same 0,0,0,0 coordinates (not shown) for each sample. The descriptor block for this format is shown in Table 11.10.


16-bit big-endian value
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
R^4 R^3 R^2 R^1 R^0 G^5 G^4 G^3 G^2 G^1 G^0 B^4 B^3 B^2 B^1 B^0
Little-endian logical bit stream
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
G^2 G^1 G^0 B^4 B^3 B^2 B^1 B^0 R^4 R^3 R^2 R^1 R^0 G^5 G^4 G^3

Sample	Bit offset	Bit length	Channel
0	13	3	$G^{0..2}$
1	0	3	$G^{3..5}$
2	3	5	$R^{0..4}$
3	8	5	$B^{0..4}$

Figure 3.3: *RGB* 565 big-endian encoding

In Figure 3.3, bit 0 of the logical bit stream corresponds to bit 3 of the virtual sample that describes the green channel; therefore the first channel to be encoded is green. Bits 0 to 2 of the green channel virtual sample correspond to bits 13..15 of the logical bit stream, so these are described by the first sample. The second sample continues describing bits 3..5 of the green channel virtual sample, in bits 0..2 of the logical bit stream. The next bit from the logical bit stream that has not yet been described is bit 3, which corresponds to bit 0 of the red channel. The third sample is therefore used to describe bits 3..7 of the logical bit stream as a 5-bit red channel. The last sample encodes the remaining 5-bit blue channel that forms bits 8..12 of the logical bit stream. Note that in the case where some bits of the data are ignored, they do not need to be covered by samples; bits may also appear repeatedly if they contribute to multiple samples.

The precision to which sample coordinates are specified depends on the size of the texel block: coordinates in a 256×256 texel block can be specified only to integer-coordinate granularity, but offsets within a texel block that is only a single coordinate wide are specified to the precision of $\frac{1}{256}$ of a coordinate; this approach allows large texel blocks, half-texel offsets for representations such as $Y'C_BC_R$ 4:2:0, and precise fractional offsets for recording multisampled pattern positions.

The sequence of bits in the (virtual) sample defines a numerical range which may be interpreted as a fixed-point or floating-point value and signed or unsigned. Many common representations specify this range. For example, 8-bit *RGB* data may be interpreted in “unsigned normalized” form as meaning “0.0” (zero color contribution) when the channel bits are 0 and “1.0” (maximum color contribution) when the channel is 255. In $Y'C_BC_R$ “narrow-range” encoding, there is head-room and foot-room to the encoding: “black” is encoded in the Y' channel as the value 16, and “white” is encoded as 235, as shown in Section 16.1. To allow the bit pattern of simply-encoded numerical encodings to be mapped to the desired values, each sample has an *upper* and *lower* value associated with it, usually representing 1.0 and either 0.0 or -1.0 depending on whether the sample is signed.

Note that it is typically part of the “format” to indicate the numbers which are being encoded; how the application chooses to process these numbers is not part of the “format”. For example, some APIs may have two separate “formats”, in which the 8-bit pattern 0x01 may be interpreted as either the float value 1.0 or the integer value 1; for the purposes of this specification, these formats are identical — “1” means “1”.

A sample has an associated color channel in the color model of the descriptor block — for example, if the descriptor block indicates an *RGB* color model, the sample’s channel field could specify the *R* channel. The descriptor block enumerates a range of common color models, color primary values and transfer functions, which apply to the samples.

3.4 Canonical representation

There is some redundancy in the data format descriptor when it comes to the ordering of planes and samples. In the interests of simplifying comparison between formats, it is helpful to define a canonical ordering.

- Planes should be described first in order of the first channel with which they are associated, then in increasing raster order of coordinates, then in increasing bit order (in a little-endian interpretation). For example:
  - In the $Y'C_BC_R$ 4:2:0 format described above, the Y' planes should come before the C_B and C_R planes in that order, because of the channel order.
  - The Y' plane corresponding to even y addresses should come before the Y' plane corresponding to odd y coordinates, because row 0 is even.
  - Planes should be ordered such that sample values that are split across multiple planes should be ordered in increasing order — e.g. in an 8-bit format with one bit per plane, planes 0 through 7 should encode bits 0 through 7 in that order (thereby minimizing the number of samples required to describe the value).

The order of samples should be defined by the following rules:

- Samples sharing a channel and position appear consecutively in increasing order of bits contributed to the virtual sample.
  - For example, a big-endian 16-bit red channel at position 0,0 may be composed of two samples: one referencing the eight consecutive virtual bit stream bits from 0..7 (***bitOffset*** = 0, ***bitLength*** = 8) and the other referencing the eight consecutive virtual bit stream bits from 8..15 (***bitOffset*** = 8, ***bitLength*** = 8). Since the least-significant 8 bits of the virtual red value come from the sample that references bits 8..15 of the virtual bit stream, this sample should appear first, immediately followed by the sample that references bits 0..8, which define the most-significant 8 bits of the virtual value. Table 11.16 shows a similar virtual sample, split across three samples of contiguous bits.
- A minimum number of samples describes each sequence of contiguous virtual bit stream bits in a virtual sample value.
  - If an additional sample is required to represent the sample's ***sampleLower*** and ***sampleUpper*** values because more than 32 bits are encoded and the existing extension rules for ***sampleLower*** and ***sampleUpper*** do not result in the desired behavior, the earlier sample(s) should be limited to 32 bits, ensuring that the subsequent sample holds at least one bit (***bitLength*** is greater than or equal to 0).
  - Otherwise, if the contiguous sequence of bits from the virtual bit stream is longer than 256 bits, samples should be concatenated such that only the last sample describes fewer than 256 bits.
- Samples that qualify an existing virtual sample immediately follow it.
  - Specifically, in an explicitly-described floating-point format, any sample describing an explicit sign bit immediately follows the unsigned mantissa, and any exponent follows thereafter, as seen in Table 11.17.
- Virtual samples are described in increasing order of the virtual bit stream bits to which they apply.
  - This means that if bit 0 of the virtual bit stream is part of a virtual sample, that virtual sample should be described first; this does not require that the first sample directly describes bit 0, as in the green channel of Table 11.10.
- If the same bit in the virtual bit stream in increasing bit order is the first to be associated with more than one virtual sample, virtual samples are listed in channel number order.
  - For example, an alpha channel may be encoded in bits 0..7 of the virtual bits stream, followed by red, green and blue channels sharing bits 8..15. The sample describing alpha should be listed first, since it uniquely describes bit 0 of the virtual bits stream. Bit 8 of the virtual bit stream is the first bit of the red, green and blue, and since red, green and blue are channel numbers 0, 1 and 2, the corresponding samples are described in this order. See, for example, Table 11.12 and Table 11.15.
- Virtual samples that share bits and channel number but not position would be extremely unusual, but would appear in increasing raster order of the position (that is, sorted first by coordinate three, then two, then one, then zero).

Finally:

- Fields which are irrelevant (for example, the alpha behavior for a format with no alpha channel) should be set to zero.
- Samples describing a channel of a single bit should have a linear transfer function — either by selecting the transfer function **`KHR_DF_TRANSFER_LINEAR`** for the descriptor as a whole if all samples are linear, or by setting the sample's **`KHR_DF_SAMPLE_DATATYPE_LINEAR`** bit if other samples have multiple bits and a nonlinear transfer function is needed.

3.5 Related concepts outside the “format”

The data format descriptor describes only concepts which are conventionally part of the “format”. Additional information is required to access the image data:

- A formula for mapping accessed coordinates to byte data for each channel.
- This may be expected to require, for each channel, a start address and a stride in each dimension.
- This transformation depends on the image size, and may be parameterized by the texel block dimensions and the number of bytes contributed by each plane.
- (Optionally) for each dimension, a maximum (and arguably minimum) range.
- Note that padding is independent of the “format”.

For example, if texels are laid out in memory in linear order:

```
int numPlanes;
char *planeBaseAddresses[8];
unsigned int strides[8][4];

// Note: The strides here are assumed to be in units of the
// corresponding dimension of the texel block
char *planeAddress(uint32_t descriptor, int plane, float coords[4]) {
  return planeBaseAddresses[plane]
    // Block stride
    + ((int) (coords[0] / descriptorSize(descriptor, 0))) * strides[plane][0]
    // Row stride
    + ((int) (coords[1] / descriptorSize(descriptor, 1))) * strides[plane][1]
    // Plane stride
    + ((int) (coords[2] / descriptorSize(descriptor, 2))) * strides[plane][2]
    // Volume(?) stride
    + ((int) (coords[3] / descriptorSize(descriptor, 3))) * strides[plane][3];
}

decodeTexelGivenCoords(uint32_t *descriptor, float coords[4]) {
  char *addresses[8];
  for (int i = 0; i < numPlanes; ++i) {
    addresses[i] = planeAddress(i, coords);
  }

  // processTexel reads bytesPlane[] bytes from each address and
  // decodes the concatenated data according to the descriptor
  processTexel(descriptor, addresses, coords);
}
```

The `processTexel` function would typically operate on the coordinates having taken the remainder of dividing them by the texel block size. For example, if the texel block size is 2×2, the block and row stride provide the offset in bytes between adjacent blocks in the first two dimensions. `processTexel` would then work with the data corresponding to the 2×2 region with `coords[0]` and `coords[1]` in the range [0..2). For formats that describe a single texel, `coords` can be considered to be an integer. Note that for more complex formats such as Bayer layouts, reconstructing an *R*,*G*,*B* value at a position may require information from more than one texel block, depending on the algorithm used, in a manner analogous to sampling using bilinear filtering.

The stride values may be stored explicitly, or derived implicitly from the ***bytesPlane*** values and image size information, with application-specific knowledge about alignment constraints.

3.6 Translation to API-specific representations

Despite being designed to balance size against flexibility, the data format container described here is too unwieldy to be expected to be used directly in most APIs, which will generally support only a subset of possible formats. The expectation is that APIs and users will define data descriptors in memory, but have API-specific names for the formats that the API supports. If these names are enumeration values, a mapping can be provided by having an array of pointers to the data descriptors, indexed by the enumeration. It may commonly be necessary to provide API-specific supplementary information in the same array structure, particularly where the API natively associates concepts with the data which is not uniquely associated with the content.

In this approach, it is likely that an API would predefine a number of common data formats which are natively supported. If there is a desire to support dynamic creation of data formats, this array could be made extensible with a manager assigning unique handles.

Even where an API supports only a fixed set of formats, it is flexible to provide a comparison with user-provided format descriptors in order to establish whether a format is compatible (and differs only in a manner irrelevant to the API).

Some APIs have the concept of a *native data type* for a format, if each channel is stored separately. Since this specification describes a number of bytes per plane and separately contiguous bit sequences, there is no such explicit concept. However, if a sample's ***bitOffset*** and ***bitLength*** are byte-aligned and no further samples contribute to the same value, the ***bitLength*** trivially defines a little-endian native data type size. Big-endian data types can be identified by observing that in a big-endian format, a sequence of bits in the top bits of byte *n* may continue in the low bits of byte *n* - 1. Finally, "packed" formats consist of consecutive bit sequences per channel in either little- or big-endian order; little-endian sequences are a single stand-alone sample, and a big-endian sequence consists of a number of samples adjacent to byte boundaries in decreasing byte order (see Figure 3.3); the packed field size can typically be deduced from the ***bytesPlane0*** value. There is no way to distinguish a logically "packed", byte-aligned samples from distinct but consecutively-stored channels that have the same in-memory representation.

3.7 Glossary

Data format: The interpretation of individual elements in bulk data. Examples include the channel ordering and bit locations in pixel data or the positions of samples in a Bayer image. The format describes the elements, not the bulk data itself: an image's size, stride, tiling, dimensionality, border control modes, and image reconstruction filter are not part of the format and are the responsibility of the application.

Data format descriptor: A contiguous block of memory containing information about how data is represented, in accordance with this specification. A data format descriptor is a container, within which can be found one or more descriptor blocks. This specification does not define where or how the the data format descriptor should be stored, only its content. For example, the descriptor may be directly prepended to the bulk data, perhaps as part of a file format header, or the descriptor may be stored in a CPU memory while the bulk data that it describes resides within GPU memory; this choice is application-specific.

(Data format) descriptor block: A contiguous block of memory with a defined layout, held within a data format descriptor. Each descriptor block has a common header that allows applications to identify and skip descriptor blocks that it does not understand, while continuing to process any other descriptor blocks that may be held in the data format descriptor.

Basic (data format) descriptor block: The initial form of descriptor block as described in this standard. Where present, it must be the first descriptor block held in the data format descriptor. This descriptor block can describe a large number of common formats and may be the only type of descriptor block that many portable applications will need to support.

Texel block: The units described by the Basic Data Format Descriptor: a repeating element within bulk data. In simple texture formats, a texel block may describe a single pixel. In formats where the bytes of each plane do not correspond uniquely to single pixels, as for example with subsampled channels, the texel block may cover several pixels. In a block-based compressed texture, the texel block typically describes the compression block unit. The basic descriptor block supports texel blocks of up to four dimensions.

Plane: In the Basic Data Format Descriptor, a plane describes a contiguous sequence of bytes that contribute to the texel block. The basic format descriptor block defines a texel block as being made of a number of concatenated bits which may come from different regions of memory, where each region is considered a separate *plane*. For common formats, it is sufficient to require that the contribution from each plane is an integer number of bytes. This specification places no requirements on the ordering of planes in memory — the plane locations are described outside the format. This allows support for multiplanar formats which have proprietary padding requirements that are hard to accommodate in a more terse representation.

Sample: In this standard, texel blocks are considered to be composed of contiguous bit patterns with a single channel or component type and a single spatial position. A typical *ARGB* pixel has four samples, one for each channel, held at the same coordinate. A texel block from a Bayer sensor might have a different position for different channels, and may have multiple samples representing the same channel at multiple positions. A $Y'C_BC_R$ buffer with downsampled chroma may have more luma samples than chroma, each at different positions.

Chapter 4

Khronos Data Format Descriptor

The data format descriptor consists of a contiguous area of memory, as shown in Table 4.1, divided into one or more *descriptor blocks*, which are tagged by the type of descriptor that they contain. The size of the data format descriptor varies according to its content.

`uint32_t`	***totalSize***
Descriptor block	*First descriptor*
Descriptor block	*Second descriptor (optional) etc.*

Table 4.1: Data Format Descriptor layout

The ***totalSize*** field, measured in bytes, allows the full format descriptor to be copied without need for details of the descriptor to be interpreted. ***totalSize*** includes its own `uint32_t`, not just the following descriptor blocks. For example, we will see below that a four-sample Khronos Basic Data Format Descriptor Block occupies 88 bytes; if there are no other descriptor blocks in the data format descriptor, the ***totalSize*** field would then indicate 88 + 4 bytes (for the ***totalSize*** field itself) for a final value of 92.

For consistency of decode, each descriptor block should be aligned to a multiple of four bytes relative to the start of the descriptor; ***totalSize*** will therefore be a multiple of four.

Note
This restriction was not present in versions of the Khronos Data Format Specification prior to version 1.3.

The layout of the data structures described here are comprised solely of 32-bit words, and for canonical communication between devices are assumed to be stored with a little-endian representation. For efficiency, applications may choose to convert the descriptor to the native endianness of the underlying hardware where all software using the data structure is prepared for this conversion. Extensions which are composed of quantities other than 32-bit words (for example if a data structure belonging to another standard is incorporated directly) may define the expected impact of endianness changes on the layout. Since the environment is expected to know its own endianness, there is no explicit means of automatically determining the endianness of a descriptor, although it can be observed that it is highly unlikely that a valid descriptor would be large enough for its size to need to be represented in more than 16 bits — meaning that the endianness of most descriptors can be deduced by which half of the `uint32_t` ***totalSize*** field is non-zero.

Note
To avoid expanding the size of the data structure, there is no “magic identifier” for a data format descriptor: applications are expected to know the type of the data structure being accessed, and to provide their own means of identifying a data format descriptor if one is embedded in a multi-purpose byte stream.

4.1 Descriptor block

Each *descriptor block* has the same prefix, shown in Table 4.2.

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="15"><b><i>descriptorType</i></b></td><td colspan="17"><b><i>vendorId</i></b></td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize</i></b></td><td colspan="16"><b><i>versionNumber</i></b></td></tr>
<tr><td colspan="32"><i>Format-specific data</i></td></tr>
</table>

Table 4.2: Descriptor Block layout

The ***vendorId*** is a 17-bit value uniquely assigned to organizations. If the organization has a 16-bit identifier assigned by the PCI SIG, this should occupy bits 0..15, with bit 16 set to 0. Other organizations should apply to Khronos of a unique identifier, which will be assigned consecutively starting with 65536. The identifier 0x1FFFF is reserved for internal use which is guaranteed not to clash with third-party implementations; this identifier should not be shipped in libraries to avoid conflicts with development code.

The ***descriptorType*** is a unique 15-bit identifier defined by the vendor to distinguish between potential data representations.

Note

Prior to version 1.3 of the Khronos Data Format Specification, the ***vendorId*** field was 16-bit, and purely assigned through the auspices of this specification; the ***descriptorType*** was consequently also 16-bit. Since no vendor has requested an identifier and Khronos does not have a descriptor block with type 1, this change should not cause any ambiguity. This change is intended to allow consistency with the vendor IDs used by the Vulkan specification.

The ***versionNumber*** is vendor-defined, and is intended to allow for backwards-compatible updates to existing descriptor blocks.

The *DescriptorBlockSize* indicates the size in bytes of this Descriptor Block, remembering that there may be multiple Descriptor Blocks within one container, as shown in Table 4.3. The ***descriptorBlockSize*** therefore gives the offset between the start of the current Descriptor Block and the start of the next — so the size includes the ***vendorId***, ***descriptorType***, ***versionNumber*** and ***descriptorBlockSize*** fields, which collectively contribute 8 bytes.

Having an explicit ***descriptorBlockSize*** allows implementations to skip a descriptor block whose format is unknown, allowing known data to be interpreted and unknown information to be ignored. Some descriptor block types may not be of a uniform size, and may vary according to the content within.

This specification initially describes only one type of stand-alone descriptor block, plus two extension blocks which modify the description in the first. Future revisions may define additional descriptor block types for additional applications — for example, to describe data with a large number of channels or pixels described in an arbitrary color space. Vendors can also implement proprietary descriptor blocks to hold vendor-specific information within the standard descriptor.

Unless otherwise specified, descriptor blocks can appear in any order, to make it easier to add and remove additional informative descriptor blocks to a preexisting data format descriptor as part of processing. Descriptor blocks that provide additional capabilities beyond a basic scheme (such as the descriptor block for supporting additional planes beyond the Khronos Basic Descriptor Block) should not be present unless their additional capabilities are needed; that is, redundancy should be resolved so as to minimize the number of descriptor blocks in the data format descriptor.

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize</i></b></td></tr>
<tr><td colspan="32">First descriptor block</td></tr>
<tr><td colspan="15"><b><i>descriptorType</i></b></td><td colspan="17"><b><i>vendorId</i></b></td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize</i></b></td><td colspan="16"><b><i>versionNumber</i></b></td></tr>
<tr><td colspan="32"><i>Descriptor body</i></td></tr>
<tr><td colspan="32">Second descriptor block</td></tr>
<tr><td colspan="15"><b><i>descriptorType</i></b></td><td colspan="17"><b><i>vendorId</i></b></td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize</i></b></td><td colspan="16"><b><i>versionNumber</i></b></td></tr>
<tr><td colspan="32"><i>Descriptor body</i></td></tr>
</table>

Table 4.3: Data format descriptor header and descriptor block headers for two descriptor blocks

Chapter 5

Khronos Basic Data Format Descriptor Block

A *basic descriptor block* (Table 5.1) is designed to encode common metadata associated with bulk data — especially image or texture data. While this descriptor holds more information about the data interpretation than is needed by many applications, a comprehensive encoding reduces the risk of metadata needed by different APIs being lost in translation.

The format is described in terms of a repeating axis-aligned *texel block* composed of *samples*. Each sample contains a single channel of information with a single spatial offset within the texel block, and consists of an amount of contiguous data. This *descriptor block* consists of information about the interpretation of the texel block as a whole, supplemented by a description of a number of samples taken from one or more *planes* of contiguous memory. For example, a 24-bit red/green/blue format may be described as a 1×1 pixel region, in one plane of three samples, one describing each channel. A $Y'C_BC_R$ 4:2:0 format may consist of a repeating 2×2 region: four Y' samples and one sample each of C_B and C_R.

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="15">***descriptorType*** = 0</td><td colspan="17">***vendorId*** = 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize*** = 24 + 16 × *#samples*</td><td colspan="16">***versionNumber*** = 2</td></tr>
<tr><td colspan="8">***flags***</td><td colspan="8">***transferFunction***</td><td colspan="8">***colorPrimaries***</td><td colspan="8">***colorModel***</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">***bytesPlane3***</td><td colspan="8">***bytesPlane2***</td><td colspan="8">***bytesPlane1***</td><td colspan="8">***bytesPlane0***</td></tr>
<tr><td colspan="8">***bytesPlane7***</td><td colspan="8">***bytesPlane6***</td><td colspan="8">***bytesPlane5***</td><td colspan="8">***bytesPlane4***</td></tr>
<tr><td colspan="32">*Sample information for the first sample*</td></tr>
<tr><td colspan="32">*Sample information for the second sample (optional), etc.*</td></tr>
</table>

Table 5.1: Basic Data Format Descriptor layout

The Basic Data Format Descriptor Block should be the first descriptor block in any data format descriptor of which it is a component.

The fields of the Basic Data Format Descriptor Block are described in the following sections.

To simplify code using the Basic Data Format Descriptor Block, the header `khr_df.h` provides enums of the following form for accessing descriptor block fields:

Word offset into basic descriptor block	**KHR_DF_WORD_xxx**	…
Word offset into descriptor	**KHR_DF_WORD_xxx** + 1	…
Start bit within word	**KHR_DF_SHIFT_xxx**	…
Bit mask of value	**KHR_DF_MASK_xxx**	…

Table 5.2: Field location information for field ***xxx***

If the basic descriptor block is treated as a **`uint32_t`** array `bdb[]`, field ***xxx*** can be accessed as follows:

xxx = **KHR_DF_MASK_xxx** & (`bdb`[**KHR_DF_WORD_xxx**] >> **KHR_DF_SHIFT_xxx**);

The macro **KHR_DFDVAL**(`BDB`, `X`) is provided to perform this calculation. For example, **KHR_DFDVAL**(`bdb`, **MODEL**) returns the value:

KHR_DF_MASK_MODEL & (`bdb`[**KHR_DF_WORD_MODEL**] >> **KHR_DF_SHIFT_MODEL**)

5.1 *vendorId*

The ***vendorId*** for the Basic Data Format Descriptor Block is 0, defined as **KHR_DF_VENDORID_KHRONOS** in the enum **khr_df_vendorid_e**.

Word offset into basic descriptor block	**KHR_DF_WORD_VENDORID**	0
Word offset into descriptor	**KHR_DF_WORD_VENDORID** + 1	1
Start bit within word	**KHR_DF_SHIFT_VENDORID**	0
Bit mask of value	**KHR_DF_MASK_VENDORID**	0x1FFFFU

Table 5.3: Field location information for ***vendorId***

khr_df_vendorid_e ***vendorId*** = **KHR_DF_MASK_VENDORID** &
(bdb[**KHR_DF_WORD_VENDORID**] >> **KHR_DF_SHIFT_VENDORID**);

5.2 *descriptorType*

The ***descriptorType*** for the Basic Data Format Descriptor Block is 0, a value reserved in the enum of Khronos-specific descriptor types, **khr_df_khr_descriptortype_e**, as **KHR_DF_KHR_DESCRIPTORTYPE_BASICFORMAT**.

Word offset into basic descriptor block	**KHR_DF_WORD_DESCRIPTORTYPE**	0
Word offset into descriptor	**KHR_DF_WORD_DESCRIPTORTYPE** + 1	1
Start bit within word	**KHR_DF_SHIFT_DESCRIPTORTYPE**	17
Bit mask of value	**KHR_DF_MASK_DESCRIPTORTYPE**	0x7FFFU

Table 5.4: Field location information for ***descriptorType***

khr_df_descriptortype_e ***descriptorType*** = **KHR_DF_MASK_DESCRIPTORTYPE** &
(bdb[**KHR_DF_WORD_DESCRIPTORTYPE**] >> **KHR_DF_SHIFT_DESCRIPTORTYPE**);

5.3 *versionNumber*

The ***versionNumber*** relating to the Basic Data Format Descriptor Block as described in this specification is 2.

Note
The ***versionNumber*** is incremented to indicate an incompatible change in the descriptor. The addition of enumerant values, for example to represent more compressed texel formats, does not constitute an “incompatible change”, and implementations should be resilient against enumerants that have been added in later minor updates.

Word offset into basic descriptor block	**KHR_DF_WORD_VERSIONNUMBER**	1
Word offset into descriptor	**KHR_DF_WORD_VERSIONNUMBER** + 1	2
Start bit within word	**KHR_DF_SHIFT_VERSIONNUMBER**	0
Bit mask of value	**KHR_DF_MASK_VERSIONNUMBER**	0xFFFFU

Table 5.5: Field location information for ***versionNumber***

uint32_t ***versionNumber*** = **KHR_DF_MASK_VERSIONNUMBER** &
(bdb[**KHR_DF_WORD_VERSIONNUMBER**] >> **KHR_DF_SHIFT_VERSIONNUMBER**);

5.4 *descriptorBlockSize*

The memory size of the Basic Data Format Descriptor Block depends on the number of samples contained within it. The memory requirements for this format are 24 bytes of shared data plus 16 bytes per sample. The ***descriptorBlockSize*** is measured in bytes.

Word offset into basic descriptor block	**KHR_DF_WORD_DESCRIPTORBLOCKSIZE**	1
Word offset into descriptor	**KHR_DF_WORD_DESCRIPTORBLOCKSIZE** + 1	2
Start bit within word	**KHR_DF_SHIFT_DESCRIPTORBLOCKSIZE**	16
Bit mask of value	**KHR_DF_MASK_DESCRIPTORBLOCKSIZE**	0xFFFFU

Table 5.6: Field location information for ***descriptorBlockSize***

uint32_t ***descriptorBlockSize*** = **KHR_DF_MASK_DESCRIPTORBLOCKSIZE** &
(bdb[**KHR_DF_WORD_DESCRIPTORBLOCKSIZE**] >> **KHR_DF_SHIFT_DESCRIPTORBLOCKSIZE**);

5.5 *colorModel*

The ***colorModel*** determines the set of color (or other data) channels which may be encoded within the data, though there is no requirement that all of the possible channels from the ***colorModel*** be present. Most data fits into a small number of common color models, but compressed texture formats each have their own color model enumeration. Note that the data need not actually represent a color — this is just the most common type of content using this descriptor. Some standards use *color container* for this concept.

The available color models are described in the **`khr_df_model_e`** enumeration, and are represented as an unsigned 8-bit value.

Word offset into basic descriptor block	**`KHR_DF_WORD_MODEL`**	2
Word offset into descriptor	**`KHR_DF_WORD_MODEL`** + 1	3
Start bit within word	**`KHR_DF_SHIFT_MODEL`**	0
Bit mask of value	**`KHR_DF_MASK_MODEL`**	0xFF

Table 5.7: Field location information for ***colorModel***

`khr_df_model_e` *colorModel* = **`KHR_DF_MASK_MODEL`** &
(`bdb`[**`KHR_DF_WORD_MODEL`**] >> **`KHR_DF_SHIFT_MODEL`**);

Note that the numbering of the component channels is chosen such that those channel types which are common across multiple color models have the same enumeration value. That is, alpha is always encoded as channel ID 15, depth is always encoded as channel ID 14, and stencil is always encoded as channel ID 13. Luma/Luminance is always in channel ID 0. This numbering convention is intended to simplify code which can process a range of color models. Note that there is no guarantee that models which do not support these channels will not use this channel ID. Particularly, *RGB* formats do not have luma in channel 0, and a 16-channel undefined format is not obligated to represent alpha in any way in channel number 15.

The value of each enumerant is shown in parentheses following the enumerant name.

5.5.1 `KHR_DF_MODEL_UNSPECIFIED` (= 0)

When the data format is unknown or does not fall into a predefined category, utilities which perform automatic conversion based on an interpretation of the data cannot operate on it. This format should be used when there is no expectation of portable interpretation of the data using only the basic descriptor block.

For portability reasons, it is recommended that pixel-like formats with up to sixteen channels, but which cannot have those channels described in the basic block, be represented with a basic descriptor block with the appropriate number of samples from **`UNSPECIFIED`** channels, and then for the channel description to be stored in an extension block. This allows software which understands only the basic descriptor to be able to perform operations that depend only on channel location, not channel interpretation (such as image cropping). For example, a camera may store a raw format taken with a modified Bayer sensor, with *RGBW* (red, green, blue and white) sensor sites, or *RGBE* (red, green, blue and “emerald”). Rather than trying to encode the exact color coordinates of each sample in the basic descriptor, these formats could be represented by a four-channel **`UNSPECIFIED`** model, with an extension block describing the interpretation of each channel.

5.5.2 KHR_DF_MODEL_RGBSDA (= 1)

This color model represents additive colors of three channels, nominally red, green and blue, supplemented by channels for alpha, depth and stencil, as shown in Table 5.8. Note that in many formats, depth and stencil are stored in a completely independent buffer, but there are formats for which integrating depth and stencil with color data makes sense.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_RGBSDA_RED**	Red
1	**KHR_DF_CHANNEL_RGBSDA_GREEN**	Green
2	**KHR_DF_CHANNEL_RGBSDA_BLUE**	Blue
13	**KHR_DF_CHANNEL_RGBSDA_STENCIL**	Stencil
14	**KHR_DF_CHANNEL_RGBSDA_DEPTH**	Depth
15	**KHR_DF_CHANNEL_RGBSDA_ALPHA**	Alpha (opacity)

Table 5.8: Basic Data Format *RGBSDA* channels

Portable representation of additive colors with more than three primaries requires an extension to describe the full color space of the channels present. There is no practical way to do this portably without taking significantly more space.

5.5.3 KHR_DF_MODEL_YUVSDA (= 2)

This color model represents color differences with three channels, nominally luma (Y') and two color-difference chroma channels, U (C_B) and V (C_R), supplemented by channels for alpha, depth and stencil, as shown in Table 5.9. These formats are distinguished by C_B and C_R being a delta between the Y' channel and the blue and red channels respectively, rather than requiring a full color matrix. The conversion between $Y'C_BC_R$ and RGB color spaces is defined in this case by the choice of value in the ***colorPrimaries*** field as described in Section 15.1.

Note
Most single-channel luma/luminance monochrome data formats should select **KHR_DF_MODEL_YUVSDA** and use only the Y channel, unless there is a reason to do otherwise.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_YUVSDA_Y**	Y/Y' (luma/luminance)
1	**KHR_DF_CHANNEL_YUVSDA_CB**	C_B (alias for U)
1	**KHR_DF_CHANNEL_YUVSDA_U**	U (alias for C_B)
2	**KHR_DF_CHANNEL_YUVSDA_CR**	C_R (alias for V)
2	**KHR_DF_CHANNEL_YUVSDA_V**	V (alias for C_R)
13	**KHR_DF_CHANNEL_YUVSDA_STENCIL**	Stencil
14	**KHR_DF_CHANNEL_YUVSDA_DEPTH**	Depth
15	**KHR_DF_CHANNEL_YUVSDA_ALPHA**	Alpha (opacity)

Table 5.9: Basic Data Format *YUVSDA* channels

Note
Terminology for this color model is often abused. This model is based on the idea of creating a representation of monochrome light intensity as a weighted average of color channels, then calculating color differences by subtracting two of the color channels from this monochrome value. Proper names vary for each variant of the ensuing numbers, but *YUV* is colloquially used for all of them. In the television standards from which this terminology is derived, $Y'C_BC_R$ is more formally used to describe the representation of these color differences. See Section 15.1 for more detail.

5.5.4 KHR_DF_MODEL_YIQSDA (= 3)

This color model represents color differences with three channels, nominally luma (Y) and two color-difference chroma channels, I and Q, supplemented by channels for alpha, depth and stencil, as shown in Table 5.10. This format is distinguished by I and Q each requiring all three additive channels to evaluate. I and Q are derived from C_B and C_R by a 33-degree rotation.

Channel number	Name	Description
0	KHR_DF_CHANNEL_YIQSDA_Y	Y (luma)
1	KHR_DF_CHANNEL_YIQSDA_I	I (in-phase)
2	KHR_DF_CHANNEL_YIQSDA_Q	Q (quadrature)
13	KHR_DF_CHANNEL_YIQSDA_STENCIL	Stencil
14	KHR_DF_CHANNEL_YIQSDA_DEPTH	Depth
15	KHR_DF_CHANNEL_YIQSDA_ALPHA	Alpha (opacity)

Table 5.10: Basic Data Format *YIQSDA* channels

5.5.5 KHR_DF_MODEL_LABSDA (= 4)

This color model represents the ICC perceptually-uniform $L^*a^*b^*$ color space, combined with the option of an alpha channel, as shown in Table 5.11.

Channel number	Name	Description
0	KHR_DF_CHANNEL_LABSDA_L	L^* (luma)
1	KHR_DF_CHANNEL_LABSDA_A	a^*
2	KHR_DF_CHANNEL_LABSDA_B	b^*
13	KHR_DF_CHANNEL_LABSDA_STENCIL	Stencil
14	KHR_DF_CHANNEL_LABSDA_DEPTH	Depth
15	KHR_DF_CHANNEL_LABSDA_ALPHA	Alpha (opacity)

Table 5.11: Basic Data Format *LABSDA* channels

5.5.6 KHR_DF_MODEL_CMYKA (= 5)

This color model represents secondary (subtractive) colors and the combined key (black) channel, along with alpha, as shown in Table 5.12.

Channel number	Name	Description
0	KHR_DF_CHANNEL_CMYKA_CYAN	Cyan
1	KHR_DF_CHANNEL_CMYKA_MAGENTA	Magenta
2	KHR_DF_CHANNEL_CMYKA_YELLOW	Yellow
3	KHR_DF_CHANNEL_CMYKA_KEY	Key/Black
15	KHR_DF_CHANNEL_CMYKA_ALPHA	Alpha (opacity)

Table 5.12: Basic Data Format *CMYKA* channels

5.5.7 `KHR_DF_MODEL_XYZW` (= 6)

This “color model” represents channel data used for coordinate values, as shown in Table 5.13 — for example, as a representation of the surface normal in a bump map. Additional channels for higher-dimensional coordinates can be used by extending the channel number within the 4-bit limit of the ***channelType*** field.

Channel number	Name	Description
0	`KHR_DF_CHANNEL_XYZW_X`	*X*
1	`KHR_DF_CHANNEL_XYZW_Y`	*Y*
2	`KHR_DF_CHANNEL_XYZW_Z`	*Z*
3	`KHR_DF_CHANNEL_XYZW_W`	*W*

Table 5.13: Basic Data Format *XYZW* channels

5.5.8 `KHR_DF_MODEL_HSVA_ANG` (= 7)

This color model represents color differences with three channels, *value* (luminance or luma), *saturation* (distance from monochrome) and *hue* (dominant wavelength), supplemented by an alpha channel, as shown in Table 5.14. In this model, the hue relates to the angular offset on a color wheel.

Channel number	Name	Description
0	`KHR_DF_CHANNEL_HSVA_ANG_VALUE`	*V* (value)
1	`KHR_DF_CHANNEL_HSVA_ANG_SATURATION`	*S* (saturation)
2	`KHR_DF_CHANNEL_HSVA_ANG_HUE`	*H* (hue)
15	`KHR_DF_CHANNEL_HSVA_ANG_ALPHA`	Alpha (opacity)

Table 5.14: Basic Data Format angular *HSVA* channels

5.5.9 `KHR_DF_MODEL_HSLA_ANG` (= 8)

This color model represents color differences with three channels, *lightness* (maximum intensity), *saturation* (distance from monochrome) and *hue* (dominant wavelength), supplemented by an alpha channel, as shown in Table 5.15. In this model, the hue relates to the angular offset on a color wheel.

Channel number	Name	Description
0	`KHR_DF_CHANNEL_HSLA_ANG_LIGHTNESS`	*L* (lightness)
1	`KHR_DF_CHANNEL_HSLA_ANG_SATURATION`	*S* (saturation)
2	`KHR_DF_CHANNEL_HSLA_ANG_HUE`	*H* (hue)
15	`KHR_DF_CHANNEL_HSLA_ANG_ALPHA`	Alpha (opacity)

Table 5.15: Basic Data Format angular *HSLA* channels

5.5.10 KHR_DF_MODEL_HSVA_HEX (= 9)

This color model represents color differences with three channels, *value* (luminance or luma), *saturation* (distance from monochrome) and *hue* (dominant wavelength), supplemented by an alpha channel, as shown in Table 5.16. In this model, the hue is generated by interpolation between extremes on a color hexagon.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_HSVA_HEX_VALUE**	*V* (value)
1	**KHR_DF_CHANNEL_HSVA_HEX_SATURATION**	*S* (saturation)
2	**KHR_DF_CHANNEL_HSVA_HEX_HUE**	*H* (hue)
15	**KHR_DF_CHANNEL_HSVA_HEX_ALPHA**	Alpha (opacity)

Table 5.16: Basic Data Format hexagonal *HSVA* channels

5.5.11 KHR_DF_MODEL_HSLA_HEX (= 10)

This color model represents color differences with three channels, *lightness* (maximum intensity), *saturation* (distance from monochrome) and hue (dominant wavelength), supplemented by an alpha channel, as shown in Table 5.17. In this model, the hue is generated by interpolation between extremes on a color hexagon.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_HSLA_HEX_LIGHTNESS**	*L* (lightness)
1	**KHR_DF_CHANNEL_HSLA_HEX_SATURATION**	*S* (saturation)
2	**KHR_DF_CHANNEL_HSLA_HEX_HUE**	*H* (hue)
15	**KHR_DF_CHANNEL_HSLA_HEX_ALPHA**	Alpha (opacity)

Table 5.17: Basic Data Format hexagonal *HSLA* channels

5.5.12 KHR_DF_MODEL_YCGCOA (= 11)

This color model represents low-cost approximate color differences with three channels, nominally luma (*Y*) and two color-difference chroma channels, *Cg* (green/purple color difference) and *Co* (orange/cyan color difference), supplemented by a channel for alpha, as shown in Table 5.18.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_YCGCOA_Y**	*Y*
1	**KHR_DF_CHANNEL_YCGCOA_CG**	*Cg*
2	**KHR_DF_CHANNEL_YCGCOA_CO**	*Co*
15	**KHR_DF_CHANNEL_YCGCOA_ALPHA**	Alpha (opacity)

Table 5.18: Basic Data Format *YCoCgA* channels

5.5.13 KHR_DF_MODEL_YCCBCCRC (= 12)

This color model represents the “Constant luminance” $Y'_C C'_{BC} C'_{RC}$ color model defined as an optional representation in ITU-T BT.2020 and described in Section 15.2.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_YCCBCCRC_YC**	Y'_C (luminance)
1	**KHR_DF_CHANNEL_YCCBCCRC_CBC**	C'_{BC}
2	**KHR_DF_CHANNEL_YCCBCCRC_CRC**	C'_{RC}
13	**KHR_DF_CHANNEL_YCCBCCRC_STENCIL**	Stencil
14	**KHR_DF_CHANNEL_YCCBCCRC_DEPTH**	Depth
15	**KHR_DF_CHANNEL_YCCBCCRC_ALPHA**	Alpha (opacity)

Table 5.19: Basic Data Format $Y'{}_C C'{}_{BC} C'{}_{RC}$ channels

5.5.14 KHR_DF_MODEL_ICTCP (= 13)

This color model represents the “Constant intensity IC_TC_P color model” defined as an optional representation in ITU-T BT.2100 and described in Section 15.3.

Channel number	Name	Description
0	**KHR_DF_CHANNEL_ICTCP_I**	I (intensity)
1	**KHR_DF_CHANNEL_ICTCP_CT**	C_T
2	**KHR_DF_CHANNEL_ICTCP_CP**	C_P
13	**KHR_DF_CHANNEL_ICTCP_STENCIL**	Stencil
14	**KHR_DF_CHANNEL_ICTCP_DEPTH**	Depth
15	**KHR_DF_CHANNEL_ICTCP_ALPHA**	Alpha (opacity)

Table 5.20: Basic Data Format IC_TC_P channels

5.5.15 KHR_DF_MODEL_CIEXYZ (= 14)

This color model represents channel data used to describe color coordinates in the CIE 1931 XYZ coordinate space, as shown in Table 5.21.

Channel number	Name	Description
0	KHR_DF_CHANNEL_CIEXYZ_X	X
1	KHR_DF_CHANNEL_CIEXYZ_Y	Y
2	KHR_DF_CHANNEL_CIEXYZ_Z	Z

Table 5.21: Basic Data Format CIE XYZ channels

5.5.16 KHR_DF_MODEL_CIEXYY (= 15)

This color model represents channel data used to describe chromaticity coordinates in the CIE 1931 xyY coordinate space, as shown in Table 5.22.

Channel number	Name	Description
0	KHR_DF_CHANNEL_CIEXYZ_X	x
1	KHR_DF_CHANNEL_CIEXYZ_YCHROMA	y
2	KHR_DF_CHANNEL_CIEXYZ_YLUMA	Y

Table 5.22: Basic Data Format CIE xyY channels

5.6 *colorModel* for compressed formats

A number of compressed formats are supported as part of **`khr_df_model_e`**. Typically, these formats will have the texel block dimensions matching the compression block size. Most are represented by a single sample of channel type 0 at ***samplePosition*** 0,0,0,0 — where further samples are required for the compression block, they should have matching ***samplePositions***. By convention, models that have multiple channels that are disjoint in memory have these channel locations described independently as separate samples; this can simplify some decoders.

The ASTC family of formats have a number of possible channels, and are distinguished by samples which reference some set of these channels. The ***texelBlockDimension*** fields determine the compression ratio for single compressed texel blocks of ASTC and PVRTC.

Compressed formats necessarily do not have an equivalent integer representation in which to describe the ***sampleLower*** and ***sampleUpper*** ranges — in particular, some have different ranges on a block-by-block format. Floating-point compressed formats have lower and upper limits specified in floating point format, since this representation indicates the output of compressed decoding. Integer compressed formats with a lower and upper of 0 and **`UINT32_MAX`** (for unsigned formats) or **`INT32_MIN`** and **`INT32_MAX`** (for signed formats) are assumed to map the full representable range to 0..1 or -1..1 respectively.

If a format has a nonlinear transfer function, any samples with channel ID 15 (that is, the format has separate alpha encoding, for example **`KHR_DF_BC2_ALPHA`**) should set the **`KHR_DF_SAMPLE_DATATYPE_LINEAR`** bit for that sample.

Example descriptors for compressed formats are provided after each model in this section. Each of these examples contains a descriptor for a single compressed texel block, with the ***texelBlockDimensions*** corresponding to the addressable texel dimensions of that single compression block.

Although the use case would be unusual, there is no reason that multiple compressed texel blocks may not fall within a single data format descriptor texel block, with appropriately offset ***samplePositions***; each compressed texel block would be spatially coherent in this case. Such a situation may be used to describe a simple nonlinear layout of compressed texel blocks, although as Section 2.3 describes, more complex layouts are best handled explicitly. For most formats, the compressed texel block may be positioned arbitrarily within the data format descriptor texel block, and as such the ***texelBlockDimensions*** do not need to match the compressed texel block size; the exception is the constraints which are imposed on compressed texel formats (ASTC and PVRTC) which support multiple compression block sizes that are distinguished by the combination of ***texelBlockDimensions*** and ***samplePositions***.

5.6.1 KHR_DF_MODEL_DXT1A/KHR_DF_MODEL_BC1A (= 128)

This model represents the DXT1 or BC1 format, described in Chapter 18. Each compressed texel block consists of 4×4 texels in 8 bytes. A single sample with channel ID 0 indicates that the “special value” should be interpreted as black, as described in Section 18.1 — a descriptor block representing this is shown in Table 5.24. A single sample with channel ID 1 indicates that the “special value” should represent transparency, as described in Section 18.2 — a descriptor block representing this is shown in Table 5.25.

Enumerant names for these channel ids are listed in Table 5.23.

Enumerant	Value
KHR_DF_CHANNEL_DXT1A_COLOR	0
KHR_DF_CHANNEL_BC1A_COLOR	
KHR_DF_CHANNEL_DXT1A_ALPHAPRESENT	1
KHR_DF_CHANNEL_DXT1A_ALPHA	
KHR_DF_CHANNEL_BC1A_ALPHAPRESENT	
KHR_DF_CHANNEL_BC1A_ALPHA	

Table 5.23: BC1A channel names

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>DXT1A</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>COLOR</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.24: Example DXT1A descriptor with no punch-through alpha

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>DXT1A</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>ALPHA</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.25: Example DXT1A descriptor with punch-through alpha

5.6.2 KHR_DF_MODEL_DXT2/3/KHR_DF_MODEL_BC2 (= 129)

This model represents the DXT2/3 format, also known as BC2, and described in Section 18.3. Each compressed texel block consists of 4×4 texels in 16 bytes. The alpha premultiplication state (the distinction between DXT2 and DXT3) is recorded separately in the descriptor in the ***flags*** field. This model has two channels, recorded as separate samples: Sample 0 with channel ID 15 contains the alpha information. Sample 1 with channel ID 0 contains the color information.

Enumerant names for these channel ids are listed in Table 5.26.

Enumerant	Value
`KHR_DF_CHANNEL_DXT2_COLOR`	0
`KHR_DF_CHANNEL_DXT3_COLOR`	
`KHR_DF_CHANNEL_BC2_COLOR`	
`KHR_DF_CHANNEL_DXT2_ALPHA`	15
`KHR_DF_CHANNEL_DXT3_ALPHA`	
`KHR_DF_CHANNEL_BC2_ALPHA`	

Table 5.26: BC2 channel names

The alpha channel is 64 bits and at offset 0; the color channel is 64 bits and at offset 64. No attempt is made to describe the 16 alpha samples for this position independently, since understanding the other channels for any pixel requires the whole texel block.

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: PREMULTIPLIED</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: DXT2</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">ALPHA</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 64</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.27: Example DXT2 descriptor (premultiplied alpha)

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: DXT3</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">ALPHA</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 64</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.28: Example DXT3 descriptor

5.6.3 KHR_DF_MODEL_DXT4/5/KHR_DF_MODEL_BC3 (= 130)

This model represents the DXT4/5 format, also known as BC3, and described in Section 18.4. Each compressed texel block consists of 4×4 texels in 16 bytes. The alpha premultiplication state (the distinction between DXT4 and DXT5) is recorded separately in the descriptor in the ***flags*** field. This model has two channels, recorded as separate samples: Sample 0 with channel ID 15 contains the alpha information. Sample 1 with channel ID 0 contains the color information.

Enumerant names for these channel ids are listed in Table 5.29.

Enumerant	Value
KHR_DF_CHANNEL_DXT4_COLOR	0
KHR_DF_CHANNEL_DXT5_COLOR	
KHR_DF_CHANNEL_BC3_COLOR	
KHR_DF_CHANNEL_DXT4_ALPHA	15
KHR_DF_CHANNEL_DXT5_ALPHA	
KHR_DF_CHANNEL_BC3_ALPHA	

Table 5.29: BC3 channel names

The alpha channel is 64 bits and at offset 0; the color channel is 64 bits and at offset 64. No attempt is made to describe the 16 alpha samples for this position independently, since understanding the other channels for any pixel requires the whole texel block.

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><i>totalSize:</i> 60</td></tr>
<tr><td colspan="15"><i>descriptorType:</i> 0</td><td colspan="17"><i>vendorId:</i> 0</td></tr>
<tr><td colspan="16"><i>descriptorBlockSize:</i> 24 + (16 × 2) = 56</td><td colspan="16"><i>versionNumber:</i> 2</td></tr>
<tr><td colspan="8"><i>flags:</i> PREMULTIPLIED</td><td colspan="8"><i>transferFunction:</i> LINEAR</td><td colspan="8"><i>colorPrimaries:</i> BT709</td><td colspan="8"><i>colorModel:</i> DXT4</td></tr>
<tr><td colspan="8"><i>texelBlockDimension3</i></td><td colspan="8"><i>texelBlockDimension2</i></td><td colspan="8"><i>texelBlockDimension1</i></td><td colspan="8"><i>texelBlockDimension0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><i>bytesPlane3:</i> 0</td><td colspan="8"><i>bytesPlane2:</i> 0</td><td colspan="8"><i>bytesPlane1:</i> 0</td><td colspan="8"><i>bytesPlane0:</i> 16</td></tr>
<tr><td colspan="8"><i>bytesPlane7:</i> 0</td><td colspan="8"><i>bytesPlane6:</i> 0</td><td colspan="8"><i>bytesPlane5:</i> 0</td><td colspan="8"><i>bytesPlane4:</i> 0</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">ALPHA</td><td colspan="8"><i>bitLength:</i> 63 (= “64”)</td><td colspan="16"><i>bitOffset:</i> 0</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><i>sampleLower:</i> 0</td></tr>
<tr><td colspan="32"><i>sampleUpper:</i> UINT32_MAX</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8"><i>bitLength:</i> 63 (= “64”)</td><td colspan="16"><i>bitOffset:</i> 64</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><i>sampleLower:</i> 0</td></tr>
<tr><td colspan="32"><i>sampleUpper:</i> UINT32_MAX</td></tr>
</table>

Table 5.30: Example DXT4 descriptor (premultiplied alpha)

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 60</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 2) = 56</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>DXT5</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>ALPHA</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>COLOR</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 64</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.31: Example DXT5 descriptor

5.6.4 KHR_MODEL_ATI1N/KHR_DF_MODEL_DXT5A/KHR_DF_MODEL_BC4 (= 131)

This model represents the BC4 format, also known as ATI1n, DXT5A, or 3Dc+, for single-channel interpolated 8-bit data, as described in Section 19.1. Each compressed texel block consists of 4×4 texels in 8 bytes. The model has a single channel of id 0 with offset 0 and length 64 bits.

The enumerant name for this channel id is listed in Table 5.32.

Enumerant	Value
KHR_DF_CHANNEL_BC4_DATA	0

Table 5.32: BC4 channel name

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 44</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 1) = 40</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* ALPHA_STRAIGHT</td><td colspan="8">*transferFunction:* LINEAR</td><td colspan="8">*colorPrimaries:* BT709</td><td colspan="8">*colorModel:* BC4</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 8</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">DATA</td><td colspan="8">*bitLength:* 63 (= “64”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* UINT32_MAX</td></tr>
</table>

Table 5.33: Example BC4 unsigned descriptor

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 44</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 1) = 40</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* ALPHA_STRAIGHT</td><td colspan="8">*transferFunction:* LINEAR</td><td colspan="8">*colorPrimaries:* BT709</td><td colspan="8">*colorModel:* BC4</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 8</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">DATA</td><td colspan="8">*bitLength:* 63 (= “64”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* INT32_MIN</td></tr>
<tr><td colspan="32">*sampleUpper:* INT32_MAX</td></tr>
</table>

Table 5.34: Example BC4 signed descriptor

5.6.5 KHR_DF_MODEL_ATI2N_XY/KHR_DF_MODEL_DXN/KHR_DF_MODEL_BC5 (= 132)

This model represents the BC5 format, also known as ATI2n_XY (A2XY), or DXN, for dual-channel interpolated 8-bit data, as described in Section 19.3.

Each compressed texel block consists of 4×4 texels in 16 bytes. The model has two channels, 0 (red) and 1 (green), which should have their bit depths and offsets independently described: the red channel has offset 0 and length 64 bits and the green channel has offset 64 and length 64 bits. A single compression block is described by one sample of each channel at the same ***samplePosition***. Either both samples should be signed, or none may be.

For historical reasons, when this format is referred to as ATI2n or 3Dc, red channel has offset 64 bits and green channel has offset 0 bits.

Enumerant names for these channel ids are listed in Table 5.35.

Enumerant	Value
KHR_DF_CHANNEL_BC5_RED	0
KHR_DF_CHANNEL_BC5_R	
KHR_DF_CHANNEL_BC5_GREEN	1
KHR_DF_CHANNEL_BC5_G	

Table 5.35: BC5 channel names

<table>
<tr><td colspan="32"><b>uint32_t bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><i>totalSize:</i> 60</td></tr>
<tr><td colspan="15"><i>descriptorType:</i> 0</td><td colspan="17"><i>vendorId:</i> 0</td></tr>
<tr><td colspan="16"><i>descriptorBlockSize:</i> 24 + (16 × 2) = 56</td><td colspan="16"><i>versionNumber:</i> 2</td></tr>
<tr><td colspan="8"><i>flags:</i> ALPHA_STRAIGHT</td><td colspan="8"><i>transferFunction:</i> LINEAR</td><td colspan="8"><i>colorPrimaries:</i> BT709</td><td colspan="8"><i>colorModel:</i> BC5</td></tr>
<tr><td colspan="8"><i>texelBlockDimension3</i></td><td colspan="8"><i>texelBlockDimension2</i></td><td colspan="8"><i>texelBlockDimension1</i></td><td colspan="8"><i>texelBlockDimension0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><i>bytesPlane3:</i> 0</td><td colspan="8"><i>bytesPlane2:</i> 0</td><td colspan="8"><i>bytesPlane1:</i> 0</td><td colspan="8"><i>bytesPlane0:</i> 16</td></tr>
<tr><td colspan="8"><i>bytesPlane7:</i> 0</td><td colspan="8"><i>bytesPlane6:</i> 0</td><td colspan="8"><i>bytesPlane5:</i> 0</td><td colspan="8"><i>bytesPlane4:</i> 0</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24">Red sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8"><i>bitLength:</i> 63 (= “64”)</td><td colspan="16"><i>bitOffset:</i> 0</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><i>sampleLower:</i> 0</td></tr>
<tr><td colspan="32"><i>sampleUpper:</i> UINT32_MAX</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24">Green sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8"><i>bitLength:</i> 63 (= “64”)</td><td colspan="16"><i>bitOffset:</i> 64</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><i>sampleLower:</i> 0</td></tr>
<tr><td colspan="32"><i>sampleUpper:</i> UINT32_MAX</td></tr>
</table>

Table 5.36: Example BC5 unsigned descriptor

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 60</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 2) = 56</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `BC5`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 16</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Red sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 63 (= “64”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** `INT32_MIN`</td></tr>
<tr><td colspan="32">***sampleUpper:*** `INT32_MAX`</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Green sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">`GREEN`</td><td colspan="8">***bitLength:*** 63 (= “64”)</td><td colspan="16">***bitOffset:*** 64</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** `INT32_MIN`</td></tr>
<tr><td colspan="32">***sampleUpper:*** `INT32_MAX`</td></tr>
</table>

Table 5.37: Example BC5 signed descriptor

A legacy variant of this format known as “ATI2n” or “3Dc” swaps the location of the two channels, and can be encoded as follows:

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: BC5</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Red sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Green sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 64</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.38: Example ATI2n unsigned descriptor

5.6.6 `KHR_DF_MODEL_BC6H` (= 133)

This model represents the BC6H format for *RGB* floating-point data, as described in Section 20.2.

Each compressed texel block consists of 4×4 texels in 16 bytes. The model has a single channel 0, representing all three channels, and occupying 128 bits.

The enumerant names for this channel id are listed in Table 5.39.

Enumerant	Value
`KHR_DF_CHANNEL_BC6H_COLOR`	0
`KHR_DF_CHANNEL_BC6H_DATA`	

Table 5.39: BC6H channel names

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> BC6H</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xBF800000U — -1.0f</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x3F800000U — 1.0f</td></tr>
</table>

Table 5.40: Example BC6H signed descriptor

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> BC6H</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0x00000000U — 0.0f</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x3F800000U — 1.0f</td></tr>
</table>

Table 5.41: Example BC6H unsigned descriptor

5.6.7 `KHR_DF_MODEL_BC7` (= 134)

This model represents the BC7 format for *RGBA* data, as described in Section 20.1.

Each compressed texel block consists of 4×4 texels in 16 bytes. The model has a single channel 0, representing all four channels, and occupying 128 bits.

The enumerant names for this channel id are listed in Table 5.42.

Enumerant	Value
`KHR_DF_CHANNEL_BC7_COLOR`	0
`KHR_DF_CHANNEL_BC7_DATA`	

Table 5.42: BC7 channel names

<table>
<tr><td colspan="32"><b><code>uint32_t</code> bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>BC7</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>COLOR</code></td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.43: Example BC7 descriptor

5.6.8 KHR_DF_MODEL_ETC1 (= 160)

This model represents the original Ericsson Texture Compression format, described in Chapter 21, with a guarantee that the format does not rely on the ETC2 extensions described in Chapter 22.

Each compressed texel block consists of 4×4 texels in 8 bytes. The model has a single channel 0, representing all three channels, and occupying 64 bits.

The enumerant names for this channel id are listed in Table 5.44.

Enumerant	Value
KHR_DF_CHANNEL_ETC1_COLOR	0
KHR_DF_CHANNEL_ETC1_DATA	

Table 5.44: ETC1 channel names

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 44</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 1) = 40</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: ETC1</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 8</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.45: Example ETC1 descriptor

5.6.9 KHR_DF_MODEL_ETC2 (= 161)

This model represents the updated Ericsson Texture Compression format, ETC2, and also the related R11 EAC and RG11 EAC formats. Each compressed texel block consists of 4×4 texels.

The enumerant names for these channel ids are listed in Table 5.46.

Enumerant	Value
KHR_DF_CHANNEL_ETC2_RED	0
KHR_DF_CHANNEL_ETC2_R	
KHR_DF_CHANNEL_ETC2_GREEN	1
KHR_DF_CHANNEL_ETC2_G	
KHR_DF_CHANNEL_ETC2_COLOR	2
KHR_DF_CHANNEL_ETC2_ALPHA	15
KHR_DF_CHANNEL_ETC2_A	

Table 5.46: ETC2 channel names

Channel ID 0 represents red, and is used for the R11 EAC format, as described in Section 22.5; the texel block size in this format is 8 bytes, represented as a single 64-bit sample.

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <b>ALPHA_STRAIGHT</b></td><td colspan="8"><b><i>transferFunction:</i></b> <b>LINEAR</b></td><td colspan="8"><b><i>colorPrimaries:</i></b> <b>BT709</b></td><td colspan="8"><b><i>colorModel:</i></b> <b>ETC2</b></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><b>RED</b></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <b>UINT32_MAX</b></td></tr>
</table>

Table 5.47: Example R11 unsigned descriptor

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 44</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 1) = 40</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* ALPHA_STRAIGHT</td><td colspan="8">*transferFunction:* LINEAR</td><td colspan="8">*colorPrimaries:* BT709</td><td colspan="8">*colorModel:* ETC2</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 8</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">*bitLength:* 63 (= “64”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* INT32_MIN</td></tr>
<tr><td colspan="32">*sampleUpper:* INT32_MAX</td></tr>
</table>

Table 5.48: Example R11 signed descriptor

Channel ID 1 represents green; the presence of samples for both red and green, in that order, indicates the RG11 EAC format as described in Section 22.6, which consists of a total of 16 bytes of data.

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 60</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 2) = 56</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* ALPHA_STRAIGHT</td><td colspan="8">*transferFunction:* LINEAR</td><td colspan="8">*colorPrimaries:* BT709</td><td colspan="8">*colorModel:* ETC2</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 16</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Red sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">*bitLength:* 63 (= “64”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* UINT32_MAX</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Green sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">*bitLength:* 63 (= “64”)</td><td colspan="16">*bitOffset:* 64</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* UINT32_MAX</td></tr>
</table>

Table 5.49: Example RG11 unsigned descriptor

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: ETC2</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Red sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: INT32_MIN</td></tr>
<tr><td colspan="32">sampleUpper: INT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Green sample information</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 64</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: INT32_MIN</td></tr>
<tr><td colspan="32">sampleUpper: INT32_MAX</td></tr>
</table>

Table 5.50: Example RG11 signed descriptor

Channel ID 2 represents *RGB* combined content, for the ETC2 format as described in Section 22.1. A single sample of ID 2 indicates RGB2 with no alpha, occupying 8 bytes.

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 44</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 1) = 40</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: ETC2</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 8</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.51: Example ETC2 descriptor (with no alpha)

Channel ID 15 indicates the presence of alpha. If the texel block size is 8 bytes and the *RGB* and alpha channels are co-sited, “punch through” alpha is supported as described in Section 22.9.

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: ETC2</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 8</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">ALPHA</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.52: Example ETC2 descriptor with punchthrough alpha

Finally, if the texel block size is 16 bytes and the alpha channel appears in the first 8 bytes, followed by 8 bytes for the *RGB* channel, 8-bit separate alpha is supported, as described in Section 22.3.

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 60</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 2) = 56</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: ETC2</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">ALPHA</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8">bitLength: 63 (= “64”)</td><td colspan="16">bitOffset: 64</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: UINT32_MAX</td></tr>
</table>

Table 5.53: Example ETC2 descriptor with separate alpha

5.6.10 KHR_DF_MODEL_ASTC (= 162)

This model represents Adaptive Scalable Texture Compression as a single channel in a texel block of 16 bytes. ASTC HDR (high dynamic range) and LDR (low dynamic range) modes are distinguished by the ***channelId*** containing the flag **KHR_DF_SAMPLE_DATATYPE_FLOAT**: an ASTC texture that is guaranteed by the user to contain only LDR-encoded blocks should have the ***channelId*** **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit clear, and an ASTC texture that may include HDR-encoded blocks should have the ***channelId*** **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit set to 1.

ASTC supports a number of compression ratios defined by different texel block sizes; for a texel block containing a single compression block, the compression ratio is selected by changing the ***texelBlockDimensions*** fields in the data format.

If the data format texel blocks contains multiple compression blocks, the compression block dimensions are determined by the combination of the data format ***texelBlockDimensions*** and the ***samplePositions*** of the samples; all the samples must describe compression blocks of the same dimensions, and gaps between them are not supported.

ASTC encoding is described in Chapter 23.

The single sample, of ID 0, has a size of 128 bits.

The enumerant name for this channel id is listed in Table 5.54.

Enumerant	Value
KHR_DF_CHANNEL_ASTC_DATA	0

Table 5.54: ASTC channel name

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>ASTC</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>DATA</code></td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.55: Example 4×4 ASTC LDR descriptor

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>ASTC</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">4 (= “5”)</td><td colspan="8">7 (= “8”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4"><code>DATA</code></td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xBF800000U — -1.0f</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x3F800000U — 1.0f</td></tr>
</table>

Table 5.56: Example 8×5 ASTC HDR descriptor

5.6.11 KHR_DF_MODEL_ETC1S (= 163)

This model, described in Section 21.1, represents a subset of the original Ericsson Texture Compression format (itself described in Chapter 21) that is restricted in order to facilitate transcoding to GPU-specific compressed models.

Each compressed texel block consists of 4×4 texels in 8 bytes. The model has a single channel, representing all three channels (RGB), and occupying 64 bits. A second plane in the same format can be used to hold, e.g., alpha in all three of its channels.

The enumerant names for this channel id are listed in Table 5.57. **AAA**, **GGG** and **RRR** can be used when the channel contains a specific channel replicated across all three channels of the block.

Enumerant	**Value**
KHR_DF_CHANNEL_ETC1S_RGB	0
KHR_DF_CHANNEL_ETC1S_RRR	3
KHR_DF_CHANNEL_ETC1S_GGG	4
KHR_DF_CHANNEL_ETC1S_AAA	15

Table 5.57: ETC1S channel names

<table>
<tr><td colspan="32"><b>uint32_t bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <b>ALPHA_STRAIGHT</b></td><td colspan="8"><b><i>transferFunction:</i></b> <b>LINEAR</b></td><td colspan="8"><b><i>colorPrimaries:</i></b> <b>BT709</b></td><td colspan="8"><b><i>colorModel:</i></b> <b>ETC1S</b></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><b>RGB</b></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <b>UINT32_MAX</b></td></tr>
</table>

Table 5.58: Example ETC1S RGB descriptor

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 60</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 2) = 56</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** ALPHA_STRAIGHT</td><td colspan="8">***transferFunction:*** LINEAR</td><td colspan="8">***colorPrimaries:*** BT709</td><td colspan="8">***colorModel:*** ETC1S</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 8</td><td colspan="8">***bytesPlane0:*** 8</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Color sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RGB</td><td colspan="8">***bitLength:*** 63 (= “64”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** UINT32_MAX</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Alpha sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">AAA</td><td colspan="8">***bitLength:*** 63 (= “64”)</td><td colspan="16">***bitOffset:*** 64</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** UINT32_MAX</td></tr>
</table>

Table 5.59: Example ETC1S RGB + alpha descriptor

5.6.12 KHR_DF_MODEL_PVRTC (= 164)

This model represents the first generation of PowerVR Texture Compression as a single channel in a texel block of 8 bytes. 4-bit-per-pixel mode represents a 4×4 texel block; 2-bit-per-pixel mode represents an 8×4 texel block, and these can be distinguished by changing the ***texelBlockDimension*** fields in the data format, or by the combination of ***texelBlockDimensions*** and the spacing between ***samplePositions*** if there are multiple compression blocks within a single data format texel block. A single sample occupies 64 bits.

The enumerant names for this channel id are listed in Table 5.60.

Enumerant	Value
KHR_DF_CHANNEL_PVRTC_COLOR	0
KHR_DF_CHANNEL_PVRTC_DATA	

Table 5.60: PVRTC channel names

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>PVRTC</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>COLOR</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.61: Example PVRTC 4bpp descriptor

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>PVRTC</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">7 (= “8”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>COLOR</code></td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> <code>UINT32_MAX</code></td></tr>
</table>

Table 5.62: Example PVRTC 2bpp descriptor

5.6.13 KHR_DF_MODEL_PVRTC2 (= 165)

This model represents the second generation of PowerVR Texture Compression as a single channel in a texel block of 8 bytes. 4-bit-per-pixel mode represents a 4×4 texel block; 2-bit-per-pixel mode represents an 8×4 texel block, and these can be distinguished by changing the ***texelBlockDimension*** fields in the data format, or by the combination of ***texelBlockDimensions*** and the spacing between ***samplePositions*** if there are multiple compression blocks within a single data format texel block. A single sample occupies 64 bits.

The enumerant names for this channel id are listed in Table 5.63.

Enumerant	Value
KHR_DF_CHANNEL_PVRTC2_COLOR	0
KHR_DF_CHANNEL_PVRTC2_DATA	

Table 5.63: PVRTC2 channel names

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> PVRTC2</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> UINT32_MAX</td></tr>
</table>

Table 5.64: Example PVRTC2 4bpp descriptor

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> PVRTC2</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">7 (= “8”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">COLOR</td><td colspan="8"><b><i>bitLength:</i></b> 63 (= “64”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> UINT32_MAX</td></tr>
</table>

Table 5.65: Example PVRTC2 2bpp descriptor

5.6.14 KHR_DF_MODEL_UASTC (= 166)

This model represents Universal Adaptive Scalable Texture Compression (UASTC) as a single channel in a texel block of 16 bytes. UASTC supports only LDR (low dynamic range) modes so the ***qualifiers*** **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit must be clear. UASTC supports a single compression ratio with texel block dimensions of 4×4.

UASTC encoding is described in Chapter 25. This model is designed to facilitate transcoding to GPU-specific compressed models.

A single 128-bit sample with channel ID 0 indicates that the texture contains no alpha-mode blocks. A single sample with channel Id 4 indicates the texture effectively contains R replicated in the G & B channels. Similarly channel Id 5 indicates it contains R effectively replicated in the G & B channels and G in the alpha channel and it contains at least one alpha-mode block. Channel Id 6 indicates that the texture contains two channels, R & G. Finally channel Id 3 indicates the texture contains at least one alpha-mode block. The non-zero channel Ids give helpful information for choosing a transcode target format and do not reflect and do not constrain the mode an encoder may select for any given block.

The enumerant name for these channel ids are listed in Table 5.66.

Enumerant	Value
KHR_DF_CHANNEL_UASTC_RGB	0
KHR_DF_CHANNEL_UASTC_RGBA	3
KHR_DF_CHANNEL_UASTC_RRR	4
KHR_DF_CHANNEL_UASTC_RRRG	5
KHR_DF_CHANNEL_UASTC_RG	6

Table 5.66: UASTC channel names

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> UASTC</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RGB</td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> UINT32_MAX</td></tr>
</table>

Table 5.67: Example UASTC descriptor with no alpha

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 44</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> UASTC</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">3 (= “4”)</td><td colspan="8">3 (= “4”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RGBA</td><td colspan="8"><b><i>bitLength:</i></b> 127 (= “128”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> UINT32_MAX</td></tr>
</table>

Table 5.68: Example UASTC descriptor with alpha

5.7 *colorPrimaries*

It is not sufficient to define a buffer as containing, for example, additive primaries. Additional information is required to define what “red” is provided by the “red” channel. A full definition of primaries requires an extension which provides the full color space of the data, but a subset of common primary spaces can be identified by the **khr_df_primaries_e** enumeration, represented as an unsigned 8-bit integer.

More information about color primaries is provided in Chapter 14.

Word offset into basic descriptor block	**KHR_DF_WORD_PRIMARIES**	2
Word offset into descriptor	**KHR_DF_WORD_PRIMARIES** + 1	3
Start bit within word	**KHR_DF_SHIFT_PRIMARIES**	8
Bit mask of value	**KHR_DF_MASK_PRIMARIES**	0xFF

Table 5.69: Field location information for ***colorPrimaries***

khr_df_primaries_e ***colorPrimaries*** = **KHR_DF_MASK_PRIMARIES** &
(bdb[**KHR_DF_WORD_PRIMARIES**] >> **KHR_DF_SHIFT_PRIMARIES**);

5.7.1 KHR_DF_PRIMARIES_UNSPECIFIED (= 0)

This “set of primaries” identifies a data representation whose color representation is unknown or which does not fit into this list of common primaries. Having an “unspecified” value here precludes users of this data format from being able to perform automatic color conversion unless the primaries are defined in another way. Formats which require a proprietary color space — for example, raw data from a Bayer sensor that records the direct response of each filtered sample — can still indicate that samples represent “red”, “green” and “blue”, but should mark the primaries here as “unspecified” and provide a detailed description in an extension block.

5.7.2 KHR_DF_PRIMARIES_BT709 (= 1)

This value represents the Color Primaries defined by the ITU-R BT.709 specification and described in Section 14.1, which are also shared by sRGB.

RGB data is distinguished between BT.709 and sRGB by the Transfer Function. Conversion to and from BT.709 $Y'C_BC_R$ (*YUV*) representation uses the color conversion matrix defined in the BT.709 specification, and described in Section 15.1.1, except in the case of sYCC (which can be distinguished by the use of the sRGB transfer function), in which case conversion to and from BT.709 $Y'C_BC_R$ representation uses the color conversion matrix defined in the BT.601 specification, and described in Section 15.1.2. This is the preferred set of color primaries used by HDTV and sRGB, and likely a sensible default set of color primaries for common rendering operations.

KHR_DF_PRIMARIES_SRGB is provided as a synonym for **KHR_DF_PRIMARIES_BT709**.

5.7.3 KHR_DF_PRIMARIES_BT601_EBU (= 2)

This value represents the Color Primaries defined in the ITU-R BT.601 specification for standard-definition television, particularly for 625-line signals, and described in Section 14.2. Conversion to and from BT.601 $Y'C_BC_R$ (*YUV*) typically uses the color conversion matrix defined in the BT.601 specification and described in Section 15.1.2.

5.7.4 KHR_DF_PRIMARIES_BT601_SMPTE (= 3)

This value represents the Color Primaries defined in the ITU-R BT.601 specification for standard-definition television, particularly for 525-line signals, and described in Section 14.3. Conversion to and from BT.601 $Y'C_BC_R$ (*YUV*) typically uses the color conversion matrix defined in the BT.601 specification and described in Section 15.1.2.

5.7.5 `KHR_DF_PRIMARIES_BT2020` (= 4)

This value represents the Color Primaries defined in the ITU-R BT.2020 specification for ultra-high-definition television and described in Section 14.4. Conversion to and from BT.2020 $Y'C_BC_R$ (YUV uses the color conversion matrix defined in the BT.2020 specification and described in Section 15.1.3.

5.7.6 `KHR_DF_PRIMARIES_CIEXYZ` (= 5)

This value represents the theoretical Color Primaries defined by the International Color Consortium for the ICC XYZ linear color space.

5.7.7 `KHR_DF_PRIMARIES_ACES` (= 6)

This value represents the Color Primaries defined for the Academy Color Encoding System and described in Section 14.7.

5.7.8 `KHR_DF_PRIMARIES_ACESCC` (= 7)

This value represents the Color Primaries defined for the Academy Color Encoding System compositor and described in Section 14.8.

5.7.9 `KHR_DF_PRIMARIES_NTSC1953` (= 8)

This value represents the Color Primaries defined for the NTSC 1953 color television transmission standard and described in Section 14.5.

5.7.10 `KHR_DF_PRIMARIES_PAL525` (= 9)

This value represents the Color Primaries defined for 525-line PAL signals, described in Section 14.6.

5.7.11 `KHR_DF_PRIMARIES_DISPLAYP3` (= 10)

This value represents the Color Primaries defined for the Display P3 color space, described in Section 14.9.

5.7.12 `KHR_DF_PRIMARIES_ADOBERGB` (= 11)

This value represents the Color Primaries defined in Adobe RGB (1998), described in Section 14.10.

5.8 *transferFunction*

Many color representations contain a nonlinear *transfer function* which maps between a linear (intensity-based) representation and a more perceptually-uniform encoding; more information is provided in Chapter 13. Common transfer functions are represented as an unsigned 8-bit integer and encoded in the enumeration **`khr_df_transfer_e`**. A fully-flexible transfer function requires an extension with a full color space definition. Where the transfer function can be described as a simple power curve, applying the function is commonly known as “gamma correction”. The transfer function is applied to a sample only when the sample’s **`KHR_DF_SAMPLE_DATATYPE_LINEAR`** bit is 0; if this bit is 1, the sample is represented linearly irrespective of the ***transferFunction***.

When a color model contains more than one channel in a sample and the transfer function should be applied only to a subset of those channels, the convention of that model should be used when applying the transfer function. For example, ASTC stores both alpha and *RGB* data but is represented by a single sample; in ASTC, any sRGB transfer function is not applied to the alpha channel of the ASTC texture. In this case, the **`KHR_DF_SAMPLE_DATATYPE_LINEAR`** bit being zero means that the transfer function is “applied” to the ASTC sample in a way that only affects the *RGB* channels. This is not a concern for most color models, which explicitly store different channels in each sample.

If all the samples are linear, **`KHR_DF_TRANSFER_LINEAR`** should be used. In this case, no sample should have the **`KHR_DF_SAMPLE_DATATYPE_LINEAR`** bit set. If the samples encode a single bit, **`KHR_DF_TRANSFER_LINEAR`** or **`KHR_DF_TRANSFER_UNSPECIFIED`** should be used, since there are no intermediate values to which the transfer function should apply.

Word offset into basic descriptor block	**`KHR_DF_WORD_TRANSFER`**	2
Word offset into descriptor	**`KHR_DF_WORD_TRANSFER`** + 1	3
Start bit within word	**`KHR_DF_SHIFT_TRANSFER`**	16
Bit mask of value	**`KHR_DF_MASK_TRANSFER`**	0xFF

Table 5.70: Field location information for ***transferFunction***

`khr_df_transfer_e` *transferFunction* = **`KHR_DF_MASK_TRANSFER`** &
(`bdb`[**`KHR_DF_WORD_TRANSFER`**] >> **`KHR_DF_SHIFT_TRANSFER`**);

The enumerant value for each of the following transfer functions is shown in parentheses alongside the title. The use of the enumerated transform (for nonlinear transforms) indicates that the value is stored in a nonlinear encoding (that is, an OETF or EOTF^{-1} has been applied to linear values), and to process the data in linear form a corresponding inverse transfer function (OETF^{-1} or EOTF) will need to be applied to the numerical encoded value. (For clarity, it is *not* the case that the value is stored in linear form and there is an expectation of converting to a nonlinear representation before use — the DFD describes how to interpret the stored representation, not how to use it after decoding.)

5.8.1 `KHR_DF_TRANSFER_UNSPECIFIED` (= 0)

This value should be used when the transfer function is unknown, or specified only in an extension block, precluding conversion of color spaces and correct filtering of the data values using only the information in the basic descriptor block.

5.8.2 `KHR_DF_TRANSFER_LINEAR` (= 1)

This value represents a linear transfer function: for color data, there is a linear relationship between numerical pixel values and the intensity of additive colors. This transfer function allows for blending and filtering operations to be applied directly to the data values.

5.8.3 KHR_DF_TRANSFER_SRGB (= 2)

(Aliases: **KHR_DF_TRANSFER_SRGB_EOTF**, **KHR_DF_TRANSFER_SCRGB**, **KHR_DF_TRANSFER_SRGB_EOTF**)

This value represents the nonlinear transfer function defined in the sRGB specification for mapping between numerical pixel values and displayed light intensity, as described in Section 13.3.

Mapping from linear intensity to encoding	EOTF $^{-1}$	Section 13.3.2
Mapping from encoding to linear intensity	EOTF	Section 13.3.1

Encoded values outside the range 0..1 (as in scRGB) use the extended formulae for EOTF and EOTF^{-1} described in Section 13.3.4.

5.8.4 KHR_DF_TRANSFER_ITU (= 3)

(Aliases: **KHR_DF_TRANSFER_ITU_OETF**, **KHR_DF_TRANSFER_BT601**, **KHR_DF_TRANSFER_BT601_OETF**, **KHR_DF_TRANSFER_BT709**, **KHR_DF_TRANSFER_BT709_OETF**, **KHR_DF_TRANSFER_BT2020**, **KHR_DF_TRANSFER_BT2020_OETF**, **KHR_DF_TRANSFER_SMPTE170M**, **KHR_DF_TRANSFER_SMPTE170M_OETF**, **KHR_DF_TRANSFER_SMPTE170M_EOTF**)

This value represents the nonlinear transfer function defined by the ITU and used in the BT.601, BT.709 and BT.2020 specifications for mapping between represented scene light intensity and numerical pixel values, as described in Section 13.2.

Mapping from linear intensity to encoding	OETF	Section 13.2.1
Mapping from encoding to linear intensity	OETF $^{-1}$	Section 13.2.2

5.8.5 KHR_DF_TRANSFER_NTSC (= 4)

(Alias: **KHR_DF_TRANSFER_NTSC_EOTF**)

This value represents the nonlinear transfer function defined by the original NTSC television broadcast specification for mapping between represented scene light intensity or display light intensity and numerical pixel values, as described in Section 13.8.

Mapping from linear intensity to encoding	EOTF $^{-1}$ / OETF
Mapping from encoding to linear intensity	EOTF / OETF $^{-1}$

Note

More recent formulations of this transfer functions, such as that defined in SMPTE 170M-2004, use the "ITU" formulation described above.

5.8.6 KHR_DF_TRANSFER_SLOG (= 5)

(Alias: **KHR_DF_TRANSFER_SLOG_OETF**)

This value represents a nonlinear Transfer Function between linear scene light intensity and nonlinear pixel values, used by some Sony video cameras to represent an increased dynamic range, and is described in Section 13.13.

Mapping from linear intensity to encoding	OETF
Mapping from encoding to linear intensity	OETF $^{-1}$

5.8.7 KHR_DF_TRANSFER_SLOG2 (= 6)

(Alias: **KHR_DF_TRANSFER_SLOG2_OETF**)

This value represents a nonlinear Transfer Function between linear scene light intensity and nonlinear pixel values, used by some Sony video cameras to represent a further increased dynamic range, and is described in Section 13.14.

Mapping from linear intensity to encoding	OETF
Mapping from encoding to linear intensity	OETF $^{-1}$

5.8.8 KHR_DF_TRANSFER_BT1886 (= 7)

(Alias: **KHR_DF_TRANSFER_BT1886_EOTF**)

This value represents the nonlinear $\gamma = 2.4$ EOTF between encoded pixel values and linear image intensity defined in BT.1886 and described in Section 13.4.

Mapping from linear intensity to encoding	EOTF $^{-1}$	$\{R',G',B'\} = \{R,G,B\}^{2.4}$
Mapping from encoding to linear intensity	EOTF	$\{R,G,B\} = \{R',G',B'\}^{\frac{1}{2.4}}$

5.8.9 KHR_DF_TRANSFER_HLG_OETF (= 8)

This value represents the Hybrid Log Gamma OETF between normalized linear scene light intensity and nonlinear pixel values, defined by the ITU in BT.2100 for high dynamic range television, and described in Section 13.5.

Note
Content marked **KHR_DF_TRANSFER_HLG_OETF** and **KHR_DF_TRANSFER_HLG_EOTF** may typically be processed identically, with whichever transfer function corresponds to the target color space desired; the two distinct enumerants can be used to express the space in which the content was authored. Most HLG video content is authored using the scene-referred OETF.

Mapping from linear intensity to encoding	OETF	Section 13.5.1
Mapping from encoding to linear intensity	OETF $^{-1}$	Section 13.5.2

5.8.10 KHR_DF_TRANSFER_HLG_EOTF (= 9)

This value represents the Hybrid Log Gamma EOTF between nonlinear pixel values and normalized linear image light intensity, defined by the ITU in BT.2100 for high dynamic range television, and described in Section 13.5.

Note
Content marked **KHR_DF_TRANSFER_HLG_OETF** and **KHR_DF_TRANSFER_HLG_EOTF** may typically be processed identically, with whichever transfer function corresponds to the target color space desired; the two distinct enumerants can be used to express the space in which the content was authored. Most HLG video content is authored using the scene-referred OETF.

Mapping from linear intensity to encoding	EOTF $^{-1}$	Section 13.5.9
Mapping from encoding to linear intensity	EOTF	Section 13.5.8

5.8.11 KHR_DF_TRANSFER_PQ_EOTF (= 10)

This value represents the Perceptual Quantization EOTF between nonlinear pixel values and linear image light intensity, defined by the ITU in BT.2100 for high dynamic range television, and described in Section 13.6.

Note
Content marked **KHR_DF_TRANSFER_PQ_OETF** and **KHR_DF_TRANSFER_PQ_EOTF** may typically be processed identically, with whichever transfer function corresponds to the target color space desired; the two distinct enumerants can be used to express the space in which the content was authored. Most PQ video content is authored using the display-referred EOTF.

Mapping from linear intensity to encoding	EOTF $^{-1}$	Section 13.6.2
Mapping from encoding to linear intensity	EOTF	Section 13.6.1

5.8.12 KHR_DF_TRANSFER_PQ_OETF (= 11)

This value represents the Perceptual Quantization OETF between linear scene light intensity and nonlinear pixel values, defined by the ITU in BT.2100 for high dynamic range television, and described in Section 13.6.

Note
Content marked **KHR_DF_TRANSFER_PQ_OETF** and **KHR_DF_TRANSFER_PQ_EOTF** may typically be processed identically, with whichever transfer function corresponds to the target color space desired; the two distinct enumerants can be used to express the space in which the content was authored. Most PQ video content is authored using the display-referred EOTF.

Mapping from linear intensity to encoding	OETF	Section 13.6.4
Mapping from encoding to linear intensity	OETF $^{-1}$	Section 13.6.6

5.8.13 KHR_DF_TRANSFER_DCIP3 (= 12)

(Alias: **KHR_DF_TRANSFER_DCIP3_EOTF**)

This value represents the transfer function between nonlinear pixel values and linear image light intensity defined in DCI P3 and described in Section 13.7.

Mapping from linear intensity to encoding	EOTF $^{-1}$
Mapping from encoding to linear intensity	EOTF

5.8.14 KHR_DF_TRANSFER_PAL_OETF (= 13)

This value represents the OETF between linear scene light intensity and nonlinear pixel values for legacy PAL systems described in Section 13.9.

Mapping from linear intensity to encoding	OETF
Mapping from encoding to linear intensity	OETF $^{-1}$

5.8.15 KHR_DF_TRANSFER_PAL625_EOTF (= 14)

This value represents the EOTF between nonlinear pixel values and linear image light intensity for legacy 625-line PAL systems described in Section 13.10.

Mapping from linear intensity to encoding	EOTF^{-1}
Mapping from encoding to linear intensity	EOTF

5.8.16 KHR_DF_TRANSFER_ST240 (= 15)

(Aliases: **KHR_DF_TRANSFER_ST240_OETF**, **KHR_DF_TRANSFER_ST240_EOTF**)

This value represents the transfer function between linear scene and display light intensity and nonlinear pixel values associated with the legacy ST-240 (SMPTE240M) standard, described in Section 13.11. Note that this standard has a linear OOTF, and therefore the EOTF and OETF are symmetrical.

Mapping from linear intensity to encoding	EOTF^{-1} / OETF
Mapping from encoding to linear intensity	EOTF / OETF^{-1}

5.8.17 KHR_DF_TRANSFER_ACESCC (= 16)

(Alias: **KHR_DF_TRANSFER_ACESCC_OETF**)

This value represents the nonlinear transfer function between linear scene light intensity and nonlinear pixel values used in the ACEScc Academy Color Encoding System logarithmic encoding system for use within Color Grading Systems, S-2014-003, defined in ACES. This is described in Section 13.15.

Mapping from linear intensity to encoding	OETF
Mapping from encoding to linear intensity	OETF^{-1}

5.8.18 KHR_DF_TRANSFER_ACESCCT (= 17)

(Alias: **KHR_DF_TRANSFER_ACESCCT_OETF**)

This value represents the nonlinear transfer function between linear scene light intensity and nonlinear pixel values used in the ACEScc Academy Color Encoding System quasi-logarithmic encoding system for use within Color Grading Systems, S-2016-001, defined in ACES. This is described in Section 13.16.

Mapping from linear intensity to encoding	OETF
Mapping from encoding to linear intensity	OETF^{-1}

5.8.19 KHR_DF_TRANSFER_ADOBERGB (= 18)

(Alias: **KHR_DF_TRANSFER_ADOBERGB_EOTF**)

This value represents the transfer function defined in the Adobe RGB (1998) specification and described in Section 13.12.

Mapping from linear intensity to encoding	EOTF^{-1}
Mapping from encoding to linear intensity	EOTF

5.8.20 KHR_DF_TRANSFER_HLG_UNNORMALIZED_OETF (= 19)

This value represents the Hybrid Log Gamma OETF between unnormalized linear scene light intensity and nonlinear pixel values, defined by the ITU in BT.2100 for high dynamic range television, and described in Section 13.5.

KHR_DF_TRANSFER_HLG_UNNORMALIZED_OETF and KHR_DF_TRANSFER_HLG_UNNORMALIZED_EOTF content may typically be processed identically, with whichever transfer function corresponds to the target color space desired; the two distinct enumerants can be used to express the space in which the content was authored. Most HLG video content is authored using the scene-referred OETF. Since the normalization affects the scale factor applied to the linear scene illumination, there is no “unnormalized version” of the EOTF.

Mapping from linear intensity to encoding	OETF	Section 13.5.3
Mapping from encoding to linear intensity	OETF^{-1}	Section 13.5.4

5.9 *flags*

The format supports some configuration options in the form of boolean flags; these are described in the enumeration **`khr_df_flags_e`** and represented in an unsigned 8-bit integer value.

Word offset into basic descriptor block	**`KHR_DF_WORD_FLAGS`**	2
Word offset into descriptor	**`KHR_DF_WORD_FLAGS`** + 1	3
Start bit within word	**`KHR_DF_SHIFT_FLAGS`**	24
Bit mask of value	**`KHR_DF_MASK_FLAGS`**	0xFF

Table 5.71: Field location information for ***flags***

`khr_df_flags_e` ***flags*** = **`KHR_DF_MASK_FLAGS`** & (`bdb`[**`KHR_DF_WORD_FLAGS`**] >> **`KHR_DF_SHIFT_FLAGS`**);

5.9.1 KHR_DF_FLAG_ALPHA_PREMULTIPLIED (= 1)

If the **`KHR_DF_FLAG_ALPHA_PREMULTIPLIED`** bit is set, any color information in the data should be interpreted as having been previously scaled/modulated by the alpha channel when performing blending operations.

The value **`KHR_DF_FLAG_ALPHA_STRAIGHT`** (= 0) is provided to represent this flag not being set, which indicates that color values in the data should be interpreted as needing to be scaled by the alpha channel when performing blending operations. This flag has no effect if there is no alpha channel in the format.

5.10 *texelBlockDimension[0..3]*

The ***texelBlockDimension*** fields define an integer bound on the range of coordinates covered by the repeating block described by the samples; that is, the texel block covers an integer range in each dimension of coordinate space. Four separate values, represented as unsigned 8-bit integers, are supported, corresponding to successive dimensions: the Basic Data Format Descriptor Block supports up to four dimensions of encoding within a texel block, supporting, for example, a texture with three spatial dimensions and one temporal dimension. Nothing stops the data structure as a whole from having higher dimensionality: for example, a two-dimensional texel block can be used as an element in a six-dimensional look-up table.

The value held in each of these fields is one fewer than the size of the block in that dimension — that is, a value of 0 represents a size of 1, a value of 1 represents a size of 2, etc. A texel block which covers fewer than four dimensions should have a size of 1 in each dimension that it lacks, and therefore the corresponding fields in the representation should be 0.

For example, a $Y'C_BC_R$ 4:2:0 representation may use a Texel Block of 2×2 pixels in the nominal coordinate space, corresponding to the four Y' samples, as shown in Table 5.72. The texel block dimensions in this case would be 2×2×1×1 (in the X, Y, Z and T dimensions, if the fourth dimension is interpreted as T). The ***texelBlockDimension[0..3]*** values would therefore be:

texelBlockDimension0	1
texelBlockDimension1	1
texelBlockDimension2	0
texelBlockDimension3	0

Table 5.72: Example Basic Data Format ***texelBlockDimension*** values for $Y'C_BC_R$ 4:2:0

In the descriptor block examples in this specification, block dimensions larger than 1 (encoded as 0) are shown as the value to be stored in the ***texelBlockDimension*** field, but with the represented number in parentheses for clarity.

Word offset into basic descriptor block	**`KHR_DF_WORD_TEXELBLOCKDIMENSION[0..3]`**	3
Word offset into descriptor	**`KHR_DF_WORD_TEXELBLOCKDIMENSION[0..3]`** + 1	4
Start bit within word	**`KHR_DF_SHIFT_TEXELBLOCKDIMENSION0`**	0
	`KHR_DF_SHIFT_TEXELBLOCKDIMENSION1`	8
	`KHR_DF_SHIFT_TEXELBLOCKDIMENSION2`	16
	`KHR_DF_SHIFT_TEXELBLOCKDIMENSION3`	24
Bit mask of value	**`KHR_DF_MASK_TEXELBLOCKDIMENSION[0..3]`**	0xFF

Table 5.73: Field location information for ***texelBlockDimension[0..3]***

`uint32_t` ***texelBlockDimension0*** = **`KHR_DF_MASK_TEXELBLOCKDIMENSION0`** &
(`bdb`[**`KHR_DF_WORD_TEXELBLOCKDIMENSION0`**] >> **`KHR_DF_SHIFT_TEXELBLOCKDIMENSION0`**);

`uint32_t` ***texelBlockDimension1*** = **`KHR_DF_MASK_TEXELBLOCKDIMENSION1`** &
(`bdb`[**`KHR_DF_WORD_TEXELBLOCKDIMENSION1`**] >> **`KHR_DF_SHIFT_TEXELBLOCKDIMENSION1`**);

`uint32_t` ***texelBlockDimension2*** = **`KHR_DF_MASK_TEXELBLOCKDIMENSION2`** &
(`bdb`[**`KHR_DF_WORD_TEXELBLOCKDIMENSION2`**] >> **`KHR_DF_SHIFT_TEXELBLOCKDIMENSION2`**);

`uint32_t` ***texelBlockDimension3*** = **`KHR_DF_MASK_TEXELBLOCKDIMENSION3`** &
(`bdb`[**`KHR_DF_WORD_TEXELBLOCKDIMENSION3`**] >> **`KHR_DF_SHIFT_TEXELBLOCKDIMENSION3`**);

5.11 *bytesPlane[0..7]*

The Basic Data Format Descriptor divides the image into a number of planes, each consisting of an integer number of consecutive bytes. The requirement that planes consist of consecutive data means that formats with distinct subsampled channels — such as $Y'C_BC_R$ 4:2:0 — may require multiple planes to describe a channel. A typical $Y'C_BC_R$ 4:2:0 image has *two* planes for the Y' channel in this representation, offset by one line vertically.

The use of byte granularity to define planes is a choice to allow large texel blocks. A consequence of this is that formats which are not byte-aligned on each addressable unit, such as 1-bit-per-pixel formats, need to represent a texel block of multiple samples, covering multiple texels — as, for example, in Table 11.4.

A maximum of eight independent planes is supported in the Basic Data Format Descriptor. Formats which require more than eight planes — which are rare — require an extension.

The ***bytesPlane[0..7]*** fields each contain an unsigned 8-bit integer which represents the number of bytes which a plane contributes to the format. If the top bit of a ***bytesPlane[n]*** field is set, bits 6..0 of the ***bytesPlane[n+1]*** field form bits 13..7 of the number of bytes in the plane (and the next plane is described by field ***bytesPlane[n+2]***). For example, if ***bytesPlane0*** is 0xC0 and ***bytesPlane1*** is 0x02, the first plane holds 0x40 + 128 × 0x02 = 0x140 bytes; ***bytesPlane2*** then describes the number of bytes in the second plane.. Since only sixteen bits are used to encode a bit offset for each sample, 14 bits (two bytes excluding the top bits) are sufficient to encode any useful number of bytes — there is no need to “extend” the higher byte. Few formats are expected to require this “extension bit”, so for most of this specification, the number of bytes in a plane is considered to be synonymous with the ***bytesPlane*** value.

The first field which contains the value 0 indicates that only a subset of the 8 possible planes are present; that is, planes which are not present should be given the ***bytesPlane*** value of 0, and any ***bytesPlane*** values after the first 0 are ignored. If no ***bytesPlane*** value is zero, 8 planes are considered to exist.

Word offset into basic descriptor block	**KHR_DF_WORD_BYTESPLANE[0..3]**	4
	KHR_DF_WORD_BYTESPLANE[4..7]	5
Word offset into descriptor	**KHR_DF_WORD_BYTESPLANE[0..3]** + 1	5
	KHR_DF_WORD_BYTESPLANE[4..7] + 1	6
Start bit within word	**KHR_DF_SHIFT_BYTESPLANE0**	0
	KHR_DF_SHIFT_BYTESPLANE1	8
	KHR_DF_SHIFT_BYTESPLANE2	16
	KHR_DF_SHIFT_BYTESPLANE3	24
	KHR_DF_SHIFT_BYTESPLANE4	0
	KHR_DF_SHIFT_BYTESPLANE5	8
	KHR_DF_SHIFT_BYTESPLANE6	16
	KHR_DF_SHIFT_BYTESPLANE7	24
Bit mask of value	**KHR_DF_MASK_BYTESPLANE[0..7]**	0xFF

Table 5.74: Field location information for ***bytesPlane[0..7]***

uint32_t *bytesPlane[0..7]* = **KHR_DF_MASK_BYTESPLANE[0..7]** &
(bdb[**KHR_DF_WORD_BYTESPLANE[0..7]**] >> **KHR_DF_SHIFT_BYTESPLANE[0..7]**);

Note

In versions of this specification prior to 1.3, there was no facility for the “extension bit”, and a ***bytesPlane0*** value of 0 indicated a paletted format. The scheme for encoding paletted formats as of version 1.3 is described in Section 5.18.

5.12 Sample information

The layout and position of the information within each plane is determined by a number of *samples*, each consisting of a single channel of data and with a single corresponding position within the texel block, as shown in Table 5.75.

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelId</i></b></td><td colspan="8"><b><i>bitLength</i></b></td><td colspan="16"><b><i>bitOffset</i></b></td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="32"><b><i>sampleLower</i></b></td></tr>
<tr><td colspan="32"><b><i>sampleUpper</i></b></td></tr>
</table>

Table 5.75: Basic Data Format Descriptor Sample Information

Bits ***F***, ***S***, ***E*** and ***L*** are abbreviations for the following qualifier flags:

F	**KHR_DF_SAMPLE_DATATYPE_FLOAT**	0x80
S	**KHR_DF_SAMPLE_DATATYPE_SIGNED**	0x40
E	**KHR_DF_SAMPLE_DATATYPE_EXPONENT**	0x20
L	**KHR_DF_SAMPLE_DATATYPE_LINEAR**	0x10

The sample information begins at word **KHR_DF_WORD_SAMPLESTART** = 6, offset from the start of the basic descriptor block. Each sample occupies **KHR_DF_WORD_SAMPLEWORDS** = 4 32-bit words, and is stored consecutively.

The bytes from the plane data contributing to the format are treated as though they have been concatenated into a bit stream, with the first byte of the lowest-numbered plane providing the lowest bits of the result. Each sample consists of a number of consecutive bits from this bit stream.

If the content for a channel cannot be represented in a single sample, for example because the data for a channel is non-consecutive within this bit stream, additional samples with the same coordinate position and channel number should follow from the first, in order increasing from the least significant bits from the channel data; the corresponding bits from the bit stream are concatenated in the increasing order of reference to provide the value representing the channel.

For example, some native big-endian formats may need to be supported with multiple samples in a channel, since the constituent bits may not be consecutive in a little-endian interpretation. There is an example, Table 11.10, in the list of example format descriptors provided.

See Section 3.4 for more information about the order in which samples should appear in the descriptor block.

The number of samples present in the format is determined by the ***descriptorBlockSize*** field:

numSamples =
(((**KHR_DFDVAL**(BDB, **DESCRIPTORBLOCKSIZE**) >> 2) - **KHR_DF_WORD_SAMPLESTART**)
/ **KHR_DF_WORD_SAMPLEWORDS**);

The macro **KHR_DFDSAMPLECOUNT**(BDB) is provided to perform this calculation.

There is no limit on the number of samples which may be present, other than the maximum size of the Data Format Descriptor Block. There is no requirement that samples should access unique parts of the bit-stream: formats such as combined intensity and alpha, or shared exponent formats, require that bits be reused. Nor is there a requirement that all the bits in a plane be used (a format may contain padding).

It is legal for a descriptor block to contain no samples provided the color model is **KHR_DF_MODEL_UNSPECIFIED**, although this is unusual. See Section 5.19 for details.

To simplify code using the Basic Data Format Descriptor Block, the header `khr_df.h` provides enums of the following form for accessing sample fields:

Word offset relative to start of sample	**KHR_DF_SAMPLEWORD_xxx** + 1	...
Start bit within word	**KHR_DF_SAMPLESHIFT_xxx**	...
Bit mask of value	**KHR_DF_SAMPLEMASK_xxx**	...

Table 5.76: Field location information for sample field ***xxx***

If the basic descriptor block is treated as a **`uint32_t`** array `bdb[]`, sample field ***xxx*** can be accessed as follows:

xxx = **KHR_DF_SAMPLEMASK_xxx** &
(bdb[**KHR_DF_WORD_SAMPLESTART** + *sample* × **KHR_DF_WORD_SAMPLEWORDS**
+ **KHR_DF_SAMPLEWORD_xxx**] >> **KHR_DF_SAMPLESHIFT_xxx**);

The macro **KHR_DFDSVAL**(BDB, S, X) is provided to perform this calculation.

For example, **KHR_DFDSVAL**(bdb, 2, **CHANNELID**) returns the value:

KHR_DF_SAMPLEMASK_CHANNELID &
(bdb[**KHR_DF_WORD_SAMPLESTART** + 2 × **KHR_DF_WORD_SAMPLEWORDS**
+ **KHR_DF_SAMPLEWORD_CHANNELID**] >> **KHR_DF_SAMPLESHIFT_CHANNELID**)

5.13 Sample *bitOffset*

The ***bitOffset*** field describes the offset of the least significant bit of this sample from the least significant bit of the least significant byte of the concatenated bit stream for the format. Typically the ***bitOffset*** of the first sample is therefore 0; a sample which begins at an offset of one byte relative to the data format would have a ***bitOffset*** of 8. The ***bitOffset*** is an unsigned 16-bit integer quantity.

A sample that only provides additional bits to ***sampleLower*** and ***sampleUpper*** without extending the size of the encoded field, as potentially required for custom floating point formats described in Section 5.20, should be encoded with values of ***bitOffset***, ***channelType*** and ***samplePosition*** identical to the sample that it extends (as in Table 11.27).

In the special case that the ***bitOffset*** field contains the reserved value 0xFFFF, the sample contributes a constant value of the specified bit length, encoded in the ***sampleLower*** field. This mechanism notably supports values that are zero-extended (that is, have implicit zeroes in their least-significant bits), since this sample can appear first.

Word offset relative to start of sample	**`KHR_DF_SAMPLEWORD_BITOFFSET`**	0
Start bit within word	**`KHR_DF_SAMPLESHIFT_BITOFFSET`**	0
Bit mask of value	**`KHR_DF_SAMPLEMASK_BITOFFSET`**	0xFFFFU

Table 5.77: Field location information for sample ***bitOffset***

`uint32_t` *bitoffset* = **`KHR_DF_SAMPLEMASK_BITOFFSET`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_BITOFFSET`**]) >> **`KHR_DF_SAMPLESHIFT_BITOFFSET`**);

5.14 Sample *bitLength*

The ***bitLength*** field describes the number of consecutive bits from the concatenated bit stream that contribute to the sample. This field is an unsigned 8-bit integer quantity, and stores the number of bits contributed minus 1; thus a single-byte channel should have a ***bitLength*** field value of 7. If a ***bitLength*** over 256 is required, further samples should be added; the final value is accumulated in increasing order from least- to most-significant bit with each subsequent sample.

Note that a large ***bitLength*** value means a sample can describe more bits than can be contained in the ***sampleLower*** and ***sampleUpper*** fields. The ***bitLength*** of the sample can exceed 32 if in this case the rules for expanding ***sampleLower*** and ***sampleUpper*** produce the desired result. Otherwise the ***bitLength*** should be limited to 32 and multiple samples used to encode additional bits of ***sampleLower*** and ***sampleUpper***, with each sample before the last contributing 32 bits.

A sample that provides additional bits to ***sampleLower*** and ***sampleUpper*** without extending the size of the encoded field, as potentially required for custom floating point formats, should have a ***bitLength*** encoding of zero (normally indicating a length of 1), as in Table 11.27. The number of bits contributed by ***sampleLower*** and ***sampleUpper*** in this case can be deduced indirectly, as described in Section 5.20.

Except in the case of a paletted texture (described in Section 5.18), where the sample provides only additional bits of ***sampleLower*** or ***sampleUpper*** data, or where the special ***bitOffset*** value 0xFFFF is used to indicate constant bits, the ***bitLength*** added to ***bitOffset*** should not exceed eight times the total number of bytes contributed to the logical bit stream by the ***bytesPlane*** values.

In the descriptor block examples in this specification, bit lengths are shown as the value to be stored in the ***bitLength*** field, but with the represented number (without the -1 offset) in parentheses for clarity.

Word offset relative to start of sample	**`KHR_DF_SAMPLEWORD_BITLENGTH`**	0
Start bit within word	**`KHR_DF_SAMPLESHIFT_BITLENGTH`**	16
Bit mask of value	**`KHR_DF_SAMPLEMASK_BITLENGTH`**	0xFF

Table 5.78: Field location information for sample ***bitLength***

`uint32_t` *bitLength* = **`KHR_DF_SAMPLEMASK_BITLENGTH`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_BITLENGTH`**]) >> **`KHR_DF_SAMPLESHIFT_BITLENGTH`**);

5.15 Sample *channelType*: *channelId* and qualifiers

The ***channelType*** field is an unsigned 8-bit quantity.

The bottom four bits of the ***channelType*** indicate the ***channelId*** which determines which channel is being described by this sample. The list of available channels is determined by the ***colorModel*** field of the Basic Data Format Descriptor Block, and the ***channelId*** field contains the number of the required channel within this list — see the colorModel field for the list of channels for each model.

Word offset relative to start of sample	**KHR_DF_SAMPLEWORD_CHANNELID**	0
Start bit within word	**KHR_DF_SAMPLESHIFT_CHANNELID**	24
Bit mask of value	**KHR_DF_SAMPLEMASK_CHANNELID**	0xF

Table 5.79: Field location information for sample ***channelType***

khr_df_model_channels_e *channelType* = **KHR_DF_SAMPLEMASK_CHANNELID** &
((bdb[**KHR_DF_WORD_SAMPLESTART** + (*sample* × **KHR_DF_WORD_SAMPLEWORDS**)
+ **KHR_DF_SAMPLEWORD_CHANNELID**]) >> **KHR_DF_SAMPLESHIFT_CHANNELID**);

The **khr_df_sample_datatype_qualifiers_e** enumeration describes the top four bits of the ***channelType***:

Word offset relative to start of sample	**KHR_DF_SAMPLEWORD_QUALIFIERS**	0
Start bit within word	**KHR_DF_SAMPLESHIFT_QUALIFIERS**	24
Bit mask of value	**KHR_DF_SAMPLEMASK_QUALIFIERS**	0xF0

Table 5.80: Field location information for sample ***qualifiers***

khr_df_sample_datatype_qualifiers_e *qualifiers* = **KHR_DF_SAMPLEMASK_QUALIFIERS** &
((bdb[**KHR_DF_WORD_SAMPLESTART** + (*sample* × **KHR_DF_WORD_SAMPLEWORDS**)
+ **KHR_DF_SAMPLEWORD_QUALIFIERS**]) >> **KHR_DF_SAMPLESHIFT_QUALIFIERS**);

If the **KHR_DF_SAMPLE_DATATYPE_EXPONENT** bit, shown as ***E*** in Table 5.75, is not set, the sample contributes to a *base value*; multiple samples with the same color channel (bottom four bits of ***channelType***) and same ***samplePos*** values are accumulated into the virtual sample in increasing bit order from lowest to highest.

For samples in which the **KHR_DF_SAMPLE_DATATYPE_EXPONENT** bit is not set:

- If the **KHR_DF_SAMPLE_DATATYPE_LINEAR** bit, shown as ***L*** in Table 5.75, is not set, the final sample value (after any modifier has been applied to the base value) is modified by the transfer function defined in the ***transferFunction*** field of the descriptor; if this bit *is* set, the sample is considered to contain a linearly-encoded value irrespective of the format's ***transferFunction***. All samples referring to the same base value should have the same value stored in the **KHR_DF_SAMPLE_DATATYPE_LINEAR** bit.
- If the **KHR_DF_SAMPLE_DATATYPE_SIGNED** bit, shown as ***S*** in Table 5.75, is set, the sample holds a signed value in two's complement form. If this bit is *not* set, the sample holds an unsigned value. It is possible to represent a sign/magnitude integer value by following a sample of unsigned integer type with a 1-bit signed sample of the same channel and sample position. By convention, the ***sampleUpper*** and ***sampleLower*** values for a sign bit are 0 and -1 respectively.
- If the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit, shown as ***F*** in Table 5.75, is set, and there is no corresponding modifier sample for the same position and channel id, this sample holds floating point data in a conventional format of 10, 11 or 16 bits, as described in Chapter 10, or of 32, or 64 bits as described in [IEEE 754]. Unless a genuine unsigned format is intended, **KHR_DF_SAMPLE_DATATYPE_SIGNED** (bit ***S***) should also be set. Less-common floating point representations can be generated with multiple samples and a combination of signed integer, unsigned integer and exponent fields, as described above and in Section 5.20, in which case the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit instead indicates the presence of an implicit "1" (as described below).

- If a sample represents part of a *base value* of a custom floating point format (which can be identified by the descriptor containing other samples of the same channel and position with the **KHR_DF_SAMPLE_DATATYPE_EXPONENT** bit set, indicating that these other samples contain a *modifier*), the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit determines the presence or absence of an "implicit 1" bit in the base value. If the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit is set, the base value is stored with an "implicit 1" above the topmost bit (as though an additional sample added a constant 1 bit at this position). Otherwise, the base value stores the 1 bit explicitly. All samples contributing to a base value (including a separate sign bit if present) should set the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit consistently.

If the **KHR_DF_SAMPLE_DATATYPE_EXPONENT** bit, shown as ***E*** in Table 5.75, *is* set, the sample applies a *modifier* to the base value, with the interpretation of the modifier determined according to Table 5.81. In this case, the virtual sample contains both a *base value* and a *modifier*.

All samples contributing to a modifier for the same base value should contain the same ***L*** and ***F*** bits (it is not legal, for example, to define both a multiplier and a divisor). Samples which apply a modifier should directly follow the samples that describe the base value, including following any sign bits. If no samples have the ***E*** bit set for this channel and position, the base value directly represents the pixel value; it is not legal for a virtual sample to describe a modifier but no base value.

Note

The same bits of the format may contribute to modifiers for more than one channel — this is commonly the case for high dynamic range formats with a shared exponent or divisor. The descriptor in this case should contain samples for each color channel in turn, with the description of the shared bits replicated for each channel, as shown in Table 11.11.

E	***L***	***F***	**Interpretation**	**Formula**
1	0	0	Exponent	$\mathit{base\ value} \times 2^{\mathit{modifier}}$
1	0	1	Multiplier	$\mathit{base\ value} \times \mathit{modifier}$
1	1	0	Divisor	$\frac{\mathit{base\ value}}{\mathit{modifier}}$
1	1	1	Power	$\mathit{base\ value}^{\mathit{modifier}}$

Table 5.81: Qualifier interpretation when **KHR_DF_SAMPLE_DATATYPE_EXPONENT** = 1

For samples in which the **KHR_DF_SAMPLE_DATATYPE_EXPONENT** bit is set:

- If the **KHR_DF_SAMPLE_DATATYPE_LINEAR** and **KHR_DF_SAMPLE_DATATYPE_FLOAT** bits are clear, this modifier holds an exponent (in integer form) describing a floating-point offset for this channel. For example, this would be used to describe the exponent of a custom floating point format, as shown in Table 11.17, or a shared exponent location in shared exponent formats (with the exponent bits listed separately under each channel as shown in Table 11.11). If this modifier is used, the base value is considered to contain mantissa information and the samples describing it would not normally have the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit set. If the **KHR_DF_SAMPLE_DATATYPE_SIGNED** bit (***S***) is also set, the exponent is considered to be two's complement — otherwise it is treated as unsigned. The bias of the exponent can be determined by the exponent's ***sampleLower*** value. The use of the exponent is described in more detail in Section 5.20.
- If the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit is set and the **KHR_DF_SAMPLE_DATATYPE_LINEAR** bit is clear, this sample holds a multiplier (in integer form) for this channel, such that the encoded value is a product of this modifier value and the base value. This approach may be useful for encoding a shared multiplier as part of a high dynamic range color image.
- If the **KHR_DF_SAMPLE_DATATYPE_LINEAR** bit is set and the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit is clear, this sample holds a divisor (in integer form) for this channel, such that the encoded value is the base value divided by this modifier value. This approach may be useful for encoding a shared divisor as part of a high dynamic range color image.
- If both **KHR_DF_SAMPLE_DATATYPE_FLOAT** and **KHR_DF_SAMPLE_DATATYPE_LINEAR** are set, this sample holds a power term (in integer form) for this channel, such that the encoded value is the base value raised to the power of the modifier value. This approach may be useful for encoding a shared power for a high dynamic range color image.

Note that in the multiplier, divisor and power cases, the ***sampleLower*** and ***sampleUpper*** values allow the modifier value to be represented in fixed-point terms, and the values may be signed depending on whether the ***S*** bit is set.

5.16 ***samplePosition[0..3]***

The sample has an associated position within the 4-dimensional space of the texel block. Therefore each sample has an offset relative to the 0,0 position of the texel block, represented as an 8-bit unsigned integer quantity.

Word offset relative to start of sample	`KHR_DF_SAMPLEWORD_SAMPLEPOSITION[0..3]`	1
Start bit within word	`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION0`	0
	`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION1`	8
	`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION2`	16
	`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION3`	24
Bit mask of value	`KHR_DF_SAMPLEMASK_SAMPLEPOSITION[0..3]`	0xF

Table 5.82: Field location information for sample ***samplePosition[0..3]***

`khr_df_model_channels_e` *samplePosition0* = **`KHR_DF_SAMPLEMASK_SAMPLEPOSITION0`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_SAMPLEPOSITION0`**]) >> **`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION0`**);

`khr_df_model_channels_e` *samplePosition1* = **`KHR_DF_SAMPLEMASK_SAMPLEPOSITION1`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_SAMPLEPOSITION1`**]) >> **`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION1`**);

`khr_df_model_channels_e` *samplePosition2* = **`KHR_DF_SAMPLEMASK_SAMPLEPOSITION2`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_SAMPLEPOSITION2`**]) >> **`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION2`**);

`khr_df_model_channels_e` *samplePosition3* = **`KHR_DF_SAMPLEMASK_SAMPLEPOSITION3`** &
((`bdb`[**`KHR_DF_WORD_SAMPLESTART`** + (*sample* × **`KHR_DF_WORD_SAMPLEWORDS`**)
+ **`KHR_DF_SAMPLEWORD_SAMPLEPOSITION3`**]) >> **`KHR_DF_SAMPLESHIFT_SAMPLEPOSITION3`**);

The interpretation of each ***samplePosition*** field depends on the corresponding ***texelBlockDimension*** value as follows:

$$n = \lceil \log_2(\boldsymbol{texelBlockDimension} + 1) \rceil$$
$$coordinateOffset = \boldsymbol{samplePosition} \times 2^{n-8}$$

For example, if ***texelBlockDimension0*** is 1 (indicating a texel block width of two units) ***samplePosition0*** is described in units of $\frac{2}{256} = \frac{1}{128}$. That is, a ***samplePosition0*** of 128 would encode an offset of “1.0” and a ***samplePosition0*** of 64 would encode an offset of “0.5”. If ***texelBlockDimension0*** is 5 (indicating a texel block width of six units), ***samplePosition0*** is described in units of $\frac{8}{256} = \frac{1}{32}$. That is, a ***samplePosition0*** of 64 would encode an offset of “2.0” and a ***samplePosition0*** of 24 would encode an offset of “0.75”.

The adjusted *coordinateOffset* must be less than the corresponding texel block dimension. That is, since *coordinateOffset* can represent fractional offsets, *coordinateOffset* < (***texelBlockDimension*** + 1) for each dimension.

This approach allows the common situation of downsampled channels to have samples conceptually sited at the midpoint between full resolution samples. The direction of the sample offsets is determined by the coordinate addressing scheme used by the API. There is no limit on the dimensionality of the data, but if more than four dimensions need to be contained within a single texel block, an extension will be required.

It is legal, but unusual, to use the same bits to represent multiple samples at different coordinate positions.

Note
Versions of this specification prior to 1.3 always recorded the sample position in a 7.1 fixed-point format (with half-coordinate granularity). This change does not affect the representation of single-coordinate texel blocks; that is, a ***samplePosition*** of “0” still represents “0.0”.

5.17 *sampleLower* and *sampleUpper*

The ***sampleLower*** and ***sampleUpper*** fields are used to define the mapping between the numerical value stored in the format and the conceptual numerical interpretation.

For unsigned formats, ***sampleLower*** typically represents the value which should be interpreted as zero (the black point). For signed formats, ***sampleLower*** typically represents “-1”. For color difference models such as $Y'C_BC_R$, ***sampleLower*** for chroma channels represents the lower extent of the color difference range (which corresponds to an encoding of -0.5 in numerical terms).

sampleUpper typically represents the value which should be interpreted as “1.0” (the “white point”). For color difference models such as $Y'C_BC_R$, ***sampleUpper*** for chroma channels represents the upper extent of the color difference range (which corresponds to an encoding of 0.5 in numerical terms).

$$\begin{aligned}
out_{unsigned} &= \left(\frac{value - \textbf{\textit{sampleLower}}}{\textbf{\textit{sampleUpper}} - \textbf{\textit{sampleLower}}}\right) \\
out_{signed} &= \left(\frac{value - \textbf{\textit{sampleLower}}}{\textbf{\textit{sampleUpper}} - \textbf{\textit{sampleLower}}} - 0.5\right) \times 2 \\
out_{color\ difference} &= \left(\frac{value - \textbf{\textit{sampleLower}}}{\textbf{\textit{sampleUpper}} - \textbf{\textit{sampleLower}}} - 0.5\right)
\end{aligned}$$

Equation 5.1: Sample range conversion rules

For example, the BT.709 television broadcast standard dictates that the Y' value stored in an 8-bit encoding should fall between the range 16 and 235, as described in Section 16.1. In this case, ***sampleLower*** should contain the value 16 and ***sampleUpper*** 235.

Sensor data from a camera typically does not cover the full range of the bit depth used to represent it. ***sampleUpper*** can be used to specify an upper limit on sensor brightness — or to specify the value which should map to white on the display, which may be less than the full dynamic range of the captured image.

There is no guarantee or expectation that image data be guaranteed to fall between ***sampleLower*** and ***sampleUpper*** unless the users of a format agree that convention. For example, high dynamic range video formats may define “1.0” as a nominal brightness level substantially lower than the maximum, and coordinates may encode an arbitrary range. In some formats, the integer value should be interpreted directly as a number, in which case ***sampleUpper*** and ***sampleLower*** should hold “1” and either “0” or “-1” depending on whether the format is signed, respectively.

5.17.1 Integer and standard floating-point formats

If the channel encoding is an integer format, the ***sampleLower*** and ***sampleUpper*** values are represented as 32-bit integers — signed or unsigned according to whether the channel encoding is signed. Signed negative values should be sign-extended if the channel has fewer than 32 bits, such that the value encoded in ***sampleLower*** and ***sampleUpper*** values are themselves negative if the encoded values are negative. If the channel encoding is a floating point value, the ***sampleLower*** and ***sampleUpper*** values are also described in floating point.

If the number of bits in the sample is greater than 32, ***sampleLower*** and ***sampleUpper*** are converted to a data type of the actual number of bits as follows: A floating point value is converted to the native representation (for example, a `float` value is converted to `double` in the normal way). An integer value is expanded by preserving any sign bit and replicating the top non-sign bit (for example, signed 0x80000000 is extended to the 40-bit value 0x8000000000, and signed 0x8FFFFFFF is extended to the 40-bit value 0x8FFFFFFFFF). If these rules do not produce the desired result, it may be necessary to describe the contribution to the channel in multiple samples of no more than 32 bits. In this case, the samples corresponding to lower ***bitOffset*** values should occupy 32 bits, with any residual bits encoded in samples corresponding to higher ***bitOffset*** values.

If multiple samples contribute to a single value, such as in cases where the bits of a channel are non-contiguous in the logical bit stream, the ***sampleLower*** and ***sampleUpper*** fields of each sample are concatenated in increasing bit order to produce virtual ***sampleLower*** and ***sampleUpper*** values; each sample contributes a number of bits equal to the number of data bits that the sample describes. If this contribution is fewer than 32 bits and the value being encoded is signed, the sign bit of the final ***sampleLower*** and ***sampleUpper*** values should be used to pad the fields of the sample.

For example, if a signed 16-bit value with a minimum value of -256 (0xFF00) is described as two 8-bit values, the first sample should have a ***sampleLower*** value of 0xFFFFFF00 — of which the bottom 8 bits (0x00) corresponds to the bottom 8 bits of the final minimum value and the upper 24 bits (0xFFFFFF00) are a result of replicating the sign of bit 15 of the final minimum value. The second sample should have a ***sampleLower*** value of 0xFFFFFFFF — of which the bottom 8 bits (0xFF) correspond to the top 8 bits of the final minimum value and the upper 24 bits (0xFFFFFF00) are a result of sign-extending this value. Only the sample corresponding to the top bits of the channel may have a ***sampleLower*** or ***sampleUpper*** occupying more bits than the input.

In OpenGL terminology, a “normalized” channel contains an integer value which is mapped to the range 0..1.0; a channel which is not normalized contains an integer value which is mapped to a floating point equivalent of the integer value. Similarly an “snorm” channel is a signed normalized value mapping from -1.0 to 1.0. Setting ***sampleLower*** to the minimum signed integer value representable in the channel (which is often the negative version of the maximum signed integer, for example -127 rather than -128 for an 8-bit value in order to allow the value 0.0 to be represented exactly) is equivalent to defining an “snorm” texture. Setting ***sampleUpper*** to the maximum signed integer value representable in the channel for a signed channel type is equivalent to defining an “snorm” texture. Setting ***sampleUpper*** to the maximum unsigned value representable in the channel for an unsigned channel type is equivalent to defining a “normalized” texture. Setting ***sampleUpper*** to “1” is equivalent to defining an “unnormalized” texture.

5.17.2 Custom floating point formats

The ***sampleLower*** value for an exponent should represent the exponent bias — the value that should be subtracted from the encoded exponent to indicate that the mantissa’s ***sampleUpper*** value will represent 1.0. The ***sampleUpper*** value for an exponent should represent the largest conventional legal exponent value. If the encoded exponent exceeds this value, the encoded floating point value encodes either an infinity or a *NaN* value, depending on the mantissa. See Section 5.20 for more detail on this.

In the channel encoding of the mantissa of a custom floating point format (that is, the encoding is integer but the same sample position and channel is shared by a sample that encodes an exponent or other modifier value), the ***sampleLower*** and ***sampleUpper*** for the mantissa should contain the entire bit sequence for representations of lower and upper values, including additional bits for the exponent, as described in Section 5.20.

5.17.3 Constant virtual bits

In the special case that the sample ***bitOffset*** field is 0xFFFF, only the bottom 16 bits of the ***sampleLower*** field indicate a contribution to the sample lower limit; the upper 16 bits are taken as a constant contribution to the interpreted value; in this case, the ***bitLength*** field of the sample must be no more than 16. For example, a 4-bit value which is interpreted as being zero-extended to eight bits before conversion may have four bits with the value 0 stored in bits 19..16 of ***sampleLower***, indicated by a ***bitOffset*** of 0xFFFF.

These “virtual bits” may be needed to encode some numerical representations. For example, if an 8-bit integer encodes the value “-0.5” as 0 and “0.5” as 255 (in the manner of the color difference channel in Equation 5.1, but if we wish to apply this mapping to a channel other than color difference), Equation 5.1 suggests that ***sampleLower*** should hold -127.5 and ***sampleUpper*** should hold 382.5. This is impossible to encode, since ***sampleLower*** and ***sampleUpper*** are integers. However, if a virtual 0-bit is added below the encoded value (such that the effective range is 0..510), storing ***sampleLower*** as -255 and ***sampleUpper*** as 765 will have the desired effect. Note that in this case, the original 8-bits of data are unsigned, but the bounds must encode a negative value; this can be achieved by describing the data as a signed value that is guaranteed to be positive by another sample storing a virtual 0 bit in bit 9 (so the data is treated as a signed 10-bit quantity, of which the top and bottom bits are guaranteed to be 0). The cost of this flexibility is that multiple samples are needed per channel, which is why the common case of chroma channels which should map to the -0.5..0.5 range are treated specially.

5.18 Paletted formats

The storage of the palette is considered to be outside the remit of this specification; however, the “format” describes both the encoding of the bits which index into the palette and the format of the entries in the palette itself.

> **Note**
> The convention for encoding paletted formats was different in revisions of this specification prior to 1.3.

If the ***bitOffset*** field of any of the samples equals eight times the total number of bytes indicated by the ***bytesPlane*** channels (that is, indicating an offset after the end of the logical bit stream), this sample indicates a palette entry. Samples with offsets within the range of the logical bit stream describe the index of the palette; ***sampleUpper*** is used to indicate the number of entries in the palette (which may be lower than could be addressed by the number of bits available). The index can be comprised of multiple samples, supporting non-contiguous bits.

The four bits encoding ***channelType*** indicate a choice of palette in the index samples. The palette entries indicate which palette they are associated with by encoding the corresponding palette id in the ***samplePosition0*** field, with the other ***samplePosition*** fields set to 0. This approach allows both a simple palette in which each entry represents a complete color and per-channel look-up tables.

The index samples should be described first, as though the format were not paletted; samples for palette entries should then follow, sorted first by palette id, then by channel id.

The descriptor’s ***colorModel***, ***colorPrimaries***, ***transferFunction*** and ***flags*** apply to the palette entries. The ***texelBlockDimension*** values on the other hand refer to the storage of per-texel indices.

Table 11.7 shows a 240-entry palette with an index encoded in eight bits, and six bits for each of *R*, *G* and *B* per palette entry. Table 11.8 shows a 24-bit format with 256-entry palettes indexed by each of three 256-bit channels, with a 10-bit *R*, *G* and *B* palette associated with the corresponding channels.

5.19 Unsized formats

The data format descriptor can be a convenient representation for describing some data which does not follow the constraint that texel blocks are of a fixed size. For example, it may be useful to use a descriptor to encode the color space of an image which is compressed with a variable-rate compressor (meaning there is no data-independent mapping between memory locations and corresponding pixels).

There are two ways to do this, each with its own uses. Only the color primaries, transfer function and flags may be encoded or these and the presence of color and alpha samples may be encoded.

In both cases an unsized format can be indicated by setting all ***bytesPlane*** values to 0.

In the first case, **`KHR_DF_MODEL_UNSPECIFIED`** is used in a descriptor with no samples. All ***texelBlockDimension*** values must be zero.

In the second case an appropriate color model is used, e.g. **`KHR_DF_MODEL_RGBSDA`**. The presence of color and alpha samples is used to indicate the presence of these samples in the image. The ***texelBlockDimension*** values and ***bitOffset***, ***bitLength*** and ***samplePosition*** fields of the samples can all be set to 0 or the values prior to variable-rate compression can be retained.

Note that an implementation may associate a DFD with compressed (or other non-repetitive) data in the expectation that these aspects of the DFD will be valid only once a conversion has been made to an addressable format. If an implementation has other means to indicate that the content is not directly addressable, and clients of the interface are expecting this, it should not be seen as inherently invalid for the DFD not to be usable directly in interpreting the compressed data.

5.20 Non-standard floating point formats

Rather than attempting to enumerate every possible floating-point format variation in this specification, the data format descriptor can be used to describe the components of arbitrary floating-point data, as follows. Note that non-standard floating point formats do not use the **KHR_DF_SAMPLE_DATATYPE_FLOAT** bit in the same way as standard floating-point formats. This section is described in terms of a mantissa and exponent, but the same encoding applies if the *modifier* field encodes a multiplier, divisor or power term (as encoded in Table 5.81). Standard floating point formats (as described in Chapter 10) should be used directly where possible, rather than replicating their definitions in explicit terms.

An example of use of the 16-bit floating point format described in Section 10.1 but described in terms of a custom floating point format is provided in Table 11.17. Note that this is provided for example only, and this particular format should in practice be described using the standard 16-bit floating point format as documented in Table 11.18.

5.20.1 The mantissa

The mantissa of a custom floating point format should be represented as an integer ***channelType***. If the mantissa represents a signed quantity encoded in two's complement, the **KHR_DF_SAMPLE_DATATYPE_SIGNED** bit should be set. To encode a signed mantissa represented in sign-magnitude format, the main part of the mantissa should be represented as an unsigned integer quantity (with **KHR_DF_SAMPLE_DATATYPE_SIGNED** not set), and an additional one-bit sample *with* **KHR_DF_SAMPLE_DATATYPE_SIGNED** set (but other qualifier bits matching the rest of the mantissa) should be used to identify the sign bit. By convention, a sign bit should be encoded in a later sample than the corresponding mantissa, but before any modifier/exponent sample.

The ***sampleUpper*** and ***sampleLower*** values for the mantissa should hold the representation of 1.0 and 0.0 (for unsigned formats) or -1.0 (for signed formats) respectively. Note that these values indicate how the value should be interpreted, not merely how the number is encoded in floating-point terms: by symmetry with the integer case, a floating point value of "2.0" may still be scaled to 1.0 by the ***sampleLower*** and ***sampleUpper*** range.

The mantissa (or *base value*) encoding should appear in the least-significant bits of the encoded ***sampleUpper*** and ***sampleLower***, including any separate sign bits, followed by the exponent (or *modifier*); note that this is not the bit order of the final data in formats such as those described by [IEEE 754], which separate the sign bit from the mantissa.

If more than 32 bits are required in the representation, these combined values are encoded in increasing samples beginning with the first mantissa sample and continuing to further mantissa samples (including any samples for the sign bits) as needed. The number of bits required is derived from the ***bitLength*** of each sample describing the value. Any unused bits are ignored and should be zero.

If additional samples are needed to encode the ***sampleLower*** and ***sampleUpper*** values beyond the available mantissa samples, these should be encoded in samples encoded identically to the last mantissa sample (including a sign bit), but with a ***bitLength*** encoding of zero. These samples can be distinguished by the repeated ***bitOffset*** value, as shown in Table 11.27.

In the example of the shared exponent format shown in Table 11.11, there is no implicit "1" bit in its representation of the mantissa. Therefore the ***sampleUpper*** values for the 9-bit mantissas for the three color channels represent 256 — this being the mantissa value used to represent 1.0 in the channel when the exponent, after the exponent bias has been subtracted, is 1. The exponent encoded in the mantissa's ***sampleUpper*** value is 16 (the bias + 1). Therefore the ***sampleUpper*** value encodes a mantissa of 256 in the lower 9 bits and an exponent of 16 in the upper 5 bits.

An exponent of 0 would require a mantissa of 512, which is not representable in the available number of mantissa bits; representing 1.0 with a mantissa encoded as 128 would require a larger value corresponding to an exponent of 2; therefore an exponent value of 1 after the bias has been subtracted is the smallest which can represent 1.0. Note that for a format with an explicit 1 bit in the mantissa, there are multiple representations of the value 1.0, corresponding to larger exponent values and smaller mantissa encodings.

For the 16-bit signed floating point format described in Section 10.1, the *F* qualifier bit of the mantissa is set to 1, indicating the implicit "1" bit. ***sampleLower*** and ***sampleUpper*** encode -1.0 and 1.0 respectively, with a 0 mantissa fraction in the low 10 bits, one bit of sign, and the exponent equal to the bias in the top 5 bits.

5.20.2 The exponent

The **`KHR_DF_SAMPLE_DATATYPE_EXPONENT`** bit should be set in a sample which contains the exponent of a custom floating point format.

The ***sampleLower*** for the exponent should indicate the exponent bias. The bias is chosen such that the value in the exponent field minus the bias is the number of places by which the binary point should be shifted right from above the topmost encoded mantissa bit. For formats which represent the mantissa with an implicit “1”, the bias is the exponent value which corresponds to placing the binary point below the implicit 1, so the stored exponent is equal to the bias when the value being encoded is 1.0. For formats with an *explicit* “1” in the mantissa, setting the exponent equal to the bias places the binary point *above* a normalized explicit 1 in the top bit of the mantissa; an encoding of 1.0 using the top bit of the mantissa therefore requires that the value be recorded with an exponent that is the bias value in ***sampleLower*** plus 1.

The ***sampleUpper*** for the exponent indicates the maximum legal exponent value. Values above this are used to encode infinities and not-a-number (*NaN*) values. The value of ***sampleUpper*** can therefore be used to indicate whether or not the format supports these encodings.

As a special case, a ***sampleUpper*** of one greater than can be represented by the number of bits assigned to the exponent (e.g. 32 for a 5-bit exponent) indicates that a *NaN* is represented by the encoding for -0.0; some formats use this representation to maximize the representable exponent range. The maximum legal exponent is then one lower than ***sampleUpper***.

If ***sampleUpper*** is encoded with an additional high bit beyond the maximum representable exponent, a *NaN* is represented by a maximum value in both the exponent and mantissa (irrespective of the sign bit).

5.20.3 Special values

Floating point values encoded with an exponent of 0 (before the bias has been subtracted) and a mantissa of 0 are used to represent the value 0.0. An explicit sign bit can distinguish between +0 and -0.

Floating point values encoded with an exponent of 0 (before bias) and a non-zero mantissa are assumed to indicate a denormalized number, if the format has an implicit “1” bit. That is, when the exponent is 0, the “1” bit becomes explicit and the exponent is considered to be the negative sample bias minus one.

Floating point values encoded with an exponent larger than the exponent’s ***sampleUpper*** value and with a mantissa of 0 are interpreted as representing +/- infinity, depending on the value of an explicit sign bit. Note that in some formats, no exponent above ***sampleUpper*** is possible — for example, Table 11.11.

Floating point values encoded with an exponent larger than the exponent’s ***sampleUpper*** value and with a mantissa of non-0 are interpreted as representing not-a-number (*NaN*).

Note that these interpretations are compatible with the corresponding numerical representations in [IEEE 754].

As mentioned in the previous section, if the exponent’s ***sampleUpper*** values is one greater than the number that can be represented in the number of bits assigned to the exponent, *NaN* is instead represented by -0.0, which then does not have a distinct representation. These representations lack a way to encode an infinity. Examples are the “E5M2FNUZ” and “E4M3FNUZ” 8-bit formats.

If ***sampleUpper*** encodes the maximum representable exponent with a prefixing high bit, *NaN* is instead encoded with a maximum exponent and mantissa value — for example, S.1111.111 (base 2) for the “E4M3FN” 8-bit float format.

5.20.4 Conversion formulae

Given an optional sign bit S (whose value is interpreted as 0 if the bit is missing), a mantissa value of M and an exponent value of E, a value in a format with an implicit “1” bit in the mantissa can be converted from its representation to a real value as follows:

$$V = \begin{cases} (-1)^S \times 0.0, & E = 0, M = 0 \\ (-1)^S \times 2^{-(E_{sampleLower}-1)} \times \frac{M}{M_{sampleUpper}}, & E = 0, M \neq 0 \\ (-1)^S \times 2^{E-E_{sampleLower}} \times \left(1 + \frac{M}{M_{sampleUpper}}\right), & 0 < E \leq E_{sampleUpper} \\ (-1)^S \times Inf, & E > E_{sampleUpper}, M = 0 \\ NaN, & E > E_{sampleUpper}, M \neq 0. \end{cases}$$

If there is no implicit “1” bit in the mantissa, the value can be converted to a real value as follows:

$$V = \begin{cases} (-1)^S \times 2^{E-E_{sampleLower}} \times \left(\frac{M}{M_{sampleUpper}}\right), & 0 < E \leq E_{sampleUpper} \\ (-1)^S \times Inf, & E > E_{sampleUpper}, M = 0 \\ NaN, & E > E_{sampleUpper}, M \neq 0. \end{cases}$$

A descriptor block for a format without an implicit “1” (and with the added complication of having the same exponent bits shared across multiple channels, which is why an implicit “1” bit does not make sense) is shown in Table 11.11. In the case of this particular example, the above equations simplify to:

$$red = red_{\text{shared}} \times 2^{(E_{\text{shared}} - B - N)}$$

$$green = green_{\text{shared}} \times 2^{(E_{\text{shared}} - B - N)}$$

$$blue = blue_{\text{shared}} \times 2^{(E_{\text{shared}} - B - N)}$$

Where:

$$N = 9 \text{ (= number of mantissa bits per component)}$$

$$B = 15 \text{ (= exponent bias)}$$

Note that in general conversion from a real number *to* any representation may require rounding, truncation and special value management rules which are beyond the scope of a data format specification and may be documented in APIs which generate these formats.

Note

One approach for converting a real number to a representation with no implicit “1” bit is as follows:

First the value *V* is clamped to the representable range. If the full range of the exponent bits *E* are used to represent valid numbers, the largest representable value is:

$$V = \frac{2^N - 1}{2^N} \times 2^{E_{max} - B}$$

A provisional exponent is calculated as:

$$E_{provisional} = \begin{cases} \lfloor \log_2(V) \rfloor + B + 1, & V \geq 2^{-(B+1)} \\ 0, & V < 2^{-(B+1)} \end{cases}$$

The second of these cases for *V* handles denormalized numbers and 0. (Some specifications use $\leq$ for the second clause, but $\left\lfloor \log_2 \left(2^{-(B+1)} \right) \right\rfloor + B + 1$ evaluates to 0 in any case, and this value is not denormalized.)

Then a provisional mantissa $M_{provisional}$ is calculated, rounding to nearest:

$$M_{provisional} = \left\lfloor \frac{V}{2^{E_{provisional} - B - N}} + \frac{1}{2} \right\rfloor$$

The rounding may cause this mantissa to exceed the representable range, which means that the actual exponent may need to be increased:

$$E_{final} = \begin{cases} E_{provisional}, & 0 \leq M_{provisional} < 2^N \\ E_{provisional} + 1, & M_{provisional} \geq 2^N \end{cases}$$

The final mantissa can then be encoded in terms of the final exponent:

$$M_{final} = \left\lfloor \frac{V}{2^{E_{final} - B - N}} + \frac{1}{2} \right\rfloor$$

This encoding represents the value 1.0 as a value of 1 in the top bit of the mantissa, and an exponent equal to the bias value *B* + 1. Other encodings that also represent a value of 1.0 exist, and an implementation may wish to specify, for consistency, whether it is preferable to minimize the exponent (as in this approach) or the encoded mantissa (for example encoding 1.0 as a mantissa of 1 and an exponent of *B* + *N*).

In the case of a format with a shared exponent, as shown in Table 11.11, the exponent E_{final} can be calculated for the largest value *V* in any of the channels. Each mantissa M_{final} for each channel can then be calculated separately using the same E_{final} exponent.

5.21 C99 struct mapping (informative)

The basic descriptor block has been specified in terms of an array of `uint32_t` value. C99 provides a more direct representation, but this relies on the bit ordering of bitfields (which is implementation-defined) and *flexible array members*, which are not supported in C++.

In the interests of portability, the following summary (which assumes that bitfields are encoded starting at bit 0) is therefore provided for information, but is not canonical:

```
typedef struct _DFDSampleType {
  uint32_t bitOffset: 16;
  uint32_t bitLength: 8;
  uint32_t channelType: 8; // Includes qualifiers
  uint32_t samplePosition0: 8;
  uint32_t samplePosition1: 8;
  uint32_t samplePosition2: 8;
  uint32_t samplePosition3: 8;
  uint32_t lower;
  uint32_t upper;
} DFDSampleType;

typedef struct _BasicDataFormatDescriptor {
  uint32_t vendorId: 17;
  uint32_t descriptorType: 15;
  uint32_t versionNumber: 16;
  uint32_t descriptorBlockSize: 16;
  uint32_t model: 8;
  uint32_t primaries: 8;
  uint32_t transfer: 8;
  uint32_t flags: 8;
  uint32_t texelBlockDimension0: 8;
  uint32_t texelBlockDimension1: 8;
  uint32_t texelBlockDimension2: 8;
  uint32_t texelBlockDimension3: 8;
  uint32_t bytesPlane0: 8;
  uint32_t bytesPlane1: 8;
  uint32_t bytesPlane2: 8;
  uint32_t bytesPlane3: 8;
  uint32_t bytesPlane4: 8;
  uint32_t bytesPlane5: 8;
  uint32_t bytesPlane6: 8;
  uint32_t bytesPlane7: 8;
  DFDSampleType samples[];
} BasicDataFormatDescriptor;
```

Chapter 6

Extension for more complex formats

Some formats will require more channels than can be described in the Basic Format Descriptor, or may have more specific color requirements. For example, it is expected than an extension will be available which places an ICC color profile block into the descriptor block, allowing more color channels to be specified in more precise ways. This will significantly enlarge the space required for the descriptor, and is not expected to be needed for most common uses. A vendor may also use an extension block to associate metadata with the descriptor — for example, information required as part of hardware rendering. So long as software which uses the data format descriptor always uses the ***totalSize*** field to determine the size of the descriptor, this should be transparent to user code.

The extension mechanism is the preferred way to support even simple extensions such as additional color spaces transfer functions that can be supported by an additional enumeration. This approach improves compatibility with code which is unaware of the additional values. Simple extensions of this form that have cross-vendor support have a good chance of being incorporated more directly into future revisions of the specification, allowing application code to distinguish them by the ***versionId*** field.

If bit 13, **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_WRITE_BIT`**, of the ***descriptorType*** field of an extension is set, an application must understand the extension in order to write data coherently. If this bit is clear, copying the bits which correspond to one texel to another can be expected to result in a correct transfer of the texel even if the application does not understand the extension.

If bit 14, **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_DECODE_BIT`**, of the ***descriptorType*** field of an extension is set, an application must understand the extension in order to decode the contents of the texel coherently. If this bit is clear, the data held in the extension can be considered to be “informative” and that ignoring the extension will still result in correct values to the extent specified by the basic descriptor block. For example, an extension may associate an absolute brightness level with a format, but software which does not have need of this concept can continue processing the texel contents correctly.

As an example of the description of an extension, consider a single-channel 32-bit depth buffer, as shown in Table 6.1. A tiled renderer may wish to indicate that this buffer is “virtual”: it will be allocated real memory only if needed, and will otherwise exist only a subset at a time in an on-chip representation. Someone developing such a renderer may choose to add a vendor-specific extension (with ID 0x1FFFF to indicate development work and avoid the need for a vendor ID) which uses a boolean to establish whether this depth buffer exists only in virtual form. Note that the mere presence or absence of this extension within the data format descriptor itself forms a boolean, but for this example we will assume that an extension block is always present, and that a boolean is stored within. We will give the enumeration 32 bits, in order to simplify the possible addition of further extensions and pad to the alignment requirements.

In this example (which should not be taken as an implementation suggestion), the data descriptor would first contain a descriptor block describing the depth buffer format as conventionally described, followed by a second descriptor block that contains only the enumeration. The descriptor itself has a ***totalSize*** that includes both of these descriptor blocks. Note that **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_WRITE_BIT`** is not set, indicating that depth data can be written without knowing about the extension, and **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_DECODE_BIT`** is not set, indicating that software can safely ignore the information about the form of allocation while reading texel values.

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 56 — total size of the two blocks plus one 32-bit value</td></tr>
<tr><td colspan="32">Basic descriptor block</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 1) = 40</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags</i></b></td><td colspan="8"><b><i>transferFunction</i></b></td><td colspan="8"><b><i>colorPrimaries</i></b></td><td colspan="8"><b><i>colorModel</i></b></td></tr>
<tr><td colspan="8"><b><code>ALPHA_STRAIGHT</code></b></td><td colspan="8"><b><code>UNSPECIFIED</code></b></td><td colspan="8"><b><code>UNSPECIFIED</code></b></td><td colspan="8"><b><code>RGBSDA</code></b></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 4</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for depth</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4"><b><code>DEPTH</code></b></td><td colspan="8"><b><i>bitLength:</i></b> 31 (= “32”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xBF800000U — -1.0f</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x3F800000U — 1.0f</td></tr>
<tr><td colspan="32">Extension descriptor block</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0x1FFFF</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 8 + (4 × 1) = 12</td><td colspan="16"><b><i>versionNumber:</i></b> 0</td></tr>
<tr><td colspan="32">Data specific to the extension follows</td></tr>
<tr><td colspan="32">1 — buffer is “virtual”</td></tr>
</table>

Table 6.1: Example of a depth buffer with an extension to indicate a virtual allocation

It is possible for a vendor to use the extension block to store peripheral information required to access the image — plane base addresses, stride, etc. Since different implementations have different kinds of nonlinear ordering and proprietary alignment requirements, this is not described as part of the standard. By many conventional definitions, this information is not part of the “format”, and particularly it ensures that an identical copy of the image will have a different descriptor block (because the addresses will have changed) and so a simple bitwise comparison of two descriptor blocks will disagree even though the “format” matches. Additionally, many APIs will use the format descriptor only for external communication, and have an internal representation that is more concise and less flexible. In this case, it is likely that address information will need to be represented separately from the format anyway. For these reasons, it is an implementation choice whether to store this information in an extension block, and how to do so, rather than being specified in this standard.

Chapter 7

Additional planes descriptor block

Under some relatively unusual circumstances, either the number of planes described by the basic descriptor block or the number of bytes that can be contributed to a texel may be insufficient to describe the memory layout of bulk data. For example, a format may describe 12-bit colors (4 bits each or red, green and blue), and have the contributing bits stored as separate planes. An extension descriptor block, with ***vendorId*** = **`KHR_DF_VENDORID_KHRONOS`** and ***descriptorType*** = **`KHR_DF_DESCRIPTORTYPE_ADDITIONAL_PLANES`**, describes additional planes.

`uint32_t` bit																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
descriptorType: 0x6001															***vendorId:*** 0																
descriptorBlockSize: 8 + (4 × *number of planes*)																***versionNumber:*** 0															
bytesPlane0																															
bytesPlane1 *(optional)*																															
(etc.)																															

Table 7.1: Additional planes descriptor block

If this descriptor block is present, the ***bytesPlane[0..7]*** fields of the basic descriptor block are ignored, and the number of bytes for plane *n* is taken directly from word *n* + 2 of the descriptor block. The number of planes described can be determined by the descriptor block size.

This extension both allows an arbitrary number of planes and makes it easy to specify planes that contribute a large number of bytes to the virtual bit stream. Note that the sample ***bitOffset*** field remains limited to 16 bits, so the total texel block memory footprint is limited.

Note

Since knowing the bit stream contribution from all planes is necessary when interpreting data, this ***descriptorType*** sets **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_DECODE_BIT`**. Since the memory mapping is necessary when writing data, this ***descriptorType*** sets **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_WRITE_BIT`**.

This descriptor block should be used only if the Khronos Basic Descriptor Block is the first descriptor block in the data format descriptor, and cannot represent the format without extension.

Chapter 8

Additional dimensions descriptor block

The basic descriptor block allows texel blocks of up to four non-trivial dimensions, and with a texel block size of up to 256 coordinate units, with sample positions described in precision up to $\frac{1}{256}$ of a coordinate. Under rare circumstances, this may provide insufficient flexibility. An extension descriptor block, with ***vendorId*** = **`KHR_DF_VENDORID_KHRONOS`** and ***descriptorType*** = **`KHR_DF_DESCRIPTORTYPE_ADDITIONAL_DIMENSIONS`**, describes additional dimensions. Note that in some cases where this solution might be useful, a texel block is an inappropriate unit. For example, this extension block allows the direct representation of large texel tiling patterns, but it does so in a manner that is very inefficient, having much more potential flexibility than is needed by the users of the layout being described.

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="16"><b><i>descriptorType:</i></b> 0x6002</td><td colspan="16"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 8+(4 × <i>dimensions</i> × (<i>samples</i>+1))</td><td colspan="16"><b><i>versionNumber:</i></b> 0</td></tr>
<tr><td colspan="32"><b><code>uint32_t</code></b> <b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="32"><b><code>uint32_t</code></b> <b><i>texelBlockDimension1</i></b> <i>(optional)</i></td></tr>
<tr><td colspan="32"><i>(etc.)</i></td></tr>
<tr><td colspan="16"><b><code>uint16_t</code></b> <b><i>sample0Pos0</i></b></td><td colspan="16"><b><code>uint16_t</code></b> <b><i>sample0Pos0Divisor</i></b></td></tr>
<tr><td colspan="16"><b><code>uint16_t</code></b> <b><i>sample0Pos1</i></b></td><td colspan="16"><b><code>uint16_t</code></b> <b><i>sample0Pos1Divisor</i></b></td></tr>
<tr><td colspan="32"><i>(etc.)</i></td></tr>
</table>

Table 8.1: Additional dimensions descriptor block

The fields ***texelBlockDimension[0..n]*** describe the size in coordinate units of the texel block in the corresponding dimension; as with the basic descriptor block, the value stored is the corresponding dimension minus 1 (so a stored value of “0” corresponds to a dimension of 1). The ***texelBlockDimension[0..7]*** fields of the basic descriptor block are ignored.

For each sample, the ***samplePos*** and ***samplePosDivisor*** fields store a numerator and denominator pair for the coordinate $\mathit{offset} = \frac{\mathit{numerator}}{\mathit{denominator}}$ for each dimension, with all dimensions for a sample described before describing the next sample. ***samplePos*** and ***samplePosDivisor*** should be minimized, leaving an irreducible fraction. The ***samplePos*** fields of the basic descriptor block are ignored. These fields are present even for samples corresponding to palette entries.

Since the number of samples in the texel block can be deduced from the size of the basic descriptor block, the number of dimensions that are to be described by the additional dimensions descriptor block can be deduced from its size: *numDimensions* = (***descriptorBlockSize*** - 8) / (*numSamples* + 1).

Note

Since knowing the mapping from coordinates to samples is necessary when interpreting data, this ***descriptorType*** sets **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_DECODE_BIT`**. Since the coordinate mapping is necessary for writing data, this ***descriptorType*** sets **`KHR_DF_KHR_DESCRIPTORTYPE_NEEDED_FOR_WRITE_BIT`**.

This descriptor block should be used only if the Khronos Basic Descriptor Block is the first descriptor block in the data format descriptor, and cannot represent the format without extension.

Chapter 9

Frequently Asked Questions

9.1 Why have a binary format rather than a human-readable one?

While it is not expected that every new container will have a unique data descriptor or that analysis of the data format descriptor will be on a critical path in an application, it is still expected that comparison between formats may be time-sensitive. The data format descriptor is designed to allow relatively efficient queries for subsets of properties, to allow a large number of format descriptors to be stored, and to be amenable to hardware interpretation or processing in shaders. These goals preclude a text-based representation such as an XML schema.

9.2 Why not use an existing representation such as those on FourCC.org?

Formats in FourCC.org do not describe in detail sufficient information for many APIs, and are sometimes inconsistent.

9.3 Why have a descriptive format?

Enumerations are fast and easy to process, but are limited in that any software can only be aware of the enumeration values in place when it was defined. Software often behaves differently according to properties of a format, and must perform a look-up on the enumeration — if it knows what it is — in order to change behaviors. A descriptive format allows for more flexible software which can support a wide range of formats without needing each to be listed, and simplifies the programming of conditional behavior based on format properties.

9.4 Why describe this standard within Khronos?

Khronos supports multiple standards that have a range of internal data representations. There is no requirement that this standard be used specifically with other Khronos standards, but it is hoped that multiple Khronos standards may use this specification as part of a consistent approach to inter-standard operation.

9.5 Why should I use this descriptor if I don't need most of the fields?

While a library may not use all the data provided in the data format descriptor that is described within this standard, it is common for users of data — particularly pixel-like data — to have additional requirements. Capturing these requirements portably reduces the need for additional metadata to be associated with a proprietary descriptor. It is also common for additional functionality to be added retrospectively to existing libraries — for example, $Y'C_BC_R$ support is often an afterthought in rendering APIs. Having a consistent and flexible representation in place from the start can reduce the pain of retrofitting this functionality.

Note that there is no expectation that the format descriptor from this standard be used directly, although it can be. The impact of providing a mapping between internal formats and format descriptors is expected to be low, but offers the opportunity both for simplified access from software outside the proprietary library and for reducing the effort needed to provide a complete, unambiguous and accurate description of a format in human-readable terms.

9.6 Why not expand each field out to be integer for ease of decoding?

There is a trade-off between size and decoding effort. It is assumed that data which occupies the same 32-bit word may need to be tested concurrently, reducing the cost of comparisons. When transferring data formats, the packing reduces the overhead. Within these constraints, it is intended that most data can be extracted with low-cost operations, typically being byte-aligned (other than sample flags) and with the natural alignment applied to multi-byte quantities.

9.7 Can this descriptor be used for text content?

For simple ASCII content, there is no reason that plain text could not be described in some way, and this may be useful for image formats that contain comment sections. However, since many multilingual text representations do not have a fixed character size, this use is not seen as an obvious match for this standard.

Chapter 10

Floating-point formats

Some common floating-point numeric representations are defined in [IEEE 754]. Additional standard floating point formats are defined in this section. A mechanism for describing custom floating-point representations is detailed in Section 5.20.

10.1 16-bit floating-point numbers

A 16-bit floating-point number has a 1-bit sign (S), a 5-bit exponent (E), and a 10-bit mantissa (M). The value V of a 16-bit floating-point number is determined by the following:

$$V = \begin{cases} (-1)^S \times 0.0, & E = 0, M = 0 \\ (-1)^S \times 2^{-14} \times \frac{M}{2^{10}}, & E = 0, M \neq 0 \\ (-1)^S \times 2^{E-15} \times \left(1 + \frac{M}{2^{10}}\right), & 0 < E < 31 \\ (-1)^S \times Inf, & E = 31, M = 0 \\ NaN, & E = 31, M \neq 0 \end{cases}$$

If the floating-point number is interpreted as an unsigned 16-bit integer N, then

$$S = \left\lfloor \frac{N \bmod 65536}{32768} \right\rfloor$$

$$E = \left\lfloor \frac{N \bmod 32768}{1024} \right\rfloor$$

$$M = N \bmod 1024.$$

10.2 Unsigned 11-bit floating-point numbers

An unsigned 11-bit floating-point number has no sign bit, a 5-bit exponent (E), and a 6-bit mantissa (M). The value V of an unsigned 11-bit floating-point number is determined by the following:

$$V = \begin{cases} 0.0, & E = 0, M = 0 \\ 2^{-14} \times \frac{M}{64}, & E = 0, M \neq 0 \\ 2^{E-15} \times \left(1 + \frac{M}{64}\right), & 0 < E < 31 \\ \mathit{Inf}, & E = 31, M = 0 \\ \mathit{NaN}, & E = 31, M \neq 0 \end{cases}$$

If the floating-point number is interpreted as an unsigned 11-bit integer N, then

$$E = \left\lfloor \frac{N}{64} \right\rfloor$$

$$M = N \bmod 64.$$

10.3 Unsigned 10-bit floating-point numbers

An unsigned 10-bit floating-point number has no sign bit, a 5-bit exponent (E), and a 5-bit mantissa (M). The value V of an unsigned 10-bit floating-point number is determined by the following:

$$V = \begin{cases} 0.0, & E = 0, M = 0 \\ 2^{-14} \times \frac{M}{32}, & E = 0, M \neq 0 \\ 2^{E-15} \times \left(1 + \frac{M}{32}\right), & 0 < E < 31 \\ \mathit{Inf}, & E = 31, M = 0 \\ \mathit{NaN}, & E = 31, M \neq 0 \end{cases}$$

If the floating-point number is interpreted as an unsigned 10-bit integer N, then

$$E = \left\lfloor \frac{N}{32} \right\rfloor$$

$$M = N \bmod 32.$$

Chapter 11

Example format descriptors

Note
Example data format descriptors for compressed formats can be found under the ***colorModel*** field in Section 5.6.

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 76</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 3) = 72</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* `ALPHA_STRAIGHT`</td><td colspan="8">*transferFunction:* `LINEAR`</td><td colspan="8">*colorPrimaries:* `BT709`</td><td colspan="8">*colorModel:* `RGBSDA`</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 2</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">First sample: low five bits blue</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`BLUE`</td><td colspan="8">*bitLength:* 4 (= “5”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 31</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Second sample: middle six bits green</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`GREEN`</td><td colspan="8">*bitLength:* 5 = (“6”)</td><td colspan="16">*bitOffset:* 6</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 63</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Third sample: top five bits red</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">*bitLength:* 4 (= “5”)</td><td colspan="16">*bitOffset:* 11</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 31</td></tr>
</table>

Table 11.1: 565 *RGB* packed 16-bit format as written to memory by a little-endian architecture

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 92</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 4) = 88</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: PREMULTIPLIED</td><td colspan="8">transferFunction: SRGB</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 4</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the first sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 255</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the second sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 8</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 255</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the third sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">BLUE</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 16</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 255</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the fourth sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>1</td><td colspan="4">ALPHA</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 24</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 255</td></tr>
</table>

Table 11.2: Four co-sited 8-bit sRGB channels, assuming premultiplied alpha

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 44</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 1) = 40</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: ITU</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: YUVSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 1</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 8</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 255</td></tr>
</table>

Table 11.3: A single 8-bit monochrome channel

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 156</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 8) = 142</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: YUVSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">7 (= “8”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 1</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the first sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 0 (= “1”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the second sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 0 (= “1”)</td><td colspan="16">bitOffset: 1</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x20</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1</td></tr>
</table>

Table 11.4: A single 1-bit monochrome channel, as an 8×1 texel block to allow byte-alignment, part 1 of 2

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24">Sample information for the third sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 2</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x40</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24"><i>Sample information for the fourth sample</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 3</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x60</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24"><i>Sample information for the fifth sample</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 4</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x80</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24"><i>Sample information for the sixth sample</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 5</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0xA0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24"><i>Sample information for the seventh sample</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 6</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0xC0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
<tr><td><i>F</i></td><td><i>S</i></td><td><i>E</i></td><td><i>L</i></td><td colspan="4"><i>channelType</i></td><td colspan="24"><i>Sample information for the eighth sample</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>Y</code></td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 7</td></tr>
<tr><td colspan="8"><i>samplePosition3</i></td><td colspan="8"><i>samplePosition2</i></td><td colspan="8"><i>samplePosition1</i></td><td colspan="8"><i>samplePosition0</i></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0xE0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 1</td></tr>
</table>

Table 11.5: A single 1-bit monochrome channel, as an 8×1 texel block to allow byte-alignment, part 2 of 2

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 92</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 4) = 88</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>SRGB</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>RGBSDA</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">1 (height = “2”)</td><td colspan="8">1 (width = “2”)</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 2</td><td colspan="8"><b><i>bytesPlane0:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the first sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x00 (<i>y</i> = “0”)</td><td colspan="8">0x00 (<i>x</i> = “0”)</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 255</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the second sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 8</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x00 (<i>y</i> = “0”)</td><td colspan="8">0x80 (<i>x</i> = “1”)</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 255</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the third sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x80 (<i>y</i> = “1”)</td><td colspan="8">0x00 (<i>x</i> = “0”)</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 255</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the fourth sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>BLUE</code></td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 24</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x80 (<i>y</i> = “1”)</td><td colspan="8">0x80 (<i>x</i> = “1”)</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 255</td></tr>
</table>

Table 11.6: 2×2 Bayer pattern: four 8-bit distributed sRGB channels, spread across two lines (as two planes)

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 92</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 4) = 88</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: SRGB</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 1</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the 8-bit index</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">0</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 239</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Red channel of the palette entries</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 3 (= “4”)</td><td colspan="16">bitOffset: 8 (palette entry)</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0 (palette id)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 15</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Green channel of the palette entries</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 3 (= “4”)</td><td colspan="16">bitOffset: 8 (palette entry)</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0 (palette id)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 15</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Blue channel of the palette entries</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">BLUE</td><td colspan="8">bitLength: 3 (= “4”)</td><td colspan="16">bitOffset: 8 (palette entry)</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0 (palette id)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 15</td></tr>
</table>

Table 11.7: Simple paletted format: 8-bit index to 240 entries of 4-bit *R*, *G*, *B* channels

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 124</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 6) = 120</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** **`ALPHA_STRAIGHT`**</td><td colspan="8">***transferFunction:*** **`LINEAR`**</td><td colspan="8">***colorPrimaries:*** **`BT709`**</td><td colspan="8">***colorModel:*** **`RGBSDA`**</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 4</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Red channel palette index</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 7 (= “8”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 255</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Green channel palette index</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`GREEN`**</td><td colspan="8">***bitLength:*** 7 (= “8”)</td><td colspan="16">***bitOffset:*** 8</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 255</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Blue channel palette index</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`BLUE`**</td><td colspan="8">***bitLength:*** 7 (= “8”)</td><td colspan="16">***bitOffset:*** 16</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 255</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Red palette entry</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 9 (= “10”)</td><td colspan="16">***bitOffset:*** 32 (palette entry)</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0 (**`RED`** palette)</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 1023</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Green palette entry</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 9 (= “10”)</td><td colspan="16">***bitOffset:*** 32 (palette entry)</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">1 (**`GREEN`** palette)</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 1023</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Blue palette entry</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 9 (= “10”)</td><td colspan="16">***bitOffset:*** 32 (palette entry)</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">2 (**`BLUE`** palette)</td></tr>
<tr><td colspan="32">***sampleLower:*** 0</td></tr>
<tr><td colspan="32">***sampleUpper:*** 1023</td></tr>
</table>

Table 11.8: Paletted color look-up table format: three 8-bit indices into separate 256-entry 10-bit channels

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 124</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 6) = 120</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: ITU</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: YUVSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">1 (height = “2”)</td><td colspan="8">1 (width = “2”)</td></tr>
<tr><td colspan="8">bytesPlane3: 1</td><td colspan="8">bytesPlane2: 1</td><td colspan="8">bytesPlane1: 2</td><td colspan="8">bytesPlane0: 2</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the first Y' sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x00 (y = “0.0”)</td><td colspan="8">0x00 (x = “0.0”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 235</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the second Y' sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 8</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x00 (y = “0.0”)</td><td colspan="8">0x80 (x = “1.0”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 235</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the third Y' sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 16</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x80 (y = “1.0”)</td><td colspan="8">0x00 (x = “0.0”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 235</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the fourth Y' sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 24</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x80 (y = “1.0”)</td><td colspan="8">0x80 (x = “1.0”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 235</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the U sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">U</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 32</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x40 (y = “0.5”)</td><td colspan="8">0x40 (x = “0.5”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 240</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information for the V sample</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">V</td><td colspan="8">bitLength: 7 (= “8”)</td><td colspan="16">bitOffset: 40</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x40 (y = “0.5”)</td><td colspan="8">0x40 (x = “0.5”)</td></tr>
<tr><td colspan="32">sampleLower: 16</td></tr>
<tr><td colspan="32">sampleUpper: 240</td></tr>
</table>

Table 11.9: $Y'C_BC_R$ 4:2:0: BT.709 reduced-range data, with C_B and C_R aligned to the midpoint of the Y' samples

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 92</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 4) = 88</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 2</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Bit 0 is green, green bits 0..2 in bits 5..7 of the higher byte address (less-significant half of the big-endian word)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 2 (= “3”)</td><td colspan="16">bitOffset: 13</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0 — lower 3 bits of 6-bit value 0</td></tr>
<tr><td colspan="32">sampleUpper: 7 — lower 3 bits of 6-bit value 63</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Continuation: green bits 3..5 in bits 0..2 of the lower byte address (more-significant half of the big-endian word)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">GREEN</td><td colspan="8">bitLength: 2 (= “3”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0 — upper 3 bits of 6-bit value 0</td></tr>
<tr><td colspan="32">sampleUpper: 7 — upper 3 bits of 6-bit value 63</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Next undescribed bit: red in bits 3..7 of the lower byte address (more-significant half of the big-endian word)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 4 (= “5”)</td><td colspan="16">bitOffset: 3</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 31</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Remaining bits: blue in bits 0..4 of the higher byte address (less-significant half of the big-endian word)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">BLUE</td><td colspan="8">bitLength: 4 (= “5”)</td><td colspan="16">bitOffset: 8</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 31</td></tr>
</table>

Table 11.10: 565 *RGB* packed 16-bit format as written to memory by a big-endian architecture

<table>
<tr><td colspan="32"><code>uint32_t</code> <b>bit</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 124</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 6) = 120</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>RGBSDA</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 4</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>R</i> mantissa (explicit 1 since <i>F</i> = 0)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 8 (= “9”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 8448 (0x2100) — 1.0 encoded as a 9-bit mantissa = 256 and 5-bit exponent = 16</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>R</i> exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 4 (= “5”)</td><td colspan="16"><b><i>bitOffset:</i></b> 27</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 15 — exponent bias</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 31 — no special exponent encodings for infinity or NaN</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>G</i> mantissa (explicit 1 since <i>F</i> = 0)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 8 (= “9”)</td><td colspan="16"><b><i>bitOffset:</i></b> 9</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 8448 (0x2100) — 1.0 encoded as a 9-bit mantissa = 256 and 5-bit exponent = 16</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>G</i> exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 4 (= “5”)</td><td colspan="16"><b><i>bitOffset:</i></b> 27</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 15 — exponent bias</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 31 — no special exponent encodings for infinity or NaN</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>B</i> mantissa (explicit 1 since <i>F</i> = 0)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>BLUE</code></td><td colspan="8"><b><i>bitLength:</i></b> 8 (= “9”)</td><td colspan="16"><b><i>bitOffset:</i></b> 18</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 8448 (0x2100) — 1.0 encoded as a 9-bit mantissa = 256 and 5-bit exponent = 16</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Sample information for the <i>B</i> exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4"><code>BLUE</code></td><td colspan="8"><b><i>bitLength:</i></b> 4 (= “5”)</td><td colspan="16"><b><i>bitOffset:</i></b> 27</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 15 — exponent bias</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 31 — no special exponent encodings for infinity or NaN</td></tr>
</table>

Table 11.11: E5B9G9R9 shared-exponent format

<table>
<tr><td colspan="32"><code>uint32_t</code> bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 108</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 5) = 104</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>RGBSDA</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 1</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24"><i>First sample: four bits of red starting at bit 0, including two shared bits 0..1</i></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 3 (= “4”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 15</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Second sample: two bits of green “tint” shared with red</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 1 (= “2”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 3</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Third sample: two bits unique to green</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>GREEN</code></td><td colspan="8"><b><i>bitLength:</i></b> 1 (= “2”)</td><td colspan="16"><b><i>bitOffset:</i></b> 4</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 3</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Fourth sample: two bits of blue “tint” shared with red</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>BLUE</code></td><td colspan="8"><b><i>bitLength:</i></b> 1 (= “2”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 3</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Fifth sample: two bits unique to blue</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4"><code>BLUE</code></td><td colspan="8"><b><i>bitLength:</i></b> 1 (= “2”)</td><td colspan="16"><b><i>bitOffset:</i></b> 6</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 3</td></tr>
</table>

Table 11.12: Acorn 256-color format (2 bits each independent *RGB*, 2 bits shared tint)

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 220</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 12) = 216</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: ITU</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: YUVSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">5 (width = “6”)</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 16</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">First sample: shared mid-sited U0/U1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">U</td><td colspan="8">bitLength: 10</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x10 (x = “0.5”)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1023</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Second sample: Y′0</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 9 (= “10”)</td><td colspan="16">bitOffset: 10</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x00 (x = “0.0”)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1023</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Third sample: shared mid-sited V0/V1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">V</td><td colspan="8">bitLength: 9 (= “10”)</td><td colspan="16">bitOffset: 20</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x10 (x = “0.5”)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1023</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Fourth sample: Y′1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Y</td><td colspan="8">bitLength: 9 (= “10”)</td><td colspan="16">bitOffset: 32</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x20 (x = “1.0”)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1023</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Fifth sample: shared mid-sited U2/U3</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">U</td><td colspan="8">bitLength: 9 (= “10”)</td><td colspan="16">bitOffset: 42</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0x50 (x = “2.5”)</td></tr>
<tr><td colspan="32">sampleLower: 0</td></tr>
<tr><td colspan="32">sampleUpper: 1023</td></tr>
</table>

Table 11.13: V210 format (full-range $Y'C_BC_R$) part 1 of 2

uint32_t bit																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F	*S*	*E*	*L*	*channelType*				Sixth sample: $Y'2$																							
0	0	0	0	Y				***bitLength:*** 9 (= “10”)								***bitOffset:*** 52															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x40 (*x* = “2.0”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Seventh sample: shared mid-sited *V2/V3*																							
0	0	0	0	V				***bitLength:*** 9 (= “10”)								***bitOffset:*** 64															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x50 (*x* = “2.5”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Eighth sample: $Y'3$																							
0	0	0	0	Y				***bitLength:*** 9 (= “10”)								***bitOffset:*** 74															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x60 (*x* = “3.0”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Ninth sample: shared mid-sited *U4/U5*																							
0	0	0	0	U				***bitLength:*** 9 (= “10”)								***bitOffset:*** 84															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x90 (*x* = “4.5”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Tenth sample: $Y'4$																							
0	0	0	0	Y				***bitLength:*** 9 (= “10”)								***bitOffset:*** 96															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x80 (*x* = “4.0”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Eleventh sample: shared mid-sited *V4/V5*																							
0	0	0	0	V				***bitLength:*** 9 (= “10”)								***bitOffset:*** 106															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0x90 (*x* = “4.5”)							
sampleLower: 0																															
sampleUpper: 1023																															
F	*S*	*E*	*L*	*channelType*				Twelfth sample: $Y'5$																							
0	0	0	0	Y				***bitLength:*** 9 (= “10”)								***bitOffset:*** 116															
samplePosition3								*samplePosition2*								*samplePosition1*								*samplePosition0*							
0								0								0								0xA0 (*x* = “5.0”)							
sampleLower: 0																															
sampleUpper: 1023																															

Table 11.14: V210 format (full-range $Y'C_BC_R$) part 2 of 2

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">*totalSize:* 92</td></tr>
<tr><td colspan="15">*descriptorType:* 0</td><td colspan="17">*vendorId:* 0</td></tr>
<tr><td colspan="16">*descriptorBlockSize:* 24 + (16 × 4) = 88</td><td colspan="16">*versionNumber:* 2</td></tr>
<tr><td colspan="8">*flags:* `ALPHA_STRAIGHT`</td><td colspan="8">*transferFunction:* `LINEAR`</td><td colspan="8">*colorPrimaries:* `BT709`</td><td colspan="8">*colorModel:* `RGBSDA`</td></tr>
<tr><td colspan="8">*texelBlockDimension3*</td><td colspan="8">*texelBlockDimension2*</td><td colspan="8">*texelBlockDimension1*</td><td colspan="8">*texelBlockDimension0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">*bytesPlane3:* 0</td><td colspan="8">*bytesPlane2:* 0</td><td colspan="8">*bytesPlane1:* 0</td><td colspan="8">*bytesPlane0:* 1</td></tr>
<tr><td colspan="8">*bytesPlane7:* 0</td><td colspan="8">*bytesPlane6:* 0</td><td colspan="8">*bytesPlane5:* 0</td><td colspan="8">*bytesPlane4:* 0</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">First sample: red</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">*bitLength:* 7 (= “8”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 255</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Second sample: green</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`GREEN`</td><td colspan="8">*bitLength:* 7 (= “8”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 255</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Third sample: blue</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`BLUE`</td><td colspan="8">*bitLength:* 7 (= “8”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 255</td></tr>
<tr><td>*F*</td><td>*S*</td><td>*E*</td><td>*L*</td><td colspan="4">*channelType*</td><td colspan="24">Fourth sample: alpha</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">`ALPHA`</td><td colspan="8">*bitLength:* 7 (= “8”)</td><td colspan="16">*bitOffset:* 0</td></tr>
<tr><td colspan="8">*samplePosition3*</td><td colspan="8">*samplePosition2*</td><td colspan="8">*samplePosition1*</td><td colspan="8">*samplePosition0*</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">*sampleLower:* 0</td></tr>
<tr><td colspan="32">*sampleUpper:* 255</td></tr>
</table>

Table 11.15: Intensity-alpha format showing aliased samples

<table>
<tr><th colspan="32"><code>uint32_t</code> bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 76</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 3) = 72</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> <code>ALPHA_STRAIGHT</code></td><td colspan="8"><b><i>transferFunction:</i></b> <code>LINEAR</code></td><td colspan="8"><b><i>colorPrimaries:</i></b> <code>BT709</code></td><td colspan="8"><b><i>colorModel:</i></b> <code>RGBSDA</code></td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 6</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">First sample: bits 0..15 of the 48-bit value, in memory bytes 4..5</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 15 (= “16”)</td><td colspan="16"><b><i>bitOffset:</i></b> 32</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xFFFF0000U — bottom 16 bits of 0x800000000000, sign-extended</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x0000FFFFU — bottom 16 bits of 0x7FFFFFFFFFFF</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Second sample: bits 16..31 of the 48-bit value, in memory bytes 2..3</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 15 (= “16”)</td><td colspan="16"><b><i>bitOffset:</i></b> 16</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xFFFF0000U — middle 16 bits of 0x800000000000, sign-extended</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x0000FFFFU — middle 16 bits of 0x7FFFFFFFFFFF</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Third sample: bits 32..47 of the 48-bit value, in memory bytes 0..1</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td colspan="4"><code>RED</code></td><td colspan="8"><b><i>bitLength:</i></b> 15 (= “16”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0xFFFF8000U — top 16 bits of 0x800000000000, sign-extended</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0x00007FFFU — top 16 bits of 0x7FFFFFFFFFFF</td></tr>
</table>

Table 11.16: A 48-bit signed middle-endian red channel: three co-sited 16-bit little-endian words, high word first

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 76</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 3) = 72</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 2</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">First sample: mantissa with implicit 1 (F = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 9 (= “10”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 31744 (0x7C00) — -1.0 encoded as 10-bit mantissa = 0, sign bit = 1, exponent = 15</td></tr>
<tr><td colspan="32">sampleUpper: 30720 (0x7800) — 1.0 encoded as 10-bit mantissa = 0, sign bit = 0, exponent = 15</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Second sample: sign bit of mantissa (F inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 0 (= “1”)</td><td colspan="16">bitOffset: 15</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0 — unused</td></tr>
<tr><td colspan="32">sampleUpper: 0 — unused</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 4 (= “5”)</td><td colspan="16">bitOffset: 10</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 15 — bias</td></tr>
<tr><td colspan="32">sampleUpper: 30 — support for infinities because 30 < $2^{\text{bitLength}}$ - 1</td></tr>
</table>

Table 11.17: A signed 16-bit floating-point red value with implicit 1, described explicitly (example only!)

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 44</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 3) = 40</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 2</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Sample information</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 15 (= “16”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0xBF800000U — IEEE 754 floating-point representation for -1.0f</td></tr>
<tr><td colspan="32">sampleUpper: 0x3F800000U — IEEE 754 floating-point representation for 1.0f</td></tr>
</table>

Table 11.18: A standard signed 16-bit floating-point red value, described normally

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 2</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 6 (= “7”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 32640 (0x7F80) — -1.0 encoded as 7-bit mantissa = 0, sign bit = 1, exponent = 127</td></tr>
<tr><td colspan="32">***sampleUpper:*** 32512 (0x7F00) — 1.0 encoded as 7-bit mantissa = 0, sign bit = 0, exponent = 127</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: sign bit of mantissa (*F* inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 15</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — unused</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — unused</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 7 (= “8”)</td><td colspan="16">***bitOffset:*** 7</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 127 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 254 — support for infinities because 254 < $2^{\textbf{bitLength}}$ - 1</td></tr>
</table>

Table 11.19: bfloat16 (Brain Floating Point — 16-bit floating point with the range of 32-bit floating point)

<table>
<tr><td colspan="32">`uint32_t` **bit**</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 1</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 1 (= “2”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 124 (0x7C) — -1.0 encoded as 2-bit mantissa = 0, sign bit = 1, exponent = 15</td></tr>
<tr><td colspan="32">***sampleUpper:*** 120 (0x78) — 1.0 encoded as 2-bit mantissa = 0, sign bit = 0, exponent = 15</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: sign bit of mantissa (*F* inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 7</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — unused</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — unused</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 4 (= “5”)</td><td colspan="16">***bitOffset:*** 2</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 15 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 30 — support for infinities because 30 < $2^{\textbf{bitLength}}$ - 1</td></tr>
</table>

Table 11.20: E5M2 (8-bit floating point, similar to IEEE754)

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 1</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 2 (= “3”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 120 (0x78) — -1.0 encoded as 3-bit mantissa = 0, sign bit = 1, exponent = 7</td></tr>
<tr><td colspan="32">***sampleUpper:*** 112 (0x70) — 1.0 encoded as 3-bit mantissa = 0, sign bit = 0, exponent = 7</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: sign bit of mantissa (*F* inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 7</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — unused</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — unused</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 3 (= “4”)</td><td colspan="16">***bitOffset:*** 3</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 7 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 31 — special case $2^{\textbf{bitLength + 1}}$ - 1 ⇒ NaN encoded as S.1111.111$_2$</td></tr>
</table>

Table 11.21: E4M3FN (8-bit floating point, no infinities, NaN encoded as maximum)

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 1</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 1 (= “2”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 132 (0x84) — -1.0 encoded as 2-bit mantissa = 0, sign bit = 1, exponent = 16</td></tr>
<tr><td colspan="32">***sampleUpper:*** 128 (0x80) — 1.0 encoded as 2-bit mantissa = 0, sign bit = 0, exponent = 16</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: sign bit of mantissa (*F* inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 7</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — unused</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — unused</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">**`RED`**</td><td colspan="8">***bitLength:*** 4 (= “5”)</td><td colspan="16">***bitOffset:*** 2</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 16 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 32 — special case $2^{\textbf{bitLength}}$ ⇒ NaN encoded as -0.0</td></tr>
</table>

Table 11.22: E5M2FNUZ (8-bit floating point, no infinities, NaN encoded as -0)

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">totalSize: 76</td></tr>
<tr><td colspan="15">descriptorType: 0</td><td colspan="17">vendorId: 0</td></tr>
<tr><td colspan="16">descriptorBlockSize: 24 + (16 × 3) = 72</td><td colspan="16">versionNumber: 2</td></tr>
<tr><td colspan="8">flags: ALPHA_STRAIGHT</td><td colspan="8">transferFunction: LINEAR</td><td colspan="8">colorPrimaries: BT709</td><td colspan="8">colorModel: RGBSDA</td></tr>
<tr><td colspan="8">texelBlockDimension3</td><td colspan="8">texelBlockDimension2</td><td colspan="8">texelBlockDimension1</td><td colspan="8">texelBlockDimension0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">bytesPlane3: 0</td><td colspan="8">bytesPlane2: 0</td><td colspan="8">bytesPlane1: 0</td><td colspan="8">bytesPlane0: 1</td></tr>
<tr><td colspan="8">bytesPlane7: 0</td><td colspan="8">bytesPlane6: 0</td><td colspan="8">bytesPlane5: 0</td><td colspan="8">bytesPlane4: 0</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">First sample: mantissa with implicit 1 (F = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 2 (= “3”)</td><td colspan="16">bitOffset: 0</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 136 (0x88) — -1.0 encoded as 3-bit mantissa = 0, sign bit = 1, exponent = 8</td></tr>
<tr><td colspan="32">sampleUpper: 128 (0x80) — 1.0 encoded as 3-bit mantissa = 0, sign bit = 0, exponent = 8</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Second sample: sign bit of mantissa (F inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 0 (= “1”)</td><td colspan="16">bitOffset: 7</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 0 — unused</td></tr>
<tr><td colspan="32">sampleUpper: 0 — unused</td></tr>
<tr><td>F</td><td>S</td><td>E</td><td>L</td><td colspan="4">channelType</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">RED</td><td colspan="8">bitLength: 3 (= “4”)</td><td colspan="16">bitOffset: 3</td></tr>
<tr><td colspan="8">samplePosition3</td><td colspan="8">samplePosition2</td><td colspan="8">samplePosition1</td><td colspan="8">samplePosition0</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">sampleLower: 8 — bias</td></tr>
<tr><td colspan="32">sampleUpper: 16 — special case $2^{\text{bitLength}}$ ⇒ NaN encoded as -0.0</td></tr>
</table>

Table 11.23: E4M3FNUZ (8-bit floating point, no infinities, NaN encoded as -0)

<table>
<tr><td colspan="32">uint32_t bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 76</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> $24 + (16 \times 3) = 72$</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> RGBSDA</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 4</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">First sample: mantissa with implicit 1 (<i>F</i> = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 9 (= “10”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 261120 (0x3FC00) — -1.0 encoded as 10-bit mantissa = 0, sign bit = 1, exponent = 127</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 260096 (0x3F800) — 1.0 encoded as 10-bit mantissa = 0, sign bit = 0, exponent = 127</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Second sample: sign bit of mantissa (<i>F</i> inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 18</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0 — unused</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0 — unused</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 10</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 127 — bias</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 254 — support for infinities because $254 < 2^{\textbf{bitLength}} - 1$</td></tr>
</table>

Table 11.24: NVIDIA TensorFloat (19-bit floating point, stored in 4 bytes)

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 3</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 15 (= “16”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 8323072 (0x7F0000) — -1.0 encoded as 16-bit mantissa = 0, sign bit = 1, exponent = 63</td></tr>
<tr><td colspan="32">***sampleUpper:*** 8257536 (0x7E0800) — 1.0 encoded as 16-bit mantissa = 0, sign bit = 0, exponent = 63</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: sign bit of mantissa (*F* inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 23</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — unused</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — unused</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 6 (= “7”)</td><td colspan="16">***bitOffset:*** 16</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 63 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 126 — support for infinities because 126 < $2^{\textbf{bitLength}}$ - 1</td></tr>
</table>

Table 11.25: AMD fp24 (24-bit floating point with 7-bit exponent, stored in 3 bytes)

<table>
<tr><th colspan="32">uint32_t bit</th></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32"><b><i>totalSize:</i></b> 76</td></tr>
<tr><td colspan="15"><b><i>descriptorType:</i></b> 0</td><td colspan="17"><b><i>vendorId:</i></b> 0</td></tr>
<tr><td colspan="16"><b><i>descriptorBlockSize:</i></b> 24 + (16 × 3) = 72</td><td colspan="16"><b><i>versionNumber:</i></b> 2</td></tr>
<tr><td colspan="8"><b><i>flags:</i></b> ALPHA_STRAIGHT</td><td colspan="8"><b><i>transferFunction:</i></b> LINEAR</td><td colspan="8"><b><i>colorPrimaries:</i></b> BT709</td><td colspan="8"><b><i>colorModel:</i></b> RGBSDA</td></tr>
<tr><td colspan="8"><b><i>texelBlockDimension3</i></b></td><td colspan="8"><b><i>texelBlockDimension2</i></b></td><td colspan="8"><b><i>texelBlockDimension1</i></b></td><td colspan="8"><b><i>texelBlockDimension0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8"><b><i>bytesPlane3:</i></b> 0</td><td colspan="8"><b><i>bytesPlane2:</i></b> 0</td><td colspan="8"><b><i>bytesPlane1:</i></b> 0</td><td colspan="8"><b><i>bytesPlane0:</i></b> 3</td></tr>
<tr><td colspan="8"><b><i>bytesPlane7:</i></b> 0</td><td colspan="8"><b><i>bytesPlane6:</i></b> 0</td><td colspan="8"><b><i>bytesPlane5:</i></b> 0</td><td colspan="8"><b><i>bytesPlane4:</i></b> 0</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">First sample: mantissa with implicit 1 (<i>F</i> = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 14 (= “15”)</td><td colspan="16"><b><i>bitOffset:</i></b> 0</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 8355840 (0x7F8000) — -1.0 encoded as 15-bit mantissa = 0, sign bit = 1, exponent = 127</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 8323072 (0x7F0800) — 1.0 encoded as 15-bit mantissa = 0, sign bit = 0, exponent = 127</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Second sample: sign bit of mantissa (<i>F</i> inherited)</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 0 (= “1”)</td><td colspan="16"><b><i>bitOffset:</i></b> 23</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 0 — unused</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 0 — unused</td></tr>
<tr><td><b><i>F</i></b></td><td><b><i>S</i></b></td><td><b><i>E</i></b></td><td><b><i>L</i></b></td><td colspan="4"><b><i>channelType</i></b></td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">RED</td><td colspan="8"><b><i>bitLength:</i></b> 7 (= “8”)</td><td colspan="16"><b><i>bitOffset:</i></b> 15</td></tr>
<tr><td colspan="8"><b><i>samplePosition3</i></b></td><td colspan="8"><b><i>samplePosition2</i></b></td><td colspan="8"><b><i>samplePosition1</i></b></td><td colspan="8"><b><i>samplePosition0</i></b></td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32"><b><i>sampleLower:</i></b> 127 — bias</td></tr>
<tr><td colspan="32"><b><i>sampleUpper:</i></b> 254 — support for infinities because 254 < $2^{\textbf{bitLength}}$ - 1</td></tr>
</table>

Table 11.26: PixarPXR24 (24-bit floating point with 8-bit exponent, stored in 3 bytes)

<table>
<tr><td colspan="32">`uint32_t` bit</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="32">***totalSize:*** 76</td></tr>
<tr><td colspan="15">***descriptorType:*** 0</td><td colspan="17">***vendorId:*** 0</td></tr>
<tr><td colspan="16">***descriptorBlockSize:*** 24 + (16 × 3) = 72</td><td colspan="16">***versionNumber:*** 2</td></tr>
<tr><td colspan="8">***flags:*** `ALPHA_STRAIGHT`</td><td colspan="8">***transferFunction:*** `LINEAR`</td><td colspan="8">***colorPrimaries:*** `BT709`</td><td colspan="8">***colorModel:*** `RGBSDA`</td></tr>
<tr><td colspan="8">***texelBlockDimension3***</td><td colspan="8">***texelBlockDimension2***</td><td colspan="8">***texelBlockDimension1***</td><td colspan="8">***texelBlockDimension0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="8">***bytesPlane3:*** 0</td><td colspan="8">***bytesPlane2:*** 0</td><td colspan="8">***bytesPlane1:*** 0</td><td colspan="8">***bytesPlane0:*** 2</td></tr>
<tr><td colspan="8">***bytesPlane7:*** 0</td><td colspan="8">***bytesPlane6:*** 0</td><td colspan="8">***bytesPlane5:*** 0</td><td colspan="8">***bytesPlane4:*** 0</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">First sample: mantissa with implicit 1 (*F* = 1)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 31 (= “32”)</td><td colspan="16">***bitOffset:*** 0</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — 0.0 (bottom 32 bits, holding mantissa = 0)</td></tr>
<tr><td colspan="32">***sampleUpper:*** 0 — 1.0 (bottom 32 bits, holding mantissa = 0)</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Second sample: Supplemental mantissa with remaining ***sampleLower/sampleUpper*** bits</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 0 (= “1”)</td><td colspan="16">***bitOffset:*** 0 (same as first sample, indicating overflow)</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 0 — 0.0 (exponent bits, stored as 8-bit overflow from the mantissa sample)</td></tr>
<tr><td colspan="32">***sampleUpper:*** 127 — 1.0 (exponent bits, stored as 8-bit overflow from the mantissa sample)</td></tr>
<tr><td>***F***</td><td>***S***</td><td>***E***</td><td>***L***</td><td colspan="4">***channelType***</td><td colspan="24">Third sample: exponent</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>0</td><td colspan="4">`RED`</td><td colspan="8">***bitLength:*** 7 (= “8”)</td><td colspan="16">***bitOffset:*** 32</td></tr>
<tr><td colspan="8">***samplePosition3***</td><td colspan="8">***samplePosition2***</td><td colspan="8">***samplePosition1***</td><td colspan="8">***samplePosition0***</td></tr>
<tr><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td><td colspan="8">0</td></tr>
<tr><td colspan="32">***sampleLower:*** 127 — bias</td></tr>
<tr><td colspan="32">***sampleUpper:*** 254 — support for infinities because 254 < $2^{\textbf{bitLength}}$ - 1</td></tr>
</table>

Table 11.27: An unsigned 40-bit (E8R32) floating-point red value with implicit 1

Part III

Color conversions

Chapter 12

Introduction to color conversions

12.1 Color space composition

A “color space” determines the meaning of decoded numerical color values: that is, it is distinct from the bit patterns, compression schemes and locations in memory used to store the data.

A color space consists of three basic components:

- Transfer functions define the relationships between linear intensity and linear numbers in the encoding scheme. Since the human eye’s sensitivity to changes in intensity is nonlinear, a nonlinear encoding scheme typically allows improved visual quality at reduced storage cost.
  - An opto-electrical transfer function (OETF) describes the conversion from “scene-referred” normalized linear light intensity to a (typically) nonlinear electronic representation. The inverse function is written “OETF $^{-1}$”.
  - An electro-optical transfer function (EOTF) describes the conversion from the electronic representation to “display-referred” normalized linear light intensity in the display system. The inverse function is written “EOTF $^{-1}$”.
  - An opto-optical transfer function (OOTF) describes the relationship between the linear scene light intensity and linear display light intensity: OOTF(x) = EOTF(OETF(x)). OETF = EOTF $^{-1}$ and EOTF = OETF $^{-1}$ only if the OOTF is linear.
  - Historically, a nonlinear transfer function has been implicit due to the nonlinear relationship between voltage and intensity provided by a CRT display. In contrast, many computer graphics applications are best performed in a representation with a linear relationship to intensity.
  - Use of an incorrect transfer function can result in images which have too much or too little contrast or saturation, particularly in mid-tones.
- Color primaries define the spectral response of a “pure color” in an additive color model - typically, what is meant by “red”, “green” and “blue” for a given system, and (allowing for the relative intensity of the primaries) consequently define the system’s white balance.
  - These primary colors might refer to the wavelengths emitted by phosphors on a CRT, transmitted by filters on an LCD for a given back-light, or emitted by the LED sub-pixels of an OLED. The primaries are typically defined in terms of a reference display, and represent the most saturated colors the display can produce, since other colors are by definition created by combining the primaries. The definition usually describes a relationship to the responses of the human visual system rather than a full spectrum.
  - Use of incorrect primaries introduces a shift of hue, most visible in saturated colors.

- Color models describe the distinction between a color representation and additive colors. Since the human visual system treats differences in absolute intensity differently from differences in the spectrum composing a color, many formats benefit from transforming the color representation into one which can separate these aspects of color. Color models are frequently "named" by listing their component color channels.
  - For example, a color model might directly represent additive primaries (*RGB*), simple color difference values ($Y'C_BC_R$ — colloquially *YUV*), or separate hue, saturation and intensity (*HSV*/*HSL*).
  - Interpreting an image with an incorrect color model typically results in wildly incorrect colors: a (0,0,0) triple in an *RGB* additive color model typically represents black, but may represent white in *CMYK*, or saturated green in color difference models.

12.2 Operations in a color conversion

Conversion between color representations may require a number of separate conversion operations:

- Conversion between representations with different color primaries can be performed directly. If the input and output of the conversion do not share the same color primaries, this transformation forms the "core" of the conversion.
- The color primary conversion operates on linear *RGB* additive color values; if the input or output are not defined in linear terms but with a nonlinear transfer function, any color primary conversion must be "wrapped" with any transfer functions; conventionally, nonlinear *RGB* values are written $R'G'B'$.
- If the input or output color model is not defined in terms of additive primaries (for example, $Y'C_BC_R$ — colloquially known as *YUV*), the model conversion is applied to the nonlinear $R'G'B'$ values; the $Y'_CC'_{BC}C'_{RC}$ and IC_TC_P color models are created from both linear and nonlinear *RGB*.
- Converting numerical values stored in memory to the representation of the color model may itself require additional operations — in order to remove dependence on bit depth, all the formulae described here work with continuous natural numbers, but some common in-memory quantization schemes must often be applied.

Details of these conversion operations are described in the following chapters.

Note
As described in the License Information at the start of this document, the Khronos Data Format Specification does not convey a right to implement the operations it describes. This is particularly true of the conversion formulae in the following sections, whose inclusion is purely informative. Please refer to the originating documents and the bodies responsible for the standards containing these formulae for the legal framework required for implementation.

Common cases such as converting a $Y'C_BC_R$ image encoded for 625-line BT.601 to a $Y'C_BC_R$ image encoded for BT.709 can involve multiple costly operations. An example is shown in the following diagram, which represents sampling a given location from a $Y'C_BC_R$ texture in one color space, and the operations needed to generate a different set of $Y'C_BC_R$ values representing the color of the sample position in a different color space:

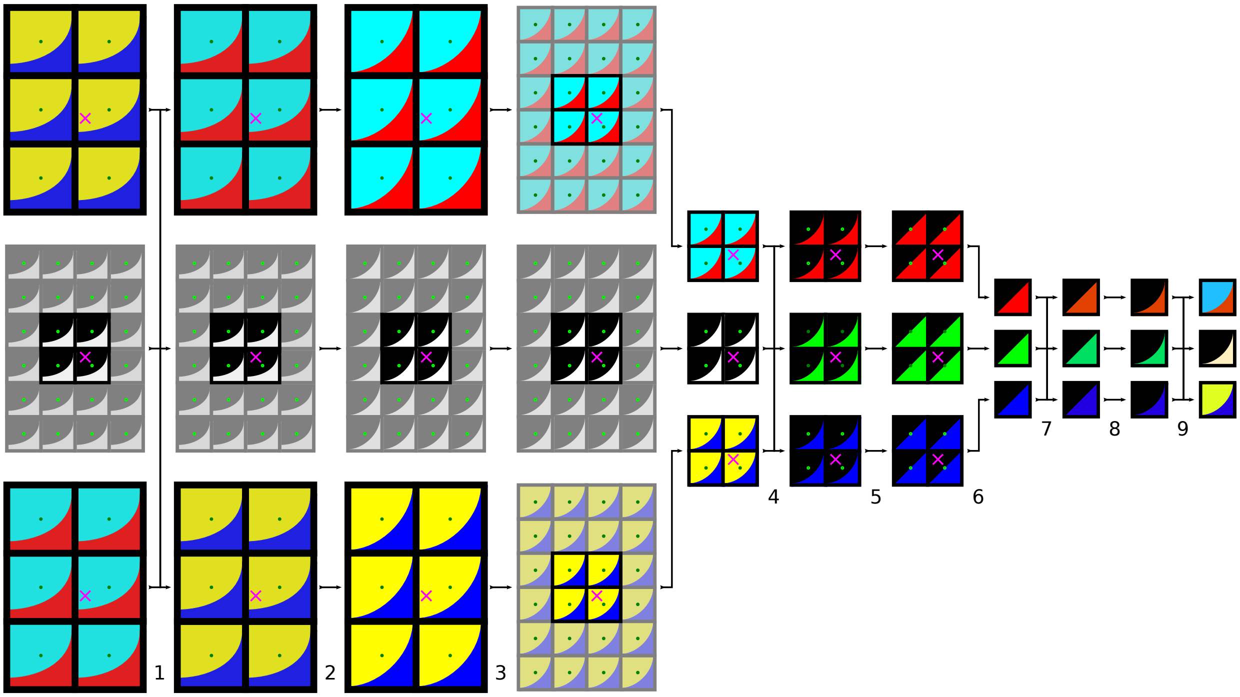


Figure 12.1: Example sampling in one space and converting to a different space

In this diagram, nonlinear luma Y' channels are shown in black and white, color difference C_B/C_R channels are shown with the colors at the extremes of their range, and color primary channels are shown as the primary color and black. Linear representations are shown diagonally divided by a straight line; nonlinear representations are shown with a gamma curve. The luma and color difference representation is discussed in Section 15.1. The interpretation of color primaries is discussed in Chapter 14. Nonlinear transfer functions are described in Chapter 13. As described below, the diagram shows a 2×3 grid of input chroma texel values, corresponding to a 4×6 grid of luma texel values, since the chroma channels are stored at half the horizontal and half the vertical resolution of the luma channel (i.e. in “4:2:0” representation). Grayed-out texel values do not contribute to the final output, and are shown only to indicate relative alignment of the coordinates.

The stages shown in this diagram assume that the chroma samples are being reconstructed at the luma positions through linear interpolation. In the days of analog video, this interpolation was an implicit part of the display process (BT.709 and earlier discuss low-pass filtering of the chroma signal), but modern standards are less explicit about how the reconstruction should be performed, other than defining the chroma sample positions. In their guidance on 8-bit YUV, Microsoft suggests that cosited chroma (with chroma samples at the same image position as either odd or even luma samples) use a four-tap Catmull-Rom interpolation on each axis for chroma samples which fall between luma samples: $\frac{9}{16}$ times the two nearest samples minus $\frac{1}{16}$ times the two surrounding samples; see Section 12.3 for an equivalent cubic interpolation for chroma samples falling at the midpoint of surrounding luma samples. Replication (nearest-neighbor sampling) can introduce aliasing at color boundaries (although the reconstructed linear RGB values can still be filtered). In contrast, bilinear interpolation reduces the chroma aliasing, but can reduce the expressible range of high spatial-frequency chroma values; this is especially true for chroma samples located at the midpoint of surrounding luma values, since all reconstructed values will be interpolated. Ideally the encoder and decoder of the image should be aware of the approach used and adjust values accordingly.

The stages numbered in Figure 12.1 show the following operations:

1. Arranging the channels from the representation correctly for the conversion operations (a "swizzle"). In this example, the implementation requires that the C_B and C_R values be swapped.

2. Range expansion to the correct range for the values in the color model (handled differently, for example, for "full" and "narrow" ranges); in this example, the result is to increase the effective dynamic range of the encoding: contrast and saturation are increased.

   In this example, operations 1 and 2 can be combined into a single sparse matrix multiplication of the input channels, although actual implementations may wish to take advantage of the sparseness.

3. Reconstruction to full resolution of channels which are not at the full sampling resolution ("chroma reconstruction"), for example by replication or interpolation at the sites of the luma samples, allowing for the chroma sample positions. In the diagram, sample positions for each channel are shown as green dots, and each channel corresponds to the same region of the image; in this example, the chroma samples are located at the horizontal and vertical midpoint of quads of luma samples, but different standards align the chroma samples differently. Note that interpolation for channel reconstruction necessarily happens in a nonlinear representation for color difference representations such as $Y'C_BC_R$: creating a linear representation would require converting to RGB, which in turn requires a full set of $Y'C_BC_R$ samples for a given position.

4. Conversion between color models — in this example, from nonlinear $Y'C_BC_R$ to nonlinear $R'G'B'$. For example, the conversion might be that between BT.601 $Y'C_BC_R$ and BT.601 nonlinear $R'G'B'$ described in Section 15.1.2. For $Y'C_BC_R$ to $R'G'B'$, this conversion is a sparse matrix multiplication.

5. Application of a transfer function to convert from nonlinear $R'G'B'$ to linear RGB, using the color primaries of the input representation. In this case, the conversion might be the ITU OETF $^{-1}$ described in Section 13.2, since all operations are being performed in a scene-referred color space. If the filtered RGB values are to be displayed directly, this conversion may instead be the EOTF described in Section 13.3.1 (for a computer monitor) or Section 13.4 (for a television), thereby incorporating the OOTF.

   The separation of stages 4 and 5 is specific to the $Y'C_BC_R$ to $R'G'B'$ color model conversion. Other representations such as $Y'_CC'_{BC}C'_{RC}$ and IC_TC_P have more complex interactions between the color model conversion and the transfer function.

6. Interpolation of linear color values at the sampling position shown with a magenta cross according to the chosen texture sampling rules.

7. Convert from the color primaries of the input representation to the desired color primaries of the output representation, which is a matrix multiplication operation. Conversion from linear BT.601 EBU primaries to BT.709 primaries, as described in Section 14.2 and Section 14.1.

8. Convert from the linear RGB representation using the target primaries to a nonlinear $R'G'B'$ representation, for example the (scene-referred) ITU OETF described in Section 13.2.

9. Conversion from nonlinear $R'G'B'$ to the $Y'C_BC_R$ color model, for example as defined in as defined in Section 15.1.1 (a matrix multiplication).

If the output is to be written to a frame buffer with reduced-resolution chroma channels, chroma values for multiple samples need to be combined. Note that it is easy to introduce inadvertent chroma blurring in this operation if the source space chroma values are generated by interpolation. This chroma rate reduction is not shown in the diagram.

In this example, generating the four linear RGB values required for linear interpolation at the magenta cross position requires *six* chroma samples. In the example shown, all four Y' values fall between the same two chroma sample centers on the horizontal axis, and therefore recreation of these samples by linear blending on the horizontal axis only requires two horizontally-adjacent samples. However, the upper pair of Y' values are sited above the sample position of the middle row of chroma sample centers, and therefore reconstruction of the corresponding chroma values requires interpolation between the upper four source chroma values. The lower pair of Y' values are sited below the sample position of the middle row of chroma sample centers, and therefore reconstruction of the corresponding chroma values requires interpolation between the lower four source chroma values. In general, reconstructing four chroma values by interpolation may require four, six or nine source chroma values, depending on which samples are required. The worst case is reduced if chroma samples are aligned ("co-sited") with the luma values, or if chroma channel reconstruction uses replication (nearest-neighbor filtering) rather than interpolation.

An approximation to the conversion described in Figure 12.1 is depicted in Figure 12.2:

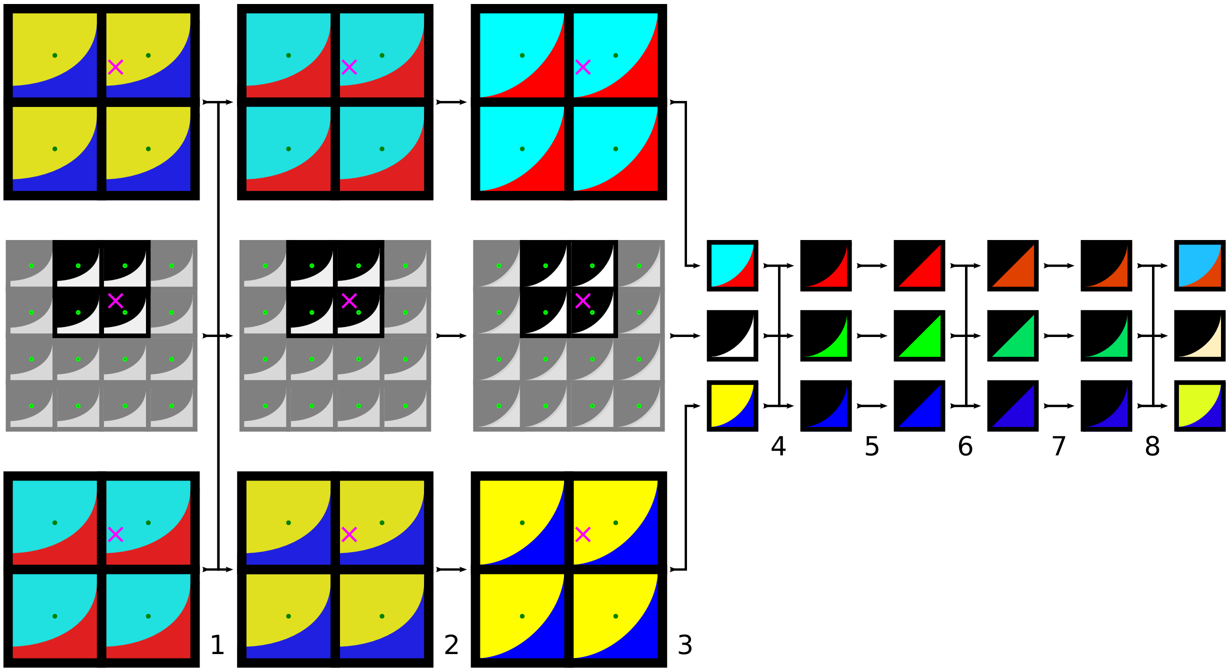


Figure 12.2: Example approximated sampling in one space and converting to a different space

A performance-optimized approximation to our example conversion may use the following steps:

1. Channel rearrangement (as in the previous example)
2. Range expansion (as in the previous example)
3. Chroma reconstruction combined with sampling. In this case, the desired chroma reconstruction operation is approximated by adjusting the sample positions to compensate for the reduced resolution and sample positions of the chroma channels, resulting in a single set of nonlinear $Y'C_BC_R$ values.
4. Model conversion from $Y'C_BC_R$ to $R'G'B'$ as described in Section 15.1.2, here performed *after* the sampling/filtering operation.
5. Conversion from nonlinear $R'G'B'$ to linear RGB, using the ITU OETF $^{-1}$ described in Section 13.2.
6. Conversion of color primaries, corresponding to step 7 of the previous example.
7. Conversion to a nonlinear representation, corresponding to step 8 of the previous example.
8. Conversion to the output color model, corresponding to step 9 of the previous example.

Note

Since stages 1 and 2 represent an affine matrix transform, linear interpolation of input values may equivalently be performed before these operations. This observation allows stages 1..4 to be combined into a single matrix transformation.

Large areas of constant color will be correctly converted by this approximation. However, there are two sources of errors near color boundaries:

1. Interpolation takes place on values with a nonlinear representation; the repercussions of this are discussed in Chapter 13, but can introduce both intensity and color shifts. Note that applying a nonlinear transfer function as part of filtering does not improve accuracy for color models other than $R'G'B'$ since the nonlinear additive values have been transformed as part of the color model representation.
2. When chroma reconstruction is bilinear and the final sample operation is bilinear, the interpolation operation now only access a maximum of four chroma samples, rather than up to nine for the precise series of operations. This has the potential to introduce a degree of aliasing in the output; image errors may be more visible if the scaling factor or sample positions change over time, for example when a video texture is projected onto a 3D surface.

This approximation produces identical results to the more explicit sequence of operations in two cases:

1. If chroma reconstruction uses nearest-neighbor replication and the sampling operation is also a nearest-neighbor operation rather than a linear interpolation.
2. If the sampling operation is a nearest-neighbor operation and chroma reconstruction uses linear interpolation, *if* the sample coordinate position is adjusted to the nearest luma sample position.

The approximation in Figure 12.2 consists of applying the sequence of operations used to reconstruct full-color samples at the luma sampling points in a more general solution, but does so instead at all final color positions. If final color values are only evaluated at the positions of the luma samples (such that the interpolation shown in stage 6 of Figure 12.1 equates to a single sample value), the two approaches are equivalent: generating an image of the original luma resolution does not require the two-stage sampling process shown in Figure 12.1.

As another example, the conversion from BT.709-encoded $Y'C_BC_R$ to sRGB $R'G'B'$ may be considered to be a simple model conversion (to BT.709 $R'G'B'$ nonlinear primaries that are encoded representing the "ITU" OETF), since sRGB shares the BT.709 color primaries and is defined as a complementary EOTF intended to be combined with BT.709's OETF. This interpretation imposes a $\gamma \approx 1.1$ OOTF between the scene described by the BT.709 (scene-referred) OETF encoding and the display output described by the sRGB (display-referred) EOTF.

$$\begin{aligned}\{R_{sRGB}, G_{sRGB}, B_{sRGB}\} &= \text{EOTF}_{sRGB}(\{R'_{BT.709}, G'_{BT.709}, B'_{BT.709}\}) \\ &= \text{OOTF}_{BT.709\rightarrow sRGB}(\{R_{BT.709}, G_{BT.709}, B_{BT.709}\})\end{aligned}$$

Matching the OOTF of a BT.709-BT.1886 system, for which $\gamma \approx 1.2$, implies applying the BT.1886 EOTF to the nonlinear BT.709 content to convert to linear display light (for a television). For a computer display whose frame buffer is represented with sRGB nonlinear encoding to match the output of a television, the output of the BT.709→BT.1886 (OETF $^{-1}$→EOTF) pair can then have the sRGB EOTF $^{-1}$ applied to the resulting display-linear RGB values to convert back to sRGB nonlinear $R'G'B'$ space:

$$\{R'_{sRGB}, G'_{sRGB}, B'_{sRGB}\} = \text{EOTF}^{-1}_{sRGB}(\text{EOTF}_{BT.1886}(\{R'_{BT.709}, G'_{BT.709}, B'_{BT.709}\}))$$

To represent scene-linear light (with a linear OOTF), BT.709-encoded content can be converted to a linear representation with the scene-referred BT.709 OETF $^{-1}$ and, if necessary, this can be treated as linear display light and converted back to a nonlinear sRGB $R'G'B'$ target by subsequently applying the sRGB EOTF $^{-1}$:

$$\{R'_{sRGB}, G'_{sRGB}, B'_{sRGB}\} = \text{EOTF}^{-1}_{sRGB}(\text{OETF}^{-1}_{BT.709}(\{R'_{BT.709}, G'_{BT.709}, B'_{BT.709}\}))$$

Note that this OOTF implies that the scene viewing conditions and the display viewing conditions match, which is unlikely unless the scene is very dim or the display is very bright.

12.3 Example chroma reconstruction results

The following images show the effects of different chroma reconstruction schemes on sample inputs. In practice, a number of proprietary schemes exist for chroma reconstruction (as with the related problem of reconstructing full-color data from filtered camera sensors), and the approaches with the highest visual quality may rely on heuristics; the mechanisms described here are relatively simplistic, but may be appropriate for real-time support in a general-purpose environment such as texture filtering on a GPU.

The initial set of images are reconstructed here assuming that chroma samples logically fall at the midpoint of (that is, half way between) luma samples: the nearest chroma samples to $Y'_{(x,y)}$ fall at $\left(2\left\lfloor\frac{x}{2}\right\rfloor+\frac{1}{2}, 2\left\lfloor\frac{y}{2}\right\rfloor+\frac{1}{2}\right)$ in luma coordinates, and the luma samples nearest to chroma $C_{B(x,y)}$ and $C_{R(x,y)}$ are at $(x \pm 0.25, y \pm 0.25)$ in chroma coordinates.

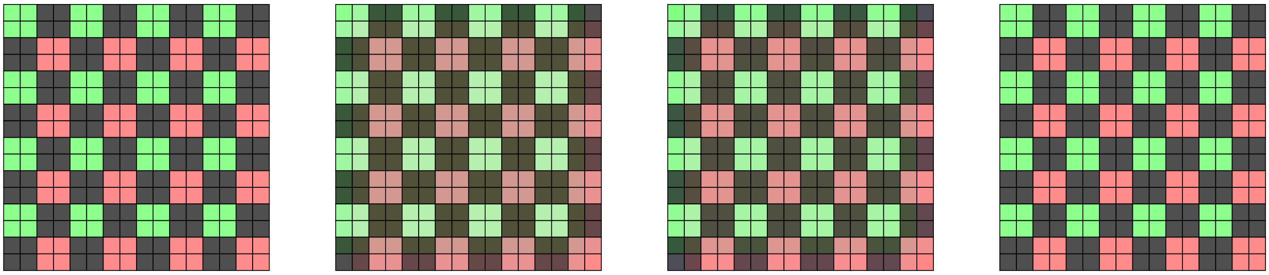


Figure 12.3: A colored checker pattern reconstructed at its original size

In Figure 12.3:

- The left-most image shows the original image: a 16×16 checkerboard of colored squares, each occupying 2×2 texels.

To generate the remaining images, the $R'G'B'$ pattern is converted to $Y'C_BC_R$ with the chroma difference channels downsampled by 2 on each axis (that is, “4:2:0” downsampling) by averaging after the color model conversion (in this example, each quad of texels has the same color, so this averaging is trivial), resulting in 16×16 Y' values and 8×8 C_B and C_R values. The chroma values are then reconstructed to the original resolution before conversion to $R'G'B'$ pixels.

- The second-from-left image shows the result of reconstructing the chroma samples to luma resolution using bilinear interpolation between adjacent chroma values, which are assumed to be at the midpoint of each 2×2 quad. Each chroma value used is therefore a weighted average of the surrounding chroma samples; since the chroma values vary quickly, the most visible effect of this is to reduce the saturation of the colored squares. This effect can be mitigated by applying a sharpening deconvolution to the encoded chroma values, although the result may result in values that cannot be encoded. Note that the pixels at the edge of the image are not interpolating because the accessed chroma coordinates are clamped, which results in increased saturation in this image.
- The second-from-right image uses a bicubic filter to reconstruct the chroma values, equivalent to using a bicubic filter for step 3 of Figure 12.1. (For this example, in the chosen filter, proposed by R. Keys in 1981, the reconstructed chroma value to the right of chroma sample p_x is calculated as $-0.070312 \times p_{x-1} + 0.867188 \times p_x + 0.226562 \times p_{x+1} - 0.023438 \times p_{x+2}$, with the x and y axes filtered separably; weightings are obviously reflected for the chroma value to the *left* of chroma sample p_x.) This has the effect of increasing the significance of the nearest chroma sample (compared with the 0.75 weight used in bilinear interpolation), in this case restoring some of the lost saturation compared with bilinear filtering.
- The rightmost sample simply reconstructs the chroma values at each luma position by replicating the nearest chroma sample, corresponding to the use of a nearest filter for chroma in step 3 of Figure 12.1. Since the chroma values for each quad in the original image are identical, for this source image the reconstruction is perfect (and matches the left-most image exactly).

The next example shows the result of scaling this 16×16 image to 21×21 pixels.

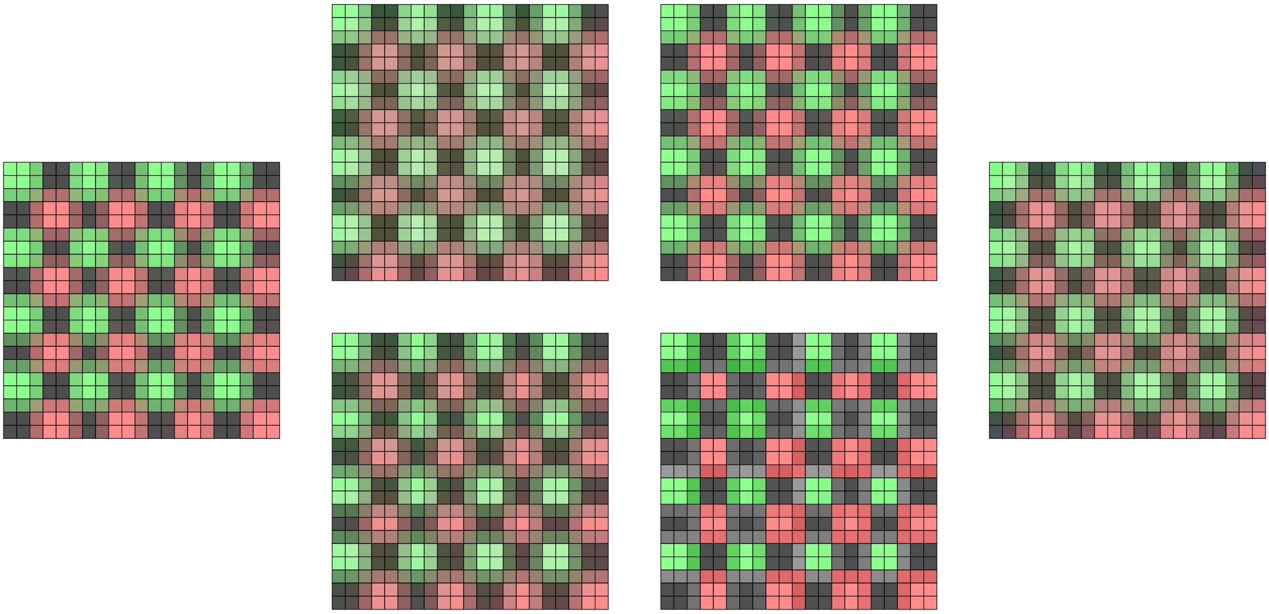


Figure 12.4: A colored checker pattern upscaled from 16×16 to 21×21

In Figure 12.4:

- The left-most image shows the original $R'G'B'$ image directly upscaled from 16×16 to 21×21 pixels with bilinear filtering (after conversion to linear RGB), for reference.
- The top-left image shows bilinear filtering for chroma reconstruction, using the explicit reconstruction used in Figure 12.1: chroma values are calculated at each 16×16 luma sample position by bilinear interpolation, the resulting "4:4:4" values are converted to $R'G'B'$, and these 16×16 color values are bilinearly interpolated (after conversion to linear RGB) to get a final color for each pixel. Since the chroma reconstruction is as shown for the linear example in Figure 12.3, the result is desaturated relative to the original image, but the effect is consistent across the image.
- The bottom-left image shows bilinear filtering of luma and chroma values by projecting the sample position directly onto the 16×16 luma and downsampled 8×8 chroma planes, as shown in Figure 12.2, prior to conversion to $R'G'B'$. Since the resulting chroma sampling positions fall at varying distances from the position of the original chroma values due to the scaling of the image (and the chroma values are nonlinear), the result is a varying saturation across the image. For a static image at a fixed scale ratio, this effect may be considered minor, since affects primarily high frequency color data — but it may be more intrusive if sample positions change over time, as with video projected onto a moving 3D surface: changes both to subpixel offset and scale factors can move the chroma sample and therefore alter saturation. Additionally, linear interpolation of nonlinear luma values results in an overall loss of image brightness at transitions.
- The top-right image shows chroma reconstruction to the 16×16 Y' resolution by replicating the nearest chroma sample values to each Y' position, converting to $R'G'B'$, and bilinearly filtering the resulting 16×16 values after linearising to RGB space — corresponding to Figure 12.1 with a nearest filter in step 3. Since this mechanism perfectly replicates the chroma of this original image example, as shown in Figure 12.3, the result matches the bilinearly-filtered $R'G'B'$ image.
- The bottom-right image shows chroma reconstruction by projecting the sample position onto the 16×16 luma and 8×8 chroma planes and accessing the nearest chroma values to the sample position (corresponding to nearest filtering in step 3 of Figure 12.2), while bilinearly interpolating Y', prior to conversion to $R'G'B'$. The result is color aliasing, with a loss of brightness from interpolation of nonlinear luma values.
- The right-most image shows bicubic reconstruction of chroma to the original Y' resolution and subsequent filtering after conversion to $R'G'B'$ — corresponding to bilinear filtering of the right-most image in Figure 12.3 (after conversion to linear RGB). As in the Figure 12.3 case, the level of color saturation is between that of bilinear and nearest filtering, and consistent across the image.

A second source image demonstrates more continuous variation in chroma, with varying spatial frequency.

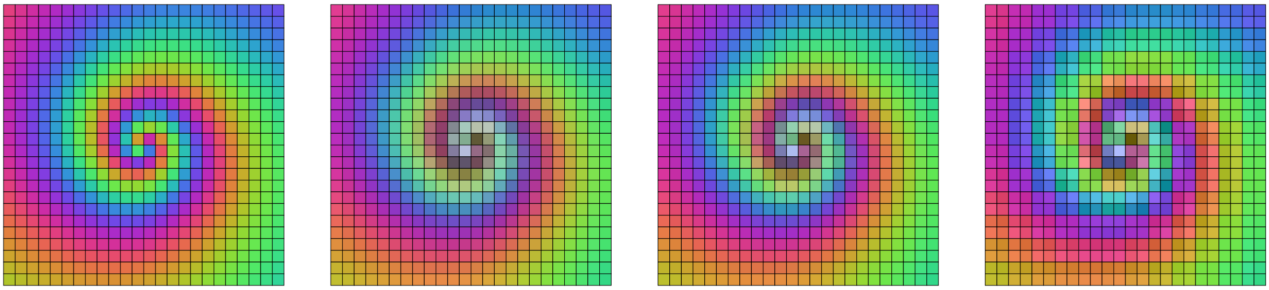


Figure 12.5: A radial rainbow pattern reconstructed at its original size

In Figure 12.5:

- The left-most image shows the original image: a 24×24 pattern of color changes that increase in frequency towards the middle of the image.

To generate the remaining images, the $R'G'B'$ pattern is converted to $Y'C_BC_R$ with the chroma difference channels downsampled by 2 on each axis (that is, “4:2:0” downsampling) by averaging after the color model conversion, resulting in 24×24 Y' values and 12×12 C_B and C_R values. These chroma values are then reconstructed to the original resolution before conversion to $R'G'B'$ pixels.

- The second-from-left image shows the result of reconstructing the chroma samples to luma resolution using bilinear interpolation between adjacent chroma values, which are assumed to be at the midpoint of each 2×2 quad. Each chroma value used is therefore a weighted average of the surrounding chroma samples; since the chroma values vary quickly, the most visible effect of this is to reduce the saturation at the higher-frequency region near the center of the image, whereas colors are recovered quite faithfully in the low-frequency regions towards the image edges.
- The second-from-right image uses a bicubic filter to reconstruct the chroma values, as in Figure 12.3. This again has the effect of increasing the significance of the nearest chroma sample, slightly restoring the lost saturation compared with bilinear filtering in the high frequency region.
- The rightmost example simply reconstructs the chroma values at each luma position by replicating the nearest chroma sample to the corresponding luma coordinates. The result retains some missing saturation relative to the interpolated examples; the chroma channels were constructed by averaging quads of chroma values corresponding to each $R'G'B'$ texel, so some saturation has still been lost in areas of high frequency chroma, but there is no further saturation loss in chroma reconstruction. However, aliasing is quite visible.

The final example shows this 24×24 image scaled up to 30×30 pixels.

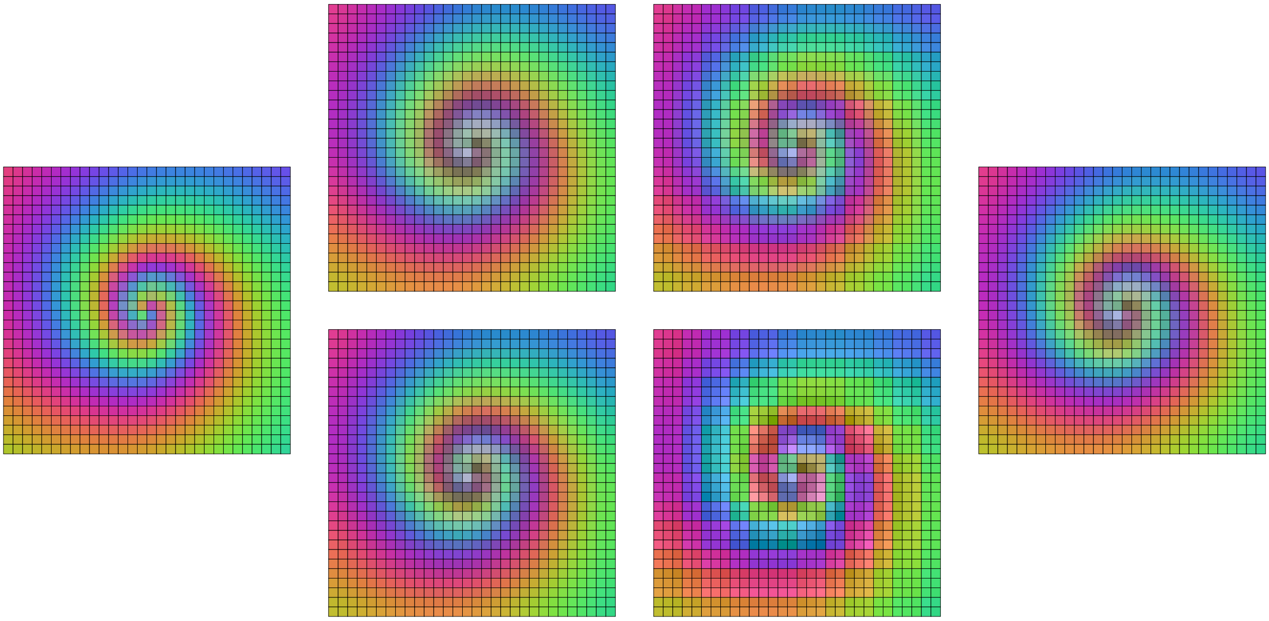


Figure 12.6: A radial rainbow pattern upscaled from 24×24 to 30×30

In Figure 12.6:

- The left-most image shows the original $R'G'B'$ image upscaled to 30×30 pixels directly (after conversion to RGB, using bilinear interpolation) for reference.
- The top-left image shows bilinear filtering for chroma reconstruction, using the explicit reconstruction used in Figure 12.1: the chroma values are reconstructed at each of the 24×24 luma sample positions by bilinear interpolation, the resulting "4:4:4" values are converted to $R'G'B'$, and the resulting 24×24 color values are bilinearly interpolated (after conversion to linear RGB) to get a final color for each pixel. Since the chroma reconstruction is as shown for the linear example in Figure 12.5, the result is desaturated in the high frequency regions relative to the original image, but the resulting filtering is consistent across the image coordinates.
- The bottom-left image shows bilinear filtering of chroma values by projecting the sample position directly onto the the 24×24 luma and downsampled 12×12 chroma planes, as shown in Figure 12.2, prior to conversion to $R'G'B'$. Since the resulting chroma sampling positions are at varying distances from the position of the original chroma values due to the scaling of the image, the result is a variation in saturation across the image — partly recovering some of the loss of saturation in the top left case (most visible in orange bands six pixels above and to the left of the spiral center), at the cost of color aliasing and inconsistency. For a static image at a fixed scale ratio, this effect may be considered minor, since it affects primarily high frequency color data — but it may be more intrusive if the sample positions change over time, as with a projection of video onto a moving 3D surface.
- The top-right image shows chroma reconstruction to the 24×24 Y' resolution by replicating the nearest chroma values to each Y' position, conversion to $R'G'B'$, and bilinearly filtering the resulting 24×24 values in RGB space (corresponding to Figure 12.1 with a nearest filter in step 3). While the chroma aliasing from Figure 12.5 is still highly visible, the interpolation helps to reduce its intrusiveness slightly, and the effect is consistent across the image.
- The bottom-right image shows chroma reconstruction by projecting the sample position onto the 16×16 luma and 8×8 chroma planes and accessing the nearest chroma values to the sample position (corresponding to nearest filtering in step 3 of Figure 12.2), while bilinearly interpolating Y', prior to conversion to $R'G'B'$. The result is color aliasing, amplified by the scaling effect relative to Figure 12.5, with luma values still interpolated.
- The right-most image shows bicubic reconstruction of chroma to the original Y' resolution and subsequent filtering after conversion to $R'G'B'$ — corresponding to bilinear filtering of the right-most image in Figure 12.5. As in the Figure 12.5 case, the level of color saturation is between that of bilinear and nearest filtering, and consistent across the image.

The remaining examples show similar chroma reconstruction, but assuming that the chroma samples are logically cosited with even luma samples (that is, aligned with even luma coordinates in each axis). That is, for each luma sample at $Y'_{(x,y)}$ there are chroma samples located at $\left(2\left\lfloor\frac{x}{2}\right\rfloor, 2\left\lfloor\frac{y}{2}\right\rfloor\right)$ in luma coordinates, and for chroma $C_{B(x,y)}$ and $C_{R(x,y)}$ there are luma samples at $(x+0.25\pm0.25, y+0.25\pm0.25)$ in chroma coordinates. Note that there are video standards for which chroma is logically cosited with luma in one axis, but falls at the midpoint of luma values in the other.

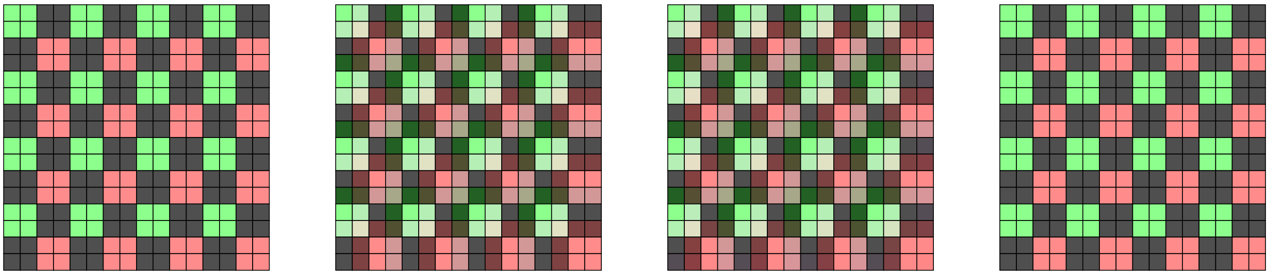


Figure 12.7: A cosited colored checker pattern reconstructed at its original size

In Figure 12.7:

- The left-most image shows the original image: a 16×16 checkerboard of colored squares, each occupying 2×2 texels.

To generate the remaining images, the $R'G'B'$ pattern is converted to $Y'C_BC_R$ with the chroma difference channels downsampled by 2 on each axis (that is, “4:2:0” downsampling) after the color model conversion by taking the top left texel chroma value of each 2×2 quad, resulting in 16×16 Y' values and 8×8 C_B and C_R values. The chroma values are then reconstructed to the original resolution before conversion to $R'G'B'$ pixels.

- The second-from-left image shows the result of reconstructing the chroma samples to luma resolution using bilinear interpolation between adjacent chroma values, which are assumed to be aligned with the the top left texel of each 2×2 quad. The top left texel of each quad therefore replicates the original color accurately, and the remaining chroma values are a weighted average of the surrounding chroma samples. Most chroma values used are therefore a weighted average of the surrounding chroma samples; since the chroma values vary quickly, the most visible effect of this is to reduce the saturation of the colored squares away from the top left texel of each quad, and to shift the chroma of the image up and to the left, since the source image has constant chroma for values which this reconstruction approach is interpolating. Note that the pixels at the edge of the image are not interpolating because the accessed chroma coordinates are clamped.
- The second-from-right image uses a bicubic filter to reconstruct the chroma values, as in Microsoft’s suggestion: the chroma of even coordinates is used directly, and at odd coordinates the chroma is calculated as $\frac{9}{16}$ times the two nearest samples minus $\frac{1}{16}$ times the two surrounding samples, on each axis. This has the effect of a mild sharpening in chroma, but the difference from the bilinear filtering case in this example is subtle.
- The rightmost sample simply reconstructs the chroma values by replicating the nearest chroma sample to the luma position (rounding the coordinate down); since the chroma values for each quad in the original image are identical, for this source image the reconstruction is perfect (matching the left-most image), and the effect is identical to the nearest chroma reconstruction in Figure 12.3.

The next example shows the result of scaling this 16×16 image to 21×21 pixels.

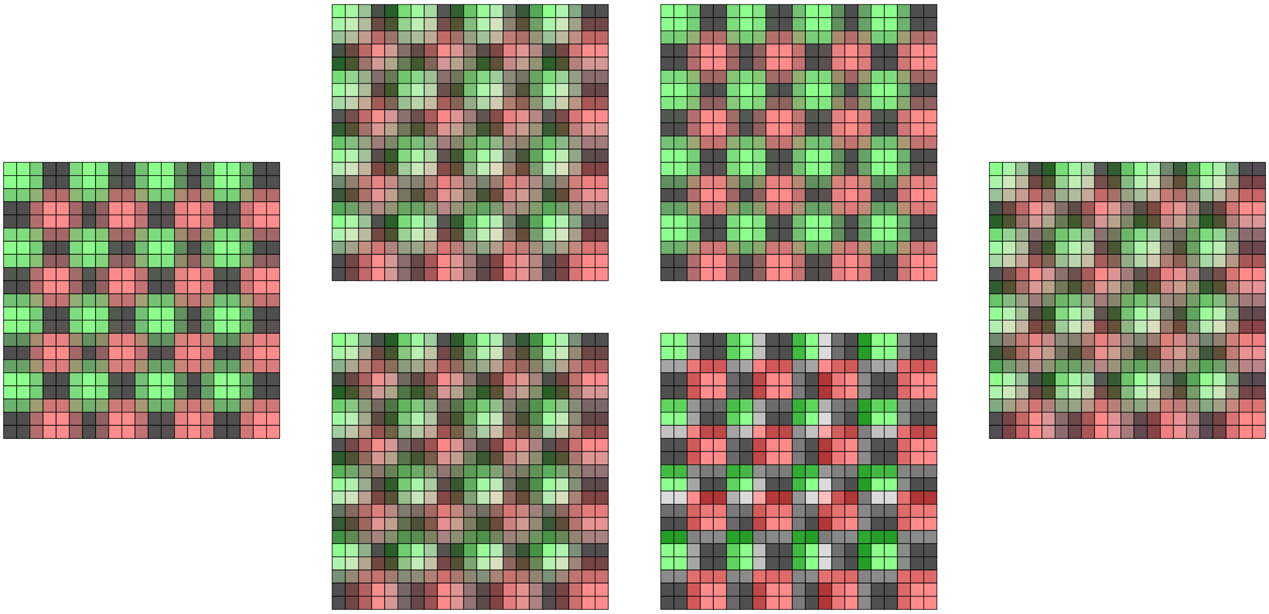


Figure 12.8: A cosited colored checker pattern upscaled from 16×16 to 21×21

In Figure 12.8:

- The left-most image shows the original $R'G'B'$ image directly upscaled from 16×16 to 21×21 pixels with bilinear filtering (after conversion to linear RGB), for reference.
- The top-left image shows bilinear filtering for chroma reconstruction, using the explicit reconstruction used in Figure 12.1: the chroma values for the top left of each quad in the 16×16 luma sample positions are used exactly and the remainder are reconstructed by bilinear interpolation, as in Figure 12.7, and the resulting "4:4:4" values are converted to $R'G'B'$; the resulting 16×16 color values are bilinearly interpolated (after conversion to linear RGB) to get a final color for each pixel. Since the chroma reconstruction is as shown for the linear example in Figure 12.7, chroma is similarly shifted up and left relative to the "correct" chroma position for this source image, and intermediate values are desaturated compared with the original; however the resulting filtering is consistent across the image.
- The bottom-left image shows bilinear filtering of luma and chroma values by projecting the sample position directly onto the 16×16 luma and downsampled 8×8 chroma planes, as shown in Figure 12.2, prior to conversion to $R'G'B'$. Since the resulting chroma sampling positions fall at varying distances from the position of the original chroma values due to the scaling of the image (and the chroma values are nonlinear), this causes saturation to vary across the image. Additionally the interpolation of luma and chroma in nonlinear space causes reduced brightness and saturation at interpolated pixels.
- The top-right image shows chroma reconstruction to the 16×16 Y' resolution by replicating the nearest chroma values to each Y' with the top left luma coordinates corresponding to the position of chroma for each 2×2 quad — but rounding the other projected coordinates down such that the same chroma values are used for the entire quad. The result is converted to $R'G'B'$, and the resulting 16×16 values are bilinearly filtered in RGB space (corresponding to Figure 12.1 with a nearest filter in step 3). Since this mechanism perfectly replicates the chroma of this original image example, as shown in Figure 12.7, the result matches the bilinearly-filtered $R'G'B'$ image, and also the equivalent image in Figure 12.4.
- The bottom-right image shows chroma reconstruction by projecting the sample position directly onto the 16×16 luma and 8×8 chroma planes, where chroma samples are aligned with the top left luma of each 2×2 quad, and accessing the nearest chroma values; this corresponds to nearest filtering in step 3 of Figure 12.2. Y' is bilinearly interpolated prior to conversion to $R'G'B'$. Reduced brightness is caused by linearly interpolating nonlinear luma values, and the chroma and luma samples are visibly out of alignment due to chroma aliasing — an effect common to analog television broadcasts.
- The right-most image shows bicubic reconstruction of chroma to the original Y' resolution and subsequent filtering after conversion to $R'G'B'$ — corresponding to bilinear filtering of the right-most image in Figure 12.7. As in the Figure 12.7 case, the distinction from the bilinearly-filtered case is subtle.

The second source image demonstrates more continuous variation in chroma, with varying spatial frequency, here again reproduced assuming that chroma samples are cosited with even luma coordinates.

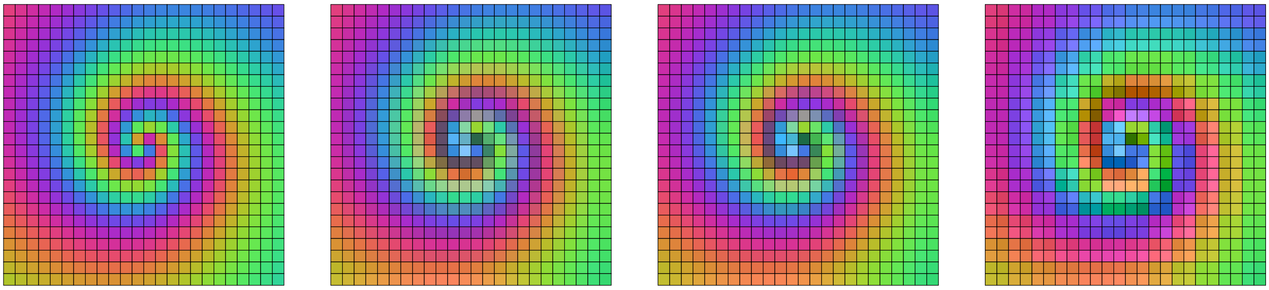


Figure 12.9: A cosited radial rainbow pattern reconstructed at its original size

In Figure 12.9:

- The left-most image shows the original image: a 24×24 pattern of color changes that increase in frequency towards the middle of the image.

To generate the remaining images, the $R'G'B'$ pattern is converted to $Y'C_BC_R$ with the chroma difference channels downsampled by 2 on each axis (that is, “4:2:0” downsampling) after the color model conversion by taking the top left chroma value of each 2×2 quad, resulting in 24×24 Y' values and 12×12 C_B and C_R values. These chroma values are then reconstructed to the original resolution before conversion to $R'G'B'$ pixels.

- The second-from-left image shows the result of reconstructing the chroma samples to luma resolution using bilinear interpolation between adjacent chroma values, which are assumed to be aligned with the the top left texel of each 2×2 quad. The top left texel of each quad therefore replicates the original color accurately, and the remaining chroma values are a weighted average of the surrounding chroma samples. Most chroma values used are therefore a weighted average of the surrounding chroma samples; since the chroma values vary quickly, the most visible effect of this is to reduce the saturation at many pixels in the higher-frequency region and introduce color aliasing near the center of the image, whereas colors are recovered quite faithfully in the low-frequency regions at the image edges.
- The second-from-right image uses a bicubic filter to reconstruct the chroma values, as in Figure 12.7. This slightly increases the saturation of some pixels due to chroma sharpening in the high chroma frequency region, but the difference from the bilinear case is subtle.
- The rightmost sample simply reconstructs the chroma values by replicating the chroma sample corresponding to the top left of each 2×2 quad. Since in this case the created chroma values were not antialiased during chroma reconstruction, the desaturation seen in the corresponding image of Figure 12.5 is replaced with chroma aliasing, with chroma regions being shifted down and right relative to the luma values with which they should be associated because of the replication of the top left chroma sample.

The final example shows this 24×24 image scaled up to 30×30 pixels.

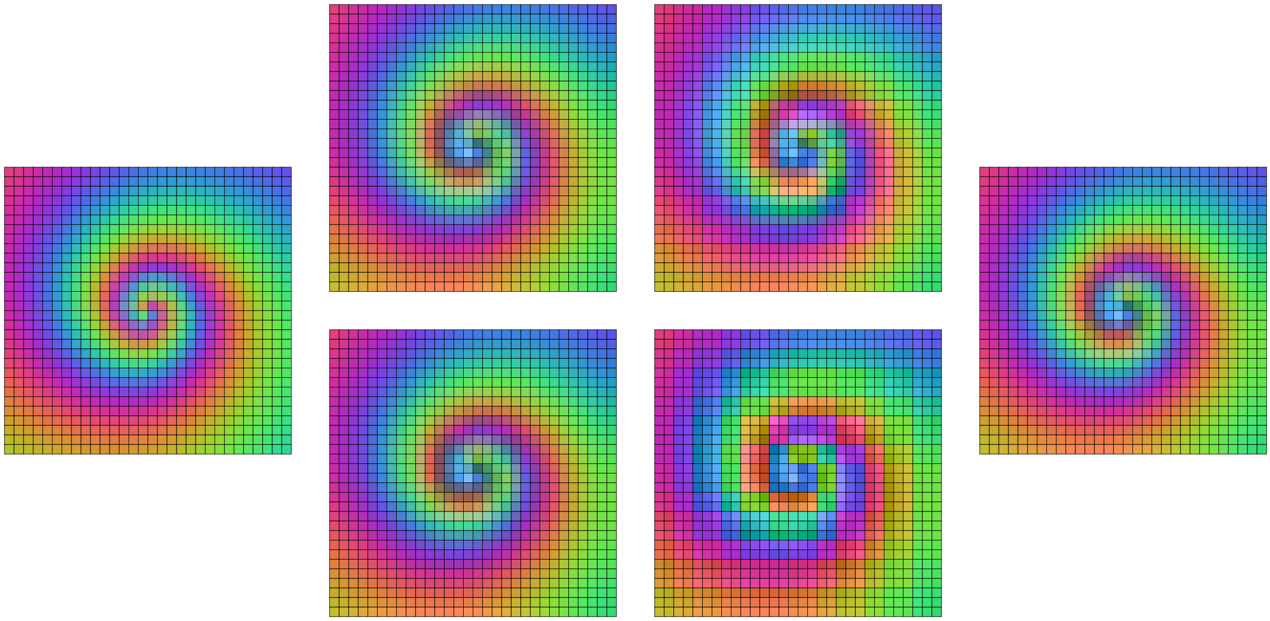


Figure 12.10: A cosited radial rainbow pattern upscaled from 24×24 to 30×30

In Figure 12.10:

- The left-most image shows the original $R'G'B'$ image upscaled to 30×30 pixels directly (after conversion to RGB, using bilinear interpolation) for reference.
- The top-left image shows bilinear filtering for chroma reconstruction, using the explicit reconstruction used in Figure 12.1: the chroma values are reconstructed at each of the 24×24 luma sample positions by bilinear interpolation as in Figure 12.9, the resulting “4:4:4” values are converted to $R'G'B'$, and the resulting 24×24 color values are bilinearly interpolated (after conversion to linear RGB) to get a final color for each pixel. Since the chroma reconstruction is as shown for the linear example in Figure 12.9, the result is desaturated at many pixels in the high frequency regions relative to the original image and some color aliasing is visible especially at the image center, but the resulting filtering is consistent across the image coordinates.
- The bottom-left image shows projection of sample positions directly onto the 24×24 luma and downsampled 12×12 chroma planes, and bilinear filtering of these nonlinear values (as shown in Figure 12.2), prior to conversion to $R'G'B'$. Since the resulting chroma sampling positions are at varying distances from the position of the original chroma values due to the scaling of the image, the result is a variation in saturation across the image; additionally the interpolation of nonlinear luma and chroma values results in a loss of image brightness and saturation.
- The top-right image shows chroma reconstruction to the 24×24 Y' resolution by replicating the nearest chroma values to each Y' (rounding coordinates down), conversion to $R'G'B'$, and bilinearly filtering the resulting 24×24 values in RGB space (corresponding to Figure 12.1 with a nearest filter in step 3). While the chroma aliasing from Figure 12.9 is still highly visible, interpolation helps to reduce its intrusiveness slightly, and the effect is consistent across the image.
- The bottom-right image reconstructs chroma by accessing the nearest chroma values to the sample position projected onto the chroma planes (corresponding to nearest filtering in step 3 of Figure 12.2) and bilinearly interpolating Y', prior to conversion to $R'G'B'$. The result is color aliasing, amplified by the scaling effect relative to Figure 12.9, with nonlinear luma values still interpolated linearly (reducing brightness) and partly displaced relative to the chroma values.
- The right-most image shows bicubic reconstruction of chroma to the original Y' resolution and subsequent filtering after conversion to $R'G'B'$ — corresponding to bilinear filtering of the right-most image in Figure 12.9. As in the Figure 12.9 case, the level of color saturation is between that of bilinear and nearest filtering, and consistent across the image; the difference from the bilinear filtering case is subtle.

Chapter 13

Transfer functions

13.1 About transfer functions (informative)

The **transfer function** describes the mapping between a linear numerical representation and a nonlinear encoding. The eye is more sensitive to relative light levels than absolute light levels. That is, if one image region is twice as bright as another, this will be more visible than if one region is 10% brighter than another, even if the absolute difference in brightness is the same in both cases. To make use of the eye's nonlinear response to light to provide better image quality with a limited number of quantization steps, it is common for color encodings to work with a nonlinear representation which dedicates a disproportionate number of bits to darker colors compared with lighter colors. The typical effect of this encoding is that mid-tones are stored with a larger (nearer-to-white) numerical value than their actual brightness would suggest, and that mid-values in the nonlinear encoding typically represent darker intensities than their fraction of the representation of white would suggest.

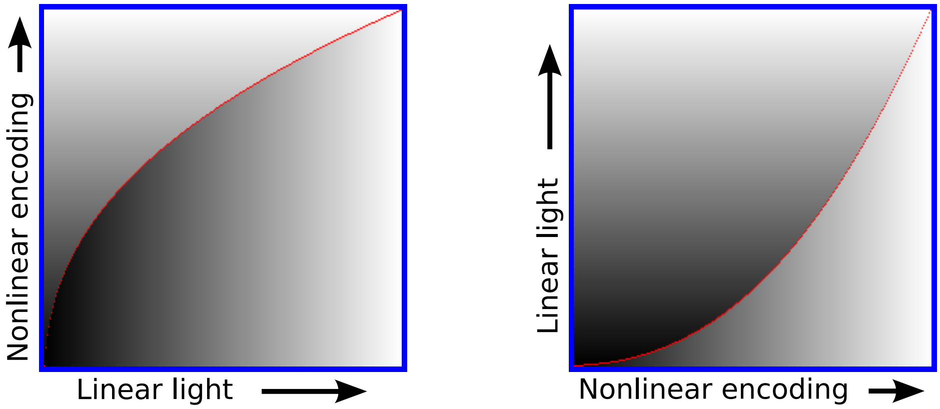


Figure 13.1: Conversion curves between linear light and encoded values (sRGB example)

The behavior has historically been approximated by a power function with an exponent conventionally called γ: $\{R,G,B\}_{\text{nonlinear}} = \{R,G,B\}_{\text{linear}}{}^{\gamma}$. Hence this conversion is colloquially known as *gamma correction*.

Note
Many practical transfer functions incorporate a small linear segment near 0, instead of being a pure power function. This linearity reduces the required resolution for representing the conversion, especially where results must be reversible, and also reduces the noise sensitivity of the function in an analog context. When combined with a linear segment, the power function has a different exponent from the pure power function that best approximates the resulting curve.

A consequence of this nonlinear encoding is that many image processing operations should not be applied directly to the raw nonlinearly-encoded numbers, but require conversion back to a linear representation. For example, linear color gradients will appear distorted unless the encoding is adjusted to compensate for the encoding; CGI lighting calculations need linear intensity values for operation, and filtering operations require texel intensities converted to linear form.

In the following example, the checker patterns are filtered in the right-most square of each row by averaging the checker colors, emulating a view of the pattern from a distance at which the individual squares are no longer distinct. The intended effect can be seen by viewing the diagram from a distance, or deliberately out of focus. The output is interpreted using the sRGB EOTF, approximating the behavior of a CRT with uncorrected signals. The background represents 50% gray.

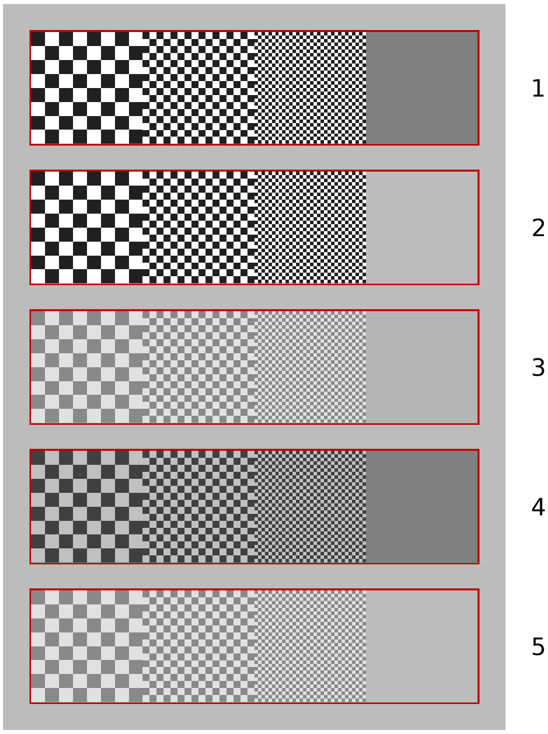


Figure 13.2: Averaging checker values with different transfer functions

- **In row 1** black (0.0) and white (1.0) texels are averaged to calculate a 0.5 value in the frame buffer. Due to the sRGB nonlinearity, the appearance of the value 0.5 is darker than the average value of the black and white texels, so the gray box appears darker than the average intensity of the checker pattern.
- **In row 2** the 0.5 average of the frame buffer is corrected using the sRGB (electro-optical) EOTF $^{-1}$ to ~0.74. The gray box accordingly appears a good match for the average intensity of the black and white squares on most media.
- **In row 3** the checker pattern instead represents values of 25% and 75% of the light intensity (the average of which should be the same as the correct average of the black and white squares in the first two rows). These checker values have been converted to their nonlinear representations, as might be the case for a texture in this format: the darker squares are represented by ~0.54, and the lighter squares are represented by ~0.88. Averaging these two values to get a value of 0.71 results in the right-most square: this appears slightly too dark compared with the correct representation of mid-gray (~0.74) because, due to the nonlinear encoding, the calculated value should not lie exactly half way between the two end points. Since the end points of the interpolation are less distant than the black and white case, the error is smaller than in the first example, and can more clearly be seen by comparing with the background gray.
- **In row 4** the checker values have been converted using the EOTF to a linear representation which can be correctly interpolated, but the resulting output represents linear light, which is therefore interpreted as too dark by the nonlinear display.
- **In row 5** the results of row 4 have been converted back to the nonlinear representation using the EOTF $^{-1}$. The checker colors are restored to their correct values, and the interpolated value is now the correct average intensity of the two colors.

Incorrectly-applied transfer functions can also introduce color shifts, as demonstrated by the saturation change in the following examples:

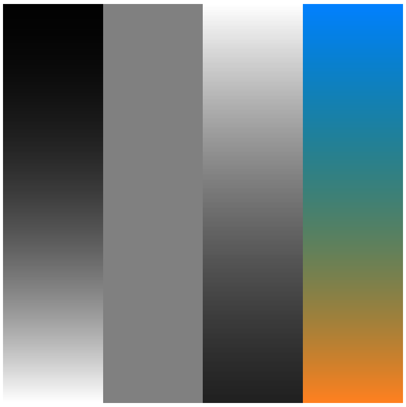


Figure 13.3: R, G, B channels and combined color gradient with linear light intensity in each channel

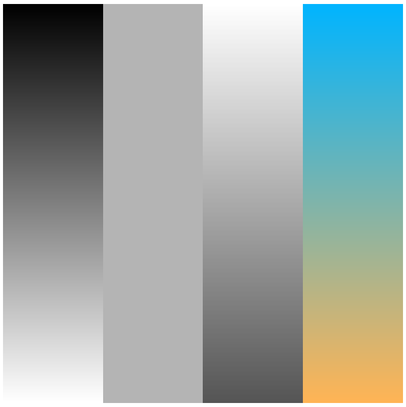


Figure 13.4: R', G', B' channels and combined color gradient with nonlinear sRGB encoding in each channel

A standard for image representation typically defines one or both of two types of transfer functions:

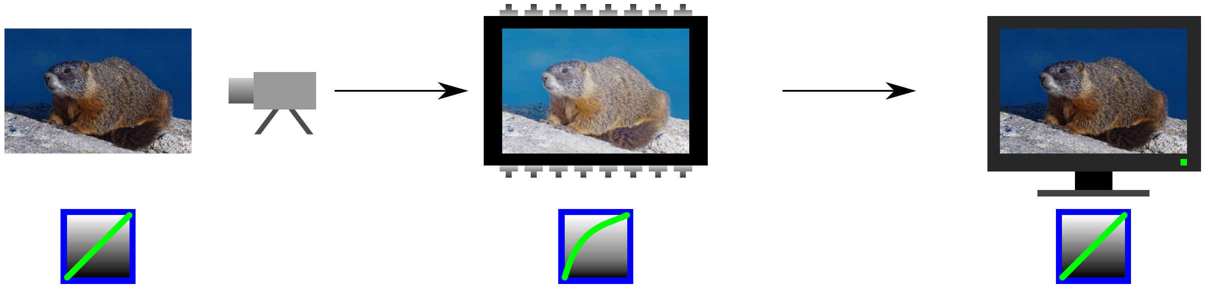


Figure 13.5: Opto-electronics and electro-optical transfer functions

- An opto-electronic transfer function (OETF) defines the conversion between a normalized linear light intensity as recorded in the scene, and a nonlinear electronic representation. Note that there is no requirement that this directly correspond to actual captured light: the content creator or scene capture hardware may adjust the apparent intensity compared to reality for aesthetic reasons, as though the colors (or lighting) of objects in the scene were similarly different from reality. For example, a camera may implement a roll-off function for highlights, and a content creator may introduce tone mapping to preserve shadow detail in the created content, with these being logically recorded as if the scene was actually modified accordingly. The inverse of the OETF (the conversion from the nonlinear electronic representation to linear scene light) is written OETF $^{-1}(n)$.
- An electro-optical transfer function (EOTF) converts between a nonlinear electronic representation and a linear light normalized intensity as produced by the output display. The inverse of the EOTF (the conversion from linear display light to the nonlinear electronic representation) is written EOTF $^{-1}(n)$. Typical CRT technology has implicitly applied a nonlinear EOTF which coincidentally offered an approximately perceptually linear gradient when supplied with a linear voltage; other display technologies must implement the EOTF explicitly. As with the OETF, the EOTF describes a logical relationship that in reality will be modified by the viewer's aesthetic configuration choices and environment, and by the implementation choices of the display medium. Modern displays often incorporate proprietary variations from the reference intensity, particularly when mapping high dynamic range content to the capabilities of the hardware.

Note

Some color models derive chroma (color difference) channels wholly or partly from nonlinear intensities. It is common for image representations which use these color models to use a reduced-resolution representation of the chroma channels, since the human eye is less sensitive to high resolution chroma errors than to errors in brightness. Despite the color shift introduced by interpolating nonlinear values, these chroma channels are typically resampled directly in their native, nonlinear representation.

The opto-optical transfer function (OOTF) of a system is the relationship between linear input light intensity and displayed output light intensity: OOTF(*input*) = EOTF(OETF(*input*)). It is common for the OOTF to be nonlinear. For example, a brightly-lit scene rendered on a display that is viewed in a dimly-lit room will typically appear washed-out and lacking contrast, despite mapping the full range of scene brightness to the full range supported by the display. A nonlinear OOTF can compensate for this by reducing the intensity of mid-tones, which is why television standards typically assume a nonlinear OOTF: logical scene light intensity is not proportional to logical display intensity.

In the following diagram, the upper pair of images are identical, as are the lower pair of images (which have mid-tones darkened but the same maximum brightness). Adaptation to the surround means that the top left and lower right images look similar.

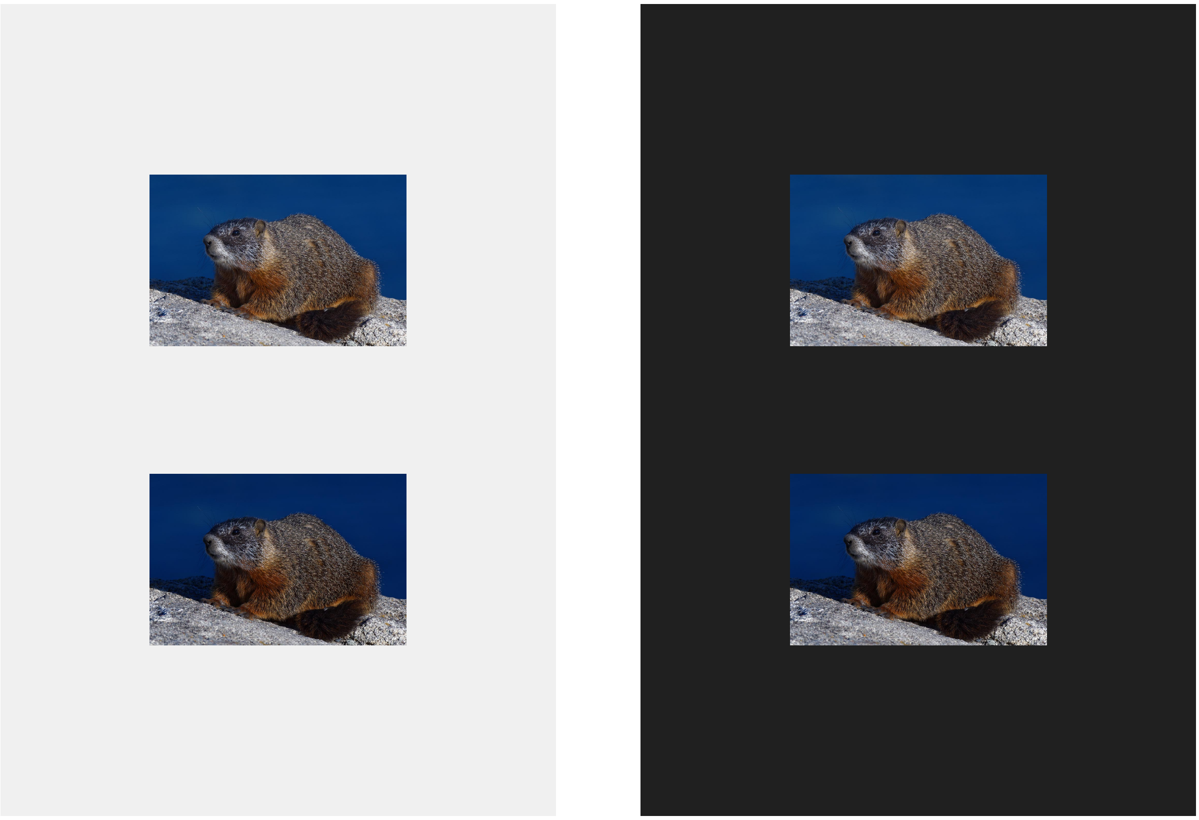


Figure 13.6: Simultaneous contrast

In the context of a nonlinear OOTF, an application should be aware of whether operations on the image are intended to reflect the representation of colors in the scene or whether the intent is to represent the output color accurately, at least when it comes to the transfer function applied. For example, an application could choose to convert lighting calculations from a linear to nonlinear representation using the OETF (to match the appearance of lighting in the scene), but to perform image scaling operations using the EOTF in order to avoid introducing intensity shifts due to filtering. Working solely with the EOTF or OETF results in ignoring the intended OOTF of the system.

In practice, the OOTF is usually near enough to linear that this distinction is subtle and rarely worth making for computer graphics, especially since computer-generated images may be designed to be viewed in brighter conditions which would merit a linear OOTF, and since a lot of graphical content is inherently not photo-realistic (or of limited realism, so that the transfer functions are not the most important factor in suspending disbelief). For video and photographic content viewed in darker conditions, the nonlinearity of the OOTF is significant. The effect of a nonlinear OOTF is usually secondary to the benefits of using nonlinear encoding to reduce quantization.

By convention, nonlinearly-encoded values are distinguished from linearly-encoded values by the addition of a prime ($'$) symbol. For example, (R,G,B) may represent a linear set of red, green and blue components; (R',G',B') would represent the nonlinear encoding of each value. Typically the nonlinear encoding is applied to additive primary colors; derived color differences may or may not retain the prime symbol.

Charles Poynton provides a further discussion on “Gamma” in http://www.poynton.com/PDFs/TIDV/Gamma.pdf.

13.2 ITU transfer functions

Note

“ITU” is used in this context as a shorthand for the OETF shared by the current BT.601, BT.709 and BT.2020 family of standard dynamic range digital television production standards. The same OETF is shared by SMPTE 170M. The ITU does define other transfer functions, for example the PQ and HLG transfer functions described below (originating in BT.2100) and the list of EOTFs listed in BT.470-6.

13.2.1 ITU OETF

The ITU-T BT.601, BT.709 and BT.2020 specifications (for standard definition television, HDTV and UHDTV respectively), and SMPTE 170M, which defines NTSC broadcasts, define an opto-electrical transfer function. The (OETF) conversion from linear (R,G,B) encoding to nonlinear (R',G',B') encoding is:

$$R' = \begin{cases} R \times 4.500, & R < \beta \\ \alpha \times R^{0.45} - (\alpha - 1), & R \geq \beta \end{cases}$$

$$G' = \begin{cases} G \times 4.500, & G < \beta \\ \alpha \times G^{0.45} - (\alpha - 1), & G \geq \beta \end{cases}$$

$$B' = \begin{cases} B \times 4.500, & B < \beta \\ \alpha \times B^{0.45} - (\alpha - 1), & B \geq \beta \end{cases}$$

Where α = 1.0993 and β = 0.0181 for 12-bit encoding in the BT.2020 specification, and $\alpha = 1.099$ and $\beta = 0.018$ otherwise.

13.2.2 ITU OETF $^{-1}$

From this the inverse (OETF $^{-1}$) transformation can be deduced:

$$R = \begin{cases} \frac{R'}{4.500}, & R' < \delta \\ \left(\frac{R'+(\alpha-1)}{\alpha}\right)^{\frac{1}{0.45}}, & R' \geq \delta \end{cases}$$

$$G = \begin{cases} \frac{G'}{4.500}, & G' < \delta \\ \left(\frac{G'+(\alpha-1)}{\alpha}\right)^{\frac{1}{0.45}}, & G' \geq \delta \end{cases}$$

$$B = \begin{cases} \frac{B'}{4.500}, & B' < \delta \\ \left(\frac{B'+(\alpha-1)}{\alpha}\right)^{\frac{1}{0.45}}, & B' \geq \delta \end{cases}$$

δ can be deduced from $\alpha \times \beta^{0.45}$ - (α - 1) ≈ 0.0812. Note that this is subtly different from 4.5 × β due to rounding. See the following section for the derivation of these values.

SMPTE 170M-2004, which defines the behavior of NTSC televisions, defines the EOTF of the “reference reproducer” as the OETF $^{-1}$ function above, with δ explicitly written as 0.0812. Therefore the SMPTE 170M-2004 EOTF $^{-1}$ equals the OETF given above. The “reference camera” of SMTPE 170M-2004 has an OETF function matching that of the ITU specifications. That is, the OOTF of the system described in SMPTE 170M-2004 provides a linear mapping of captured scene intensity to display intensity: the SMPTE 170M-2004 OETF is described as being chosen to result in a linear OOTF on a typical display. This is distinct from the current ITU specifications, which assume a nonlinear OOTF. SMPTE 170M-2004 also represents a change from the “assumed gamma” of 2.2 associated with most NTSC display devices as described in ITU-T BT.470-6 and BT.2043, although these standards also define a linear OOTF.

This “ITU” OETF is closely approximated by a simple power function with an exponent of 0.5 (and therefore the OETF $^{-1}$ is quite closely approximated by a simple power function with an exponent of 2.0); the linear segment and offset mean that the best match is *not* the exponent of 0.45 that forms part of the exact equation. ITU standards deliberately chose a different transfer curve from that of a typical CRT in order to introduce a nonlinear OOTF, as a means to compensate for the typically dim conditions in which a television is viewed. ITU BT.2087 refers to the approximation of the OETF with a square root $\left(\gamma = \frac{1}{2}\right)$ function.

The following graph shows the close relationship between the ITU OETF (shown in red) and a pure power function with $\gamma = \frac{1}{2}$ (in blue). The difference between the curves is shown in black. The largest difference between the curve values at the same point when quantized to 8 bits is 15, mostly due to the sharp vertical gradient near 0.

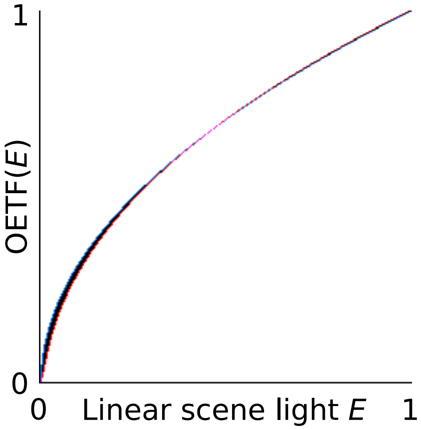


Figure 13.7: ITU OETF (red) vs pure gamma $^1/_2$ (blue)

Note

SMPTE 170M-2004 contains a note that the OETF is a more “technically correct” definition of the transfer function, and compares it to a “transfer gradient (gamma exponent) of 2.2” in previous specifications, and that the OETF in older documents is described as “1/2.2 (0.455. . .)”. While both versions define a linear OOTF, there is no explicit mention that curve has substantially changed; this might be due to conflation of the 0.455 exponent in older specifications with the 0.45 exponent in the new formulae. The ITU OETF is actually a closer match to a gamma exponent of $\frac{1}{2.0}$, as shown above; it is a relatively poor match to a gamma exponent of $\frac{1}{2.2}$; the following graph shows the difference between the ITU OETF (shown in red) and a pure power function with $\gamma = \frac{1}{2.2}$ (in blue). The difference between the curves is shown in black.

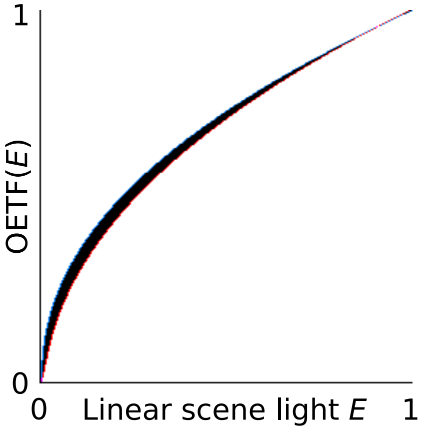


Figure 13.8: ITU OETF (red) vs pure gamma $^1/_{2.2}$ (blue)

13.2.3 Derivation of the ITU alpha and beta constants (informative)

Using the 12-bit encoding values for α and β from Rec.2020, there is an overlap around a nonlinear value of 0.08145. In other cases, the conversion from linear to nonlinear representation with encoding introduces a discontinuity between (0.018 × 4.500) = 0.081 and ($1.099 \times 0.018^{0.45}$ - 0.099) ≈ 0.0812, corresponding to roughly a single level in a 12-bit range. SMPTE 170M-2004 provides formulae for both transformations and uses 0.0812 as a case selector for the nonlinear-to-linear transformation.

The values of α and β in the ITU function were apparently chosen such that the linear segment and power segment meet at the same value and with the same derivative (that is, the linear segment meets the power segment at a tangent). The α and β values can be derived as follows:

At $\{R,G,B\} = \beta$, the linear and nonlinear segments of the curve must calculate the same value:

$$4.5 \times \beta = \alpha \times \beta^{0.45} - (\alpha - 1)$$

Additionally, the derivatives of the linear and nonlinear segments of the curve must match:

$$4.5 = 0.45 \times \alpha \times \beta^{-0.55}$$

The derivative can be rearranged to give the equation:

$$\alpha = 10 \times \beta^{0.55}$$

Substituting this into the original equation results in the following:

$$4.5 \times \beta = 10 \times \beta^{0.55} \times \beta^{0.45} - (10 \times \beta^{0.55} - 1)$$

This simplifies to:

$$5.5 \times \beta - 10 \times \beta^{0.55} + 1 = 0$$

This can be solved numerically (for example by Newton-Raphson iteration), and results in values of:

$$\begin{aligned} \beta &\approx 0.018053968510808 \\ \alpha &\approx 1.099296826809443 \\ \delta &= \alpha \times \beta^{0.45} - (\alpha - 1) = 4.5 \times \beta \\ &\approx 0.081242858298635 \end{aligned}$$

13.3 sRGB transfer functions

13.3.1 sRGB EOTF

The sRGB specification defines an electro-optical transfer function. The EOTF conversion from nonlinear (R',G',B') encoding to linear (R,G,B) encoding is:

$$R = \begin{cases} \frac{R'}{12.92}, & R' \leq 0.04045 \\ \left(\frac{R'+0.055}{1.055}\right)^{2.4}, & R' > 0.04045 \end{cases}$$

$$G = \begin{cases} \frac{G'}{12.92}, & G' \leq 0.04045 \\ \left(\frac{G'+0.055}{1.055}\right)^{2.4}, & G' > 0.04045 \end{cases}$$

$$B = \begin{cases} \frac{B'}{12.92}, & B' \leq 0.04045 \\ \left(\frac{B'+0.055}{1.055}\right)^{2.4}, & B' > 0.04045 \end{cases}$$

13.3.2 sRGB EOTF^{-1}

The corresponding sRGB EOTF^{-1} conversion from linear (R,G,B) encoding to nonlinear (R',G',B') encoding is:

$$R' = \begin{cases} R \times 12.92, & R \leq 0.0031308 \\ 1.055 \times R^{\frac{1}{2.4}} - 0.055, & R > 0.0031308 \end{cases}$$

$$G' = \begin{cases} G \times 12.92, & G \leq 0.0031308 \\ 1.055 \times G^{\frac{1}{2.4}} - 0.055, & G > 0.0031308 \end{cases}$$

$$B' = \begin{cases} B \times 12.92, & B \leq 0.0031308 \\ 1.055 \times B^{\frac{1}{2.4}} - 0.055, & B > 0.0031308 \end{cases}$$

13.3.3 sRGB EOTF vs gamma 2.2

The sRGB EOTF approximates a simple power function with an exponent of 2.2, which is intended to be consistent with legacy CRT content, particularly for NTSC devices, and to approximate the expected EOTF for BT.709 content, given the implicit OOTF used in production video content. sRGB is distinct from ITU-T BT.1886, which offers a (different) reference EOTF for flat panels used for HDTV and is also intended to complement BT.709; in addition to the change in EOTF, sRGB specifies a reference display maximum luminance of 80cd/m^2, compared with 100cd/m^2 for BT.1886. sRGB is also distinct from SMPTE 170M, which defines its EOTF as the inverse of its (and BT.709's) OETF.

The following graph compares the sRGB EOTF (in red) and a pure power function with $\gamma = 2.2$ (in blue); the area between the two curves is shown in black. The largest nonlinear difference at the same linear value when quantized to 8 bits is 3.

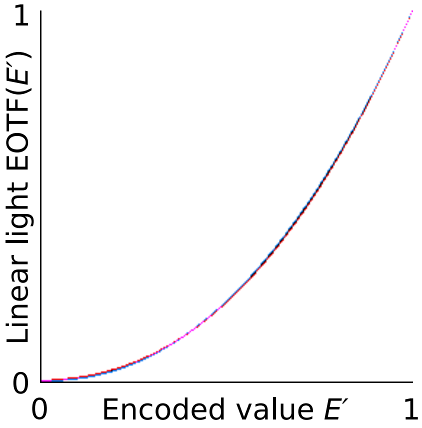


Figure 13.9: sRGB EOTF (red) vs pure gamma 2.2 (blue)

Note
The sRGB standard assumes a quantization scheme in which 0.0 is represented by the value 0 and 1.0 is represented by 255. Despite the goal of complementing ITU-T Rec. BT.709, this is different from the ITU "full-range" encoding scheme defined in ITU-T Rec. BT.2100, which represents 1.0 as a power of two (not $2^n - 1$) and therefore cannot exactly represent 1.0.

The following graph shows the relationship between the sRGB EOTF (shown in red, with nonlinear encoded input horizontal) and the ITU OETF (shown in blue, with nonlinear encoded output vertical). The result of applying the two functions in turn, resulting in the OOTF of a combined ITU-sRGB system, is shown in black. Since the sRGB EOTF approximates a power function with $\gamma = 2.2$ and the ITU OETF approximates a power function with $\gamma = 2.0$, also shown in green is the resulting OOTF corresponding to a power function with $\gamma = \frac{2.2}{2.0} = 1.1$.

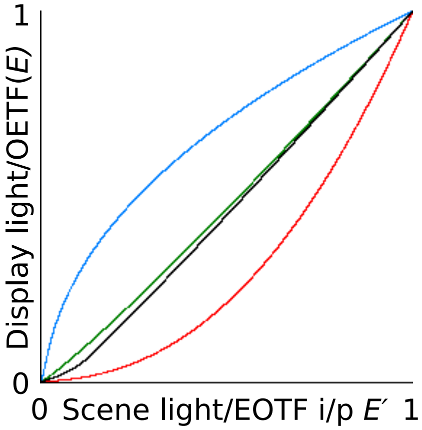


Figure 13.10: sRGB EOTF (red) and ITU OETF (blue)

13.3.4 scRGB EOTF and EOTF^{-1}

The original sRGB specification was defined only in terms of positive values between 0 and 1. Subsequent standards, such as scRGB annex B, use the same transfer function but expand the range to incorporate values less than 0 and greater than 1.0. In these cases, when the input channel to the conversion is negative, the output should be the negative version of the conversion applied to the absolute value of the input. That is:

$$R' = \begin{cases} -1.055 \times (-R)^{\frac{1}{2.4}} + 0.055, & R \leq -0.0031308 \\ R \times 12.92, & -0.0031308 < R < 0.0031308 \\ 1.055 \times R^{\frac{1}{2.4}} - 0.055, & R \geq 0.0031308 \end{cases}$$

$$G' = \begin{cases} -1.055 \times (-G)^{\frac{1}{2.4}} + 0.055, & G \leq -0.0031308 \\ G \times 12.92, & -0.0031308 < G < 0.0031308 \\ 1.055 \times G^{\frac{1}{2.4}} - 0.055, & G \geq 0.0031308 \end{cases}$$

$$B' = \begin{cases} -1.055 \times (-B)^{\frac{1}{2.4}} + 0.055, & B \leq -0.0031308 \\ B \times 12.92, & -0.0031308 < B < 0.0031308 \\ 1.055 \times B^{\frac{1}{2.4}} - 0.055, & B \geq 0.0031308 \end{cases}$$

Note

scRGB annex B changes the behavior of the $\{R, G, B\} = 0.0031308$ case compared with the sRGB specification. Since both calculations agree to seven decimal places, this is unlikely to be significant in most applications. scRGB annex B does not define the EOTF $^{-1}$, so the formulae below are derived by extending the sRGB formulae.

$$R = \begin{cases} -\left(\frac{0.055-R'}{1.055}\right)^{2.4}, & R' < -0.04045 \\ \frac{R'}{12.92}, & -0.04045 \leq R' \leq 0.04045 \\ \left(\frac{R'+0.055}{1.055}\right)^{2.4}, & R' > 0.04045 \end{cases}$$

$$G = \begin{cases} -\left(\frac{0.055-G'}{1.055}\right)^{2.4}, & G' < -0.04045 \\ \frac{G'}{12.92}, & -0.04045 \leq G' \leq 0.04045 \\ \left(\frac{G'+0.055}{1.055}\right)^{2.4}, & G' > 0.04045 \end{cases}$$

$$B = \begin{cases} -\left(\frac{0.055-B'}{1.055}\right)^{2.4}, & B' < -0.04045 \\ \frac{B'}{12.92}, & -0.04045 \leq B' \leq 0.04045 \\ \left(\frac{B'+0.055}{1.055}\right)^{2.4}, & B' > 0.04045 \end{cases}$$

Note

sYCC includes a hint that a 1cd/m^2 level of flare should be assumed for the reference 80cd/m^2 output, and that the black level should therefore be assumed to be $\frac{1}{80} = 0.0125$. It notes that the nonlinear sRGB $\{R', G', B'\}$ values can be corrected as follows:

$$E_{sYCC} = \begin{cases} 0.0125 - \left(\frac{1-0.0125}{1.055^{2.4}}\right) \times (0.055 - E'_{sRGB})^{2.4}, & E'_{sRGB} \leq -0.04045 \text{ [sic]} \\ 0.0125 + \frac{1-0.0125}{12.92} \times E'_{sRGB}, & -0.04045 \leq E'_{sRGB} \leq 0.04045 \\ 0.0125 + \left(\frac{1-0.0125}{1.055^{2.4}}\right) \times (0.055 + E'_{sRGB})^{2.4}, & E'_{sRGB} > 0.04045 \end{cases}$$

$$E_{sYCC} = (\text{linear})\{R_{sYCC}, G_{sYCC}, B_{sYCC}\}$$

$$E'_{sRGB} = (\text{nonlinear})\{R'_{sRGB}, G'_{sRGB}, B'_{sRGB}\}$$

This is equivalent to applying $E_{sYCC} = 0.0125 + \frac{1}{1-0.0125} \times E_{sRGB}$ to linear $\{R, G, B\}$ values. The resulting linear E_{sYCC} values then need to be nonlinearly encoded with the EOTF.

13.3.5 Derivation of the sRGB constants (informative)

Similar to the ITU transfer function, the EOTF $^{-1}$ of the sRGB function can be written as:

$$\{R,G,B\} = \begin{cases} \{R',G',B'\} \times 12.92, & \{R',G',B'\} \leq \beta \\ \alpha \times \{R',G',B'\}^{\frac{1}{2.4}} - (\alpha - 1), & \{R',G',B'\} < \beta \end{cases}$$

Like the ITU transfer function above, the values of α and β in the sRGB function appear to have been chosen such that the linear segment and power segment meet at the same value and with the same derivative (that is, the linear segment meets the power segment at a tangent). The α and β values can be derived as follows:

At $\{R',G',B'\} = \beta$, the linear and nonlinear segments of the function must calculate the same value:

$$12.92 \times \beta = \alpha \times \beta^{\frac{1}{2.4}} - (\alpha - 1)$$

Additionally, the derivatives of the linear and nonlinear segments of the function must match:

$$12.92 = \frac{\alpha \times \beta^{\frac{1}{2.4}-1}}{2.4}$$

This formula can be rearranged to give α in terms of β:

$$\alpha = 12.92 \times 2.4 \times \beta^{1-\frac{1}{2.4}}$$

Substituting this into the formula for $\{R,G,B\}$:

$$12.92 \times \beta = 12.92 \times 2.4 \times \beta^{1-\frac{1}{2.4}} \times \beta^{\frac{1}{2.4}} - (12.92 \times 2.4 \times \beta^{1-\frac{1}{2.4}} - 1)$$

This equation simplifies to:

$$1.4 \times 12.92 \times \beta - 2.4 \times 12.92 \times \beta^{1-\frac{1}{2.4}} + 1 = 0$$

This can be further simplified to:

$$1.4 \times \beta - 2.4 \times \beta^{1-\frac{1}{2.4}} + \frac{1}{12.92} = 0$$

The value of β can be found numerically (for example by Newton-Raphson iteration, with a derivative of $1.4 - 1.4\beta^{-\frac{1}{2.4}}$), and results in values of:

$$\begin{aligned} \beta &\approx 0.003041282560128 \\ \alpha &\approx 1.055010718947587 \\ \delta &= 12.92 \times \beta = \alpha \times \beta^{\frac{1}{2.4}} - (\alpha - 1.0) \\ &\approx 0.039293370676848 \end{aligned}$$

Where δ is the value of the EOTF $^{-1}$ at $\{R',G',B'\} = \beta$.

Note

These deduced values are appreciably different from those in the sRGB specification, which does not state the origin of its constants. The intersection point of the sRGB EOTF has less numerical stability (and more nearby local minima in curves being optimized) that the corresponding ITU function - it is sensitive to the start value used for numerical approximations. This may explain how different values were reached for the sRGB specification. However, the errors both in value and derivative at the point of selection between the linear and exponent segments are small in practice.

The EOTF can be written with these derived values as:

$$\{R,G,B\} = \begin{cases} \frac{\{R',G',B'\}}{12.92}, & \{R',G',B'\} \leq \delta \\ \left(\frac{\{R',G',B'\}}{\alpha} + \frac{\alpha-1}{\alpha}\right)^{2.4}, & \{R',G',B'\} > \delta \end{cases}$$

Note

Apple describes the Display P3 color space as using the sRGB transfer function. The profile viewer in Apple's ColorSync utility reports that the EOTF is of the following form:

$$f(x) = \begin{cases} cx, & x < d \\ (ax+b)^{\gamma}, & x \geq d \end{cases}$$

The reported figures for $\gamma = 2.4,\ a = 0.948,\ b = 0.52$ and $c = 0.077$ correspond to the equivalent values in the sRGB specification:

$$\frac{1}{\alpha} \approx 0.948 = a$$
$$\frac{\alpha - 1}{\alpha} \approx 0.52 = b$$
$$\frac{1}{12.92} \approx 0.077 = c$$

These values are correct to the reported precision both for the value $\alpha = 1.055$ in the sRGB specification and for the more precise $\alpha \approx 1.055010718947587$ derived above.

However, where the sRGB specification states that $\delta = 0.04045$, the profile viewer reports a corresponding d = 0.039. The disparity can be explained if the profile values have been derived as described in this section:

$$\delta \approx 0.039293370676848 \approx 0.039 = d$$

Note that this value assumes a correspondingly corrected version of α rather than $a = 1.055$.

The extra precision may be needed over the constants in the sRGB specification due to the use of additional bits of accuracy in the Display P3 representation, which may expose a discontinuity due to rounding with the original numbers, particularly in the gradient of the curve. However, this distinction is subtle: when calculated over a [0..1] range, the derived EOTF and EOTF $^{-1}$ agree with the official sRGB formulae to greater than 16-bit precision.

Without allowing for adjusting the $\alpha = 1.055$ constant in the sRGB formula, the power function cannot be made to intersect perfectly at a tangent to the linear segment with gradient of 12.92. However, the intersection point β can be found by solving:

$$1.055 \times \beta^{\frac{1}{2.4}} - 12.92 \times \beta - 0.055 = 0$$

This equation can give us a slightly more precise pair of values for the original sRGB equation:

$$\beta \approx 0.003130668$$
$$\delta \approx 0.040448236$$

In practice this makes no measurable difference, but does suggest that the values of $\beta = 0.0031308$ in the sRGB specification may have been incorrectly rounded.

13.4 BT.1886 transfer functions

The BT.1886 standard for the “Reference electro-optical transfer function for flat panel displays used in HDTV studio production” is intended to represent a typical EOTF for CRTs and to document this to ensure consistency between other display technologies:

$$L = a(\max(V+b,0))^{\gamma}$$

L = screen luminance in cd/m^2

V = input signal normalized to [0..1]

a = user gain (legacy “contrast”)

b = black level lift (legacy “brightness”)

$\gamma = 2.4$

If L_W is the screen luminance of maximum white and L_B is the screen luminance of minimum black:

$$\begin{aligned}
L_B &= a \times b^{\gamma} \\
L_W &= a \times (1+b)^{\gamma} \\
a &= (L_W^{\frac{1}{\gamma}} - L_B^{\frac{1}{\gamma}})^{\gamma} \\
b &= \frac{L_B^{\frac{1}{\gamma}}}{L_W^{\frac{1}{\gamma}} - L_B^{\frac{1}{\gamma}}}
\end{aligned}$$

ITU BT.2087 proposes the use of a simple power function with a $\gamma = 2.4$ as an approximation to this EOTF for the purposes of color conversion, effectively assuming $b = 0$ and L_B is pure black. The reference display described in BT.1886 has a maximum luminance level of 100cd/m^2 (brighter than the equivalent sRGB reference display).

The following graph shows the relationship between the BT.1886 EOTF (shown in red, with nonlinear encoded input horizontal) and the ITU OETF such as used for BT.709 (shown in blue, with nonlinear encoded output vertical). The result of applying the two functions in turn, resulting in the OOTF of a combined BT.709-BT.1886 system, is shown in black. Since the ITU OETF approximates a power function with $\gamma = 2.0$, also shown in green is the resulting OOTF corresponding to a power function with $\gamma = \frac{2.4}{2.0} = 1.2$.

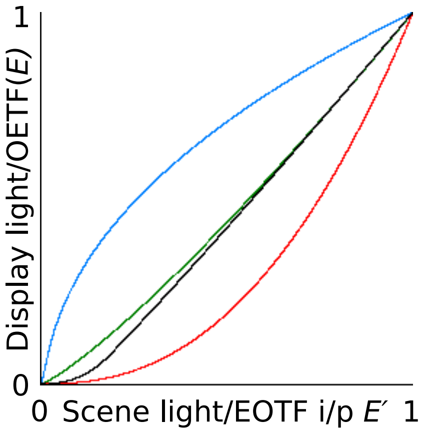


Figure 13.11: BT.1886 EOTF (red) and BT.709 OETF (blue)

Note

BT.1886 also offers an alternative EOTF which may provide a better match to CRT measured luminance than the standard formula listed above:

$$L = \begin{cases} k(V_C + b)^{(\alpha_1 - \alpha_2)}(V + b)^{\alpha_2}, & V < V_C \\ k(V + b)^{\alpha_1}, & V_C \leq V \end{cases}$$

V_C = 0.35

α_1 = 2.6

α_2 = 3.0

k = coefficient of normalization (so that *V* = 1 gives white),

$k = L_W(1+b)^{-\alpha_1}$

b = black level lift (legacy “brightness”)

13.5 BT.2100 HLG transfer functions

HLG (and PQ, below) are intended to allow a better encoding of high-dynamic-range content compared with the standard ITU OETF.

13.5.1 HLG OETF (normalized)

The BT.2100-2 Hybrid Log Gamma description defines the following OETF for linear scene light:

$$E'_{norm} = \text{OETF}(E) = \begin{cases} \sqrt{3E}, & 0 \leq E \leq \frac{1}{12} \\ a \times \ln((12 \times E) - b) + c, & \frac{1}{12} < E \leq 1 \end{cases}$$

E = the R_S, G_S or B_S color component of linear scene light, normalized to [0..1]

E' = the resulting nonlinear R'_S, G'_S or B'_S nonlinear scene light value in in the range [0..1]

a = 0.17883277

$b = 1 - 4 \times a = 0.28466892$

$c = 0.5 - a \times ln(4 \times a) \approx 0.55991073$

Note

BT.2100-0, in note 5b, defines these formulae equivalently, but slightly differently:

$$E'_{norm} = \text{OETF}(E) = \begin{cases} \sqrt{3E}, & 0 \leq E \leq \frac{1}{12} \\ a \times \ln(E - b_0) + c_0, & \frac{1}{12} < E \leq 1 \end{cases}$$

This formulation in BT.2100-0 uses different constants for *b* and *c* (*a* is unmodified), as follows:

	BT.2100-2, BT.2100-1	BT.2100-0
b	b_1 = 0.28466892	b_0 = 0.02372241
c	c_1 = 0.55991073	c_0 = 1.00429347

The BT.2100-0 variations can be derived from the BT.2100-2 numbers as:

$$\begin{aligned} a \times \ln((12 \times E) - b_1) + c_1 &= a \times \ln\left(12 \times \left(E - \frac{b_1}{12}\right)\right) + c_1 \\ &= a \times \ln\left(E - \frac{b_1}{12}\right) + a \times \ln(12) + c_1 \end{aligned}$$

$$\frac{b_1}{12} = \frac{0.28466892}{12} = 0.023772241 = b_0$$

$$a \times \ln(12) + c_1 = 0.17883277 \times \ln(12) + 0.55991073 = 1.00429347 = c_0$$

13.5.2 HLG OETF $^{-1}$ (normalized)

The OETF $^{-1}$ of normalized HLG is:

$$E = \mathrm{OETF}^{-1}(E') = \begin{cases} \frac{E'^2}{3}, & 0 \leq E' \leq \frac{1}{2} \\ \frac{1}{12} \times \left(b + e^{(E'-c)/a} \right), & \frac{1}{2} < E' \leq 1 \end{cases}$$

a, b and c are defined as for the normalized HLG OETF. BT.2100-0 again defines an equivalent formula without the $\frac{1}{12}$ scale factor in the $\frac{1}{2} < E' \leq 1$ term, using the modified b_0 and c_0 constants described in the note in the HLG OETF above.

13.5.3 Unnormalized HLG OETF

BT.2100-0 describes the HLG OETF formulae with E "normalized" to the range [0..12], with the variant with the range normalized to [0..1] as an alternative. Only the variant normalized to the range [0..1] is described in the updated versions of the specification, BT.2100-1 and BT.2100-2.

$$E' = \mathrm{OETF}(E) = \begin{cases} \frac{\sqrt{E}}{2}, & 0 \leq E \leq 1 \\ a \times \ln(E - b) + c, & 1 < E \end{cases}$$

E' = the R_S, G_S or B_S color component of linear scene light, normalized to [0..12]

E'_S = the resulting nonlinear R'_S, G'_S or B'_S value in in the range [0..1]

a = 0.17883277

b = 0.28466892

c = 0.55991073

Note that these constants are the same as those used in the BT.2100-1 version of the normalized formulae.

Since this "unnormalized" representation refers to a scale factor between the scene light and the encoded nonlinear signal, there is no corresponding "unnormalized" EOTF.

13.5.4 Unnormalized HLG OETF $^{-1}$

The OETF $^{-1}$ of "unnormalized" HLG (producing E in the range [0..12]) is:

$$E = \mathrm{OETF}^{-1}(E') = \begin{cases} 4 \times E'^2, & 0 \leq E' \leq \frac{1}{2} \\ b + e^{(E'-c)/a}, & \frac{1}{2} < E' \end{cases}$$

a, b and c are defined as for the unnormalized HLG OETF.

BT.2100-0 describes this "unnormalized" version of the formulae, with the variant with the E normalized to [0..1] as an alternative. Only the variant with E normalized to [0..1] is described in the updated versions, BT.2100-1 and BT.2100-2.

13.5.5 Derivation of the HLG constants (informative)

HLG constants appear to have chosen a, b and c to meet the following constraints, which are easiest to express in terms of the unnormalized OETF $^{-1}$:

- The derivative of the $0 \leq E' \leq \frac{1}{2}$ term of the unnormalized OETF $^{-1}$ has the same value as the derivative of the $\frac{1}{2} < E' \leq 1$ term of the unnormalized OETF $^{-1}$ at $E' = \frac{1}{2}$:

$$
\begin{aligned}
\frac{d(4 \times E'^2)}{dE'} &= 8 \times E' = 8 \times \frac{1}{2} = 4 \text{ (derivative of the } 0 \leq E' \leq \frac{1}{2} \text{ case)}\\
\frac{d(e^{(E'-c)/a} + b)}{dE'} &= \frac{d(e^{E'/a} \times e^{-c/a} + b)}{dE'} \text{ (derivative of the } \frac{1}{2} < E' \text{ case)}\\
&= \frac{d((e^{E'} \times e^{-c})^{1/a} + b)}{dE'}\\
&= \frac{1}{a} \times \left(e^{E'} \times e^{-c}\right)^{(1/a)-1} \times \left(e^{E'} \times e^{-c}\right)\\
&= \frac{1}{a} \times \left(e^{E'} \times e^{-c}\right)^{1/a}\\
4 &= \frac{1}{a} \times \left(e^{0.5} \times e^{-c}\right)^{1/a} \text{ at } E' = \frac{1}{2}\\
\Longrightarrow\ (4 \times a)^a &= e^{0.5} \times e^{-c}\\
\Longrightarrow\ c &= -\ln\left(\frac{(4 \times a)^a}{e^{0.5}}\right)\\
&= 0.5 - a \times \ln(4 \times a)
\end{aligned}
$$

- The $0 \leq E' \leq \frac{1}{2}$ term of the unnormalized OETF $^{-1}$ has the same value as the $\frac{1}{2} < E' \leq 1$ term of the unnormalized OETF $^{-1}$ at $E' = \frac{1}{2}$:

$$
\begin{aligned}
4 \times E'^2 &= e^{\frac{E'-c}{a}} + b \text{ (from the } 0 \leq E' \leq \frac{1}{2} \text{ and } \frac{1}{2} < E' \text{ cases)}\\
4 \times \frac{1}{2}^2 &= 1 = e^{\frac{0.5-c}{a}} + b \text{ (at } E' = \frac{1}{2})\\
&= e^{\frac{0.5-0.5+a \times \ln(4 \times a)}{a}} + b\\
&= e^{\ln(4 \times a)} + b\\
b &= 1 - 4 \times a
\end{aligned}
$$

- At E' = 1, the $\frac{1}{2} < E'$ term of the unnormalized OETF $^{-1}$ = 12:

$$
\begin{aligned}
12 &= e^{\frac{E'-c}{a}} + b\\
&= e^{\frac{1-0.5+a \times \ln(4 \times a)}{a}} + 1 - 4 \times a\\
11 + 4 \times a &= e^{\frac{0.5}{a} + \ln(4 \times a)}\\
11 + 4 \times a &= (4 \times a) \times e^{\frac{0.5}{a}}\\
\frac{11}{4 \times a} + 1 &= \sqrt{e^{\frac{1}{a}}}\\
\frac{121}{16 \times a^2} + \frac{11}{2 \times a} + 1 &= e^{\frac{1}{a}}\\
\frac{121}{16} + \frac{a \times 11}{2} + a^2 \times (1 - e^{\frac{1}{a}}) &= 0
\end{aligned}
$$

This last equation can be solved numerically to find:

$$a \approx 0.17883277265694977656312771$$

With this precision, more accurate values of the other constants are:

$$b = 0.28466890937$$
$$c = 0.55991072776$$

The b = 0.28466892 official figure assumes the rounded a = 0.17883277 value as an input to the $b = 1 - 4 \times a$ relation.

Note

No explanation for the choice of [0..12] range in the official version of the formula is explicitly offered in BT.2100-0 (it does *not*, for example, appear to relate to the BT.1886 OOTF $\gamma = 1.2$ combined with the $10\times$ ratio between the 1000cd/m^2 of a standard HLG HDR TV and the 100cd/m^2 of a standard dynamic range set). However, allowing for the difference in the maximum display brightness of HDR and SDR systems there is deliberate (scaled) compatibility between the HLG OETF and the BT.2020 OETF (which itself approximates a square root function) over much of the encodable dynamic range of a BT.2020 system. Since HDR content is intended to support accurate highlights more than to maintain a higher persistent screen brightness (many HDR displays can only support maximum brightness in a small area or over a small period without overheating), agreement over a significant chunk of the tone curve allows a simple adaptation between HDR and SDR devices: fed HLG-encoded content, an SDR display may represent darker tones accurately and simply under-represent highlights. The origins of both HLG and PQ are discussed in ITU-R BT.2390.

As graphed in ITU-R BT.2390, the “unnormalized” HLG OETF (red) is a good approximation to the standard dynamic range ITU transfer function (blue, output scaled by 0.5) up to $E \approx 1$ and $\mathrm{OETF}(E) = E' \approx 0.5$, with a smooth curve up to the maximum HLG representable scene light value of “12”:

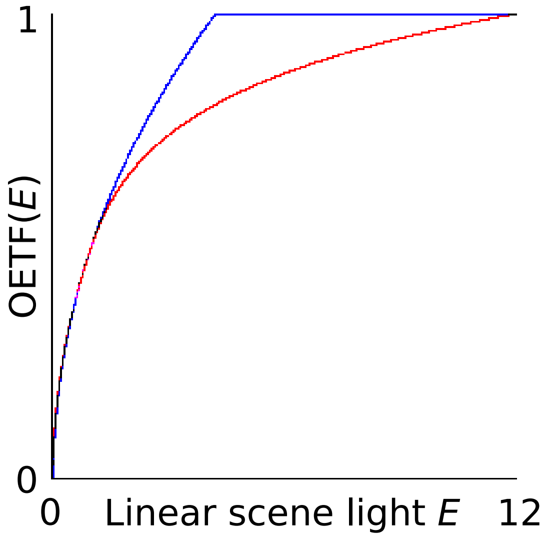


Figure 13.12: HLG OETF (red) vs ITU OETF/2 (blue)

13.5.6 HLG OOTF

The OOTF of HLG is described as:

$$
\begin{aligned}
R_D &= \alpha \times Y_S^{\gamma-1} \times R_S \\
G_D &= \alpha \times Y_S^{\gamma-1} \times G_S \\
B_D &= \alpha \times Y_S^{\gamma-1} \times B_S
\end{aligned}
$$

where R_D, G_D and B_D describe the luminance of the displayed linear component in cd/m^2 and R_S, G_S and B_S describe each color component in scene linear light, scaled by camera exposure and normalized to the representable range.

Note

BT.2100 notes that some legacy displays apply the γ function to each channel separately, rather than to the luminance component. That is, $\{R_D, G_D, B_D\} = \alpha \times \{R_S, G_S, B_S\}^{\gamma} + \beta$. This is an approximation to the official OOTF.

Y_S is the normalized scene luminance, defined as:

$$Y_S = 0.2627 \times R_S + 0.6780 \times G_S + 0.0593 \times B_S$$

α represents adjustable user gain (display “contrast”) representing L_W, the nominal peak luminance of achromatic pixels.

Note

Versions of BT.2100 prior to BT.2100-2 incorporated a β black level offset (display “brightness”) representing the display luminance of black in cd/m^2:

$$
\begin{aligned}
R_D &= \alpha \times Y_S^{\gamma-1} \times R_S + \beta \\
G_D &= \alpha \times Y_S^{\gamma-1} \times G_S + \beta \\
B_D &= \alpha \times Y_S^{\gamma-1} \times B_S + \beta
\end{aligned}
$$

α then represented the relative display “contrast”:

	Scene light normalized to [0..1]	Scene light normalized to [0..12]
α	$L_W - L_B$	$\frac{L_W - L_B}{(12)^{\gamma}}$

where L_W is the nominal peak luminance of the display in cd/m^2, and L_B is the display luminance of black in cd/m^2. That is, in older versions of BT.2100, α represented the difference between minimum and maximum brightness, whereas in BT.2100-2 α is independent of black level.

$\gamma = 1.2$ for a nominal peak display luminance of 1000cd/m^2. For displays with higher peak luminance or if peak luminance is reduced through a contrast control, $\gamma = 1.2 + 0.42 \times \log_{10}\left(\frac{L_W}{1000}\right)$.

For the purposes of general conversion, L_W can be assumed to be 1000cd/m^2, and L_B can be approximated as 0, removing the constant offset from the above equations and meaning $\gamma = 1.2$.

13.5.7 HLG OOTF $^{-1}$

The inverse OOTF for HLG can be defined as:

$$
\begin{aligned}
R_S &= \left(\frac{Y_D}{\alpha}\right)^{(1/\gamma)-1} \times \left(\frac{R_D}{\alpha}\right) \\
G_S &= \left(\frac{Y_D}{\alpha}\right)^{(1/\gamma)-1} \times \left(\frac{G_D}{\alpha}\right) \\
B_S &= \left(\frac{Y_D}{\alpha}\right)^{(1/\gamma)-1} \times \left(\frac{B_D}{\alpha}\right) \\
Y_D &= 0.2627 \times R_D + 0.6780 \times G_D + 0.0593 \times B_D
\end{aligned}
$$

For processing without reference to a specific display, α can be assumed to be 1.0cd/m^2.

Note

Versions of BT.2100 prior to BT.2100-2 incorporated a β term into the OOTF. Using this formula from the OOTF leads to the following relationship between Y_D and Y_S:

$$
\begin{aligned}
Y_D &= 0.2627 \times R_D + 0.6780 \times G_D + 0.0593 \times B_D \\
&= 0.2627 \times (\alpha \times Y_S^{\gamma-1} \times R_S + \beta) + 0.6780 \times (\alpha \times Y_S^{\gamma-1} \times G_S + \beta) + 0.0593 \times (\alpha \times Y_S^{\gamma-1} \times B_S + \beta) \\
&= \alpha \times Y_S^{\gamma-1} \times (0.2627 \times R_S + 0.6780 \times G_S + 0.0593 \times B_S) + \beta \\
&= \alpha \times Y_S^{\gamma} + \beta \\
\therefore Y_S &= \left(\frac{Y_D - \beta}{\alpha}\right)^{\frac{1}{\gamma}} \\
Y_S^{1-\gamma} &= \left(\frac{Y_D - \beta}{\alpha}\right)^{(1-\gamma)/\gamma}
\end{aligned}
$$

From this, the following relations can be derived:

$$
\begin{aligned}
R_S &= \frac{(R_D - \beta)}{\alpha \times Y_S^{\gamma-1}} = Y_S^{1-\gamma} \times \frac{(R_D - \beta)}{\alpha} = \left(\frac{Y_D - \beta}{\alpha}\right)^{(1-\gamma)/\gamma} \times \left(\frac{R_D - \beta}{\alpha}\right) \\
G_S &= \frac{(G_D - \beta)}{\alpha \times Y_S^{\gamma-1}} = Y_S^{1-\gamma} \times \frac{(G_D - \beta)}{\alpha} = \left(\frac{Y_D - \beta}{\alpha}\right)^{(1-\gamma)/\gamma} \times \left(\frac{G_D - \beta}{\alpha}\right) \\
B_S &= \frac{(B_D - \beta)}{\alpha \times Y_S^{\gamma-1}} = Y_S^{1-\gamma} \times \frac{(B_D - \beta)}{\alpha} = \left(\frac{Y_D - \beta}{\alpha}\right)^{(1-\gamma)/\gamma} \times \left(\frac{B_D - \beta}{\alpha}\right)
\end{aligned}
$$

For processing without knowledge of the display, α can be treated as 1.0cd/m^2 and β can be considered to be 0.0cd/m^2. This simplifies the equations as follows:

$$
\begin{aligned}
Y_S &= Y_D^{1/\gamma} \\
Y_S^{1-\gamma} &= Y_D^{(1/\gamma)-1} \\
R_S &= Y_D^{(1/\gamma)-1} \times R_D \\
G_S &= Y_D^{(1/\gamma)-1} \times G_D \\
B_S &= Y_D^{(1/\gamma)-1} \times B_D
\end{aligned}
$$

13.5.8 HLG EOTF

The EOTF of BT.2100 HLG is defined in terms of the OETF and OOTF defined above:

$$R_D = \mathrm{OOTF}\left(\mathrm{OETF}^{-1}\left(\max(0, (1-\beta)R'_S + \beta)\right)\right)$$
$$G_D = \mathrm{OOTF}\left(\mathrm{OETF}^{-1}\left(\max(0, (1-\beta)G'_S + \beta)\right)\right)$$
$$B_D = \mathrm{OOTF}\left(\mathrm{OETF}^{-1}\left(\max(0, (1-\beta)B'_S + \beta)\right)\right)$$
$$\beta = \sqrt{3 \times \left(\frac{L_B}{L_W}\right)^{1/\gamma}}$$

where L_W is the nominal peak luminance of the display in cd/m^2, and L_B is the display luminance of black in cd/m^2.

Note

Versions of BT.2100 prior to BT.2100-2 included the black level offset (display "brightness") β into the OOTF:

$$\{R_D, G_D, B_D\} = \mathrm{OOTF}(\mathrm{OETF}^{-1}(\{R'_S, G'_S, B'_S\}))$$

13.5.9 HLG EOTF -1

The EOTF -1 can be derived as:

$$R'_S = \frac{\mathrm{OETF}\left(\mathrm{OOTF}^{-1}(R'_D)\right) - \beta}{1-\beta}$$
$$G'_S = \frac{\mathrm{OETF}\left(\mathrm{OOTF}^{-1}(G'_D)\right) - \beta}{1-\beta}$$
$$B'_S = \frac{\mathrm{OETF}\left(\mathrm{OOTF}^{-1}(B'_D)\right) - \beta}{1-\beta}$$
$$\beta = \sqrt{3 \times \left(\frac{L_B}{L_W}\right)^{1/\gamma}}$$

Note

Versions of BT.2100 prior to BT.2100-2 included the black level offset (display "brightness") β into the OOTF:

$$\{R'_S, G'_S, B'_S\} = \mathrm{OETF}(\mathrm{OOTF}^{-1}(\{R_D, G_D, B_D\}))$$

This graph shows the normalized HLG OETF (blue), OOTF (black) and EOTF (red) for $\beta = 0$ and white light. Linear scene light/nonlinear encoded EOTF input are on the x axis, with linear display output/nonlinear OETF output on y.

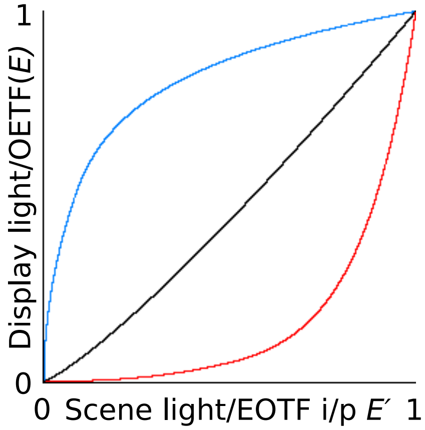


Figure 13.13: HLG normalized OETF (blue) and EOTF (red)

13.6 BT.2100 PQ transfer functions

Note
Unlike BT.2100 HLG and other ITU broadcast standards, PQ is defined in terms of an EOTF (mapping from the encoded values to the display output), not an OETF (mapping from captured scene content to the encoded values).

13.6.1 PQ EOTF

The BT.2100 Perceptual Quantization description defines the following EOTF:

$$
\begin{aligned}
F_D &= \mathrm{EOTF}(E') = 10000 \times Y \\
Y &= \left(\frac{\max((E'^{\frac{1}{m_2}} - c_1), 0)}{c_2 - c_3 \times E'^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}
\end{aligned}
$$

E' is a nonlinear color channel $\{R', G', B'\}$ or $\{L', M', S'\}$ encoded as PQ in the range [0..1].
F_D is the luminance of the displayed component in cd/m^2 (where the luminance of an $\{R_D, G_D, B_D\}$ or Y_D or I_D component is considered to be the luminance of the color with all channels set to the same value as the component).
When $R' = G' = B'$ the displayed pixel is monochromatic.
Y is a linear color value normalized to [0..1].

$$
\begin{aligned}
m_1 &= \frac{2610}{16384} = 0.1593017578125 \\
m_2 &= \frac{2523}{4096} \times 128 = 78.84375 \\
c_1 &= \frac{3424}{4096} = 0.8359375 = c_3 - c_2 + 1 \\
c_2 &= \frac{2413}{4096} \times 32 = 18.8515625 \\
c_3 &= \frac{2392}{4096} \times 32 = 18.6875
\end{aligned}
$$

13.6.2 PQ EOTF $^{-1}$

The corresponding EOTF $^{-1}$ is:

$$
\begin{aligned}
Y &= \frac{F_D}{10000} \\
\mathrm{EOTF}^{-1}(F_D) &= \left(\frac{c_1 + c_2 \times Y^{m_1}}{1 + c_3 \times Y^{m_1}} \right)^{m_2}
\end{aligned}
$$

13.6.3 PQ OOTF

The OOTF of PQ matches that of BT.1886's EOTF combined with BT.709's OETF:

$$F_D = \mathrm{OOTF}(E) = \mathrm{G}_{1886}(\mathrm{G}_{709}(E))$$

where E is one of $\{R_S, G_S, B_S, Y_S, I_S\}$, the linear representation of scene light scaled by camera exposure and in the range $[0..1]$, G_{1886} is the EOTF described in BT.1886, and G_{709} is the OETF described in BT.709 with a scale factor of 59.5208 applied to E:

$$\begin{aligned} F_D = \mathrm{G}_{1886}(\mathrm{G}_{709}(E)) & = \mathrm{G}_{1886}(E') = 100 \times E'^{2.4} \\ E' = \mathrm{G}_{709}(E) & = \begin{cases} 1.099 \times (59.5208 \times E)^{0.45} - 0.099, & 1 > E > 0.0003024 \\ 267.84 \times E, & 0.0003024 \geq E \geq 0 \end{cases} \end{aligned}$$

Note

ITU-R BT.2390 explains the derivation of the scale factor:

PQ can encode 100 times the display brightness of a standard dynamic range ("SDR") encoding (10000cd/m^2 compared with the 100cd/m^2 SDR reference display described in BT.1886). High dynamic range (HDR) displays are intended to represent the majority of scene content within a "standard" dynamic range, and exposure of a normalized SDR signal is chosen to provide suitable exposure. HDR displays offer extra capability for representation of small or transient highlights (few HDR displays can actually reach the maximum 10000cd/m^2 encodable brightness, and few HDR displays can maintain their maximum intensity over a large area for an extended period without overheating). Therefore the behavior of HDR displays is intended to approximate a conventional standard dynamic range display for most of the image, while retaining the ability to encode extreme values.

As described in BT.2390, the OOTF of SDR is roughly $\gamma = 1.2$ (deviating from this curve more near a 0 value), so the maximum *scene* light intensity that can be represented is roughly $100^{\frac{1}{1.2}} \approx 46.42$ times that of a SDR encoding.

Using exact equations from BT.709 and BT.1886 to create the OOTF, rather than the $\gamma = 1.2$ approximation, the maximum representable scene brightness, if 1.0 is the maximum normalized SDR brightness is:

$$\left(\frac{100^{\frac{1}{2.4}} + 0.099}{1.099}\right)^{\frac{1}{0.45}} \approx 59.5208$$

The other constants in the G_{709} formula are derived as follows:

$$\frac{0.018}{59.5208} \approx 0.0003024$$
$$4.5 \times 59.5208 \approx 267.84$$

Note that these constants differ slightly if the more accurate $\alpha = 1.0993$ figure from BT.2020 is used instead of 1.099.

13.6.4 PQ OETF

The OETF of PQ is described in terms of the above OOTF:

$$E' = \mathrm{OETF}(E) = \mathrm{EOTF}^{-1}(\mathrm{OOTF}(E)) = \mathrm{EOTF}^{-1}(F_D)$$

13.6.5 PQ OOTF $^{-1}$

The PQ OOTF $^{-1}$ is:

$$E = \mathrm{OOTF}^{-1}(F_D) = \mathrm{G}_{709}^{-1}(\mathrm{G}_{1886}^{-1}(F_D))$$

where F_D, display intensity, is one of $\{R_D, G_D, B_D, Y_D, I_D\}$, and E is the corresponding normalized scene intensity.

$$E' = \mathrm{G}_{1886}^{-1}(F_D) = \left(\frac{F_D}{100}\right)^{\frac{1}{2.4}}$$

$$E = \mathrm{G}_{709}^{-1}(E') = \begin{cases} \left(\frac{(E'+0.099)}{1.099\times 59.5208^{0.45}}\right)^{\frac{1}{0.45}}, & E' > 0.081 \implies F_D > 8.1^{2.4} \\ \frac{E'}{267.84}, & 0.081 \geq E' \geq 0 \implies 8.1^{2.4} \geq F_D \geq 0 \end{cases}$$

13.6.6 PQ OETF $^{-1}$

The PQ OETF $^{-1}$ is described in terms of the OOTF $^{-1}$:

$$E = \mathrm{OETF}^{-1}(E') = \mathrm{OOTF}^{-1}(\mathrm{EOTF}(E')) = \mathrm{OOTF}^{-1}(F_D)$$

The following graph shows the relationship between the PQ EOTF (in red) and OETF (in blue), with the OOTF from which the OETF is derived in black. Linear scene light and nonlinear encoded input to the EOTF are on the horizontal axis, and linear display output and nonlinear output of the OETF are on the vertical axis. All values have been normalized to the range 0..1 for comparison.

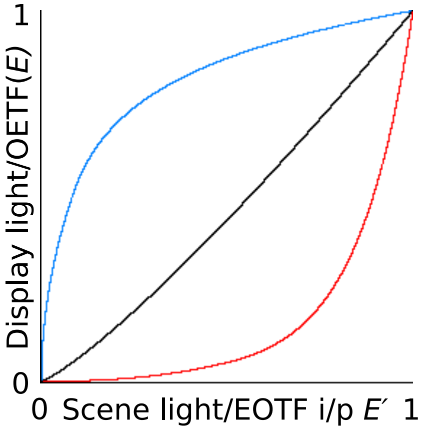


Figure 13.14: PQ EOTF (red) and OETF (blue), normalized 0..1

13.7 DCI P3 transfer functions

DCI P3 defines a simple power function with an exponent of 2.6 (applied to scaled CIE *XYZ* values):

EOTF $^{-1}$	EOTF
$X' = \left(\frac{X}{52.37}\right)^{\frac{1}{2.6}}$ $Y' = \left(\frac{Y}{52.37}\right)^{\frac{1}{2.6}}$ $Z' = \left(\frac{Z}{52.37}\right)^{\frac{1}{2.6}}$	$X = X'^{2.6} \times 52.37$ $Y = Y'^{2.6} \times 52.37$ $Z = Z'^{2.6} \times 52.37$

This power function is applied directly to scaled CIE *XYZ* color coordinates: the "primaries" in DCI define the bounds of the gamut, but the actual color encoding uses *XYZ* coordinates. DCI scales the resulting nonlinear values to the range [0..4095] prior to quantization, rounding to nearest.

Note

"Display P3" uses the sRGB transfer function, modified in some implementations to have more accurate constants (see the section on the derivation of the sRGB constants).

13.8 Legacy NTSC transfer functions

ITU-R BT.470-6, which has now been deprecated, lists a number of regional TV standard variants; an updated list of variant codes used by country is defined in ITU-R BT.2043. This standard, along with e-CFR title 47 section 73.682, documents a simple EOTF power function with $\gamma = 2.2$ for NTSC display devices.

EOTF $^{-1}$	EOTF
$R' = R^{\frac{1}{2.2}}$ $G' = G^{\frac{1}{2.2}}$ $B' = B^{\frac{1}{2.2}}$	$R = R'^{2.2}$ $G = G'^{2.2}$ $B = B'^{2.2}$

This value of γ is also used for N/PAL signals in the Eastern Republic of Uruguay, and was also adopted by ST-240.

Combined with the reference in SMPTE 170M to a $\gamma = 2.2$ being used in "older documents", this suggests a linear design OOTF for NTSC systems.

ITU-R BT.1700, which partly replaced BT.470, also describes an "assumed gamma of display device" of 2.2 for PAL and SECAM systems; this is distinct from the $\gamma = 2.8$ value listed in ITU-R BT.470-6. Combined with the ITU OETF which approximates $\gamma = \frac{1}{2.0}$, the PAL OOTF retains a $\gamma \approx 1.1$ when this value of $\gamma = 2.2$ is used for the EOTF, similar to the figure described under the legacy PAL EOTF.

In contrast, ITU-R BT.1700 also includes SMPTE 170m, which defines the assumed EOTF of the display device as being the inverse of the current ITU OETF. Hence the new NTSC formulation also assumes a linear OOTF.

13.9 Legacy PAL OETF

ITU-R BT.472, "Video-frequency characteristics of a television system to be used for the international exchange of programmes between countries that have adopted 625-line colour or monochrome systems", defines that the "gamma of the picture signal" should be "approximately 0.4". The reciprocal of this value is 2.5.

That is, this standard defines an approximate OETF and OETF $^{-1}$ for PAL content:

OETF	OETF $^{-1}$
$R' \approx R^{0.4}$ $G' \approx G^{0.4}$ $B' \approx B^{0.4}$	$R \approx R'^{2.5}$ $G \approx G'^{2.5}$ $B \approx B'^{2.5}$

13.10 Legacy PAL 625-line EOTF

ITU-R BT.470-6, which has now been deprecated in favor of BT.1700, lists a number of regional TV standard variants; an updated list of variant codes used by country is defined in ITU-R BT.2043.

This specification describes a simple EOTF power function with $\gamma_{\text{EOTF}} = 2.8$ for most PAL and SECAM display devices:

EOTF $^{-1}$	EOTF
$R' = R^{\frac{1}{2.8}}$ $G' = G^{\frac{1}{2.8}}$ $B' = B^{\frac{1}{2.8}}$	$R = R'^{2.8}$ $G = G'^{2.8}$ $B = B'^{2.8}$

Note

Poynton describes a γ of 2.8 as being "unrealistically high" for actual CRT devices.

Combined with the corresponding legacy OETF that specifies $\gamma_{\text{OETF}} = 0.4$, the described system OOTF is:

$$R_{display} \approx R_{scene}^{\frac{2.8}{2.5}}$$

$$G_{display} \approx G_{scene}^{\frac{2.8}{2.5}}$$

$$B_{display} \approx B_{scene}^{\frac{2.8}{2.5}}$$

Or $\gamma_{\text{OOTF}} \approx 1.12$.

The value of $\gamma_{\text{EOTF}} = 2.8$ is described in BT.470-6 as being chosen for "an overall system gamma" (OOTF power function exponent) of "approximately 1.2"; this suggests that the "approximately 0.4" exponent in BT.472-6 should be interpreted as nearer to $\frac{1.2}{2.8} \approx 0.43$, or at least that there was enough variation in early devices for precise formulae to be considered irrelevant.

Note

The EOTF power function of $\gamma_{\text{EOTF}} = 2.2$ described in BT.1700 combines with the ITU OETF described in BT.601 (which approximates $\gamma_{\text{OETF}} \approx 0.5$) to give a similar system $\gamma_{\text{OOTF}} \approx 1.1$. As described above, the ITU OETF combined with the BT.1886 EOTF results in a more strongly nonlinear $\gamma_{\text{OOTF}} \approx \frac{2.4}{2.0} = 1.2$.

13.11 ST240/SMPTE240M transfer functions

The ST-240, formerly SMPTE240M, interim standard for HDTV defines the following OETF:

$$R' = \begin{cases} R \times 4, & 0 \leq R < 0.0228 \\ 1.1115 \times R^{0.45} - 0.1115, & 1 \geq R \geq 0.0228 \end{cases}$$

$$G' = \begin{cases} G \times 4, & 0 \leq G < 0.0228 \\ 1.1115 \times G^{0.45} - 0.1115, & 1 \geq G \geq 0.0228 \end{cases}$$

$$B' = \begin{cases} B \times 4, & 0 \leq B < 0.0228 \\ 1.1115 \times B^{0.45} - 0.1115, & 1 \geq B \geq 0.0228 \end{cases}$$

Like SMPTE170m, ST-240 defines a linear OOTF. Therefore the above relationship also holds for the EOTF $^{-1}$.

The EOTF, and also OETF $^{-1}$, is:

$$R = \begin{cases} \frac{R'}{4}, & 0 \leq R < 0.0913 \\ \left(\frac{R'+0.1115}{1.1115}\right)^{\frac{1}{0.45}} - 0.1115, & 1 \geq R' \geq 0.0228 \end{cases}$$

$$G = \begin{cases} \frac{G'}{4}, & 0 \leq R < 0.0913 \\ \left(\frac{G'+0.1115}{1.1115}\right)^{\frac{1}{0.45}} - 0.1115, & 1 \geq G' \geq 0.0228 \end{cases}$$

$$B = \begin{cases} \frac{B'}{4}, & 0 \leq R < 0.0913 \\ \left(\frac{B'+0.1115}{1.1115}\right)^{\frac{1}{0.45}} - 0.1115, & 1 \geq B' \geq 0.0228 \end{cases}$$

13.12 Adobe RGB (1998) transfer functions

The Adobe RGB (1998) specification defines the following EOTF between nonlinear encoding and linear light intensity (notable for not including a linear component):

$$R = R'^{2.19921875}$$
$$G = G'^{2.19921875}$$
$$B = B'^{2.19921875}$$

2.19921875 is obtained from $2\frac{51}{256}$ or hexadecimal 2.33. Therefore the EOTF $^{-1}$ between linear light intensity and nonlinear encoding is:

$$R' = R^{\frac{256}{563}}$$
$$G' = G^{\frac{256}{563}}$$
$$B' = B^{\frac{256}{563}}$$

13.13 Sony S-Log transfer functions

The Sony S-Log OETF is defined for each color channel as:

$$y = (0.432699 \times \log_{10}(t + 0.037584) + 0.616596) + 0.03$$

Linear camera input scaled by exposure t ranges from 0 to 10.0; y is the nonlinear encoded value.

The OETF $^{-1}$ is:

$$Y = 10.0^{\frac{t-0.616596-0.03}{0.432699}} - 0.037584$$

The encoded nonlinear value t ranges from 0 to 1.09; Y is the linear scene light.

13.14 Sony S-Log2 transfer functions

S-Log2 defines the following OETF:

$$y = \begin{cases} (0.432699 \times \log_{10}\left(\frac{155.0 \times x}{219.0} + 0.037584\right) + 0.616596 + 0.03, & x \geq 0 \\ x \times 3.53881278538813 + 0.030001222851889303, & x < 0 \end{cases}$$

x is the IRE in scene-linear space.
y is the IRE in S-Log2 space.

The OETF $^{-1}$ is:

$$y = \begin{cases} \frac{219.0 \times 10.0^{\frac{x-0.616596-0.03}{0.432699}}}{155.0}, & x \geq 0.030001222851889303 \\ \frac{x-0.030001222851889303}{3.53881278538813}, & x < 0.030001222851889303 \end{cases}$$

x is the IRE in S-Log2 space.
y is the IRE in scene-linear space.

A reflection is calculated by multiplying an IRE by 0.9.

13.15 ACEScc transfer function

ACES is scene-referred; therefore ACEScc defines an OETF.

For each linear color channel lin_{AP1} transformed to the ACEScc primaries, the $ACEScc$ nonlinear encoding is:

$$ACEScc = \begin{cases} \frac{\log_2(2^{-16})+9.72}{17.52}, & lin_{AP1} \leq 0 \\ \frac{\log_2(2^{-16}+lin_{AP1} \times 0.5)+9.72}{17.52}, & lin_{AP1} < 2^{-15} \\ \frac{\log_2(lin_{AP1})+9.72}{17.52}, & lin_{AP1} \geq 2^{-15} \end{cases}$$

13.16 ACEScct transfer function

ACES is scene-referred; therefore ACEScct defines an OETF.

For each linear color channel lin_{AP1} transformed to the ACEScc primaries, the $ACEScct$ nonlinear encoding is:

$$ACEScct = \begin{cases} 10.5402377416545 \times lin_{AP1} + 0.0729055341958355, & lin_{AP1} \leq 0.0078125 \\ \frac{\log_2(lin_{AP1})+9.72}{17.52}, & lin_{AP1} > 0.0078125 \end{cases}$$

Chapter 14

Color primaries

Color primaries define the interpretation of each channel of the color model, particularly with respect to the *RGB* model. In the context of a typical display, **color primaries** describe the color of the red, green and blue phosphors or filters.

Primaries are typically defined using the CIE 1931 XYZ color space, which is a color space which preserves the linearity of light intensity. Consequently, the transform from linear-intensity (R, G, B) to (X, Y, Z) is a simple matrix multiplication. Conversion between two sets of (R, G, B) color primaries can be performed by converting to the (X, Y, Z) space and back.

The (X, Y, Z) space describes absolute intensity. Since most standards do not make a requirement about the absolute intensity of the display, color primaries are typically defined using the x and y components of the xyY color space, in which the Y channel represents linear luminance. xyY is related to XYZ via the following formulae:

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z} = 1-x-y$$

$$X = \frac{Y}{y}x \qquad Z = \frac{Y}{y}(1-x-y)$$

This is relevant because, although the brightness of the display in a color space definition is typically undefined, the **white point** is known: the x and y coordinates in xyY color space which corresponds to equal amounts of R, G and B. This makes it possible to determine the relative intensities of these color primaries.

Note

Many color standards use the CIE D65 standard illuminant as a white point. D65 is intended to represent average daylight, and has a color temperature of approximately 6500K. In CIE 1931 terms, this white point is defined in ITU standards as $x = 0.3127,\ y = 0.3290$, but elsewhere given as $x = 0.312713,\ y = 0.329016$. Different coordinates will affect the conversion matrices given below. The definition of the D65 white point is complicated by the constants in Planck's Law (which is a component in calculating the white point from the color temperature) having been revised since D65 was standardized, such that the standard formula for calculating CIE coordinates from the color temperature do not agree with the D65 standard. The actual color temperature of D65 is nearer to $6500 \times \frac{1.4388}{1.438} \approx 6503.6\mathrm{K}$.

Assuming an arbitrary white luminance (Y value) of 1.0, it is possible to express the following identity for the X, Y and Z coordinates of each color channel R, G and B, and of the white point W:

$$W_X = R_X + G_X + B_X \qquad W_Y = R_Y + G_Y + B_Y = 1.0 \qquad W_Z = R_Z + G_Z + B_Z$$

The identities $X = Y\frac{x}{y}$ and $Z = Y\frac{(1-x-y)}{y}$ can be used to re-express the above terms in the xyY space:

$$R_Y\left(\frac{R_x}{R_y}\right) + G_Y\left(\frac{G_x}{G_y}\right) + B_Y\left(\frac{B_x}{B_y}\right) = W_Y\left(\frac{W_x}{W_y}\right) = \frac{W_x}{W_y}$$

$$R_Y + G_Y + B_Y = W_Y = 1.0$$

$$R_Y\left(\frac{1-R_x-R_y}{R_y}\right) + G_Y\left(\frac{1-G_x-G_y}{G_y}\right) + B_Y\left(\frac{1-B_x-B_y}{B_y}\right) = W_Y\left(\frac{1-W_x-W_y}{W_y}\right) = \frac{1-W_x-W_y}{W_y}$$

This equation for W_Z can be simplified to:

$$R_Y\left(\frac{1-R_x}{R_y}-1\right)+G_Y\left(\frac{1-G_x}{G_y}-1\right)+B_Y\left(\frac{1-B_x}{B_y}-1\right)=W_Y\left(\frac{1-W_x}{W_y}-1\right)=\frac{1-W_x}{W_y}-1$$

Since $R_Y+G_Y+B_Y=W_Y=1$, this further simplifies to:

$$R_Y\left(\frac{1-R_x}{R_y}\right)+G_Y\left(\frac{1-G_x}{G_y}\right)+B_Y\left(\frac{1-B_x}{B_y}\right)=\frac{1-W_x}{W_y}$$

The $R_Y+G_Y+B_Y$ term for W_Y can be multiplied by $\frac{R_x}{R_y}$ and subtracted from the equation for W_X:

$$G_Y\left(\frac{G_x}{G_y}-\frac{R_x}{R_y}\right)+B_Y\left(\frac{B_x}{B_y}-\frac{R_x}{R_y}\right)=\frac{W_x}{W_y}-\frac{R_x}{R_y}$$

Similarly, the $R_Y+G_Y+B_Y$ term can be multiplied by $\frac{1-R_x}{R_y}$ and subtracted from the simplified W_Z line:

$$G_Y\left(\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}\right)+B_Y\left(\frac{1-B_x}{B_y}-\frac{1-R_x}{R_y}\right)=\frac{1-W_x}{W_y}-\frac{1-R_x}{R_y}$$

Finally, the G_Y term can be eliminated by multiplying the former of these two equations by $\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}$ and subtracting it from the latter multiplied by $\frac{G_x}{G_y}-\frac{R_x}{R_y}$, giving:

$$\begin{aligned}B_Y&\left(\left(\frac{1-B_x}{B_y}-\frac{1-R_x}{R_y}\right)\left(\frac{G_x}{G_y}-\frac{R_x}{R_y}\right)-\left(\frac{B_x}{B_y}-\frac{R_x}{R_y}\right)\left(\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}\right)\right)\\&=\left(\frac{1-W_x}{W_y}-\frac{1-R_x}{R_y}\right)\left(\frac{G_x}{G_y}-\frac{R_x}{R_y}\right)-\left(\frac{W_x}{W_y}-\frac{R_x}{R_y}\right)\left(\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}\right)\end{aligned}$$

Thus:

$$B_Y=\frac{\left(\frac{1-W_x}{W_y}-\frac{1-R_x}{R_y}\right)\left(\frac{G_x}{G_y}-\frac{R_x}{R_y}\right)-\left(\frac{W_x}{W_y}-\frac{R_x}{R_y}\right)\left(\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}\right)}{\left(\frac{1-B_x}{B_y}-\frac{1-R_x}{R_y}\right)\left(\frac{G_x}{G_y}-\frac{R_x}{R_y}\right)-\left(\frac{B_x}{B_y}-\frac{R_x}{R_y}\right)\left(\frac{1-G_x}{G_y}-\frac{1-R_x}{R_y}\right)}$$

This allows G_Y to be calculated by rearranging an earlier equation:

$$G_Y=\frac{\frac{W_x}{W_y}-\frac{R_x}{R_y}-B_Y\left(\frac{B_x}{B_y}-\frac{R_x}{R_y}\right)}{\frac{G_x}{G_y}-\frac{R_x}{R_y}}$$

And finally:

$$R_Y=1-G_Y-B_Y$$

These relative magnitudes allow the definition of vectors representing the color primaries in the *XYZ* space, which in turn provides a transformation between colors specified in terms of the color primaries and the *XYZ* space. Without an absolute magnitude the transformation to *XYZ* is incomplete, but sufficient to allow transformation to another set of color primaries.

The transform from the defined color primaries to *XYZ* space is:

$$\begin{pmatrix}X\\Y\\Z\end{pmatrix}=\begin{pmatrix}R_X, & G_X, & B_X\\R_Y, & G_Y, & B_Y\\R_Z, & G_Z, & B_Z\end{pmatrix}\begin{pmatrix}R\\G\\B\end{pmatrix}=\begin{pmatrix}\frac{R_Y}{R_y}R_x, & \frac{G_Y}{G_y}G_x, & \frac{B_Y}{B_y}B_x\\R_Y, & G_Y, & B_Y\\\frac{R_Y}{R_y}(1-R_x-R_y), & \frac{G_Y}{G_y}(1-G_x-G_y), & \frac{B_Y}{B_y}(1-B_x-B_y)\end{pmatrix}\begin{pmatrix}R\\G\\B\end{pmatrix}$$

Since the Y channel represents luminance, the second row of this matrix provides suitable weights for monochrome conversion. In practice, many such conversions contain an artistic input to the weighting of channels, corresponding to photographic filters and their effect on the contribution to exposure contributed by continuous real-world wavelengths. For example, black and white landscape photography often uses a red filter to darken a (blue) sky.

The transform from *XYZ* space to the defined color primaries is therefore:

$$\begin{pmatrix}R\\G\\B\end{pmatrix}=\begin{pmatrix}R_X, & G_X, & B_X\\R_Y, & G_Y, & B_Y\\R_Z, & G_Z, & B_Z\end{pmatrix}^{-1}\begin{pmatrix}X\\Y\\Z\end{pmatrix}=\begin{pmatrix}\frac{R_Y}{R_y}R_x, & \frac{G_Y}{G_y}G_x, & \frac{B_Y}{B_y}B_x\\R_Y, & G_Y, & B_Y\\\frac{R_Y}{R_y}(1-R_x-R_y), & \frac{G_Y}{G_y}(1-G_x-G_y), & \frac{B_Y}{B_y}(1-B_x-B_y)\end{pmatrix}^{-1}\begin{pmatrix}X\\Y\\Z\end{pmatrix}$$

Note

These transforms assume that the black point for the color space is at $(X,Y,Z) = (0,0,0)$. If the black point is non-zero, these transforms require a translational component. In some color spaces the black point has the same color as the white point, in which case it is also possible to adjust the (R,G,B) values outside the matrix.

Note

Real-world objects and light sources typically emit a full spectrum of wavelengths in varying intensities. Describing the color of an object in terms of three wavelengths is necessarily an approximation, and effective only because the human eye typically sees the world mostly in terms of combinations of three color cone cell responses — "tristimulus values". The typical response of these "long", "medium" and "short" wavelength-sensitive cones is the basis of the CIE XYZ color space, so a linear combination of primaries described in this color space can be mapped to a linear combination of other primaries. Two colors with a different spectrum but an identical appearance are known as *metamers*, and the tristimulus model of color relies on "metameric matching": picking a linear combination of some set of primaries that will elicit the same cone cell response as the desired color.

Each of the cone cells can appear in mutated form which results in a change to its response to different frequencies of light. Since the genes for cone cells are encoded on the X chromosome, some women have more than one variant of the same cone cell, being "tetrachromats" — and there is evidence that such people can distinguish more colors than the general "trichromat" population, with only a subset of these colors describable with three color primaries. There is some evidence for people with two variants of more than one cone cell, thereby perceiving color in a five-dimensional space, although the processing performed by the human visual system is complex and it is not clear how independently these color dimensions are in practice. In the animal kingdom, it is not uncommon to have more than three types of cone cell, and mantis shrimp have up to sixteen kinds of photoreceptors. Note that rod cells, which dominate the human visual system in low light conditions, are typically ignored at higher illumination levels for the purposes of color matching.

The difference between a primary color representation and the full spectrum emitted by a real-world object is particularly visible for printed media. Printing colors are typically described assuming that they will reflect the spectrum of a theoretical illuminant; changing this light source may change the appearance of the printed object in a more complex manner than scaling the primary values. This can lead to "metameric failure", where two colors may appear identical under some lighting conditions and different under others. This effect is present in nature, notably in the mineral alexandrite, which may appear reddish purple under incandescent light but green in daylight. Camera sensors and film have a related problem that the spectrum of filters does not perfectly match that of cone cells, which can lead some colors (particularly with sharp peaks in their spectra) to appear different. Inkjet printing often uses many more than three inks in order to maximize the representable gamut and control metamerism.

Adaptation to a different white point is often performed by a linear scaling of primaries, known as the "von Kries transform". The Bradford color adaptation transform incorporates a slight nonlinear term to the blue component of colors to more accurately reflect visual behavior.

It is common for production rendering systems to represent each pixel with more than three channels. For example, the contributions from different lights may be recorded separately in order to allow later adjustment to color and relative intensity, specular and diffuse reflectance from a surface may be recorded separately (which is valuable, for example, in denoising algorithms), and virtual "channels" may be used to control shader effects. A larger number of wavelengths may also be used when rendering effects such as chromatic dispersion, which is important for rendering jewelry. Currently these are typically represented as multiple images or in a proprietary representation, although one could imagine a data format descriptor for such a pixel.

14.1 BT.709 color primaries

ITU-T BT.709 (HDTV) defines the following chromaticity coordinates:

$$\begin{aligned} R_x &= 0.640 & R_y &= 0.330 \\ G_x &= 0.300 & G_y &= 0.600 \\ B_x &= 0.150 & B_y &= 0.060 \\ W_x &= 0.3127 & W_y &= 0.3290 \text{ (D65)} \end{aligned}$$

These chromaticity coordinates are also shared by sRGB and scRGB.

Therefore to convert from linear color values defined in terms of BT.709 color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.412391, & 0.357584, & 0.180481 \\ 0.212639, & 0.715169, & 0.072192 \\ 0.019331, & 0.119195, & 0.950532 \end{pmatrix} \begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix}$$

The inverse transformation, from the *XYZ* space to a color defined in terms of BT.709 color primaries, is:

$$\begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix} \approx \begin{pmatrix} 3.240970, & -1.537383, & -0.498611 \\ -0.969244, & 1.875968, & 0.041555 \\ 0.055630, & -0.203977, & 1.056972 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Note

sYCC lists a slightly different version of this matrix, possibly due to rounding errors.

14.2 BT.601 625-line color primaries

ITU-T Rec.601 defines different color primaries for 625-line systems (as used in most PAL systems) and for 525-line systems (as used in the SMPTE 170M-2004 standard for NTSC).

The following chromaticity coordinates are defined for 625-line “EBU” systems:

$$\begin{aligned} R_x &= 0.640 & R_y &= 0.330 \\ G_x &= 0.290 & G_y &= 0.600 \\ B_x &= 0.150 & B_y &= 0.060 \\ W_x &= 0.3127 & W_y &= 0.3290 \end{aligned}$$

Note

BT.470-6, which also describes these constants in a legacy context, approximates D65 as $x = 0.313,\ y = 0.329$.

Therefore to convert from linear color values defined in terms of BT.601 color primaries for 625-line systems to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.430554, & 0.341550, & 0.178352 \\ 0.222004, & 0.706655, & 0.071341 \\ 0.020182, & 0.129553, & 0.939322 \end{pmatrix} \begin{pmatrix} R_{601\text{EBU}} \\ G_{601\text{EBU}} \\ B_{601\text{EBU}} \end{pmatrix}$$

The inverse transformation, from the *XYZ* space to a color defined in terms of BT.601 “EBU” 625-line color primaries, is:

$$\begin{pmatrix} R_{601\text{EBU}} \\ G_{601\text{EBU}} \\ B_{601\text{EBU}} \end{pmatrix} \approx \begin{pmatrix} 3.063361, & -1.393390, & -0.475824 \\ -0.969244, & 1.875968, & 0.041555 \\ 0.067861, & -0.228799, & 1.069090 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

14.3 BT.601 525-line color primaries

ITU-T Rec.601 defines different color primaries for 625-line systems (as used in most PAL systems) and for 525-line systems (as used in the SMPTE 170M-2004 standard for NTSC).

The following chromaticity coordinates are defined in BT.601 for 525-line digital systems and in SMPTE-170M:

$$\begin{aligned} R_x &= 0.630 & R_y &= 0.340 \\ G_x &= 0.310 & G_y &= 0.595 \\ B_x &= 0.155 & B_y &= 0.070 \\ W_x &= 0.3127 & W_y &= 0.3290 \end{aligned}$$

Therefore to convert from linear color values defined in terms of BT.601 color primaries for 525-line systems to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.393521, & 0.365258, & 0.191677 \\ 0.212376, & 0.701060, & 0.086564 \\ 0.018739, & 0.111934, & 0.958385 \end{pmatrix} \begin{pmatrix} R_{601\mathrm{SMPTE}} \\ G_{601\mathrm{SMPTE}} \\ B_{601\mathrm{SMPTE}} \end{pmatrix}$$

The inverse transformation, from the *XYZ* space to a color defined in terms of BT.601 525-line color primaries, is:

$$\begin{pmatrix} R_{601\mathrm{SMPTE}} \\ G_{601\mathrm{SMPTE}} \\ B_{601\mathrm{SMPTE}} \end{pmatrix} \approx \begin{pmatrix} 3.506003,-1.739791, & -0.544058 \\ -1.069048,1.977779, & 0.035171 \\ 0.056307,-0.196976, & 1.049952 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Note

Analog 525-line PAL systems used a different white point, and therefore have a different conversion matrix.

14.4 BT.2020 color primaries

The following chromaticity coordinates are defined in BT.2020 for ultra-high-definition television:

$$\begin{aligned} R_x &= 0.708 & R_y &= 0.292 \\ G_x &= 0.170 & G_y &= 0.797 \\ B_x &= 0.131 & B_y &= 0.046 \\ W_x &= 0.3127 & W_y &= 0.3290 \end{aligned}$$

The same primaries are used for BT.2100 for HDR TV.

Therefore to convert from linear color values defined in terms of BT.2020 color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.636958, & 0.144617, & 0.168881 \\ 0.262700, & 0.677998, & 0.059302 \\ 0.000000, & 0.028073, & 1.060985 \end{pmatrix} \begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix}$$

The inverse transformation, from the *XYZ* space to a color defined in terms of BT.2020 color primaries, is:

$$\begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix} \approx \begin{pmatrix} 1.716651, & -0.355671, & -0.253366 \\ -0.666684, & 1.616481, & 0.015769 \\ 0.017640, & -0.042771, & 0.942103 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

14.5 NTSC 1953 color primaries

The following chromaticity coordinates are defined in ITU-R BT.470-6 and SMPTE 170m as a reference to the legacy NTSC standard:

$$
\begin{array}{ll}
R_x = 0.67 & R_y = 0.33 \\
G_x = 0.21 & G_y = 0.71 \\
B_x = 0.14 & B_y = 0.08 \\
W_x = 0.310 & W_y = 0.316 \text{ (Illuminant C)}
\end{array}
$$

Note

These primaries apply to the 1953 revision of the NTSC standard. Modern NTSC systems, which reflect displays that are optimized for brightness over saturation, use the color primaries as described in Section 14.3. The white point used in the original NTSC 1953 specification is CIE Standard Illuminant C, 6774K, as distinct from the CIE Illuminant D65 used by most modern standards. BT.470-6 notes that SECAM systems may use these NTSC primaries and white point. Japanese legacy NTSC systems used the same primaries but with the white point set to D-white at 9300K.

Therefore to convert from linear color values defined in terms of NTSC 1953 color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$
\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.606993, & 0.173449, & 0.200571 \\ 0.298967, & 0.586421, & 0.114612 \\ 0.000000, & 0.066076, & 1.117469 \end{pmatrix} \begin{pmatrix} R_{\text{NTSC}} \\ G_{\text{NTSC}} \\ B_{\text{NTSC}} \end{pmatrix}
$$

The inverse transformation, from the *XYZ* space to a color defined in terms of NTSC 1953 color primaries, is:

$$
\begin{pmatrix} R_{\text{NTSC}} \\ G_{\text{NTSC}} \\ B_{\text{NTSC}} \end{pmatrix} \approx \begin{pmatrix} 1.909675, & -0.532365, & -0.288161 \\ -0.984965, & 1.999777, & -0.028317 \\ 0.058241, & -0.118246, & 0.896554 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}
$$

14.6 PAL 525-line analog color primaries

ITU-R BT.1700 defines the following chromaticity coordinates for legacy 525-line PAL systems:

$$
\begin{array}{ll}
R_x = 0.630 & R_y = 0.340 \\
G_x = 0.310 & G_y = 0.595 \\
B_x = 0.155 & B_y = 0.070 \\
W_x = 0.3101 & W_y = 0.3162 \text{ (Illuminant C)}
\end{array}
$$

Note

This matches the color primaries from SMPTE-170m analog NTSC and BT.601 525-line encoding, but the white point used is CIE Standard Illuminant C, 6774K, as distinct from the CIE Illuminant D65 white point used by most modern standards.

Therefore to convert from linear color values defined in terms of PAL 525-line color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$
\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.415394, & 0.354637, & 0.210677 \\ 0.224181, & 0.680675, & 0.095145 \\ 0.019781, & 0.108679, & 1.053387 \end{pmatrix} \begin{pmatrix} R_{\text{PAL525}} \\ G_{\text{PAL525}} \\ B_{\text{PAL525}} \end{pmatrix}
$$

The inverse transformation, from the *XYZ* space to a color defined in terms of PAL 525-line 1953 color primaries, is:

$$
\begin{pmatrix} R_{\text{PAL525}} \\ G_{\text{PAL525}} \\ B_{\text{PAL525}} \end{pmatrix} \approx \begin{pmatrix} 3.321392, & -1.648181, & -0.515410 \\ -1.101064, & 2.037011, & 0.036225 \\ 0.051228, & -0.179211, & 0.955260 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}
$$

14.7 ACES color primaries

The following chromaticity coordinates are defined in SMPTE ST 2065-1

$$\begin{aligned} R_x &= 0.73470 & R_y &= 0.26530 \\ G_x &= 0.0 & G_y &= 1.0 \\ B_x &= 0.00010 & B_y &= -0.0770 \\ W_x &= 0.32168 & W_y &= 0.33767 \end{aligned}$$

Therefore to convert from linear color values defined in terms of ACES color primaries to XYZ space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.9525523959, & 0.0, & 0.0000936786 \\ 0.3439664498, & 0.7281660966, & -0.0721325464 \\ 0.0, & 0.0, & 1.0088251844 \end{pmatrix} \begin{pmatrix} R_{\text{ACES}} \\ G_{\text{ACES}} \\ B_{\text{ACES}} \end{pmatrix}$$

The inverse transformation, from the XYZ space to a color defined in terms of ACES color primaries, is:

$$\begin{pmatrix} R_{\text{ACES}} \\ G_{\text{ACES}} \\ B_{\text{ACES}} \end{pmatrix} \approx \begin{pmatrix} 1.0498110175, & 0.0, & -0.0000974845 \\ -0.4959030231, & 1.3733130458, & 0.0982400361 \\ 0.0, & 0.0, & 0.9912520182 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

14.8 ACEScc color primaries

The following chromaticity coordinates are defined in Academy S-2016-001 (ACEScct) and S-2014-003 (ACEScc), which share the same primaries:

$$\begin{aligned} R_x &= 0.713 & R_y &= 0.293 \\ G_x &= 0.165 & G_y &= 0.830 \\ B_x &= 0.128 & B_y &= 0.044 \\ W_x &= 0.32168 & W_y &= 0.33767 \end{aligned}$$

Therefore to convert from linear color values defined in terms of ACEScc/ACEScct color primaries to XYZ space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.6624541811, & 0.1340042065, & 0.1561876870 \\ 0.2722287168, & 0.6740817658, & 0.0536895174 \\ -0.0055746495, & 0.0040607335, & 1.0103391003 \end{pmatrix} \begin{pmatrix} R_{\text{ACEScct}} \\ G_{\text{ACEScct}} \\ B_{\text{ACEScct}} \end{pmatrix}$$

The inverse transformation, from the XYZ space to a color defined in terms of ACEScc/ACEScct color primaries, is:

$$\begin{pmatrix} R_{\text{ACEScc}} \\ G_{\text{ACEScc}} \\ B_{\text{ACEScc}} \end{pmatrix} \approx \begin{pmatrix} 1.6410233797, & -0.3248032942, & -0.2364246952 \\ -0.6636628587, & 1.6153315917, & 0.0167563477 \\ 0.0117218943, & -0.0082844420, & 0.9883948585 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

14.9 Display P3 color primaries

The following chromaticity coordinates are defined in Display P3:

$$\begin{aligned} R_x &= 0.6800 & R_y &= 0.3200 \\ G_x &= 0.2650 & G_y &= 0.6900 \\ B_x &= 0.1500 & B_y &= 0.0600 \\ W_x &= 0.3127 & W_y &= 0.3290 \end{aligned}$$

Note
The DCI P3 color space defines the bounds of its gamut using these primaries, but actual color data in DCI P3 is encoded using CIE *XYZ* coordinates. Display P3, on the other hand, uses these values as primaries in an *RGB* color space, with a D65 white point.

Therefore to convert from linear color values defined in terms of Display P3 color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \approx \begin{pmatrix} 0.4865709486, & 0.2656676932, & 0.1982172852 \\ 0.2289745641, & 0.6917385218, & 0.0792869141 \\ 0.0000000000, & 0.0451133819, & 1.0439443689 \end{pmatrix} \begin{pmatrix} R_{\text{DisplayP3}} \\ G_{\text{DisplayP3}} \\ B_{\text{DisplayP3}} \end{pmatrix}$$

The inverse transformation, from the *XYZ* space to a color defined in terms of DisplayP3 color primaries, is:

$$\begin{pmatrix} R_{\text{DisplayP3}} \\ G_{\text{DisplayP3}} \\ B_{\text{DisplayP3}} \end{pmatrix} \approx \begin{pmatrix} 2.4934969119, & -0.9313836179, & -0.4027107845 \\ -0.8294889696, & 1.7626640603, & 0.0236246858 \\ 0.0358458302, & -0.0761723893, & 0.9568845240 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Note
These matrices differ from those given in SMPTE EG 432-1 due to the choice of a D65 white point in Display P3. The matrices in 432-1 can be reproduced by applying a white point of $W_x = 0.314,\ W_y = 0.351$ to the above primaries.

14.10 Adobe RGB (1998) color primaries

The following chromaticity coordinates are defined in Adobe RGB (1998):

$$\begin{aligned} R_x &= 0.6400 & R_y &= 0.3300 \\ G_x &= 0.2100 & G_y &= 0.7100 \\ B_x &= 0.1500 & B_y &= 0.0600 \\ W_x &= 0.3127 & W_y &= 0.3290 \end{aligned}$$

Therefore to convert from linear color values defined in terms of Adobe RGB (1998) color primaries to *XYZ* space the formulae in Chapter 14 result in the following matrix:

$$\left(\begin{array}{c} X \\ Y \\ Z \end{array}\right) \approx \left(\begin{array}{ccc} 0.5766690429, & 0.1855582379, & 0.1882286462 \\ 0.2973449753, & 0.6273635663, & 0.0752914585 \\ 0.0270313614, & 0.0706888525, & 0.9913375368 \end{array}\right) = \left(\begin{array}{c} R_{\text{AdobeRGB}} \\ G_{\text{AdobeRGB}} \\ B_{\text{AdobeRGB}} \end{array}\right)$$

The inverse transformation, from the *XYZ* space to a color defined in terms of Adobe RGB (1998) color primaries, is:

$$\left(\begin{array}{c} R_{\text{AdobeRGB}} \\ G_{\text{AdobeRGB}} \\ B_{\text{AdobeRGB}} \end{array}\right) \approx \left(\begin{array}{rrr} 2.0415879038, & -0.5650069743, & -0.3447313508 \\ -0.9692436363, & 1.8759675015, & 0.0415550574 \\ 0.0134442806, & -0.1183623922, & 1.0151749944 \end{array}\right) \left(\begin{array}{c} X \\ Y \\ Z \end{array}\right)$$

Adobe RGB (1998) defines a reference display white brightness of 160cd/m^2 and a black point 0.34731% of this brightness, or 0.5557cd/m^2, for a contrast ratio of 287.9. The black point has the same color temperature as the white point, and this does not affect the above matrices.

14.11 BT.709/BT.601 625-line primary conversion example

Conversion from BT.709 to BT.601 625-line primaries can be performed using the matrices in Section 14.1 and Section 14.2 as follows:

$$\begin{pmatrix} R_{601\mathrm{EBU}} \\ G_{601\mathrm{EBU}} \\ B_{601\mathrm{EBU}} \end{pmatrix} \approx \begin{pmatrix} 3.063361, & -1.393390, & -0.475824 \\ -0.969244, & 1.875968, & 0.041555 \\ 0.067861, & -0.228799, & 1.069090 \end{pmatrix} \begin{pmatrix} 0.412391, & 0.357584, & 0.180481 \\ 0.212639, & 0.715169, & 0.072192 \\ 0.019331, & 0.119195, & 0.950532 \end{pmatrix} \begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix}$$

$$\begin{pmatrix} R_{601\mathrm{EBU}} \\ G_{601\mathrm{EBU}} \\ B_{601\mathrm{EBU}} \end{pmatrix} \approx \begin{pmatrix} 0.957815, & 0.042184, & 0.0 \\ 0.0, & 1.0, & 0.0 \\ 0.0, & -0.011934, & 1.011934 \end{pmatrix} \begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix}$$

Conversion from BT.601 625-line to BT.709 primaries can be performed using these matrices:

$$\begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix} \approx \begin{pmatrix} 3.240970, & -1.537383, & -0.498611 \\ -0.969244, & 1.875968, & 0.041555 \\ 0.055630, & -0.203977, & 1.056972 \end{pmatrix} \begin{pmatrix} 0.430554, & 0.341550, & 0.178352 \\ 0.222004, & 0.706655, & 0.071341 \\ 0.020182, & 0.129553, & 0.939322 \end{pmatrix} \begin{pmatrix} R_{601\mathrm{EBU}} \\ G_{601\mathrm{EBU}} \\ B_{601\mathrm{EBU}} \end{pmatrix}$$

$$\begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix} \approx \begin{pmatrix} 1.044044, & -0.044043, & 0.0 \\ 0.0, & 1.0, & 0.0 \\ 0.0, & 0.011793, & 0.988207 \end{pmatrix} \begin{pmatrix} R_{601\mathrm{EBU}} \\ G_{601\mathrm{EBU}} \\ B_{601\mathrm{EBU}} \end{pmatrix}$$

14.12 BT.709/BT.2020 primary conversion example

Conversion from BT.709 to BT.2020 primaries can be performed using the matrices in Section 14.4 and Section 14.1 as follows:

$$\begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix} \approx \begin{pmatrix} 1.716651, & -0.355671, & -0.253366 \\ -0.666684, & 1.616481, & 0.015769 \\ 0.017640, & -0.042771, & 0.942103 \end{pmatrix} \begin{pmatrix} 0.412391, & 0.357584, & 0.180481 \\ 0.212639, & 0.715169, & 0.072192 \\ 0.019331, & 0.119195, & 0.950532 \end{pmatrix} \begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix}$$

$$\begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix} \approx \begin{pmatrix} 0.627404, & 0.329282, & 0.043314 \\ 0.069097, & 0.919541, & 0.011362 \\ 0.016392, & 0.088013, & 0.895595 \end{pmatrix} \begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix}$$

Conversion from BT.2020 primaries to BT.709 primaries can be performed with the following matrices:

$$\begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix} \approx \begin{pmatrix} 3.240970, & -1.537383, & -0.498611 \\ -0.969244, & 1.875968, & 0.041555 \\ 0.055630, & -0.203977, & 1.056972 \end{pmatrix} \begin{pmatrix} 0.636958, & 0.144617, & 0.168881 \\ 0.262700, & 0.677998, & 0.059302 \\ 0.000000, & 0.028073, & 1.060985 \end{pmatrix} \begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix}$$

$$\begin{pmatrix} R_{709} \\ G_{709} \\ B_{709} \end{pmatrix} \approx \begin{pmatrix} 1.660491, & -0.587641, & -0.072850 \\ -0.124551, & 1.132900, & -0.008349 \\ -0.018151, & -0.100579, & 1.118730 \end{pmatrix} \begin{pmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{pmatrix}$$

Chapter 15

Color models

The human eye is more sensitive to high-frequency changes in intensity (absolute quantity of light) than to high-frequency changes in the dominant wavelength and saturation of a color. Additionally the eye does not exhibit equal sensitivity to all wavelengths. Many image representations take advantage of these facts to distribute the number of bits used to represent a texel in a more perceptually-uniform manner than is achieved by representing the color primaries independently - for example by encoding the chroma information at a reduced spatial resolution.

15.1 $Y'C_BC_R$ color model

Color models based on color differences are often referred to with incorrect or ambiguous terminology, the most common of which is *YUV*.

In the broadcast standards which define these models:

- A prime mark ($'$) is used to refer to what the ITU standards call a “gamma pre-corrected” representation of a value; that is, the value encoded with a nonlinear transfer function between physical light intensity and representation. The transfer function creates an approximately linear relationship between the “gamma pre-corrected” value and perceived intensity; the absence of a prime mark indicates that the value is linear with respect to absolute light intensity. The nonlinear transfer function resembles an exponentiation operation, in many cases with a linear segment near zero for mathematical stability; the exponent is conventionally referred to as “gamma”. The encoding reduces the required bandwidth by de-emphasising details that are hard for humans to perceive. Historical CRTs had a nonlinear response to (analog) input voltage, which is approximately the inverse of the nonlinear response of the human visual system, thus making the CRT an ideal decoder for this encoded signal, converting the transmitted value back to linear intensity. “Gamma correction” can be seen as compensating for the nonlinearity of the display; thus “gamma pre-correction” is applying the compensation before transmitting the signal (though noting that the OETF used to encode video signals is often not the EOTF exhibited by the display). The encoding efficiency benefits of nonlinearity persist despite modern display technology and standards no longer exhibiting this inherent nonlinear behavior. See Chapter 12 for an introduction to transfer functions, and Section 13.2 for details of the transfer function typically used with $\mathrm{Y'C_BC_R}$.
- $R'G'B'$ is used to refer to the red, green and blue reference values in “gamma pre-corrected” form, whereas R, G and B (without $'$ symbols) are represented linearly with respect to physical light intensity, as explained above.
- IEEE standards BT.601 and BT.709 use a prefix of E to refer to a continuous signal value in the range [0..1], mirroring the terminology in analog standards such as BT.1700 and SMPTE-170M. For example, in these standards, the continuous encoding of R' is written E'_R. BT.2020 and BT.2100 no longer use the E convention, and refer to continuous values as, for example, R' directly. For brevity, this specification does not use the E-prefix convention for model conversions, and all values can be assumed to be continuous. BT.601 refers to the quantized digital version of E'_R, E'_G and E'_B as E'_{R_D}, E'_{G_D} and E'_{B_D}. In BT.709 the quantized digital representation is instead D'_R, D'_G and D'_B, in BT.2020 and BT.2100 written as DR', DG' and DB'.

- Y' is a weighted sum of R', G' and B' values, and represents physically-nonlinear (but perceptually-linear) light intensity, as distinct from physically-linear light intensity. Note that the ITU broadcast standards use "luminance" for Y' despite some authorities reserving that term for a linear intensity representation. Since this is a weighted sum of nonlinear values, Y' is not mathematically equivalent to applying the nonlinear transfer function to a weighted sum of linear R, G and B values: $R^\gamma + G^\gamma + B^\gamma \neq (R+G+B)^\gamma$. The prime symbol is often omitted so that Y' is confusingly written Y. BT.601 and BT.709 refers to the continuous nonlinear "luminance" signal as E'_Y; in BT.2020 and BT.2100 this value is just Y'. The quantized digital representation is written as simply Y' in BT.601, as D'_Y in BT.709, and as DY' in BT.2020 and BT.2100. In this standard, Y' refers to a continuous value.
- For the purposes of this section, we will refer to the weighting factor applied to R' as K_R and the weighting factor applied to B' as K_B. The weighting factor of G' is therefore $1 - K_R - K_B$. Thus $Y' = K_R \times R' + (1 - K_R - K_B) \times G' + Kb \times B'$.

Color differences are calculated from the nonlinear Y' and color components as:

$$\begin{aligned} B' - Y' &= (1 - K_B) \times B' - (1 - K_R - K_B) \times G' - K_R \times R' \\ R' - Y' &= (1 - K_R) \times R' - (1 - K_R - K_B) \times G' - K_B \times B' \end{aligned}$$

Note that, for R', G', B' in the range [0..1]:

$$\begin{aligned} (1 - K_B) \geq B' - Y' \geq -(1 - K_B) \\ (1 - K_R) \geq R' - Y' \geq -(1 - K_R) \end{aligned}$$

- $(B' - Y')$ scaled appropriately for incorporation into a PAL sub-carrier signal is referred to in BT.1700 as U; note that the scale factor (0.493) is not the same as that used for digital encoding of this color difference. U is colloquially used for other representations of this value.
- $(R' - Y')$ scaled appropriately for incorporation into a PAL sub-carrier signal is referred to in BT.1700 as V; note that the scale factor (0.877) is not the same as that used for digital encoding of this color difference. V is colloquially used for other representations of this value.
- $(B' - Y')$ scaled to the range $[-0.5..0.5]$ is referred to in BT.601 and BT.709 as E'_{C_B}, and in BT.2020 and BT.2100 as simply C'_B. In ST-240 this value is referred to as E'_{PB}, and the analog signal is colloquially known as P_B. This standard uses the C'_B terminology for brevity and consistency with $Y'_C C'_{BC} C'_{RC}$. It is common, especially in the name of a color model, to omit the prime symbol and write simply C_B.
- $(R' - Y')$ scaled to the range $[-0.5..0.5]$ is referred to in BT.601 and BT.709 as E'_{C_R}, and in BT.2020 and BT.2100 as simply C'_R. In ST-240 this value is referred to as E'_{PR}, and the analog signal is colloquially known as P_R. This standard uses the C'_R terminology for brevity and consistency with $Y'_C C'_{BC} C'_{RC}$. It is common, especially in the name of a color model, to omit the prime symbol and write simply C_R.
- $(B' - Y')$ scaled and quantized for digital representation is known as simply C'_B in BT.601, D'_{CB} in BT.709 and DC'_B in BT.2020 and BT.2100.
- $(R' - Y')$ scaled and quantized for digital representation is known as simply C'_R in BT.601, D'_{CR} in BT.709 and DC'_R in BT.2020 and BT.2100.
- This section considers the color channels in continuous terms; the terminology DC'_B and DC'_R is used in Chapter 16.

Using this terminology, the following conversion formulae can be derived:

$$\begin{aligned} Y' &= K_r \times R' + (1 - K_R - K_B) \times G' + K_B \times B' \\ C'_B &= \frac{(B' - Y')}{2(1 - K_B)} \\ &= \frac{B'}{2} - \frac{K_R \times R' + (1 - K_R - K_B) \times G'}{2(1 - K_B)} \\ C'_R &= \frac{(R' - Y')}{2(1 - K_R)} \\ &= \frac{R'}{2} - \frac{K_B \times B' + (1 - K_R - K_B) \times G'}{2(1 - K_R)} \end{aligned}$$

For the inverse conversion:

$$R' = Y' + 2(1 - K_R) \times C'_R$$
$$B' = Y' + 2(1 - K_B) \times C'_B$$

The formula for G' can be derived by substituting the formulae for R' and B' into the derivation of Y':

$$\begin{aligned}
Y' &= K_R \times R' + (1 - K_R - K_B) \times G' + K_B \times B' \\
&= K_R \times (Y' + 2(1 - K_R) \times C'_R) + \\
&\quad (1 - K_R - K_B) \times G' + \\
&\quad K_B \times (Y' + 2(1 - K_B) \times C'_B) \\
Y' \times (1 - K_R - K_B) &= (1 - K_R - K_B) \times G' + \\
&\quad K_R \times 2(1 - K_R) \times C'_R + \\
&\quad K_B \times 2(1 - K_B) \times C'_B \\
G' &= Y' - \frac{2(K_R(1 - K_R) \times C'_R + K_B(1 - K_B) \times C'_B)}{1 - K_R - K_B}
\end{aligned}$$

The values chosen for K_R and K_B vary between standards.

Since luma is logically a weighted sum of red, green and blue values (albeit not a linear one), in most standards K_R and K_B correspond to the Y line of the corresponding (R, G, B) to (X, Y, Z) color primary conversion matrix, subject to rounding (the values stated below come directly from the corresponding standards). For example, for BT.709 the Y row of the color primary conversion matrix is shown as (0.212639, 0.715169, 0.072192), which are approximately the (0.2126, 0.7152, 0.0722) triple defined for (K_R, (1-K_R), K_B) in the corresponding color model version. Non-standard $Y'C_BC_R$ representations could be derived for different color primaries using this observation.

Note that the K_R and K_B used in the BT.601 $Y'C_BC_R$ conversion correspond (approximately) to the NTSC 1953 color primaries. The BT.601 525-line primaries correspond to the $Y'C_BC_R$ conversion from ST-240, but there is no corresponding standard model conversion that corresponds to the BT.601 625-line color primaries.

Note
The required color model conversion between $Y'C_BC_R$ and $R'G'B'$ can typically be deduced from other color space parameters:

Primaries		OETF		Color model conversion	
Defined in	Described in	Defined in	Described in	Defined in	Described in
BT.709 sRGB	Section 14.1	BT.709	Section 13.2	BT.709	Section 15.1.1
BT.709 sRGB sYCC	Section 14.1	sRGB sYCC	Section 13.3	BT.601	Section 15.1.2
BT.601 (625-line)	Section 14.2	BT.601	Section 13.2	BT.601	Section 15.1.2
BT.601 (525-line) ST-240	Section 14.3	BT.601	Section 13.2	BT.601	Section 15.1.2
BT.601 (525-line) ST-240	Section 14.3	ST-240	Section 13.11	ST-240	Section 15.1.4
BT.2020 BT.2100	Section 14.4	BT.2020	Section 13.2	BT.2020	Section 15.1.3

15.1.1 BT.709 $Y'C_BC_R$ conversion

ITU Rec.709 defines $K_R = 0.2126$ and $K_B = 0.0722$.

That is, for conversion between (R', G', B') defined in BT.709 color primaries and using the ITU transfer function:

$$
\begin{aligned}
Y' &= 0.2126 \times R' + 0.7152 \times G' + 0.0722 \times B' \\
C'_B &= \frac{(B' - Y')}{1.8556} \\
C'_R &= \frac{(R' - Y')}{1.5748}
\end{aligned}
$$

Alternatively:

$$
\begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} = \begin{pmatrix} 0.2126, & 0.7152, & 0.0722 \\ -\frac{0.2126}{1.8556}, & -\frac{0.7152}{1.8556}, & 0.5 \\ 0.5, & -\frac{0.7152}{1.5748}, & -\frac{0.0722}{1.5748} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} \approx \begin{pmatrix} 0.2126, & 0.7152, & 0.0722 \\ -0.114572, & -0.385428, & 0.5 \\ 0.5, & 0.454153, & -0.045847 \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}
$$

For the inverse conversion:

$$
\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1, & 0, & 1.5748 \\ 1, & -\frac{0.13397432}{0.7152}, & -\frac{0.33480248}{0.7152} \\ 1, & 1.8556, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} \approx \begin{pmatrix} 1, & 0, & 1.5748 \\ 1, & -0.187324, & -0.468124 \\ 1, & 1.8556, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix}
$$

15.1.2 BT.601 $Y'C_BC_R$ conversion

ITU Rec.601 defines $K_R = 0.299$ and $K_B = 0.114$.

That is, for conversion between (R', G', B') defined in BT.601 EBU color primaries or BT.601 SMPTE color primaries, and using the ITU transfer function:

$$
\begin{aligned}
Y' &= 0.299 \times R' + 0.587 \times G' + 0.114 \times B' \\
C'_B &= \frac{(B' - Y')}{1.772} \\
C'_R &= \frac{(R' - Y')}{1.402}
\end{aligned}
$$

Alternatively:

$$
\begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} = \begin{pmatrix} 0.299, & 0.587, & 0.114 \\ -\frac{0.299}{1.772}, & -\frac{0.587}{1.772}, & 0.5 \\ 0.5, & -\frac{0.587}{1.402}, & -\frac{0.114}{1.402} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} \approx \begin{pmatrix} 0.299, & 0.587, & 0.114 \\ -0.168736, & -0.331264, & 0.5 \\ 0.5, & -0.418688, & -0.081312 \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}
$$

For the inverse conversion:

$$
\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1, & 0, & 1.402 \\ 1, & -\frac{0.202008}{0.587}, & -\frac{0.419198}{0.587} \\ 1, & 1.772, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} \approx \begin{pmatrix} 1, & 0, & 1.402 \\ 1, & -0.344136, & -0.714136 \\ 1, & 1.772, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix}
$$

15.1.3 BT.2020 $Y'C_BC_R$ conversion

ITU Rec.2020 and ITU Rec.2100 define $K_R = 0.2627$ and $K_B = 0.0593$.

That is, for conversion between (R', G', B') defined in BT.2020 color primaries and using the ITU transfer function:

$$\begin{aligned} Y' &= 0.2627 \times R' + 0.6780 \times G' + 0.0593 \times B' \\ C'_B &= \frac{(B' - Y')}{1.8814} \\ C'_R &= \frac{(R' - Y')}{1.4746} \end{aligned}$$

Alternatively:

$$\begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} = \begin{pmatrix} 0.2627, & 0.6780, & 0.0593 \\ -\frac{0.2627}{1.8814}, & -\frac{0.6780}{1.8814}, & 0.5 \\ 0.5, & -\frac{0.6780}{1.4746}, & -\frac{0.0593}{1.4746} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} \approx \begin{pmatrix} 0.2627, & 0.6780, & 0.0593 \\ -0.139630, & -0.360370, & 0.5 \\ 0.5, & -0.459786, & -0.040214 \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$

For the inverse conversion:

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1, & 0, & 1.4746 \\ 1, & -\frac{0.11156702}{0.6780}, & -\frac{0.38737742}{0.6780} \\ 1, & 1.8814, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} \approx \begin{pmatrix} 1, & 0, & 1.4746 \\ 1, & -0.164553, & -0.571353 \\ 1, & 1.8814, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix}$$

15.1.4 ST-240/SMPTE 240M $Y'C_BC_R$ conversion

ST240, formerly SMPTE 240M, defines $K_R = 0.212$ and $K_B = 0.087$.

That is, for conversion using the ST240 transfer function:

$$\begin{aligned} Y' &= 0.212 \times R' + 0.701 \times G' + 0.087 \times B' \\ C'_B &= \frac{(B' - Y')}{1.826} \\ C'_R &= \frac{(R' - Y')}{1.576} \end{aligned}$$

Alternatively:

$$\begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} = \begin{pmatrix} 0.212, & 0.701, & 0.087 \\ -\frac{0.212}{1.826}, & -\frac{0.701}{1.826}, & 0.5 \\ 0.5, & -\frac{0.701}{1.576}, & -\frac{0.087}{1.576} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} \approx \begin{pmatrix} 0.212, & 0.701, & 0.087 \\ -0.116101, & -0.383899, & 0.5 \\ 0.5, & -0.444797, & -0.055203 \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$

For the inverse conversion:

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1, & 0, & 1.576 \\ 1, & -\frac{0.158862}{0.701}, & -\frac{0.334112}{0.701} \\ 1, & 1.826, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix} \approx \begin{pmatrix} 1, & 0, & 1.576 \\ 1, & -0.226622, & -0.476622 \\ 1, & 1.826, & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C'_B \\ C'_R \end{pmatrix}$$

15.2 $Y'_C C'_{BC} C'_{CR}$ constant luminance color model

ITU-T Rec. BT.2020 introduced a “constant luminance” color representation as an alternative representation to $Y'C_BC_R$:

$$Y'_C = (0.2627R + 0.6780G + 0.0593B)'$$

$$C'_{BC} = \begin{cases} \frac{B'-Y'_C}{1.9404}, & -0.9702 \leq B' - Y'_C \leq 0 \\ \frac{B'-Y'_C}{1.5816}, & 0 < B' - Y'_C \leq 0.7908 \end{cases}$$

$$C'_{RC} = \begin{cases} \frac{R'-Y'_C}{1.7184}, & -0.8592 \leq R' - Y'_C \leq 0 \\ \frac{R'-Y'_C}{0.9936}, & 0 < R' - Y'_C \leq 0.4968 \end{cases}$$

This terminology follows BT.2020’s convention of describing the continuous values as Y'_C, C'_{BC} and C'_{RC}; BT.2020 uses DY'_C, DC'_{BC} and DC'_{RC} to represent the quantized integer representations of the same values.

Note

Y'_C is derived from applying a nonlinear transfer function to a combination of linear RGB components and applying a nonlinear transfer function to the result, but the C'_{BC} and C'_{RC} color differences still encode differences between nonlinear values.

The inverse transformation can be derived from the above:

$$B' = \begin{cases} Y'_C + 1.9404C'_{BC}, & C'_{BC} \leq 0 \\ Y'_C + 1.5816C'_{BC}, & C'_{BC} > 0 \end{cases}$$

$$R' = \begin{cases} Y'_C + 1.7184C'_{RC}, & C'_{RC} \leq 0 \\ Y'_C + 0.9936C'_{RC}, & C'_{RC} > 0 \end{cases}$$

$$G = Y_C - 0.2627R - 0.0593B$$

Note

Performing these calculations requires conversion between a linear representation and a nonlinear transfer function during the transformation. This is distinct from the non-constant-luminance case, which is a simple matrix transform.

15.3 IC_TC_P constant intensity color model

ITU-T Rec. BT.2100 introduced a “constant intensity” color representation as an alternative representation to $Y'C_BC_R$:

$$L = \frac{(1688R + 2146G + 262B)}{4096}$$

$$M = \frac{(683R + 2951G + 462B)}{4096}$$

$$S = \frac{(99R + 309G + 3688B)}{4096}$$

$$L' = \begin{cases} \text{EOTF}^{-1}(L_D), & \text{PQ transfer function} \\ \text{OETF}(L_S), & \text{HLG transfer function} \end{cases}$$

$$M' = \begin{cases} \text{EOTF}^{-1}(M_D), & \text{PQ transfer function} \\ \text{OETF}(M_S), & \text{HLG transfer function} \end{cases}$$

$$S' = \begin{cases} \text{EOTF}^{-1}(S_D), & \text{PQ transfer function} \\ \text{OETF}(S_S), & \text{HLG transfer function} \end{cases}$$

$$I = 0.5L' + 0.5M'$$

$$C_T = \frac{(6610L' - 13613M' + 7003S')}{4096}$$

$$C_P = \frac{(17933L' - 17390M' - 543S')}{4096}$$

Note that the suffix $_D$ indicates that PQ encoding is *display-referred* and the suffix $_S$ indicates that HLG encoding is *scene-referred* — that is, they refer to display and scene light respectively.

To invert this, it can be observed that:

$$\begin{pmatrix} L' \\ M' \\ S' \end{pmatrix} = 4096 \times \begin{pmatrix} 2048, & 2048, & 0 \\ 6610, & -13613, & 7003 \\ 17933, & -17390, & -543 \end{pmatrix}^{-1} \begin{pmatrix} I \\ C_T \\ C_P \end{pmatrix}$$

$$\begin{pmatrix} L' \\ M' \\ S' \end{pmatrix} = \begin{pmatrix} 1, & 1112064/129174029, & 14342144/129174029 \\ 1, & -1112064/129174029, & -14342144/129174029 \\ 1, & 72341504/129174029, & -41416704/129174029 \end{pmatrix} \begin{pmatrix} I \\ C_T \\ C_P \end{pmatrix}$$

$$\begin{pmatrix} L' \\ M' \\ S' \end{pmatrix} \approx \begin{pmatrix} 1, & 0.0086090370, & 0.1110296250 \\ 1, & -0.0086090370, & -0.1110296250 \\ 1, & 0.5600313357, & -0.3206271750 \end{pmatrix} \begin{pmatrix} I \\ C_T \\ C_P \end{pmatrix}$$

$$\{L_D, M_D, S_D\} = \mathrm{EOTF_{PQ}}(\{L', M', S'\})$$

$$\{L_S, M_S, S_S\} = \mathrm{OETF_{HLG}^{-1}}(\{L', M', S'\})$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = 4096 \times \begin{pmatrix} 1688, & 2146, & 262 \\ 683, & 2951, & 462 \\ 99, & 309, & 3688 \end{pmatrix}^{-1} \begin{pmatrix} L \\ M \\ S \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \frac{4096}{12801351680} \times \begin{pmatrix} 10740530, & -7833490, & 218290 \\ -2473166, & 6199406, & -600910 \\ -81102, & -309138, & 3515570 \end{pmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} \approx \begin{pmatrix} 3.4366066943, & -2.5064521187, & 0.0698454243 \\ -0.7913295556, & 1.9836004518, & -0.1922708962 \\ -0.0259498997, & -0.0989137147, & 1.1248636144 \end{pmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix}$$

Chapter 16

Quantization schemes

The formulae in the previous sections are described in terms of operations on continuous values. These values are typically represented by quantized integers. There are standard encodings for representing some color models within a given bit depth range.

16.1 “Narrow range” encoding

ITU broadcast standards typically reserve values at the ends of the representable integer range for rounding errors and for signal control data. The nominal range of representable values between these limits is represented by the following encodings, for bit depth $n = \{8, 10, 12\}$:

$$\begin{array}{rr}
DG' = \lfloor 0.5 + (219 \times G' + 16) \times 2^{n-8} \rfloor & DB' = \lfloor 0.5 + (219 \times B' + 16) \times 2^{n-8} \rfloor \\
 & DR' = \lfloor 0.5 + (219 \times R' + 16) \times 2^{n-8} \rfloor \\
DY' = \lfloor 0.5 + (219 \times Y' + 16) \times 2^{n-8} \rfloor & DC'_B = \lfloor 0.5 + (224 \times C'_B + 128) \times 2^{n-8} \rfloor \\
 & DC'_R = \lfloor 0.5 + (224 \times C'_R + 128) \times 2^{n-8} \rfloor \\
DY'_C = \lfloor 0.5 + (219 \times Y'_C + 16) \times 2^{n-8} \rfloor & DC'_{CB} = \lfloor 0.5 + (224 \times C'_{CB} + 128) \times 2^{n-8} \rfloor \\
 & DC'_{CR} = \lfloor 0.5 + (224 \times C'_{CR} + 128) \times 2^{n-8} \rfloor \\
DI = \lfloor 0.5 + (219 \times I + 16) \times 2^{n-8} \rfloor & DC'_T = \lfloor 0.5 + (224 \times C'_T + 128) \times 2^{n-8} \rfloor \\
 & DC'_P = \lfloor 0.5 + (224 \times C'_P + 128) \times 2^{n-8} \rfloor
\end{array}$$

Note that these scale factors correspond to 1.0 being encoded as $235 \times 2^{n-8}$ (for R', G', B' and Y'), not $235 \times \left(2^{n-8} - 1\right)$ as might be expected for “normalized” representations.

The dequantization formulae are therefore:

$$\begin{array}{cccc}
G' = \frac{\frac{DG'}{2^{n-8}} - 16}{219} & Y' = \frac{\frac{DY'}{2^{n-8}} - 16}{219} & Y'_C = \frac{\frac{DY'_C}{2^{n-8}} - 16}{219} & I = \frac{\frac{DI'}{2^{n-8}} - 16}{219} \\
B' = \frac{\frac{DB'}{2^{n-8}} - 16}{219} & C'_B = \frac{\frac{DC'_B}{2^{n-8}} - 128}{224} & C'_{CB} = \frac{\frac{DC'_{CB}}{2^{n-8}} - 128}{224} & C'_T = \frac{\frac{DC'_T}{2^{n-8}} - 128}{224} \\
R' = \frac{\frac{DR'}{2^{n-8}} - 16}{219} & C'_R = \frac{\frac{DC'_R}{2^{n-8}} - 128}{224} & C'_{CR} = \frac{\frac{DC'_{CR}}{2^{n-8}} - 128}{224} & C'_P = \frac{\frac{DC'_P}{2^{n-8}} - 128}{224}
\end{array}$$

For consistency with $Y'_C C'_{BC} C'_{RC}$, these formulae use the BT.2020 and BT.2100 terminology of prefixing a D to represent the digital quantized encoding of a numerical value.

That is, in “narrow range” encoding:

Value	Continuous encoding value	Quantized encoding
Black	$\{R', G', B', Y', Y'_C, I\}$ = 0.0	$\{DR', DG', DB', DY', DY'_C, DI\} = 16 \times 2^{n-8}$
Peak brightness	$\{R', G', B', Y', Y'_C, I\}$ = 1.0	$\{DR', DG', DB', DY', DY'_C, DI\} = 235 \times 2^{n-8}$
Minimum color difference value	$\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\}$ = -0.5	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 16 \times 2^{n-8}$
Maximum color difference value	$\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\}$ = 0.5	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 240 \times 2^{n-8}$
Achromatic colors	$R' = G' = B'$ $\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\}$ = 0.0	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 128 \times 2^{n-8}$

If, instead of the quantized values, the input is interpreted as fixed-point n-bit values in the range 0.0..1.0, as might be the case if the values were treated as unsigned “normalized” quantities in a computer graphics API, the following conversions can be applied instead:

$$G' = \frac{G'_{norm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$Y' = \frac{Y'_{norm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$Y'_C = \frac{Y'_{Cnorm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$I = \frac{I'_{norm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$B' = \frac{B'_{norm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$R' = \frac{R'_{norm} \times (2^n - 1) - 16 \times 2^{n-8}}{219 \times 2^{n-8}}$$

$$C'_B = \frac{DC'_{Bnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$C'_R = \frac{DC'_{Rnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$C'_{CB} = \frac{DC'_{CBnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$C'_{CR} = \frac{DC'_{CRnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$C'_T = \frac{DC'_{Tnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$C'_P = \frac{DC'_{Pnorm} \times (2^n - 1) - 128 \times 2^{n-8}}{224 \times 2^{n-8}}$$

$$G'_{norm} = \frac{G' \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$Y'_{norm} = \frac{Y' \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$Y'_{Cnorm} = \frac{Y'_C \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$I_{norm} = \frac{I \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$B'_{norm} = \frac{B' \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$R'_{norm} = \frac{R' \times 219 \times 2^{n-8} + 16 \times 2^{n-8}}{2^n - 1}$$

$$C'_{Bnorm} = \frac{DC'_B \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

$$C'_{Rnorm} = \frac{DC'_R \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

$$C'_{CBnorm} = \frac{DC'_{CB} \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

$$C'_{CRnorm} = \frac{DC'_{CR} \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

$$C'_{Tnorm} = \frac{DC'_T \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

$$C'_{Pnorm} = \frac{DC'_P \times 224 \times^{n-8} + 128 \times 2^{n-8}}{2^n - 1}$$

16.2 “Full range” encoding

ITU-T Rec. BT.2100-1 and the current Rec. T.871 JFIF specification define the following quantization scheme that does not incorporate any reserved head-room or foot-room, which is optional and described as “full range” in BT.2100, and integral to Rec. T.871.

Note
Both these specifications modify a definition used in previous versions of their specifications, which is described below.

For bit depth n = {8 (JFIF),10,12 (Rec.2100)}:

$$DG' = \text{Round}\left(G' \times (2^n - 1)\right) \qquad DB' = \text{Round}\left(B' \times (2^n - 1)\right)$$
$$DR' = \text{Round}\left(R' \times (2^n - 1)\right)$$
$$DY' = \text{Round}\left(Y' \times (2^n - 1)\right) \qquad DC'_B = \text{Round}\left(C'_B \times (2^n - 1) + 2^{n-1}\right)$$
$$DC'_R = \text{Round}\left(C'_R \times (2^n - 1) + 2^{n-1}\right)$$
$$DY'_C = \text{Round}\left(Y'_C \times (2^n - 1)\right) \qquad DC'_{CB} = \text{Round}\left(C'_{CB} \times (2^n - 1) + 2^{n-1}\right)$$
$$DC'_{CR} = \text{Round}\left(C'_{CR} \times (2^n - 1) + 2^{n-1}\right)$$
$$DI = \text{Round}\left(I \times (2^n - 1)\right) \qquad DC'_T = \text{Round}\left(C'_T \times (2^n - 1) + 2^{n-1}\right)$$
$$DC'_P = \text{Round}\left(C'_P \times (2^n - 1) + 2^{n-1}\right)$$

BT.2100-1 defines Round() as:

$$\text{Round}(x) = \text{Sign}(x) \times \lfloor |x| + 0.5 \rfloor$$
$$\text{Sign}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

Note that a chroma channel value of exactly 0.5 corresponds to a quantized encoding of 2^n, and must therefore be clamped to the nominal peak value of $2^n - 1$. Narrow-range encoding does not have this problem. A chroma channel value of -0.5 corresponds to a quantized encoding of 1, which is the nominal minimum peak value.

In Rec. T.871 (which defines only n = 8), the corresponding formula is:

$$\text{Round}(x) = \text{Clamp}(\lfloor |x| + 0.5 \rfloor)$$
$$\text{clamp}(x) = \begin{cases} 255, & x > 255 \\ 0, & x < 0 \\ x, & \text{otherwise} \end{cases}$$

Allowing for the clamping at a chroma value of 0.5, these formulae are equivalent across the expected -0.5..0.5 range for chroma and 0.0..1.0 range for luma values.

The dequantization formulae are therefore:

$$G' = \frac{DG'}{2^n - 1} \qquad Y' = \frac{DY'}{2^n - 1} \qquad Y'_C = \frac{DY'_C}{2^n - 1} \qquad I = \frac{DI'}{2^n - 1}$$
$$B' = \frac{DB'}{2^n - 1} \qquad C'_B = \frac{DC'_B - 2^{n-1}}{2^n - 1} \qquad C'_{CB} = \frac{DC'_{CB} - 2^{n-1}}{2^n - 1} \qquad C'_T = \frac{DC'_T - 2^{n-1}}{2^n - 1}$$
$$R' = \frac{DR'}{2^n - 1} \qquad C'_R = \frac{DC'_R - 2^{n-1}}{2^n - 1} \qquad C'_{CR} = \frac{DC'_{CR} - 2^{n-1}}{2^n - 1} \qquad C'_P = \frac{DC'_P - 2^{n-1}}{2^n - 1}$$

That is, in “full range” encoding:

Value	Continuous encoding value	Quantized encoding
Black	$\{R', G', B', Y', Y'_C, I\} = 0.0$	$\{DR', DG', DB', DY', DY'_C, DI\} = 0$
Peak brightness	$\{R', G', B', Y', Y'_C, I\} = 1.0$	$\{DR', DG', DB', DY', DY'_C, DI\} = 2^n$ - 1
Minimum color difference value	$\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\} = -0.5$	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 1$
Maximum color difference value	$\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\} = 0.5$	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 2^n - 1$ (clamped)
Achromatic colors	$R' = G' = B'$ $\{C'_B, C'_R, C'_{BC}, C'_{RC}, C_T, C_P\} = 0.0$	$\{DC'_B, DC'_R, DC'_{BC}, DC'_{CR}, DC_T, DC_P\} = 2^{n-1}$

If, instead of the quantized values, the input is interpreted as fixed-point values in the range 0.0..1.0, as might be the case if the values were treated as unsigned normalized quantities in a computer graphics API, the following conversions can be applied instead:

$$G' = G'_{norm} \qquad B' = B'_{norm}$$

$$R' = R'_{norm}$$

$$Y' = Y'_{norm} \qquad C'_B = DC'_{Bnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$C'_R = DC'_{Rnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$Y'_C = Y'_{Cnorm} \qquad C'_{CB} = DC'_{CBnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$C'_{CR} = DC'_{CRnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$I = I'_{norm} \qquad C'_T = DC'_{Tnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$C'_P = DC'_{Pnorm} - \frac{2^{n-1}}{2^n - 1}$$

$$G'_{norm} = G' \qquad B'_{norm} = B'$$

$$R'_{norm} = R'$$

$$Y'_{norm} = Y' \qquad C'_{Bnorm} = DC'_B + \frac{2^{n-1}}{2^n - 1}$$

$$C'_{Rnorm} = DC'_R + \frac{2^{n-1}}{2^n - 1}$$

$$Y'_{Cnorm} = Y'_C \qquad C'_{CBnorm} = DC'_{CB} + \frac{2^{n-1}}{2^n - 1}$$

$$C'_{CRnorm} = DC'_{CR} + \frac{2^{n-1}}{2^n - 1}$$

$$I_{norm} = I \qquad C'_{Tnorm} = DC'_T + \frac{2^{n-1}}{2^n - 1}$$

$$C'_{Pnorm} = DC'_P + \frac{2^{n-1}}{2^n - 1}$$

16.3 Legacy “full range” encoding.

ITU-T Rec. BT.2100-0 formalized an optional encoding scheme that does not incorporate any reserved head-room or foot-room. The legacy JFIF specification similarly used the full range of 8-bit channels to represent $Y'C_BC_R$ color. For bit depth n = {8 (JFIF),10,12 (Rec.2100)}:

$$\begin{aligned} DG' &= \lfloor 0.5 + G' \times 2^n \rfloor & DB' &= \lfloor 0.5 + B' \times 2^n \rfloor \\ & & DR' &= \lfloor 0.5 + R' \times 2^n \rfloor \\ DY' &= \lfloor 0.5 + Y' \times 2^n \rfloor & DC'_B &= \lfloor 0.5 + (C'_B + 0.5) \times 2^n \rfloor \\ & & DC'_R &= \lfloor 0.5 + (C'_R + 0.5) \times 2^n \rfloor \\ DY'_C &= \lfloor 0.5 + Y'_C \times 2^n \rfloor & DC'_{CB} &= \lfloor 0.5 + (C'_{CB} + 0.5) \times 2^n \rfloor \\ & & DC'_{CR} &= \lfloor 0.5 + (C'_{CR} + 0.5) \times 2^n \rfloor \\ DI &= \lfloor 0.5 + I \times 2^n \rfloor & DC'_T &= \lfloor 0.5 + (C'_T + 0.5) \times 2^n \rfloor \\ & & DC'_P &= \lfloor 0.5 + (C'_P + 0.5) \times 2^n \rfloor \end{aligned}$$

The dequantization formulae are therefore:

$$\begin{aligned} G' &= DG' \times 2^{-n} & Y' &= DY' \times 2^{-n} & Y'_C &= DY'_C \times 2^{-n} & I &= DI' \times 2^{-n} \\ B' &= DB' \times 2^{-n} & C'_B &= DC'_B \times 2^{-n} - 0.5 & C'_{CB} &= DC'_{CB} \times 2^{-n} - 0.5 & C'_T &= DC'_T \times 2^{-n} - 0.5 \\ R' &= DR' \times 2^{-n} & C'_R &= DC'_R \times 2^{-n} - 0.5 & C'_{CR} &= DC'_{CR} \times 2^{-n} - 0.5 & C'_P &= DC'_P \times 2^{-n} - 0.5 \end{aligned}$$

Note

These formulae map luma values of 1.0 and chroma values of 0.5 to 2^n, for bit depth n. This has the effect that the maximum value (e.g. pure white) cannot be represented directly. Out-of-bounds values must be clamped to the largest representable value.

Note

ITU-R BT.2100-0 dictates that in 12-bit coding, the largest values encoded should be 4092 (“for consistency” with 10-bit encoding, with a maximum value of 1023). This slightly reduces the maximum intensity which can be expressed, and slightly reduces the saturation range. The achromatic color point is still 2048 in the 12-bit case, so no offset is applied in the transformation to compensate for this range reduction. BT.2100-1 removes this recommendation and lists 4095 as the nominal peak value.

If, instead of the quantized values, the input is interpreted as fixed-point values in the range 0.0..1.0, as might be the case if the values were treated as unsigned normalized quantities in a computer graphics API, the following conversions can be applied instead:

$$\begin{aligned} G' &= \frac{G'_{norm} \times (2^n - 1)}{2^n} & B' &= \frac{B'_{norm} \times (2^n - 1)}{2^n} & R' &= \frac{R'_{norm} \times (2^n - 1)}{2^n} \\ Y' &= \frac{Y'_{norm} \times (2^n - 1)}{2^n} & C'_B &= \frac{C'_{Bnorm} \times (2^n - 1)}{2^n} - 0.5 & C'_R &= \frac{C'_{Rnorm} \times (2^n - 1)}{2^n} - 0.5 \\ Y'_C &= \frac{Y'_{Cnorm} \times (2^n - 1)}{2^n} & C'_{CB} &= \frac{C'_{CBnorm} \times (2^n - 1)}{2^n} - 0.5 & C'_{CR} &= \frac{C'_{CRnorm} \times (2^n - 1)}{2^n} - 0.5 \\ I &= \frac{I'_{norm} \times (2^n - 1)}{2^n} & C'_T &= \frac{C'_{Tnorm} \times (2^n - 1)}{2^n} - 0.5 & C'_P &= \frac{C'_{Pnorm} \times (2^n - 1)}{2^n} - 0.5 \end{aligned}$$

$$\begin{aligned} G'_{norm} &= \frac{G' \times 2^n}{2^n - 1} & B'_{norm} &= \frac{B' \times 2^n}{2^n - 1} & R'_{norm} &= \frac{R' \times 2^n}{2^n - 1} \\ Y'_{norm} &= \frac{Y' \times 2^n}{2^n - 1} & C'_{Bnorm} &= \frac{(C'_B + 0.5) \times 2^n}{2^n - 1} & C'_{Rnorm} &= \frac{(C'_R + 0.5) \times 2^n}{2^n - 1} \\ Y'_{Cnorm} &= \frac{Y'_C \times 2^n}{2^n - 1} & C'_{CBnorm} &= \frac{(C'_{CB} + 0.5) \times 2^n}{2^n - 1} & C'_{CRnorm} &= \frac{(C'_{CR} + 0.5) \times 2^n}{2^n - 1} \\ I_{norm} &= \frac{I' \times 2^n}{2^n - 1} & C'_{Tnorm} &= \frac{(C'_T + 0.5) \times 2^n}{2^n - 1} & C'_{Pnorm} &= \frac{(C'_P + 0.5) \times 2^n}{2^n - 1} \end{aligned}$$

That is, to match the behavior described in these specifications, the inputs to color model conversion should be expanded such that the maximum representable value is that defined by the quantization of these encodings $\left(\frac{255}{256}, \frac{1023}{1024} \text{ or } \frac{4095}{4096}\right)$, and the inverse operation should be applied to the result of the model conversion.

For example, a legacy shader-based JPEG decoder may read values in a normalized 0..1 range, where the in-memory value 0 represents 0.0 and the in-memory value 1 represents 1.0. The decoder should scale the Y' value by a factor of $\frac{255}{256}$ to match the encoding in the JFIF3 document, and C'_B and C_R should be scaled by $\frac{255}{256}$ and offset by 0.5. After the model conversion matrix has been applied, the R', G' and B' values should be scaled by $\frac{256}{255}$, restoring the ability to represent pure white.

16.4 Combined dequantization and $Y'C_BC_R$

Since the above quantization/dequantization conversions are linear scale factors, they can practically be combined with the matrix transform of $Y'C_BC_R$ color model conversion. A common conversion is between a narrow-range $Y'C_BC_R$ representation and full-range set of $R'G'B'$ values.

Simplifying by considering all values to be encoded in $n = 8$ bits, the following combined matrices can be used for these transforms.

16.4.1 BT.709

$$\begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \end{pmatrix} = \frac{1}{255} \times \begin{pmatrix} 219, & 0, & 0, & 16 \\ 0, & 224, & 0, & 128 \\ 0, & 0, & 224, & 128 \end{pmatrix} \begin{pmatrix} 0.2126, & 0.7152, & 0.0722, & 0 \\ -\frac{0.2126}{1.8556}, & -\frac{0.7152}{1.8556}, & 0.5, & 0 \\ 0.5, & -\frac{0.7152}{1.5748}, & -\frac{0.0722}{1.5748}, & 0 \\ 0, & 0, & 0, & 1 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 255 \end{pmatrix}$$

$$\approx \begin{pmatrix} 0.182586, & 0.614231, & 0.062007, & 16 \\ -0.100644, & -0.338572, & 0.439216, & 128 \\ 0.439216, & -0.398942, & -0.040274, & 128 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \end{pmatrix} = 255 \times \begin{pmatrix} 1, & 0, & 1.5748 \\ 1, & -\frac{0.13397432}{0.7152}, & -\frac{0.33480248}{0.7152} \\ 1, & 1.8556, & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{219}, & 0, & 0, & -\frac{16}{219} \\ 0, & \frac{1}{224}, & 0, & -\frac{128}{224} \\ 0, & 0, & \frac{1}{224}, & -\frac{128}{224} \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.792741, & -248.100994 \\ 1.164384, & -0.213249, & -0.532909, & 76.878080 \\ 1.164384, & 2.112402, & 0, & -289.017566 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.792741 \\ 1.164384, & -0.213249, & -0.532909 \\ 1.164384, & 2.112402, & 0 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' - 16 \\ D_{narrow}C'_B - 128 \\ D_{narrow}C'_R - 128 \end{pmatrix}$$

16.4.2 BT.601

$$\begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \end{pmatrix} = \frac{1}{255} \times \begin{pmatrix} 219, & 0, & 0, & 16 \\ 0, & 224, & 0, & 128 \\ 0, & 0, & 224, & 128 \end{pmatrix} \begin{pmatrix} 0.299, & 0.587, & 0.114, & 0 \\ -\frac{0.299}{1.772}, & -\frac{0.587}{1.772}, & 0.5, & 0 \\ 0.5, & -\frac{0.587}{1.402}, & -\frac{0.114}{1.402}, & 0 \\ 0, & 0, & 0, & 1 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 255 \end{pmatrix}$$

$$\approx \begin{pmatrix} 0.256788, & 0.504129, & 0.097906, & 16 \\ -0.148223, & -0.290993, & 0.439216, & 128 \\ 0.439216, & -0.367788, & -0.071427, & 128 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \end{pmatrix} = 255 \times \begin{pmatrix} 1, & 0, & 1.402 \\ 1, & -\frac{0.202008}{0.587}, & -\frac{0.419198}{0.587} \\ 1, & 1.772, & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{219}, & 0, & 0, & -\frac{16}{219} \\ 0, & \frac{1}{224}, & 0, & -\frac{128}{224} \\ 0, & 0, & \frac{1}{224}, & -\frac{128}{224} \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.596027, & -222.921566 \\ 1.164384, & -0.391762, & -0.812968, & 135.575295 \\ 1.164384, & 2.017232, & 0, & -276.835851 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.596027 \\ 1.164384, & -0.391762, & -0.812968 \\ 1.164384, & 2.017232, & 0 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' - 16 \\ D_{narrow}C'_B - 128 \\ D_{narrow}C'_R - 128 \end{pmatrix}$$

Note

In their recommendations for 8-bit YUV, Microsoft suggests the following integer approximations to the above formulae for converting between 8-bit reduced-range $Y'C_BC_R$ and 8-bit full-range $R'G'B'$ in BT.601:

```
Y  = ( (  66 * R’ + 129 * G’ +  25 * B’ + 128 ) >> 8 ) + 16
Cb = ( ( -38 * R’ -  74 * G’ + 112 * B’ + 120 ) >> 8 ) + 128
Cr = ( ( 112 * R’ -  94 * G’ -  18 * B’ + 128 ) >> 8 ) + 128
R’ = ( 298 * (Y’ - 16) + 409 * (Cr - 128) + 128 ) >> 8
G’ = ( 298 * (Y’ - 16) + 100 * (Cb - 128) - 208 * (Cr - 128) + 128 ) >> 8
B’ = ( 298 * (Y’ - 16) + 516 * (Cb - 128) + 128 ) >> 8
```

The resulting values should be clamped to a [0..255] range.

16.4.3 BT.2020

$$\begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \end{pmatrix} = \frac{1}{255} \times \begin{pmatrix} 219, & 0, & 0, & 16 \\ 0, & 224, & 0, & 128 \\ 0, & 0, & 224, & 128 \end{pmatrix} \begin{pmatrix} 0.2627, & 0.6780, & 0.0539, & 0 \\ -\frac{0.2627}{1.8814}, & -\frac{0.678}{1.8814}, & 0.5, & 0 \\ 0.5, & -\frac{0.678}{1.4746}, & -\frac{0.0593}{1.4746}, & 0 \\ 0, & 0, & 0, & 1 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 255 \end{pmatrix}$$

$$\approx \begin{pmatrix} 0.225613, & 0.582282, & 0.050928, & 16 \\ -0.122655, & -0.316560, & 0.439216, & 128 \\ 0.439216, & -0.403890, & -0.035325, & 128 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \end{pmatrix} = 255 \times \begin{pmatrix} 1, & 0, & 1.4746 \\ 1, & -\frac{0.11156702}{0.678}, & -\frac{0.38737742}{0.678} \\ 1, & 1.8814, & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{219}, & 0, & 0, & -\frac{16}{219} \\ 0, & \frac{1}{224}, & 0, & -\frac{128}{224} \\ 0, & 0, & \frac{1}{224}, & -\frac{128}{224} \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.678674, & -233.500423 \\ 1.164384, & -0.187326, & -0.650424, & 88.601917 \\ 1.164384, & 2.141772, & 0, & -292.776994 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.678674 \\ 1.164384, & -0.187326, & -0.650424 \\ 1.164384, & 2.141772, & 0 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' - 16 \\ D_{narrow}C'_B - 128 \\ D_{narrow}C'_R - 128 \end{pmatrix}$$

16.4.4 ST.240

$$\begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \end{pmatrix} = \frac{1}{255} \times \begin{pmatrix} 219, & 0, & 0, & 16 \\ 0, & 224, & 0, & 128 \\ 0, & 0, & 224, & 128 \end{pmatrix} \begin{pmatrix} 0.212, & 0.701, & 0.087, & 0 \\ -\frac{0.212}{1.826}, & -\frac{0.701}{1.826}, & 0.5, & 0 \\ 0.5, & -\frac{0.701}{1.576}, & -\frac{0.087}{1.576}, & 0 \\ 0, & 0, & 0, & 1 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 255 \end{pmatrix}$$

$$\approx \begin{pmatrix} 0.182071, & 0.602035, & 0.074718, & 16 \\ -0.101987, & -0.337229, & 0.439216, & 128 \\ 0.439216, & -0.390724, & -0.048492, & 128 \end{pmatrix} \begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} D_{full}R' \\ D_{full}G' \\ D_{full}B' \end{pmatrix} = 255 \times \begin{pmatrix} 1, & 0, & 1.576 \\ 1, & -\frac{0.158862}{0.701}, & -\frac{0.334112}{0.701} \\ 1, & 1.826, & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{219}, & 0, & 0, & -\frac{16}{219} \\ 0, & \frac{1}{224}, & 0, & -\frac{128}{224} \\ 0, & 0, & \frac{1}{224}, & -\frac{128}{224} \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.794107, & -248.275851 \\ 1.164384, & -0.257985, & -0.542583, & 83.842551 \\ 1.164384, & 2.078705, & 0, & -284.704423 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' \\ D_{narrow}C'_B \\ D_{narrow}C'_R \\ 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} 1.164384 & 0, & 1.794107 \\ 1.164384, & -0.257985, & -0.542583 \\ 1.164384, & 2.078705, & 0 \end{pmatrix} \begin{pmatrix} D_{narrow}Y' - 16 \\ D_{narrow}C'_B - 128 \\ D_{narrow}C'_R - 128 \end{pmatrix}$$

Part IV

Compressed Texture Formats

Chapter 17

Compressed Texture Image Formats

For computer graphics, a number of texture compression schemes exist which reduce both the overall texture memory footprint and the bandwidth requirements of using the textures. In this context, “texture compression” is distinct from “image compression” in that texture compression schemes are designed to allow efficient random access as part of texture sampling: “image compression” can further reduce image redundancy by considering the image as a whole, but doing so is impractical for efficient texture access operations. The common texture compression schemes are “block-based”, relying on similarities between nearby texel regions to describe “blocks” of nearby texels in a unit:

- “S3TC” describes a block of 4×4 *RGB* texels in terms of a low-precision pair of color “endpoints”, and allow each texel to specify an interpolation point between these endpoints. Alpha channels, if present, may be described similarly or with an explicit per-texel alpha value.
- “RGTC” provides one- and two-channel schemes for interpolating between two “endpoints” per 4×4 texel block, and are intended to provide efficient schemes for normal encoding, complementing the three-channel approach of S3TC.
- “BPTC” offers a number of ways of encoding and interpolating endpoints, and allows the 4×4 texel block to be divided into multiple “subsets” which can be encoded independently, which can be useful for managing different regions with sharp transitions.
- “ETC1” provides ways of encoding 4×4 texel blocks as two regions of 2×4 or 4×2 texels, each of which are specified as a base color; texels are then encoded as offsets relative to these bases, varying by a grayscale offset.
- “ETC2” is a superset of ETC1, adding schemes for color patterns that would fit poorly into ETC1 options.
- “ASTC” allows a wide range of ways of encoding each color block, and supports choosing different block sizes to encode the texture, providing a range of compression ratios; it also supports 3D and HDR textures.
- “PVRTC” describes several encoding schemes with two colors per block of 4×4 or 8×4 texels, interpolated between adjacent texel blocks, and means of modulating between them.
- “UASTC” describes a compressed format designed for efficient transcoding to ASTC, BC7 and other compressed formats.

Example data format descriptors for compressed formats can be found under the ***colorModel*** field in Section 5.6.

17.1 Terminology

As can be seen above, the compression schemes have a number of features in common — particularly in having a number of endpoints described encoded in some of the bits of the texel block. For consistency and to make the terms more concise, the following descriptions use some slightly unusual terminology: The value $X_{\mathrm{n}}{}^{\mathrm{m}}$ refers to bit m (starting at 0) of the n^{th} X value. For example, $R_1{}^3$ would refer to bit 3 of red value 1 — R, G, B and A (capitalized and italicized) are generally used to refer to color channels. Similarly, $R_1{}^{2..3}$ refers to bits 2..3 of red value 1. Although unusual, this terminology should be unambiguous (e.g. none of the formats require exponentiation of arguments).

Chapter 18

S3TC Compressed Texture Image Formats

This description is derived from the EXT_texture_compression_s3tc extension.

Compressed texture images stored using the S3TC compressed image formats are represented as a collection of 4×4 texel blocks, where each block contains 64 or 128 bits of texel data. The image is encoded as a normal 2D raster image in which each 4×4 block is treated as a single pixel. If an S3TC image has a width or height that is not a multiple of four, the data corresponding to texels outside the image are irrelevant and undefined.

When an S3TC image with a width of w, height of h, and block size of $blocksize$ (8 or 16 bytes) is decoded, the corresponding image size (in bytes) is:

$$\left\lceil \frac{w}{4} \right\rceil \times \left\lceil \frac{h}{4} \right\rceil \times blocksize$$

When decoding an S3TC image, the block containing the texel at offset (x, y) begins at an offset (in bytes) relative to the base of the image of:

$$blocksize \times \left(\left\lceil \frac{w}{4} \right\rceil \times \left\lfloor \frac{y}{4} \right\rfloor + \left\lfloor \frac{x}{4} \right\rfloor \right)$$

The data corresponding to a specific texel (x, y) are extracted from a 4×4 texel block using a relative (x, y) value of

$$(x \bmod 4, y \bmod 4)$$

Note
There is an analysis of the precise conversions performed by a range of real-world GPU hardware in Fabian “ryg” Giesen’s blog.

There are four distinct S3TC image formats:

18.1 BC1 with no alpha

Each 4×4 block of texels consists of 64 bits of RGB image data.

Each RGB image data block is encoded as a sequence of 8 bytes, called (in order of increasing address):

$$c0_{lo}, c0_{hi}, c1_{lo}, c1_{hi}, bits_0, bits_1, bits_2, bits_3$$

The 8 bytes of the block are decoded into three quantities:

$$\begin{aligned} color_0 &= c0_{lo} + c0_{hi} \times 256 \\ color_1 &= c1_{lo} + c1_{hi} \times 256 \\ bits &= bits_0 + 256 \times (bits_1 + 256 \times (bits_2 + 256 \times bits_3)) \end{aligned}$$

$color_0$ and $color_1$ are 16-bit unsigned integers that are unpacked to RGB colors RGB_0 and RGB_1 as though they were 16-bit unsigned packed pixels with the R channel in the high 5 bits, G in the next 6 bits and B in the low 5 bits:

$$R_n = \frac{color_n^{15..11}}{31}$$

$$G_n = \frac{color_n^{10..5}}{63}$$

$$B_n = \frac{color_n^{4..0}}{31}$$

$bits$ is a 32-bit unsigned integer, from which a two-bit control code is extracted for a texel at position (x, y) in the block using:

$$code(x,y) = bits[2 \times (4 \times y + x) + 1 \ \dots \ 2 \times (4 \times y + x) + 0]$$

where $bits[31]$ is the most significant and $bits[0]$ is the least significant bit.

The RGB color for a texel at position (x, y) in the block is given in Table 18.1.

Texel value	Condition
RGB_0	$color_0 > color_1$ and $code(x, y) = 0$
RGB_1	$color_0 > color_1$ and $code(x, y) = 1$
$\frac{(2\times RGB_0+RGB_1)}{3}$	$color_0 > color_1$ and $code(x, y) = 2$
$\frac{(RGB_0+2\times RGB_1)}{3}$	$color_0 > color_1$ and $code(x, y) = 3$
RGB_0	$color_0 \leq color_1$ and $code(x, y) = 0$
RGB_1	$color_0 \leq color_1$ and $code(x, y) = 1$
$\frac{(RGB_0+RGB_1)}{2}$	$color_0 \leq color_1$ and $code(x, y) = 2$
BLACK	$color_0 \leq color_1$ and $code(x, y) = 3$

Table 18.1: Block decoding for BC1

Arithmetic operations are done per component, and BLACK refers to an RGB color where red, green, and blue are all zero.

Since this image has an RGB format, there is no alpha component and the image is considered fully opaque.

18.2 BC1 with alpha

Each 4×4 block of texels consists of 64 bits of RGB image data and minimal alpha information. The RGB components of a texel are extracted in the same way as BC1 with no alpha.

The alpha component for a texel at position (x, y) in the block is given by Table 18.2.

Alpha value	Condition
0.0	$color_0 \leq color_1$ and $code(x, y) = 3$
1.0	otherwise

Table 18.2: BC1 with alpha

The red, green, and blue components of any texels with a final alpha of 0 should be encoded as zero (black).

Note

Figure 18.1 shows an example BC1 texel block: *color*$_0$, encoded as $\left(\frac{29}{31}, \frac{60}{63}, \frac{1}{31}\right)$, and *color*$_1$, encoded as $\left(\frac{20}{31}, \frac{2}{63}, \frac{30}{31}\right)$, are shown as circles. The interpolated values are shown as small diamonds. Since 29 > 20, there are two interpolated values, accessed when *code*(*x*, *y*) = 2 and *code*(*x*, *y*) = 3.

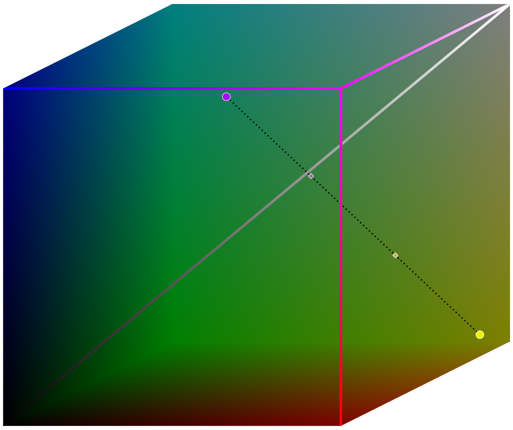


Figure 18.1: BC1 two interpolated colors

Figure 18.2 shows the example BC1 texel block with the colors swapped: *color*$_0$, encoded as $\left(\frac{20}{31}, \frac{2}{63}, \frac{30}{31}\right)$, and *color*$_1$, encoded as $\left(\frac{29}{31}, \frac{60}{63}, \frac{1}{31}\right)$, are shown as circles. The interpolated value is shown as a small diamonds. Since 20 $\leq$ 29, there is one interpolated value for *code*(*x*, *y*) = 2, and *code*(*x*, *y*) = 3 represents (*R*, *G*, *B*) = (0, 0, 0).

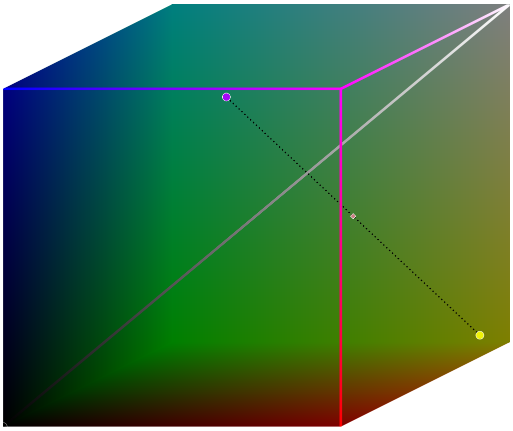


Figure 18.2: BC1 one interpolated color + black

If the format is BC1 with alpha, *code*(*x*, *y*) = 3 is transparent (alpha = 0). If the format is BC1 with no alpha, *code*(*x*, *y*) = 3 represents opaque black.

18.3 BC2

Each 4×4 block of texels consists of 64 bits of uncompressed alpha image data followed by 64 bits of *RGB* image data.

Each *RGB* image data block is encoded according to the BC1 formats, with the exception that the two code bits always use the non-transparent encodings. In other words, they are treated as though $color_0 > color_1$, regardless of the actual values of $color_0$ and $color_1$.

Each alpha image data block is encoded as a sequence of 8 bytes, called (in order of increasing address):

$$a_0, a_1, a_2, a_3, a_4, a_5, a_6, a_7$$

The 8 bytes of the block are decoded into one 64-bit integer:

$$alpha = a_0 + 256 \times (a_1 + 256 \times (a_2 + 256 \times (a_3 + 256 \times (a_4 + 256 \times (a_5 + 256 \times (a_6 + 256 \times a_7))))))$$

alpha is a 64-bit unsigned integer, from which a four-bit alpha value is extracted for a texel at position (x, y) in the block using:

$$alpha(x,y) = bits[4 \times (4 \times y + x) + 3 \ldots 4 \times (4 \times y + x) + 0]$$

where $bits[63]$ is the most significant and $bits[0]$ is the least significant bit.

The alpha component for a texel at position (x, y) in the block is given by $\frac{alpha(x,y)}{15}$.

18.4 BC3

Each 4×4 block of texels consists of 64 bits of compressed alpha image data followed by 64 bits of *RGB* image data.

Each *RGB* image data block is encoded according to the BC1 formats, with the exception that the two code bits always use the non-transparent encodings. In other words, they are treated as though $color_0 > color_1$, regardless of the actual values of $color_0$ and $color_1$.

Each alpha image data block is encoded as a sequence of 8 bytes, called (in order of increasing address):

$$alpha_0, alpha_1, bits_0, bits_1, bits_2, bits_3, bits_4, bits_5$$

The $alpha_0$ and $alpha_1$ are 8-bit unsigned bytes converted to alpha components by multiplying by $\frac{1}{255}$.

The 6 *bits* bytes of the block are decoded into one 48-bit integer:

$$bits = bits_0 + 256 \times (bits_1 + 256 \times (bits_2 + 256 \times (bits_3 + 256 \times (bits_4 + 256 \times bits_5))))$$

bits is a 48-bit unsigned integer, from which a three-bit control code is extracted for a texel at position (x, y) in the block using:

$$code(x,y) = bits[3 \times (4 \times y + x) + 2 \ldots 3 \times (4 \times y + x) + 0]$$

where $bits[47]$ is the most-significant and $bits[0]$ is the least-significant bit.

The alpha component for a texel at position (x, y) in the block is given by Table 18.3.

Alpha value	Condition
$alpha_0$	$code(x, y) = 0$
$alpha_1$	$code(x, y) = 1$
$\frac{(6\times alpha_0+1\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 2$
$\frac{(5\times alpha_0+2\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 3$
$\frac{(4\times alpha_0+3\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 4$
$\frac{(3\times alpha_0+4\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 5$
$\frac{(2\times alpha_0+5\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 6$
$\frac{(1\times alpha_0+6\times alpha_1)}{7}$	$alpha_0 > alpha_1$ and $code(x, y) = 7$
$\frac{(4\times alpha_0+1\times alpha_1)}{5}$	$alpha_0 \leq alpha_1$ and $code(x, y) = 2$
$\frac{(3\times alpha_0+2\times alpha_1)}{5}$	$alpha_0 \leq alpha_1$ and $code(x, y) = 3$
$\frac{(2\times alpha_0+3\times alpha_1)}{5}$	$alpha_0 \leq alpha_1$ and $code(x, y) = 4$
$\frac{(1\times alpha_0+4\times alpha_1)}{5}$	$alpha_0 \leq alpha_1$ and $code(x, y) = 5$
0.0	$alpha_0 \leq alpha_1$ and $code(x, y) = 6$
1.0	$alpha_0 \leq alpha_1$ and $code(x, y) = 7$

Table 18.3: Alpha encoding for BC3 blocks

Chapter 19

RGTC Compressed Texture Image Formats

This description is derived from the "RGTC Compressed Texture Image Formats" section of the OpenGL 4.4 specification.

Compressed texture images stored using the RGTC compressed image encodings are represented as a collection of 4×4 texel blocks, where each block contains 64 or 128 bits of texel data. The image is encoded as a normal 2D raster image in which each 4×4 block is treated as a single pixel. If an RGTC image has a width or height that is not a multiple of four, the data corresponding to texels outside the image are irrelevant and undefined.

When an RGTC image with a width of w, height of h, and block size of *blocksize* (8 or 16 bytes) is decoded, the corresponding image size (in bytes) is:

$$\left\lceil \frac{w}{4} \right\rceil \times \left\lceil \frac{h}{4} \right\rceil \times blocksize$$

When decoding an RGTC image, the block containing the texel at offset (x, y) begins at an offset (in bytes) relative to the base of the image of:

$$blocksize \times \left(\left\lceil \frac{w}{4} \right\rceil \times \left\lfloor \frac{y}{4} \right\rfloor + \left\lfloor \frac{x}{4} \right\rfloor \right)$$

The data corresponding to a specific texel (x, y) are extracted from a 4×4 texel block using a relative (x, y) value of

$$(x \bmod 4, y \bmod 4)$$

Note
There is an analysis of the precise conversions performed by a range of real-world GPU hardware in Fabian "ryg" Giesen's blog.

There are four distinct RGTC image formats described in the following sections.

19.1 BC4 unsigned

Each 4×4 block of texels consists of 64 bits of unsigned red image data.

Each red image data block is encoded as a sequence of 8 bytes, called (in order of increasing address):

$$red_0, red_1, bits_0, bits_1, bits_2, bits_3, bits_4, bits_5$$

The 6 $bits_{\{0..5\}}$ bytes of the block are decoded into a 48-bit bit vector:

$$bits = bits_0 + 256 \times (bits_1 + 256 \times (bits_2 + 256 \times (bits_3 + 256 \times (bits_4 + 256 \times bits_5))))$$

red_0 and red_1 are 8-bit unsigned integers that are unpacked to red values RED_0 and RED_1 by multiplying by $\frac{1}{255}$.

$bits$ is a 48-bit unsigned integer, from which a three-bit control code is extracted for a texel at position (x, y) in the block using:

$$code(x,y) = bits\,[3 \times (4 \times y + x) + 2 \ldots 3 \times (4 \times y + x) + 0]$$

where $bits[47]$ is the most-significant and $bits[0]$ is the least-significant bit.

The red value R for a texel at position (x, y) in the block is given by Table 19.1.

R value	Condition
RED_0	$red_0 > red_1$, $code(x, y) = 0$
RED_1	$red_0 > red_1$, $code(x, y) = 1$
$\frac{6 \times RED_0 + RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 2$
$\frac{5 \times RED_0 + 2 \times RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 3$
$\frac{4 \times RED_0 + 3 \times RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 4$
$\frac{3 \times RED_0 + 4 \times RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 5$
$\frac{2 \times RED_0 + 5 \times RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 6$
$\frac{RED_0 + 6 \times RED_1}{7}$	$red_0 > red_1$, $code(x, y) = 7$
RED_0	$red_0 \leq red_1$, $code(x, y) = 0$
RED_1	$red_0 \leq red_1$, $code(x, y) = 1$
$\frac{4 \times RED_0 + RED_1}{5}$	$red_0 \leq red_1$, $code(x, y) = 2$
$\frac{3 \times RED_0 + 2 \times RED_1}{5}$	$red_0 \leq red_1$, $code(x, y) = 3$
$\frac{2 \times RED_0 + 3 \times RED_1}{5}$	$red_0 \leq red_1$, $code(x, y) = 4$
$\frac{RED_0 + 4 \times RED_1}{5}$	$red_0 \leq red_1$, $code(x, y) = 5$
RED_{min}	$red_0 \leq red_1$, $code(x, y) = 6$
RED_{max}	$red_0 \leq red_1$, $code(x, y) = 7$

Table 19.1: Block decoding for BC4

RED_{min} and RED_{max} are 0.0 and 1.0 respectively.

Since the decoded texel has a red format, the resulting $RGBA$ value for the texel is (R, 0, 0, 1).

19.2 BC4 signed

Each 4×4 block of texels consists of 64 bits of signed red image data. The red values of a texel are extracted in the same way as BC4 unsigned except red_0, red_1, RED_0, RED_1, RED_{min}, and RED_{max} are signed values defined as follows:

$$RED_0 = \begin{cases} \frac{red_0}{127.0}, & red_0 > -128 \\ -1.0, & red_0 = -128 \end{cases}$$

$$RED_1 = \begin{cases} \frac{red_1}{127.0}, & red_1 > -128 \\ -1.0, & red_1 = -128 \end{cases}$$

$$RED_{min} = -1.0$$

$$RED_{max} = 1.0$$

red_0 and red_1 are 8-bit signed (two's complement) integers.

CAVEAT: For signed red_0 and red_1 values: the expressions red_0 > red_1 and $red_0 \leq red_1$ above are considered undefined (read: may vary by implementation) when red_0 = -127 and red_1 = -128. This is because if red_0 were remapped to -127 prior to the comparison to reduce the latency of a hardware decompressor, the expressions would reverse their logic. Encoders for the signed red-green formats should avoid encoding blocks where red_0 = -127 and red_1 = -128.

19.3 BC5 unsigned

Each 4×4 block of texels consists of 64 bits of compressed unsigned red image data followed by 64 bits of compressed unsigned green image data.

The first 64 bits of compressed red are decoded exactly like BC4 unsigned above. The second 64 bits of compressed green are decoded exactly like BC4 unsigned above except the decoded value *R* for this second block is considered the resulting green value *G*.

Since the decoded texel has a red-green format, the resulting *RGBA* value for the texel is (*R*, *G*, 0, 1).

19.4 BC5 signed

Each 4×4 block of texels consists of 64 bits of compressed signed red image data followed by 64 bits of compressed signed green image data.

The first 64 bits of compressed red are decoded exactly like BC4 signed above. The second 64 bits of compressed green are decoded exactly like BC4 signed above except the decoded value *R* for this second block is considered the resulting green value *G*.

Since this image has a red-green format, the resulting *RGBA* value is (*R*, *G*, 0, 1).

Chapter 20

BPTC Compressed Texture Image Formats

This description is derived from the "BPTC Compressed Texture Image Formats" section of the OpenGL 4.4 specification. More information on BC7, BC7 modes and BC6h can be found in Microsoft's online documentation.

Compressed texture images stored using the BPTC compressed image formats are represented as a collection of 4×4 texel blocks, each of which contains 128 bits of texel data stored in little-endian order. The image is encoded as a normal 2D raster image in which each 4×4 block is treated as a single pixel. If a BPTC image has a width or height that is not a multiple of four, the data corresponding to texels outside the image are irrelevant and undefined. When a BPTC image with width w, height h, and block size *blocksize* (16 bytes) is decoded, the corresponding image size (in bytes) is:

$$\left\lceil \frac{w}{4} \right\rceil \times \left\lceil \frac{h}{4} \right\rceil \times blocksize$$

When decoding a BPTC image, the block containing the texel at offset (x, y) begins at an offset (in bytes) relative to the base of the image of:

$$blocksize \times \left(\left\lceil \frac{w}{4} \right\rceil \times \left\lfloor \frac{y}{4} \right\rfloor + \left\lfloor \frac{x}{4} \right\rfloor \right)$$

The data corresponding to a specific texel (x, y) are extracted from a 4×4 texel block using a relative (x, y) value of:

$$(x \bmod 4, y \bmod 4)$$

There are two distinct BPTC image formats each of which has two variants. BC7 with or without an sRGB transform function used in the encoding of the *RGB* channels compresses 8-bit unsigned, normalized fixed-point data. BC6H in signed or unsigned form compresses high dynamic range floating-point values. The formats are similar, so the description of the BC6H format will reference significant sections of the BC7 description.

20.1 BC7

Each 4×4 block of texels consists of 128 bits of *RGBA* image data, of which the *RGB* channels may be encoded linearly or with the sRGB transfer function.

Each block contains enough information to select and decode a number of colors called endpoints, pairs of which forms subsets, then to interpolate between those endpoints in a variety of ways, and finally to remap the result into the final output by indexing into these interpolated values according to a partition layout which maps each relative coordinate to a subset.

Each block can contain data in one of eight modes. The mode is identified by the lowest bits of the lowest byte. It is encoded as zero or more zeros followed by a one. For example, using 'x' to indicate a bit not included in the mode number, mode 0 is encoded as xxxxxxx1 in the low byte in binary, mode 5 is xx100000, and mode 7 is 10000000. Encoding the low byte as zero is reserved and should not be used when encoding a BC7 texture. Hardware decoders processing a texel block with a low byte of 0 should return 0 for all channels of all texels, but may return 1.0 in the *A* channel.

All further decoding is driven by the values derived from the mode listed in Table 20.1 and Table 20.2. The fields in the block are always in the same order for all modes. In increasing bit order after the mode, these fields are: partition pattern selection, rotation, index selection, color, alpha, per-endpoint P-bit, shared P-bit, primary indices, and secondary indices. The number of bits to be read in each field is determined directly from these tables, as shown in Table 20.3.

Note

Per texel block, *CB* = 3(each of *R*, *G*, *B*)×2(endpoints)×NS(#subsets)×CB(bits/channel/endpoint). *AB* = 2(endpoints)×NS(#subsets)×AB(bits/endpoint). $\{IB, IB_2\}$ = 16(texels)×$\{\mathrm{IB}, \mathrm{IB}_2\}$(#index bits/texel) - NS(1bit/subset).

Mode	**NS**	**PB**	**RB**	**ISB**	**CB**	**AB**	**EPB**	**SPB**	**IB**	**IB_2**	**M**	***CB***	***AB***	***EPB***	***SPB***	***IB***	***IB_2***
Bits per...		...texel block			...channel/endpoint		...endpoint	...subset	...texel		Bits per texel block (total)						
0	3	4	0	0	4	0	1	0	3	0	1	72	0	6	0	45	0
1	2	6	0	0	6	0	0	1	3	0	2	72	0	0	2	46	0
2	3	6	0	0	5	0	0	0	2	0	3	90	0	0	0	29	0
3	2	6	0	0	7	0	1	0	2	0	4	84	0	4	0	30	0
4	1	0	2	1	5	6	0	0	2	3	5	30	12	0	0	31	47
5	1	0	2	0	7	8	0	0	2	2	6	42	16	0	0	31	31
6	1	0	0	0	7	7	1	0	4	0	7	42	14	2	0	63	0
7	2	6	0	0	5	5	1	0	2	0	8	60	20	4	0	30	0

Table 20.1: Mode-dependent BPTC parameters

M	Mode identifier bits
NS	Number of subsets
PB	Partition selection bits
RB	Rotation bits
ISB	Index selection bit
CB	Color bits
AB	Alpha bits
EPB	Endpoint P-bits (all channels)
SPB	Shared P-bits
IB	Index bits
IB_2	Secondary index bits

Table 20.2: Full descriptions of the BPTC mode columns

Each block can be divided into between 1 and 3 groups of pixels called *subsets*, which have different endpoints. There are two endpoint colors per subset, grouped first by endpoint, then by subset, then by channel. For example, mode 1, with two subsets and six color bits, would have six bits of red for endpoint 0 of the first subset, then six bits of red for endpoint 1, then the two ends of the second subset, then green and blue stored similarly. If a block has any alpha bits, the alpha data follows the color data with the same organization. If not, alpha is overridden to 255. These bits are treated as the high bits of a fixed-point value in a byte for each color channel of the endpoints: $\{E_R{}^{7..0}, E_G{}^{7..0}, E_B{}^{7..0}, E_A{}^{7..0}\}$ per endpoint. If the mode has shared P-bits, there are two endpoint bits, the lower of which applies to both endpoints of subset 0 and the upper of which applies to both endpoints of subset 1. If the mode has per-endpoint P-bits, then there are 2 × *subsets* P-bits stored in the same order as color and alpha. Both kinds of P-bits are added as a bit below the color data stored in the byte. So, for mode 1 with six red bits, the P-bit ends up in bit 1. For final scaling, the top bits of the value are replicated into any remaining bits in the byte. For the example of mode 1, bit 7 (which originated as bit 5 of the 6-bit encoded channel) would be replicated to bit 0. Table 20.4 and Table 20.5 show the origin of each endpoint color bit for each mode.

Mode 0	*0:* $\mathbf{M^{0} = 1}$		*1..4:* $\mathrm{PB}^{0..3}$			
	5..8: $R_0{}^{0..3}$	*9..12:* $R_1{}^{0..3}$	*13..16:* $R_2{}^{0..3}$	*17..20:* $R_3{}^{0..3}$	*21..24:* $R_4{}^{0..3}$	*25..28:* $R_5{}^{0..3}$
	29..32: $G_0{}^{0..3}$	*33..36:* $G_1{}^{0..3}$	*37..40:* $G_2{}^{0..3}$	*41..44:* $G_3{}^{0..3}$	*45..48:* $G_4{}^{0..3}$	*49..52:* $G_5{}^{0..3}$
	53..56: $B_0{}^{0..3}$	*57..60:* $B_1{}^{0..3}$	*61..64:* $B_2{}^{0..3}$	*65..68:* $B_3{}^{0..3}$	*69..72:* $B_4{}^{0..3}$	*73..76:* $B_5{}^{0..3}$
	77: $\mathrm{EPB}_0{}^{0}$	*78:* $\mathrm{EPB}_1{}^{0}$	*79:* $\mathrm{EPB}_2{}^{0}$	*80:* $\mathrm{EPB}_3{}^{0}$	*81:* $\mathrm{EPB}_4{}^{0}$	*82:* $\mathrm{EPB}_5{}^{0}$
	83..127: $\mathrm{IB}^{0..44}$					
Mode 1	*0..1:* $\mathbf{M^{0..1} = 01}$		*2..7:* $\mathrm{PB}^{0..5}$			
	8..13: $R_0{}^{0..5}$	*14..19:* $R_1{}^{0..5}$	*20..25:* $R_2{}^{0..5}$	*26..31:* $R_3{}^{0..5}$		
	32..37: $G_0{}^{0..5}$	*38..43:* $G_1{}^{0..5}$	*44..49:* $G_2{}^{0..5}$	*50..55:* $G_3{}^{0..5}$		
	56..61: $B_0{}^{0..5}$	*62..67:* $B_1{}^{0..5}$	*68..73:* $B_2{}^{0..5}$	*74..79:* $B_3{}^{0..5}$		
	80: $\mathrm{SPB}_0{}^{0}$	*81:* $\mathrm{SPB}_1{}^{0}$	*82..127:* $\mathrm{IB}^{0..45}$			
Mode 2	*0..2:* $\mathbf{M^{0..2} = 001}$		*3..8:* $\mathrm{PB}^{0..5}$			
	9..13: $R_0{}^{0..4}$	*14..18:* $R_1{}^{0..4}$	*19..23:* $R_2{}^{0..4}$	*24..28:* $R_3{}^{0..4}$	*29..33:* $R_4{}^{0..4}$	*34..38:* $R_5{}^{0..4}$
	39..43: $G_0{}^{0..4}$	*44..48:* $G_1{}^{0..4}$	*49..53:* $G_2{}^{0..4}$	*54..58:* $G_3{}^{0..4}$	*59..63:* $G_4{}^{0..4}$	*64..68:* $G_5{}^{0..4}$
	69..73: $B_0{}^{0..4}$	*74..78:* $B_1{}^{0..4}$	*79..83:* $B_2{}^{0..4}$	*84..88:* $B_3{}^{0..4}$	*89..93:* $B_4{}^{0..4}$	*94..98:* $B_5{}^{0..4}$
	99..127: $\mathrm{IB}^{0..28}$					
Mode 3	*0..3:* $\mathbf{M^{0..3} = 0001}$		*4..9:* $\mathrm{PB}^{0..5}$			
	10..16: $R_0{}^{0..6}$	*17..23:* $R_1{}^{0..6}$	*24..30:* $R_2{}^{0..6}$	*31..37:* $R_3{}^{0..6}$		
	38..44: $G_0{}^{0..6}$	*45..51:* $G_1{}^{0..6}$	*52..58:* $G_2{}^{0..6}$	*59..65:* $G_3{}^{0..6}$		
	66..72: $B_0{}^{0..6}$	*73..79:* $B_1{}^{0..6}$	*80..86:* $B_2{}^{0..6}$	*87..93:* $B_3{}^{0..6}$		
	94: $\mathrm{EPB}_0{}^{0}$	*95:* $\mathrm{EPB}_1{}^{0}$	*96:* $\mathrm{EPB}_2{}^{0}$	*97:* $\mathrm{EPB}_3{}^{0}$	*98..127:* $\mathrm{IB}^{0..29}$	
Mode 4	*0..4:* $\mathbf{M^{0..4} = 00001}$		*5..6:* $\mathrm{RB}^{0..1}$		*7:* ISB^{0}	
	8..12: $R_0{}^{0..4}$	*13..17:* $R_1{}^{0..4}$	*18..22:* $G_0{}^{0..4}$	*23..27:* $G_1{}^{0..4}$	*28..32:* $B_0{}^{0..4}$	*33..37:* $B_1{}^{0..4}$
	38..43: $A_0{}^{0..5}$	*44..49:* $A_1{}^{0..5}$	*50..80:* $\mathrm{IB}^{0..30}$		*81..127:* $\mathrm{IB}_2{}^{0..46}$	
Mode 5	*0..5:* $\mathbf{M^{0..5} = 000001}$		*6..7:* $\mathrm{RB}^{0..1}$			
	8..14: $R_0{}^{0..6}$	*15..21:* $R_1{}^{0..6}$	*22..28:* $G_0{}^{0..6}$	*29..35:* $G_1{}^{0..6}$	*36..42:* $B_0{}^{0..6}$	*43..49:* $B_1{}^{0..6}$
	50..57: $A_0{}^{0..7}$	*58..65:* $A_1{}^{0..7}$	*66..96:* $\mathrm{IB}^{0..30}$		*97..127:* $\mathrm{IB}_2{}^{0..30}$	
Mode 6	*0..6:* $\mathbf{M^{0..6} = 0000001}$					
	7..13: $R_0{}^{0..6}$	*14..20:* $R_1{}^{0..6}$	*21..27:* $G_0{}^{0..6}$	*28..34:* $G_1{}^{0..6}$	*35..41:* $B_0{}^{0..6}$	*42..48:* $B_1{}^{0..6}$
	49..55: $A_0{}^{0..6}$	*56..62:* $A_1{}^{0..6}$	*63:* $\mathrm{EPB}_0{}^{0}$	*64:* $\mathrm{EPB}_1{}^{0}$	*65..127:* $\mathrm{IB}^{0..62}$	
Mode 7	*0..7:* $\mathbf{M^{0..7} = 00000001}$		*8..13:* $\mathrm{PB}^{0..5}$			
	14..18: $R_0{}^{0..4}$	*19..23:* $R_1{}^{0..4}$	*24..28:* $R_2{}^{0..4}$	*29..33:* $R_3{}^{0..4}$		
	34..38: $G_0{}^{0..4}$	*39..43:* $G_1{}^{0..4}$	*44..48:* $G_2{}^{0..4}$	*49..53:* $G_3{}^{0..4}$		
	54..58: $B_0{}^{0..4}$	*59..63:* $B_1{}^{0..4}$	*64..68:* $B_2{}^{0..4}$	*69..73:* $B_3{}^{0..4}$		
	74..78: $A_0{}^{0..4}$	*79..83:* $A_1{}^{0..4}$	*84..88:* $A_2{}^{0..4}$	*89..93:* $A_3{}^{0..4}$		
	94: $\mathrm{EPB}_0{}^{0}$	*95:* $\mathrm{EPB}_1{}^{0}$	*96:* $\mathrm{EPB}_2{}^{0}$	*97:* $\mathrm{EPB}_3{}^{0}$	*98..127:* $\mathrm{IB}^{0..29}$	

Table 20.3: Bit layout for BC7 modes (LSB..MSB)

Mode 0																								
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$
8	7	6	5	77	8	7	6	32	31	30	29	77	32	31	30	56	55	54	53	77	56	55	54	*255*
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$
12	11	10	9	78	12	11	10	36	35	34	33	78	36	35	34	60	59	58	57	78	60	59	58	*255*
$E_{R2}^{7..0}$								$E_{G2}^{7..0}$								$E_{B2}^{7..0}$								$E_{A2}^{7..0}$
16	15	14	13	79	16	15	14	40	39	38	37	79	40	39	38	64	63	62	61	79	64	63	62	*255*
$E_{R3}^{7..0}$								$E_{G3}^{7..0}$								$E_{B3}^{7..0}$								$E_{A3}^{7..0}$
20	19	18	17	80	20	19	18	44	43	42	41	80	44	43	42	68	67	66	65	80	68	67	66	*255*
$E_{R4}^{7..0}$								$E_{G4}^{7..0}$								$E_{B4}^{7..0}$								$E_{A4}^{7..0}$
24	23	22	21	81	24	23	22	48	47	46	45	81	48	47	46	72	71	70	69	81	72	71	70	*255*
$E_{R5}^{7..0}$								$E_{G5}^{7..0}$								$E_{B5}^{7..0}$								$E_{A5}^{7..0}$
28	27	26	25	82	28	27	26	52	51	50	49	82	52	51	50	76	75	74	73	82	76	75	74	*255*
Mode 1																								
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$
13	12	11	10	9	8	80	13	37	36	35	34	33	32	80	37	61	60	59	58	57	56	80	61	*255*
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$
19	18	17	16	15	14	80	19	43	42	41	40	39	38	80	43	67	66	65	64	63	62	80	67	*255*
$E_{R2}^{7..0}$								$E_{G2}^{7..0}$								$E_{B2}^{7..0}$								$E_{A2}^{7..0}$
25	24	23	22	21	20	81	25	49	48	47	46	45	44	81	49	73	72	71	70	69	68	81	73	*255*
$E_{R3}^{7..0}$								$E_{G3}^{7..0}$								$E_{B3}^{7..0}$								$E_{A3}^{7..0}$
31	30	29	28	27	26	81	31	55	54	53	52	51	50	81	55	79	78	77	76	75	74	81	79	*255*
Mode 2																								
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$
13	12	11	10	9	13	12	11	43	42	41	40	39	43	42	41	73	72	71	70	69	73	72	71	*255*
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$
18	17	16	15	14	18	17	16	48	47	46	45	44	48	47	46	78	77	76	75	74	78	77	76	*255*
$E_{R2}^{7..0}$								$E_{G2}^{7..0}$								$E_{B2}^{7..0}$								$E_{A2}^{7..0}$
23	22	21	20	19	23	22	21	53	52	51	50	49	53	52	51	83	82	81	80	79	83	82	81	*255*
$E_{R3}^{7..0}$								$E_{G3}^{7..0}$								$E_{B3}^{7..0}$								$E_{A3}^{7..0}$
28	27	26	25	24	28	27	26	58	57	56	55	54	58	57	56	88	87	86	85	84	88	87	86	*255*
$E_{R4}^{7..0}$								$E_{G4}^{7..0}$								$E_{B4}^{7..0}$								$E_{A4}^{7..0}$
33	32	31	30	29	33	32	31	63	62	61	60	59	63	62	61	93	92	91	90	89	93	92	91	*255*
$E_{R5}^{7..0}$								$E_{G5}^{7..0}$								$E_{B5}^{7..0}$								$E_{A5}^{7..0}$
38	37	36	35	34	38	37	36	68	67	66	65	64	68	67	66	98	97	96	95	94	98	97	96	*255*

Table 20.4: Bit sources for BC7 endpoints (modes 0..2, MSB..LSB per channel)

Mode 3																															
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$							
16	15	14	13	12	11	10	94	44	43	42	41	40	39	38	94	72	71	70	69	68	67	66	94	*255*							
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$							
23	22	21	20	19	18	17	95	51	50	49	48	47	46	45	95	79	78	77	76	75	74	73	95	*255*							
$E_{R2}^{7..0}$								$E_{G2}^{7..0}$								$E_{B2}^{7..0}$								$E_{A2}^{7..0}$							
30	29	28	27	26	25	24	96	58	57	56	55	54	53	52	96	86	85	84	83	82	81	80	96	*255*							
$E_{R3}^{7..0}$								$E_{G3}^{7..0}$								$E_{B3}^{7..0}$								$E_{A3}^{7..0}$							
37	36	35	34	33	32	31	97	65	64	63	62	61	60	59	97	93	92	91	90	89	88	87	97	*255*							
Mode 4																															
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$							
12	11	10	9	8	12	11	10	22	21	20	19	18	22	21	20	32	31	30	29	28	32	31	30	43	42	41	40	39	38	43	42
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$							
17	16	15	14	13	17	16	15	27	26	25	24	23	27	26	25	37	36	35	34	33	37	36	35	49	48	47	46	45	44	49	48
Mode 5																															
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$							
14	13	12	11	10	9	8	14	28	27	26	25	24	23	22	28	42	41	40	39	38	37	36	42	57	56	55	54	53	52	51	50
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$							
21	20	19	18	17	16	15	21	35	34	33	32	31	30	29	35	49	48	47	46	45	44	43	49	65	64	63	62	61	60	59	58
Mode 6																															
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$							
13	12	11	10	9	8	7	63	27	26	25	24	23	22	21	63	41	40	39	38	37	36	35	63	55	54	53	52	51	50	49	63
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$							
20	19	18	17	16	15	14	64	34	33	32	31	30	29	28	64	48	47	46	45	44	43	42	64	62	61	60	59	58	57	56	64
Mode 7																															
$E_{R0}^{7..0}$								$E_{G0}^{7..0}$								$E_{B0}^{7..0}$								$E_{A0}^{7..0}$							
18	17	16	15	14	94	18	17	38	37	36	35	34	94	38	37	58	57	56	55	54	94	58	57	78	77	76	75	74	94	78	77
$E_{R1}^{7..0}$								$E_{G1}^{7..0}$								$E_{B1}^{7..0}$								$E_{A1}^{7..0}$							
23	22	21	20	19	95	23	22	43	42	41	40	39	95	43	42	63	62	61	60	59	95	63	62	83	82	81	80	79	95	83	82
$E_{R2}^{7..0}$								$E_{G2}^{7..0}$								$E_{B2}^{7..0}$								$E_{A2}^{7..0}$							
28	27	26	25	24	96	28	27	48	47	46	45	44	96	48	47	68	67	66	65	64	96	68	67	88	87	86	85	84	96	88	87
$E_{R3}^{7..0}$								$E_{G3}^{7..0}$								$E_{B3}^{7..0}$								$E_{A3}^{7..0}$							
33	32	31	30	29	97	33	32	53	52	51	50	49	97	53	52	73	72	71	70	69	97	73	72	93	92	91	90	89	97	93	92

Table 20.5: Bit sources for BC7 endpoints (modes 3..7, MSB..LSB per channel)

A texel in a block with one subset is always considered to be in subset zero. Otherwise, a number encoded in the partition bits is used to look up a partition pattern in Table 20.6 or Table 20.7 for 2 subsets and 3 subsets respectively. This partition pattern is accessed by the relative x and y offsets within the block to determine the subset which defines the pixel at these coordinates.

The endpoint colors are interpolated using index values stored in the block. The index bits are stored in y-major order. That is, the bits for the index value corresponding to a relative (x, y) position of (0, 0) are stored in increasing order in the lowest index bits of the block (but see the next paragraph about anchor indices), the next bits of the block in increasing order store the index bits of (1, 0), followed by (2, 0) and (3, 0), then (0, 1) etc.

Each index has the number of bits indicated by the mode except for one special index per subset called the anchor index. Since the interpolation scheme between endpoints is symmetrical, we can save one bit on one index per subset by ordering the endpoints such that the highest bit for that index is guaranteed to be zero — and not storing that bit.

Each anchor index corresponds to an index in the corresponding partition number in Table 20.6 or Table 20.7, and are indicated in bold italics in those tables. In partition zero, the anchor index is always index zero — that is, at a relative position of (0,0) (as can be seen in Table 20.6 and Table 20.7, index 0 always corresponds to partition zero). In other partitions, the anchor index is specified by Table 20.10, Table 20.8, and Table 20.9.

Note

In summary, the bit offset for index data with relative *x,y* coordinates within the texel block is:

$$\text{index offset}_{x,y} = \begin{cases} 0, & x = y = 0 \\ \text{IB} \times (x + 4 \times y) - 1, & \text{NS} = 1,\ 0 < x + 4 \times y \\ \text{IB} \times (x + 4 \times y) - 1, & \text{NS} = 2,\ 0 < x + 4 \times y \leq \text{anchor}_2[\mathit{part}] \\ \text{IB} \times (x + 4 \times y) - 2, & \text{NS} = 2,\ \text{anchor}_2[\mathit{part}] < x + 4 \times y \\ \text{IB} \times (x + 4 \times y) - 1, & \text{NS} = 3,\ 0 < x + 4 \times y \leq \text{anchor}_{3,2}[\mathit{part}],\ x + 4 \times y \leq \text{anchor}_{3,3}[\mathit{part}] \\ \text{IB} \times (x + 4 \times y) - 3, & \text{NS} = 3,\ x + 4 \times y > \text{anchor}_{3,2}[\mathit{part}],\ x + 4 \times y > \text{anchor}_{3,3}[\mathit{part}] \\ \text{IB} \times (x + 4 \times y) - 2, & \text{NS} = 3,\ \text{otherwise} \end{cases}$$

where anchor_2 is Table 20.10, $\text{anchor}_{3,2}$ is Table 20.8, $\text{anchor}_{3,3}$ is Table 20.9, and *part* is encoded in the partition selection bits PB.

If secondary index bits are present, they follow the primary index bits and are read in the same manner. The anchor index information is only used to determine the number of bits each index has when read from the block data.

The endpoint color and alpha values used for final interpolation are the decoded values corresponding to the applicable subset as selected above. The index value for interpolating color comes from the secondary index bits for the texel if the mode has an index selection bit and its value is one, and from the primary index bits otherwise. The alpha index comes from the secondary index bits if the block has a secondary index and the block either doesn't have an index selection bit or that bit is zero, and from the primary index bits otherwise.

Note

As an example of the texel decode process, consider a block encoded with mode 2 — that is, M^0 = 0, M^1 = 0, M^2 = 1. This mode has three subsets, so Table 20.7 is used to determine which subset applies to each texel. Let us assume that this block has partition pattern 6 encoded in the partition selection bits, and that we wish to decode the texel at relative (*x*, *y*) offset (1, 2) — that is, index 9 in y-major order. We can see from Table 20.7 that this texel is partitioned into subset 1 (the second of three), and therefore by endpoints 2 and 3. Mode 2 stores two index bits per texel, except for index 0 (which is the anchor index for subset 0), index 15 (for subset 1, as indicated in Table 20.8) and index 3 (for subset 2, as indicated in Table 20.9). Index 9 is therefore stored in two bits starting at index bits offset 14 (for indices 1..2 and 4..8) plus 2 (for indices 0 and 3) — a total of 16 bit offset into the index bits or, as seen in Table 20.3, bits 115 and 116 of the block. These two bits are used to interpolate between endpoints 2 and 3 using Equation 20.1 with weights from the two-bit index row of Table 20.11, as described below.

0				1				2				3				4				5				6				7			
0	0	1	1	***0***	0	0	1	***0***	1	1	1	***0***	0	0	1	***0***	0	0	0	***0***	0	1	1	***0***	0	0	1	***0***	0	0	0
0	0	1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	1
0	0	1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	1	0	1	1	1	0	1	1	1	0	0	1	1
0	0	1	***1***	0	0	0	***1***	0	1	1	***1***	0	1	1	***1***	0	0	1	***1***	1	1	1	***1***	1	1	1	***1***	0	1	1	***1***
8				9				10				11				12				13				14				15			
0	0	0	0	***0***	0	1	1	***0***	0	0	0	***0***	0	0	0	***0***	0	0	1	***0***	0	0	0	***0***	0	0	0	***0***	0	0	0
0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0
0	0	0	1	1	1	1	1	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
0	0	1	***1***	1	1	1	***1***	1	1	1	***1***	0	1	1	***1***	1	1	1	***1***	1	1	1	***1***	1	1	1	***1***	1	1	1	***1***
16				17				18				19				20				21				22				23			
0	0	0	0	***0***	1	***1***	1	***0***	0	0	0	***0***	1	***1***	1	***0***	0	***1***	1	***0***	0	0	0	***0***	0	0	0	***0***	1	1	1
1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1
1	1	1	0	0	0	0	0	***1***	0	0	0	0	0	0	1	0	0	0	0	***1***	1	0	0	***1***	0	0	0	0	0	1	1
1	1	1	***1***	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0	0	***1***
24				25				26				27				28				29				30				31			
0	0	***1***	1	***0***	0	0	0	***0***	1	***1***	0	***0***	0	***1***	1	***0***	0	0	1	***0***	0	0	0	***0***	1	***1***	1	***0***	0	***1***	1
0	0	0	1	1	0	0	0	0	1	1	0	0	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	0	0	1
0	0	0	1	***1***	0	0	0	0	1	1	0	0	1	1	0	***1***	1	1	0	***1***	1	1	1	1	0	0	0	1	0	0	1
0	0	0	0	1	1	0	0	0	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0
32				33				34				35				36				37				38				39			
0	1	0	1	***0***	0	0	0	***0***	1	0	1	***0***	0	***1***	1	***0***	0	***1***	1	***0***	1	0	1	***0***	1	1	0	***0***	1	0	1
0	1	0	1	1	1	1	1	1	0	***1***	0	0	0	1	1	1	1	0	0	0	1	0	1	1	0	0	1	1	0	1	0
0	1	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	***1***	0	1	0	0	1	1	0	1	0	1	0
0	1	0	***1***	1	1	1	***1***	1	0	1	0	1	1	0	0	1	1	0	0	1	0	1	0	1	0	0	***1***	0	1	0	***1***
40				41				42				43				44				45				46				47			
0	1	***1***	1	***0***	0	0	1	***0***	0	***1***	1	***0***	0	***1***	1	***0***	1	***1***	0	***0***	0	1	1	***0***	1	1	0	***0***	0	0	0
0	0	1	1	0	0	1	1	0	0	1	0	1	0	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	1	***1***	0
1	1	0	0	***1***	1	0	0	0	1	0	0	1	1	0	1	1	0	0	1	1	1	0	0	1	0	0	1	0	1	1	0
1	1	1	0	1	0	0	0	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	***1***	1	0	0	***1***	0	0	0	0
48				49				50				51				52				53				54				55			
0	1	0	0	***0***	0	***1***	0	***0***	0	0	0	***0***	0	0	0	***0***	1	1	0	***0***	0	1	1	***0***	1	***1***	0	***0***	0	***1***	1
1	1	***1***	0	0	1	1	1	0	0	***1***	0	0	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	0	0	1
0	1	0	0	0	0	1	0	0	1	1	1	***1***	1	1	0	1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	***1***	1	0	0	***1***	1	1	0	0	0	1	1	0
56				57				58				59				60				61				62				63			
0	1	1	0	***0***	1	1	0	***0***	1	1	1	***0***	0	0	1	***0***	0	0	0	***0***	0	***1***	1	***0***	0	***1***	0	***0***	1	0	0
1	1	0	0	0	0	1	1	1	1	1	0	1	0	0	0	1	1	1	1	0	0	1	1	0	0	1	0	0	1	0	0
1	1	0	0	0	0	1	1	1	0	0	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1
1	0	0	***1***	1	0	0	***1***	0	0	0	***1***	0	1	1	***1***	0	0	1	***1***	0	0	0	0	1	1	1	0	0	1	1	***1***

Table 20.6: Partition table for 2-subset BPTC, with the 4×4 block of values for each partition number

0				1				2				3				4				5				6				7			
0	0	1	***1***	***0***	0	0	***1***	***0***	0	0	0	***0***	2	2	***2***	***0***	0	0	0	***0***	0	1	***1***	***0***	0	2	***2***	***0***	0	1	1
0	0	1	1	0	0	1	1	2	0	0	1	0	0	2	2	0	0	0	0	0	0	1	1	0	0	2	2	0	0	1	1
0	2	2	1	***2***	2	1	1	***2***	2	1	1	0	0	1	1	***1***	1	2	2	0	0	2	2	1	1	1	1	***2***	2	1	1
2	2	2	***2***	2	2	2	***1***	2	2	1	***1***	0	1	1	***1***	1	1	2	***2***	0	0	2	***2***	1	1	1	***1***	2	2	1	***1***
8				9				10				11				12				13				14				15			
0	0	0	0	***0***	0	0	0	***0***	0	0	0	***0***	0	1	2	***0***	1	1	2	***0***	1	2	2	***0***	0	1	***1***	***0***	0	1	***1***
0	0	0	0	1	1	1	1	1	1	***1***	1	0	0	***1***	2	0	1	***1***	2	0	***1***	2	2	0	1	1	2	2	0	0	1
1	1	1	1	***1***	1	1	1	2	2	2	2	0	0	1	2	0	1	1	2	0	1	2	2	1	1	2	2	***2***	2	0	0
2	2	2	***2***	2	2	2	***2***	2	2	2	***2***	0	0	1	***2***	0	1	1	***2***	0	1	2	***2***	1	2	2	***2***	2	2	2	0
16				17				18				19				20				21				22				23			
0	0	0	***1***	***0***	1	1	***1***	***0***	0	0	0	***0***	0	2	***2***	***0***	1	1	***1***	***0***	0	0	***1***	***0***	0	0	0	***0***	0	0	0
0	0	1	1	0	0	1	1	1	1	2	2	0	0	2	2	0	1	1	1	0	0	0	1	0	0	***1***	1	1	1	0	0
0	1	1	2	***2***	0	0	1	***1***	1	2	2	0	0	2	2	0	2	2	2	***2***	2	2	1	0	1	2	2	***2***	2	***1***	0
1	1	2	***2***	2	2	0	0	1	1	2	***2***	1	1	1	***1***	0	2	2	***2***	2	2	2	1	0	1	2	***2***	2	2	1	0
24				25				26				27				28				29				30				31			
0	1	2	***2***	***0***	0	1	2	***0***	1	1	0	***0***	0	0	0	***0***	0	2	2	***0***	1	1	0	***0***	0	1	1	***0***	0	0	0
0	***1***	2	2	0	0	1	2	1	2	***2***	1	0	1	***1***	0	1	1	0	2	0	***1***	1	0	0	1	2	2	2	0	0	0
0	0	1	1	***1***	1	2	2	***1***	2	2	1	1	2	***2***	1	***1***	1	0	2	2	0	0	2	0	1	***2***	2	***2***	2	1	1
0	0	0	0	2	2	2	***2***	0	1	1	0	1	2	2	1	0	0	2	***2***	2	2	2	***2***	0	0	1	***1***	2	2	2	***1***
32				33				34				35				36				37				38				39			
0	0	0	0	***0***	2	2	***2***	***0***	0	1	***1***	***0***	1	2	0	***0***	0	0	0	***0***	1	2	0	***0***	1	2	0	***0***	0	1	1
0	0	0	2	0	0	2	2	0	0	1	2	0	***1***	2	0	1	1	***1***	1	1	2	0	1	2	0	1	2	2	2	0	0
1	1	2	2	0	0	1	2	0	0	2	2	0	1	***2***	0	2	2	***2***	2	***2***	0	***1***	2	***1***	***2***	0	1	1	1	***2***	2
1	2	2	***2***	0	0	1	***1***	0	2	2	***2***	0	1	2	0	0	0	0	0	0	1	2	0	0	1	2	0	0	0	1	***1***
40				41				42				43				44				45				46				47			
0	0	1	1	***0***	1	0	***1***	***0***	0	0	0	***0***	0	2	2	***0***	0	2	***2***	***0***	2	2	0	***0***	1	0	1	***0***	0	0	0
1	1	***2***	2	0	1	0	1	0	0	0	0	1	***1***	2	2	0	0	1	1	1	2	***2***	1	2	2	***2***	2	2	1	2	1
2	2	0	0	2	2	2	2	***2***	1	2	1	0	0	2	2	0	0	2	2	0	2	2	0	2	2	2	2	***2***	1	2	1
0	0	1	***1***	2	2	2	***2***	2	1	2	***1***	1	1	2	***2***	0	0	1	***1***	1	2	2	***1***	0	1	0	***1***	2	1	2	***1***
48				49				50				51				52				53				54				55			
0	1	0	***1***	***0***	2	2	***2***	***0***	0	0	2	***0***	0	0	0	***0***	2	2	2	***0***	0	0	2	***0***	1	1	0	***0***	0	0	0
0	1	0	1	0	1	1	1	1	***1***	1	2	2	***1***	1	2	0	***1***	1	1	1	1	1	2	0	***1***	1	0	0	0	0	0
0	1	0	1	0	2	2	2	0	0	0	2	2	1	1	2	0	1	1	1	***1***	1	1	2	0	1	1	0	2	1	***1***	2
2	2	2	***2***	0	1	1	***1***	1	1	1	***2***	2	1	1	***2***	0	2	2	***2***	0	0	0	***2***	2	2	2	***2***	2	1	1	***2***
56				57				58				59				60				61				62				63			
0	1	1	0	***0***	0	2	2	***0***	0	2	2	***0***	0	0	0	***0***	0	0	***2***	***0***	2	2	2	***0***	1	0	***1***	***0***	1	1	***1***
0	***1***	1	0	0	0	1	1	1	1	2	2	0	0	0	0	0	0	0	1	1	2	2	2	2	2	2	2	2	0	1	1
2	2	2	2	0	0	***1***	1	***1***	1	2	2	0	0	0	0	0	0	0	2	0	2	2	2	2	2	2	2	***2***	2	0	1
2	2	2	***2***	0	0	2	***2***	0	0	2	***2***	2	***1***	1	***2***	0	0	0	***1***	***1***	2	2	***2***	2	2	2	***2***	2	2	2	0

Table 20.7: Partition table for 3-subset BPTC, with the 4×4 block of values for each partition number

0	1	2	3	4	5	6	7
3	3	15	15	8	3	15	15
8	9	10	11	12	13	14	15
8	8	6	6	6	5	3	3
16	17	18	19	20	21	22	23
3	3	8	15	3	3	6	10
24	25	26	27	28	29	30	31
5	8	8	6	8	5	15	15
32	33	34	35	36	37	38	39
8	15	3	5	6	10	8	15
40	41	42	43	44	45	46	47
15	3	15	5	15	15	15	15
48	49	50	51	52	53	54	55
3	15	5	5	5	8	5	10
56	57	58	59	60	61	62	63
5	10	8	13	15	12	3	3

Table 20.8: BPTC anchor index values for the second subset of three-subset partitioning, by partition number

0	1	2	3	4	5	6	7
15	8	8	3	15	15	3	8
8	9	10	11	12	13	14	15
15	15	15	15	15	15	15	8
16	17	18	19	20	21	22	23
15	8	15	3	15	8	15	8
24	25	26	27	28	29	30	31
3	15	6	10	15	15	10	8
32	33	34	35	36	37	38	39
15	3	15	10	10	8	9	10
40	41	42	43	44	45	46	47
6	15	8	15	3	6	6	8
48	49	50	51	52	53	54	55
15	3	15	15	15	15	15	15
56	57	58	59	60	61	62	63
15	15	15	15	3	15	15	8

Table 20.9: BPTC anchor index values for the third subset of three-subset partitioning, by partition number

0	1	2	3	4	5	6	7
15	15	15	15	15	15	15	15
8	9	10	11	12	13	14	15
15	15	15	15	15	15	15	15
16	17	18	19	20	21	22	23
15	2	8	2	2	8	8	15
24	25	26	27	28	29	30	31
2	8	2	2	8	8	2	2
32	33	34	35	36	37	38	39
15	15	6	8	2	8	15	15
40	41	42	43	44	45	46	47
2	8	2	2	2	15	15	6
48	49	50	51	52	53	54	55
6	2	6	8	15	15	2	2
56	57	58	59	60	61	62	63
15	15	15	15	15	2	2	15

Table 20.10: BPTC anchor index values for the second subset of two-subset partitioning, by partition number

Interpolation is always performed using a 6-bit interpolation factor. The effective interpolation factors for 2-, 3-, and 4-bit indices are given in Table 20.11.

<table>
<tr><td rowspan="2"><b>2</b></td><td>Index</td><td colspan="4">0</td><td colspan="4">1</td><td colspan="4">2</td><td colspan="4">3</td></tr>
<tr><td><i>Weight</i></td><td colspan="4">0</td><td colspan="4">21</td><td colspan="4">43</td><td colspan="4">64</td></tr>
<tr><td rowspan="2"><b>3</b></td><td>Index</td><td colspan="2">0</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2">4</td><td colspan="2">5</td><td colspan="2">6</td><td colspan="2">7</td></tr>
<tr><td><i>Weight</i></td><td colspan="2">0</td><td colspan="2">9</td><td colspan="2">18</td><td colspan="2">27</td><td colspan="2">37</td><td colspan="2">46</td><td colspan="2">55</td><td colspan="2">64</td></tr>
<tr><td rowspan="2"><b>4</b></td><td>Index</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td><i>Weight</i></td><td>0</td><td>4</td><td>9</td><td>13</td><td>17</td><td>21</td><td>26</td><td>30</td><td>34</td><td>38</td><td>43</td><td>47</td><td>51</td><td>55</td><td>60</td><td>64</td></tr>
</table>

Table 20.11: BPTC interpolation factors

These weights may also be calculated as follows:

2-bit weights:

```
weight = (index * 21) + (index >> 1)
```

3-bit weights:

```
weight = (index * 9) + (index >> 2)
```

4-bit weights:

```
weight = (index << 2) + (index >> 2) + ((index >> 1) & 1)
```

Given E_0 and E_1, unsigned integer endpoints [0 .. 255] for each channel and *weight* as an unsigned integer interpolation factor from Table 20.11:

$$\textit{interpolated value} = ((64 - \textit{weight}) \times E_0 + \textit{weight} \times E_1 + 32) \gg 6$$

Equation 20.1: BPTC endpoint interpolation formula where $\gg$ performs a (truncating) bitwise right-shift, and *interpolated value* is an (unsigned) integer in the range [0..255]. The interpolation results in an *RGBA* color. If rotation bits are present, this interpolated color is remapped according to Table 20.12.

0	no change
1	$swap(A, R)$
2	$swap(A, G)$
3	$swap(A, B)$

Table 20.12: BPTC Rotation bits

These 8-bit values should be interpreted as *RGBA* 8-bit normalized channels, either linearly encoded (by multiplying by $\frac{1}{255}$) or with the sRGB transfer function.

20.2 BC6H

Each 4×4 block of texels consists of 128 bits of *RGB* data. The signed and unsigned formats are very similar and will be described together. In the description and pseudocode below, *signed* will be used as a condition which is true for the signed version of the format and false for the unsigned version of the format. Both formats only contain *RGB* data, so the returned alpha value is 1.0. If a block uses a reserved or invalid encoding, the return value is (0.0, 0.0, 0.0, 1.0).

Note

Where BC7 encodes a fixed-point 8-bit value, BC6H encodes a 16-bit integer which will be interpreted as a 16-bit half float. Interpolation in BC6H is therefore nonlinear, but monotonic.

Each block can contain data in one of 14 modes. The mode number is encoded in either the low two bits or the low five bits. If the low two bits are less than two, that is the mode number, otherwise the low five bits is the mode number. Mode numbers not listed in Table 20.13 (19, 23, 27, and 31) are reserved.

Mode number	**Transformed endpoints**	**Partition bits (PB)**	**Endpoint bits (EPB)**	**Delta bits**	**Mode**	**Endpoint**	**Delta**
		Bits per texel block	{*R*,*G*,*B*} bits per endpoint		Bits per texel block (total)		
0	✓	5	{10, 10, 10}	{5, 5, 5}	2	30	45
1	✓	5	{7, 7, 7}	{6, 6, 6}	2	21	54
2	✓	5	{11, 11, 11}	{5, 4, 4}	5	33	39
6	✓	5	{11, 11, 11}	{4, 5, 4}	5	33	39
10	✓	5	{11, 11, 11}	{4, 4, 5}	5	33	39
14	✓	5	{9, 9, 9}	{5, 5, 5}	5	27	45
18	✓	5	{8, 8, 8}	{6, 5, 5}	5	24	48
22	✓	5	{8, 8, 8}	{5, 6, 5}	5	24	48
26	✓	5	{8, 8, 8}	{5, 5, 6}	5	24	48
30		5	{6, 6, 6}	-	5	72	0
3		0	{10, 10, 10}	-	5	60	0
7	✓	0	{11, 11, 11}	{9, 9, 9}	5	33	27
11	✓	0	{12, 12, 12}	{8, 8, 8}	5	36	24
15	✓	0	{16, 16, 16}	{4, 4, 4}	5	48	12

Table 20.13: Endpoint and partition parameters for BPTC block modes

The data for the compressed blocks is stored in a different manner for each mode. The interpretation of bits for each mode are specified in Table 20.14. The descriptions are intended to be read from left to right with the LSB on the left. Each element is of the form $v^{a..b}$. If $a \geq b$, this indicates extracting b - a + 1 bits from the block at that location and put them in the corresponding bits of the variable v. If $a < b$, then the bits are reversed. v^{a} is used as a shorthand for the one bit $v^{a..a}$. As an example, $\mathrm{M}^{1..0}$, $G_2{}^4$ would move the low two bits from the block into the low two bits of mode number M, then the next bit of the block into bit 4 of G_2. The resultant bit interpretations are shown explicitly in Table 20.15 and Table 20.16. The variable names given in the table will be referred to in the language below.

Subsets and indices work in much the same way as described for the BC7 formats above. If a float block has no partition bits, then it is a single-subset block. If it has partition bits, then it is a two-subset block. The partition number references the first half of Table 20.6.

Mode Number	Block description
0	$\mathrm{M}^{1..0}, G_2{}^4, B_2{}^4, B_3{}^4, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{4..0}, G_3{}^4, G_2{}^{3..0}, G_1{}^{4..0}, B_3{}^0, G_3{}^{3..0}, B_1{}^{4..0}, B_3{}^1, B_2{}^{3..0}, R_2{}^{4..0}, B_3{}^2, R_3{}^{4..0}, B_3{}^3, \mathrm{PB}^{4..0}$
1	$\mathrm{M}^{1..0}, G_2{}^5, G_3{}^4, G_3{}^5, R_0{}^{6..0}, B_3{}^0, B_3{}^1, B_2{}^4, G_0{}^{6..0}, B_2{}^5, B_3{}^2, G_2{}^4, B_0{}^{6..0}, B_3{}^3, B_3{}^5, B_3{}^4, R_1{}^{5..0}, G_2{}^{3..0}, G_1{}^{5..0}, G_3{}^{3..0}, B_1{}^{5..0}, B_2{}^{3..0}, R_2{}^{5..0}, R_3{}^{5..0}, \mathrm{PB}^{4..0}$
2	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{4..0}, R_0{}^{10}, G_2{}^{3..0}, G_1{}^{3..0}, G_0{}^{10}, B_3{}^0, G_3{}^{3..0}, B_1{}^{3..0}, B_0{}^{10}, B_3{}^1, B_2{}^{3..0}, R_2{}^{4..0}, B_3{}^2, R_3{}^{4..0}, B_3{}^3, \mathrm{PB}^{4..0}$
6	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{3..0}, R_0{}^{10}, G_3{}^4, G_2{}^{3..0}, G_1{}^{4..0}, G_0{}^{10}, G_3{}^{3..0}, B_1{}^{3..0}, B_0{}^{10}, B_3{}^1, B_2{}^{3..0}, R_2{}^{3..0}, B_3{}^0, B_3{}^2, R_3{}^{3..0}, G_2{}^4, B_3{}^3, \mathrm{PB}^{4..0}$
10	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{3..0}, R_0{}^{10}, B_2{}^4, G_2{}^{3..0}, G_1{}^{3..0}, G_0{}^{10}, B_3{}^0, G_3{}^{3..0}, B_1{}^{4..0}, B_0{}^{10}, B_2{}^{3..0}, R_2{}^{3..0}, B_3{}^1, B_3{}^2, R_3{}^{3..0}, B_3{}^4, B_3{}^3, \mathrm{PB}^{4..0}$
14	$\mathrm{M}^{4..0}, R_0{}^{8..0}, B_2{}^4, G_0{}^{8..0}, G_2{}^4, B_0{}^{8..0}, B_3{}^4, R_1{}^{4..0}, G_3{}^4, G_2{}^{3..0}, G_1{}^{4..0}, B_3{}^0, G_3{}^{3..0}, B_1{}^{4..0}, B_3{}^1, B_2{}^{3..0}, R_2{}^{4..0}, B_3{}^2, R_3{}^{4..0}, B_3{}^3, \mathrm{PB}^{4..0}$
18	$\mathrm{M}^{4..0}, R_0{}^{7..0}, G_3{}^4, B_2{}^4, G_0{}^{7..0}, B_3{}^2, G_2{}^4, B_0{}^{7..0}, B_3{}^3, B_3{}^4, R_1{}^{5..0}, G_2{}^{3..0}, G_1{}^{4..0}, B_3{}^0, G_3{}^{3..0}, B_1{}^{4..0}, B_3{}^1, B_2{}^{3..0}, R_2{}^{5..0}, R_3{}^{5..0}, \mathrm{PB}^{4..0}$
22	$\mathrm{M}^{4..0}, R_0{}^{7..0}, B_3{}^0, B_2{}^4, G_0{}^{7..0}, G_2{}^5, G_2{}^4, B_0{}^{7..0}, G_3{}^5, B_3{}^4, R_1{}^{4..0}, G_3{}^4, G_2{}^{3..0}, G_1{}^{5..0}, G_3{}^{3..0}, B_1{}^{4..0}, B_3{}^1, B_2{}^{3..0}, R_2{}^{4..0}, B_3{}^2, R_3{}^{4..0}, B_3{}^3, \mathrm{PB}^{4..0}$
26	$\mathrm{M}^{4..0}, R_0{}^{7..0}, B_3{}^1, B_2{}^4, G_0{}^{7..0}, B_2{}^5, G_2{}^4, B_0{}^{7..0}, B_3{}^5, B_3{}^4, R_1{}^{4..0}, G_3{}^4, G_2{}^{3..0}, G_1{}^{4..0}, B_3{}^0, G_3{}^{3..0}, B_1{}^{5..0}, B_2{}^{3..0}, R_2{}^{4..0}, B_3{}^2, R_3{}^{4..0}, B_3{}^3, \mathrm{PB}^{4..0}$
30	$\mathrm{M}^{4..0}, R_0{}^{5..0}, G_3{}^4, B_3{}^0, B_3{}^1, B_2{}^4, G_0{}^{5..0}, G_2{}^5, B_2{}^5, B_3{}^2, G_2{}^4, B_0{}^{5..0}, G_3{}^5, B_3{}^3, B_3{}^5, B_3{}^4, R_1{}^{5..0}, G_2{}^{3..0}, G_1{}^{5..0}, G_3{}^{3..0}, B_1{}^{5..0}, B_2{}^{3..0}, R_2{}^{5..0}, R_3{}^{5..0}, \mathrm{PB}^{4..0}$
3	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{9..0}, G_1{}^{9..0}, B_1{}^{9..0}$
7	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{8..0}, R_0{}^{10}, G_1{}^{8..0}, G_0{}^{10}, B_1{}^{8..0}, B_0{}^{10}$
11	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{7..0}, R_0{}^{10..11}, G_1{}^{7..0}, G_0{}^{10..11}, B_1{}^{7..0}, B_0{}^{10..11}$
15	$\mathrm{M}^{4..0}, R_0{}^{9..0}, G_0{}^{9..0}, B_0{}^{9..0}, R_1{}^{3..0}, R_0{}^{10..15}, G_1{}^{3..0}, G_0{}^{10..15}, B_1{}^{3..0}, B_0{}^{10..15}$

Table 20.14: Block descriptions for BC6H block modes (LSB..MSB)

Indices are read in the same way as the BC7 formats including obeying the anchor values for index 0 and as needed by Table 20.10. That is, for modes with only one partition, the mode and endpoint data are followed by 63 bits of index data (four index bits $\mathrm{IB}_{x,y}{}^{0..3}$ per texel, with one implicit bit for $\mathrm{IB}_{x,y}{}^3$) starting at bit 65 with $\mathrm{IB}_{0,0}{}^0$. For modes with two partitions, the mode, endpoint and partition data are followed by 46 bits of index data (three per texel $\mathrm{IB}_{x,y}{}^{0..2}$, with two implicit bits, one for partition 0 at $\mathrm{IB}_{0,0}{}^2$ and one $\mathrm{IB}_{x,y}{}^2$ bit for partition 1 at an offset determined by the partition pattern selected) starting at bit 82 with $\mathrm{IB}_{0,0}{}^0$. In both cases, index bits are stored in y-major offset order by increasing little-endian bit number, with the bits for each index stored consecutively:

$$\text{Bit offset of } \mathrm{IB}_{x,y}{}^0 = \begin{cases} 65, & 1 \text{ subset}, \ x = y = 0 \\ 65 + 4 \times (x + 4 \times y) - 1, & 1 \text{ subset}, \ 0 < x + 4 \times y \\ 82, & 2 \text{ subsets}, \ x = y = 0 \\ 82 + 3 \times (x + 4 \times y) - 1, & 2 \text{ subsets}, \ 0 < x + 4 \times y \leq \text{anchor}_2[part] \\ 82 + 3 \times (x + 4 \times y) - 2, & 2 \text{ subsets}, \ \text{anchor}_2[part] < x + 4 \times y \end{cases}$$

Note

Table 20.15 and Table 20.16 show bits 0..81 for each mode. Since modes 3, 7, 11 and 15 each have only one partition, only the first index is an anchor index, and there is a fixed mapping between texels and index bits. These modes also have four index bits $\mathrm{IB}_{x,y}{}^{0..3}$ per texel (except for the anchor index), and these pixel indices start at bit 65 with $\mathrm{IB}_{0,0}{}^0$. The interpretation of bits 82 and later is not tabulated. For modes with two partitions, the mapping from index bits $\mathrm{IB}_{x,y}$ to coordinates depends on the choice of anchor index for the secondary partition (determined by the pattern selected by the partition bits $\mathrm{PB}^{4..0}$), and is therefore not uniquely defined by the mode — and not useful to tabulate in this form.

	Mode													
Bit	**0**	**1**	**2**	**6**	**10**	**14**	**18**	**22**	**26**	**30**	**3**	**7**	**11**	**15**
0	M^0: **0**	M^0: **1**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **0**	M^0: **1**	M^0: **1**	M^0: **1**	M^0: **1**
1	M^1: **0**	M^1: **0**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**	M^1: **1**
2	$G_2{}^4$	$G_2{}^5$	M^2: **0**	M^2: **1**	M^2: **0**	M^2: **1**	M^2: **0**	M^2: **1**	M^2: **0**	M^2: **1**	M^2: **0**	M^2: **1**	M^2: **0**	M^2: **1**
3	$B_2{}^4$	$G_3{}^4$	M^3: **0**	M^3: **0**	M^3: **1**	M^3: **1**	M^3: **0**	M^3: **0**	M^3: **1**	M^3: **1**	M^3: **0**	M^3: **0**	M^3: **1**	M^3: **1**
4	$B_3{}^4$	$G_3{}^5$	M^4: **0**	M^4: **0**	M^4: **0**	M^4: **0**	M^4: **1**	M^4: **1**	M^4: **1**	M^4: **1**	M^4: **0**	M^4: **0**	M^4: **0**	M^4: **0**
5	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$	$R_0{}^0$
6	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$	$R_0{}^1$
7	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$	$R_0{}^2$
8	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$	$R_0{}^3$
9	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$	$R_0{}^4$
10	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$	$R_0{}^5$
11	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$G_3{}^4$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$	$R_0{}^6$
12	$R_0{}^7$	$B_3{}^0$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$B_3{}^0$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$	$R_0{}^7$
13	$R_0{}^8$	$B_3{}^1$	$R_0{}^8$	$R_0{}^8$	$R_0{}^8$	$R_0{}^8$	$G_3{}^4$	$B_3{}^0$	$B_3{}^1$	$B_3{}^1$	$R_0{}^8$	$R_0{}^8$	$R_0{}^8$	$R_0{}^8$
14	$R_0{}^9$	$B_2{}^4$	$R_0{}^9$	$R_0{}^9$	$R_0{}^9$	$B_2{}^4$	$B_2{}^4$	$B_2{}^4$	$B_2{}^4$	$B_2{}^4$	$R_0{}^9$	$R_0{}^9$	$R_0{}^9$	$R_0{}^9$
15	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$	$G_0{}^0$
16	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$	$G_0{}^1$
17	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$	$G_0{}^2$
18	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$	$G_0{}^3$
19	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$	$G_0{}^4$
20	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$	$G_0{}^5$
21	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_2{}^5$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$	$G_0{}^6$
22	$G_0{}^7$	$B_2{}^5$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$B_2{}^5$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$	$G_0{}^7$
23	$G_0{}^8$	$B_3{}^2$	$G_0{}^8$	$G_0{}^8$	$G_0{}^8$	$G_0{}^8$	$B_3{}^2$	$G_2{}^5$	$B_2{}^5$	$B_3{}^2$	$G_0{}^8$	$G_0{}^8$	$G_0{}^8$	$G_0{}^8$
24	$G_0{}^9$	$G_2{}^4$	$G_0{}^9$	$G_0{}^9$	$G_0{}^9$	$G_2{}^4$	$G_2{}^4$	$G_2{}^4$	$G_2{}^4$	$G_2{}^4$	$G_0{}^9$	$G_0{}^9$	$G_0{}^9$	$G_0{}^9$
25	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$	$B_0{}^0$
26	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$	$B_0{}^1$
27	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$	$B_0{}^2$
28	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$	$B_0{}^3$
29	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$	$B_0{}^4$
30	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$	$B_0{}^5$
31	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$G_3{}^5$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$	$B_0{}^6$
32	$B_0{}^7$	$B_3{}^3$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_3{}^3$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$	$B_0{}^7$
33	$B_0{}^8$	$B_3{}^5$	$B_0{}^8$	$B_0{}^8$	$B_0{}^8$	$B_0{}^8$	$B_3{}^3$	$G_3{}^5$	$B_3{}^5$	$B_3{}^5$	$B_0{}^8$	$B_0{}^8$	$B_0{}^8$	$B_0{}^8$
34	$B_0{}^9$	$B_3{}^4$	$B_0{}^9$	$B_0{}^9$	$B_0{}^9$	$B_3{}^4$	$B_3{}^4$	$B_3{}^4$	$B_3{}^4$	$B_3{}^4$	$B_0{}^9$	$B_0{}^9$	$B_0{}^9$	$B_0{}^9$
35	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$	$R_1{}^0$
36	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$	$R_1{}^1$
37	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$	$R_1{}^2$
38	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$	$R_1{}^3$
39	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_0{}^{10}$	$R_0{}^{10}$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_1{}^4$	$R_0{}^{15}$
40	$G_3{}^4$	$R_1{}^5$	$R_0{}^{10}$	$G_3{}^4$	$B_2{}^4$	$G_3{}^4$	$R_1{}^5$	$G_3{}^4$	$G_3{}^4$	$R_1{}^5$	$R_1{}^5$	$R_1{}^5$	$R_1{}^5$	$R_0{}^{14}$

Table 20.15: Interpretation of lower bits for BC6H block modes

	Mode													
Bit	**0**	**1**	**2**	**6**	**10**	**14**	**18**	**22**	**26**	**30**	**3**	**7**	**11**	**15**
41	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	G_2^0	R_1^6	R_1^6	R_1^6	R_0^{13}
42	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	G_2^1	R_1^7	R_1^7	R_1^7	R_0^{12}
43	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	G_2^2	R_1^8	R_1^8	R_0^{11}	R_0^{11}
44	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	G_2^3	R_1^9	R_0^{10}	R_0^{10}	R_0^{10}
45	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0	G_1^0
46	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1	G_1^1
47	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2	G_1^2
48	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3	G_1^3
49	G_1^4	G_1^4	G_0^{10}	G_1^4	G_0^{10}	G_1^4	G_1^4	G_1^4	G_1^4	G_1^4	G_1^4	G_1^4	G_1^4	G_0^{15}
50	B_3^0	G_1^5	B_3^0	G_0^{10}	B_3^0	B_3^0	B_3^0	G_1^5	B_3^0	G_1^5	G_1^5	G_1^5	G_1^5	G_0^{14}
51	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_3^0	G_1^6	G_1^6	G_1^6	G_0^{13}
52	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_3^1	G_1^7	G_1^7	G_1^7	G_0^{12}
53	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_3^2	G_1^8	G_1^8	G_0^{11}	G_0^{11}
54	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_3^3	G_1^9	G_0^{10}	G_0^{10}	G_0^{10}
55	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0	B_1^0
56	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1	B_1^1
57	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2	B_1^2
58	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3	B_1^3
59	B_1^4	B_1^4	B_0^{10}	B_0^{10}	B_1^4	B_1^4	B_1^4	B_1^4	B_1^4	B_1^4	B_1^4	B_1^4	B_1^4	B_0^{15}
60	B_3^1	B_1^5	B_3^1	B_3^1	B_0^{10}	B_3^1	B_3^1	B_3^1	B_1^5	B_1^5	B_1^5	B_1^5	B_1^5	B_0^{14}
61	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_2^0	B_1^6	B_1^6	B_1^6	B_0^{13}
62	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_2^1	B_1^7	B_1^7	B_1^7	B_0^{12}
63	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_2^2	B_1^8	B_1^8	B_0^{11}	B_0^{11}
64	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_2^3	B_1^9	B_0^{10}	B_0^{10}	B_0^{10}
65	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	R_2^0	$\mathrm{IB}_{0,0}^0$	$\mathrm{IB}_{0,0}^0$	$\mathrm{IB}_{0,0}^0$	$\mathrm{IB}_{0,0}^0$
66	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	R_2^1	$\mathrm{IB}_{0,0}^1$	$\mathrm{IB}_{0,0}^1$	$\mathrm{IB}_{0,0}^1$	$\mathrm{IB}_{0,0}^1$
67	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	R_2^2	$\mathrm{IB}_{0,0}^2$	$\mathrm{IB}_{0,0}^2$	$\mathrm{IB}_{0,0}^2$	$\mathrm{IB}_{0,0}^2$
68	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	R_2^3	$\mathrm{IB}_{1,0}^0$	$\mathrm{IB}_{1,0}^0$	$\mathrm{IB}_{1,0}^0$	$\mathrm{IB}_{1,0}^0$
69	R_2^4	R_2^4	R_2^4	B_3^0	B_3^1	R_2^4	R_2^4	R_2^4	R_2^4	R_2^4	$\mathrm{IB}_{1,0}^1$	$\mathrm{IB}_{1,0}^1$	$\mathrm{IB}_{1,0}^1$	$\mathrm{IB}_{1,0}^1$
70	B_3^2	R_2^5	B_3^2	B_3^2	B_3^2	B_3^2	R_2^5	B_3^2	B_3^2	R_2^5	$\mathrm{IB}_{1,0}^2$	$\mathrm{IB}_{1,0}^2$	$\mathrm{IB}_{1,0}^2$	$\mathrm{IB}_{1,0}^2$
71	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	R_3^0	$\mathrm{IB}_{1,0}^3$	$\mathrm{IB}_{1,0}^3$	$\mathrm{IB}_{1,0}^3$	$\mathrm{IB}_{1,0}^3$
72	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	R_3^1	$\mathrm{IB}_{2,0}^0$	$\mathrm{IB}_{2,0}^0$	$\mathrm{IB}_{2,0}^0$	$\mathrm{IB}_{2,0}^0$
73	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	R_3^2	$\mathrm{IB}_{2,0}^1$	$\mathrm{IB}_{2,0}^1$	$\mathrm{IB}_{2,0}^1$	$\mathrm{IB}_{2,0}^1$
74	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	R_3^3	$\mathrm{IB}_{2,0}^2$	$\mathrm{IB}_{2,0}^2$	$\mathrm{IB}_{2,0}^2$	$\mathrm{IB}_{2,0}^2$
75	R_3^4	R_3^4	R_3^4	G_2^4	B_3^4	R_3^4	R_3^4	R_3^4	R_3^4	R_3^4	$\mathrm{IB}_{2,0}^3$	$\mathrm{IB}_{2,0}^3$	$\mathrm{IB}_{2,0}^3$	$\mathrm{IB}_{2,0}^3$
76	B_3^3	R_3^5	B_3^3	B_3^3	B_3^3	B_3^3	R_3^5	B_3^3	B_3^3	R_3^5	$\mathrm{IB}_{3,0}^0$	$\mathrm{IB}_{3,0}^0$	$\mathrm{IB}_{3,0}^0$	$\mathrm{IB}_{3,0}^0$
77	PB^0	PB^0	PB^0	PB^0	PB^0	PB^0	PB^0	PB^0	PB^0	PB^0	$\mathrm{IB}_{3,0}^1$	$\mathrm{IB}_{3,0}^1$	$\mathrm{IB}_{3,0}^1$	$\mathrm{IB}_{3,0}^1$
78	PB^1	PB^1	PB^1	PB^1	PB^1	PB^1	PB^1	PB^1	PB^1	PB^1	$\mathrm{IB}_{3,0}^2$	$\mathrm{IB}_{3,0}^2$	$\mathrm{IB}_{3,0}^2$	$\mathrm{IB}_{3,0}^2$
79	PB^2	PB^2	PB^2	PB^2	PB^2	PB^2	PB^2	PB^2	PB^2	PB^2	$\mathrm{IB}_{3,0}^3$	$\mathrm{IB}_{3,0}^3$	$\mathrm{IB}_{3,0}^3$	$\mathrm{IB}_{3,0}^3$
80	PB^3	PB^3	PB^3	PB^3	PB^3	PB^3	PB^3	PB^3	PB^3	PB^3	$\mathrm{IB}_{0,1}^0$	$\mathrm{IB}_{0,1}^0$	$\mathrm{IB}_{0,1}^0$	$\mathrm{IB}_{0,1}^0$
81	PB^4	PB^4	PB^4	PB^4	PB^4	PB^4	PB^4	PB^4	PB^4	PB^4	$\mathrm{IB}_{0,1}^1$	$\mathrm{IB}_{0,1}^1$	$\mathrm{IB}_{0,1}^1$	$\mathrm{IB}_{0,1}^1$

Table 20.16: Interpretation of upper bits for BC6H block modes

In a single-subset blocks, the two endpoints are contained in R_0, G_0, B_0 (collectively referred to as E_0) and R_1, G_1, B_1 (collectively E_1). In a two-subset block, the endpoints for the second subset are in R_2, G_2, B_2 and R_3, G_3, B_3 (collectively E_2 and E_3 respectively). The values in E_0 are sign-extended to the implementation's internal integer representation if the format of the texture is signed. The values in E_1 (and E_2 and E_3 if the block has two subsets) are sign-extended if the format of the texture is signed or if the block mode has transformed endpoints. If the mode has transformed endpoints, the values from E_0 are used as a base to offset all other endpoints, wrapped at the number of endpoint bits. For example, $R_1 = (R_0 + R_1)\ \&\ ((1 \ll \mathrm{EPB}) - 1)$.

Note

In BC7, all modes represent endpoint values independently. This means it is always possible to represent the endpoints nearest to the anchor indices by choosing the endpoint order appropriately. Since in BC6H transformed endpoints are represented as two's complement offsets relative to the first endpoint, there is an asymmetry: it is possible to represent larger negative values in two's complement than positive values, so E_1, E_2 and E_3 can be more distant from E_0 in a negative direction than positive in modes with transformed endpoints. This means that endpoints cannot necessarily be chosen independently of the anchor index in BC6H, since the order of endpoints cannot necessarily be reversed. In addition, E_2 and E_3 always depends on E_0, so swapping E_0 and E_1 to suit the anchor bit for the first subset may make make the relative offsets of E_2 and E_3 unrepresentable in a given mode if they fall out of range.

Next, the endpoints are unquantized to maximize the usage of the bits and to ensure that the negative ranges are oriented properly to interpolate as a two's complement value. The following pseudocode assumes the computation uses sufficiently large intermediate values to avoid overflow. For the unsigned float format, we unquantize a value *x* to *unq* by:

```
if (EPB >= 15)
    unq = x;
else if (x == 0)
    unq = 0;
else if (x == ((1 << EPB)-1))
    unq = 0xFFFF;
else
    unq = ((x << 15) + 0x4000) >> (EPB-1);
```

The signed float unquantization is similar, but needs to worry about orienting the negative range:

```
s = 0;
if (EPB >= 16) {
    unq = x;
} else {
    if (x < 0) {
        s = 1;
        x = -x;
    }

    if (x == 0)
        unq = 0;
    else if (x >= ((1 << (EPB-1))-1))
        unq = 0x7FFF;
    else
        unq = ((x << 15) + 0x4000) >> (EPB-1);

    if (s)
        unq = -unq;
}
```

After the endpoints are unquantized, interpolation proceeds as in the fixed-point formats above using Equation 20.1, including the interpolation weight table, Table 20.11.

The interpolated values are passed through a final unquantization step. For the unsigned format, this limits the range of the integer representation to those bit sequences which, when interpreted as a 16-bit half float, represent [0.0..65504.0], where 65504.0 is the largest finite value representable in a half float. The bit pattern that represents 65504.0 is integer 0x7BFF, so the integer input range 0..0xFFFF can be mapped to this range by scaling the interpolated integer i by $\frac{31}{64}$:

```
out = (i * 31) >> 6;
```

For the signed format, the final unquantization step limits the range of the integer representation to the bit sequences which, when interpreted as a 16-bit half float, represent the range $[-\infty..65504.0]$, where $-\infty$ is represented in half float as the bit pattern 0xFC00. The signed 16-bit integer range [-0x8000..0x7FFF] is remapped to this float representation by taking the absolute value of the interpolated value i, scaling it by $\frac{31}{32}$, and restoring the sign bit:

```
out = i < 0 ? (((-i) * 31) >> 5) | 0x8000 : (i * 31) >> 5;
```

The resultant bit pattern should be interpreted as a 16-bit half float.

Note

The ability to support $-\infty$ is considered "accidental" due to the asymmetry of two's complement representation: in order to map integer 0x7FFF to 65504.0 and 0x0000 to 0.0, -0x7FFF maps to the largest finite negative value, -65504.0, represented as 0xFBFF. A two's complement signed integer can also represent -0x8000; it happens that the same unquantization formula maps 0x8000 to 0xFC00, which is the half float bit pattern for $-\infty$. Although decoders for BC6H should be bit-exact, encoders for this format are encouraged to map $-\infty$ to -65504.0 (and to map ∞ to 65504.0 and NaN values to 0.0) prior to encoding.

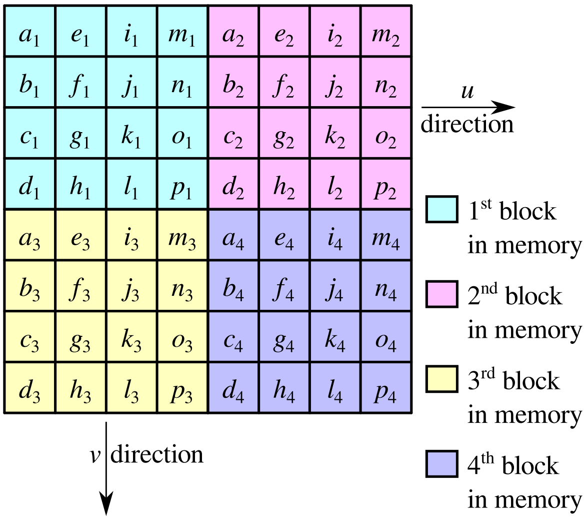
Chapter 21

ETC1 Compressed Texture Image Formats

This description is derived from the OES_compressed_ETC1_RGB8_texture OpenGL extension.

The texture is described as a number of 4×4 pixel blocks. If the texture (or a particular mip-level) is smaller than 4 pixels in any dimension (such as a 2×2 or a 8×1 texture), the texture is found in the upper left part of the block(s), and the rest of the pixels are not used. For instance, a texture of size 4×2 will be placed in the upper half of a 4×4 block, and the lower half of the pixels in the block will not be accessed.

Pixel a_1 (see Figure 21.1) of the first block in memory will represent the texture coordinate (u=0, v=0). Pixel a_2 in the second block in memory will be adjacent to pixel m_1 in the first block, etc. until the width of the texture. Then pixel a_3 in the following block (third block in memory for a 8×8 texture) will be adjacent to pixel d_1 in the first block, etc. until the height of the texture. The data storage for an 8×8 texture using the first, second, third and fourth block if stored in that order in memory would have the texels encoded in the same order as a simple linear format as if the bytes describing the pixels came in the following memory order: a_1 e_1 i_1 m_1 a_2 e_2 i_2 m_2 b_1 f_1 i_1 n_1 b_2 f_2 i_2 n_2 c_1 g_1 k_1 o_1 c_2 g_2 k_2 o_2 d_1 h_1 l_1 p_1 d_2 h_2 l_2 p_2 a_3 e_3 i_3 m_3 a_4 e_4 i_4 m_4 b_3 f_3 i_3 n_3 b_4 f_4 i_4 n_4 c_3 g_3 k_3 o_3 c_4 g_4 k_4 o_4 d_3 h_3 l_3 p_3 d_4 h_4 l_4 p_4.



a_1	e_1	i_1	m_1	a_2	e_2	i_2	m_2
b_1	f_1	j_1	n_1	b_2	f_2	j_2	n_2
c_1	g_1	k_1	o_1	c_2	g_2	k_2	o_2
d_1	h_1	l_1	p_1	d_2	h_2	l_2	p_2
a_3	e_3	i_3	m_3	a_4	e_4	i_4	m_4
b_3	f_3	j_3	n_3	b_4	f_4	j_4	n_4
c_3	g_3	k_3	o_3	c_4	g_4	k_4	o_4
d_3	h_3	l_3	p_3	d_4	h_4	l_4	p_4

Figure 21.1: Pixel layout for an 8×8 texture using four ETC1 compressed blocks

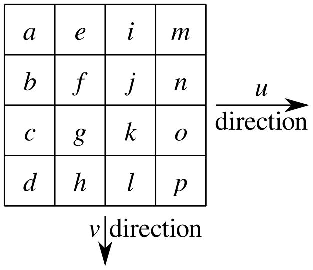
Note how pixel a_2 in the second block is adjacent to pixel m_1 in the first block.

The number of bits that represent a 4×4 texel block is 64 bits.

The data for a block is stored as a number of bytes, q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7, where byte q_0 is located at the lowest memory address and q_7 at the highest. The 64 bits specifying the block are then represented by the following 64 bit integer:

$$int64bit = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$

Each 64-bit word contains information about a 4×4 pixel block as shown in Figure 21.2.



a	*e*	*i*	*m*
b	*f*	*j*	*n*
c	*g*	*k*	*o*
d	*h*	*l*	*p*

Figure 21.2: Pixel layout for an ETC1 compressed block

There are two modes in ETC1: the 'individual' mode and the 'differential' mode. Which mode is active for a particular 4×4 block is controlled by bit 33, which we call *diff bit*. If *diff bit* = 0, the 'individual' mode is chosen, and if *diff bit* = 1, then the 'differential' mode is chosen. The bit layout for the two modes are different: The bit layout for the individual mode is shown in Table 21.1 part a and part c, and the bit layout for the differential mode is laid out in Table 21.1 part b and part c.

a) Bit layout in bits 63 through 32 if *diff bit* = 0															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
Base color 1 R (4 bits)				Base color 2 R_2 (4 bits)				Base color 1 G (4 bits)				Base color 2 G_2 (4 bits)			
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Base color 1 B (4 bits)				Base color 2 B_2 (4 bits)				*Table* *codeword* 1			*Table* *codeword* 2			*diff* *bit*	*flip* *bit*
b) Bit layout in bits 63 through 32 if *diff bit* = 1															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
Base color R (5 bits)					Color delta R_d			Base color G (5 bits)					Color delta G_d		
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Base color B (5 bits)					Color delta B_d			*Table* *codeword* 1			*Table* *codeword* 2			*diff* *bit*	*flip* *bit*
c) Bit layout in bits 31 through 0 (in both cases)															
More significant pixel index bits															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
p^1	o^1	n^1	m^1	l^1	k^1	j^1	i^1	h^1	g^1	f^1	e^1	d^1	c^1	b^1	a^1
Less significant pixel index bits															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
p^0	o^0	n^0	m^0	l^0	k^0	j^0	i^0	h^0	g^0	f^0	e^0	d^0	c^0	b^0	a^0

Table 21.1: Texel Data format for ETC1 compressed textures

In both modes, the 4×4 block is divided into two subblocks of either size 2×4 or 4×2. This is controlled by bit 32, which we call *flip bit*. If *flip bit* = 0, the block is divided into two 2×4 subblocks side-by-side, as shown in Figure 21.3. If *flip bit* = 1, the block is divided into two 4×2 subblocks on top of each other, as shown in Figure 21.4.

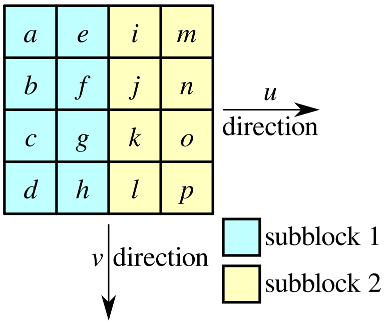


Figure 21.3: Two 2×4-pixel ETC1 subblocks side-by-side

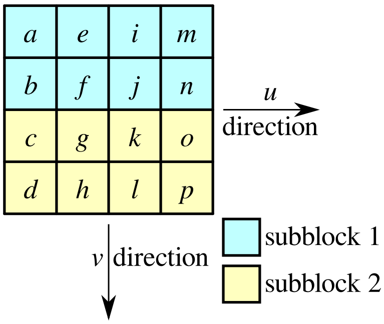


Figure 21.4: Two 4×2-pixel ETC1 subblocks on top of each other

In both individual and differential mode, a *base color* for each subblock is stored, but the way they are stored is different in the two modes:

In the 'individual' mode (*diff bit* = 0), the *base color* for subblock 1 is derived from the codewords R (bits 63..60), G (bits 55..52) and B (bits 47..44), see section a of Table 21.1. These four bit values are extended to *RGB*:888 by replicating the four higher order bits in the four lower order bits. For instance, if R = 14 = 1110b, G = 3 = 0011b and B = 8 = 1000b, then the red component of the *base color* of subblock 1 becomes 11101110b = 238, and the green and blue components become 00110011b = 51 and 10001000b = 136. The *base color* for subblock 2 is decoded the same way, but using the 4-bit codewords R_2 (bits 59..56), G_2 (bits 51..48) and B_2 (bits 43..40) instead. In summary, the *base colors* for the subblocks in the individual mode are:

$$\begin{aligned} \textit{base color}_{\textit{subblock1}} &= \textit{extend\_4to8bits}(R, G, B) \\ \textit{base color}_{\textit{subblock2}} &= \textit{extend\_4to8bits}(R_2, G_2, B_2) \end{aligned}$$

In the 'differential' mode (*diff bit* = 1), the *base color* for subblock 1 is derived from the five-bit codewords R, G and B. These five-bit codewords are extended to eight bits by replicating the top three highest-order bits to the three lowest order bits. For instance, if R = 28 = 11100b, the resulting eight-bit red color component becomes 11100111b = 231. Likewise, if G = 4 = 00100b and B = 3 = 00011b, the green and blue components become 00100001b = 33 and 00011000b = 24 respectively. Thus, in this example, the *base color* for subblock 1 is (231, 33, 24). The five-bit representation for the *base color* of subblock 2 is obtained by modifying the five-bit codewords R, G and B by the codewords R_d, G_d and B_d. Each of R_d, G_d and B_d is a three-bit two's-complement number that can hold values between -4 and +3. For instance, if R= 28 as above, an R_d = 100b = -4, then the five-bit representation for the red color component is 28+(-4) = 24 = 11000b, which is then extended to eight bits, to 11000110b = 198. Likewise, if G = 4, G_d = 2, B = 3 and B_d = 0, the *base color* of subblock 2 will be *RGB* = (198, 49, 24). In summary, the *base colors* for the subblocks in the differential mode are:

$$\begin{aligned} \textit{base color}_{\textit{subblock1}} &= \textit{extend\_5to8bits}(R, G, B) \\ \textit{base color}_{\textit{subblock2}} &= \textit{extend\_5to8bits}(R + R_d, G + G_d, B + B_d) \end{aligned}$$

Note that these additions are not allowed to under- or overflow (go below zero or above 31). (The compression scheme can easily make sure they don't.) For over- or underflowing values, the behavior is undefined for all pixels in the 4×4 block. Note also that the extension to eight bits is performed *after* the addition.

After obtaining the base color, the operations are the same for the two modes 'individual' and 'differential'. First a table is chosen using the table codewords: For subblock 1, table codeword 1 is used (bits 39..37), and for subblock 2, table codeword 2 is used (bits 36..34), see Table 21.1. The table codeword is used to select one of eight modifier tables, see Table 21.2. For instance, if the table code word is 010b = 2, then the modifier table [-29, -9, 9, 29] is selected. Note that the values in Table 21.2 are valid for all textures and can therefore be hardcoded into the decompression unit.

Next, we identify which *modifier* value to use from the modifier table using the two 'pixel index' bits. The pixel index bits are unique for each pixel. For instance, the pixel index for pixel *d* (see Figure 21.2) can be found in bits 19 (most significant bit, MSB), and 3 (least significant bit, LSB), see section c of Table 21.1. Note that the pixel index for a particular texel is always stored in the same bit position, irrespectively of bits *diff bit* and *flip bit*. The pixel index bits are decoded using Table 21.3. If, for instance, the pixel index bits are 01b = 1, and the modifier table [-29, -9, 9, 29] is used, then the modifier value selected for that pixel is 29 (see Table 21.3). This modifier value is now used to additively modify the base color. For example, if we have the base color (231, 8, 16), we should add the modifier value 29 to all three components: (231+29, 8+29, 16+29) resulting in (260, 37, 45). These values are then clamped to [0..255], resulting in the color (255, 37, 45), and we are finished decoding the texel.

Table codeword	**Modifier table**			
0	-8	-2	2	8
1	-17	-5	5	17
2	-29	-9	9	29
3	-42	-13	13	42
4	-60	-18	18	60
5	-80	-24	24	80
6	-106	-33	33	106
7	-183	-47	47	183

Table 21.2: Intensity modifier sets for ETC1 compressed textures

***Pixel index* value**		**Resulting modifier value**
MSB	**LSB**	
1	1	-b (large negative value)
1	0	-a (small negative value)
0	0	+a (small positive value)
0	1	+b (large positive value)

Table 21.3: Mapping from pixel index values to modifier values for ETC1 compressed textures

Note
ETC1 is a proper subset of ETC2. There are examples of "individual" and "differential" decoding in Chapter 22.

21.1 ETC1S

The ETC1S format is a subset the ETC1, simplified to facilitate image compression. The blocks use differential encoding (*diff bit* = 1); Color deltas $R_d = G_d = B_d = 0$, so the two subblocks share base colors. The *Table codeword* for each subblock is identical. Finally, the *flip bit* is encoded as 0 — the subsets are identical anyway.

Chapter 22

ETC2 Compressed Texture Image Formats

This description is derived from the "ETC Compressed Texture Image Formats" section of the OpenGL 4.4 specification.

The ETC formats form a family of related compressed texture image formats. They are designed to do different tasks, but also to be similar enough that hardware can be reused between them. Each one is described in detail below, but we will first give an overview of each format and describe how it is similar to others and the main differences.

RGB ETC2 is a format for compressing *RGB* data. It is a superset of the older ETC1 format. This means that an older ETC1 texture can be decoded using an ETC2-compliant decoder. The main difference is that the newer version contains three new modes; the 'T-mode' and the 'H-mode' which are good for sharp chrominance blocks and the 'Planar' mode which is good for smooth blocks.

RGB ETC2 with sRGB encoding is the same as linear RGB ETC2 with the difference that the values should be interpreted as being encoded with the sRGB transfer function instead of linear *RGB*-values.

RGBA ETC2 encodes *RGBA* 8-bit data. The *RGB* part is encoded exactly the same way as RGB ETC2. The alpha part is encoded separately.

RGBA ETC2 with sRGB encoding is the same as RGBA ETC2 but here the *RGB* values (but not the alpha value) should be interpreted as being encoded with the sRGB transfer function.

Unsigned R11 EAC is a one-channel unsigned format. It is similar to the alpha part of RGBA ETC2 but not exactly the same; it delivers higher precision. It is possible to make hardware that can decode both formats with minimal overhead.

Unsigned RG11 EAC is a two-channel unsigned format. Each channel is decoded exactly as Unsigned R11 EAC.

Signed R11 EAC is a one-channel signed format. This is good in situations when it is important to be able to preserve zero exactly, and still use both positive and negative values. It is designed to be similar enough to Unsigned R11 EAC so that hardware can decode both with minimal overhead, but it is not exactly the same. For example; the signed version does not add 0.5 to the *base codeword*, and the extension from 11 bits differ. For all details, see the corresponding sections.

Signed RG11 EAC is a two-channel signed format. Each channel is decoded exactly as signed R11 EAC.

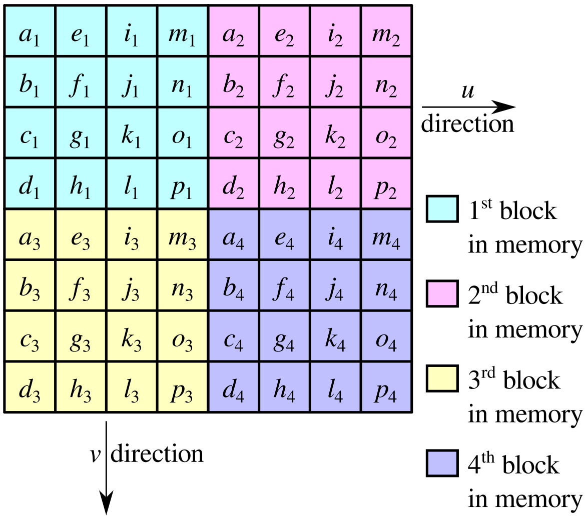
RGB ETC2 with "punchthrough" alpha is very similar to RGB ETC2, but has the ability to represent "punchthrough" alpha (completely opaque or transparent). Each block can select to be completely opaque using one bit. To fit this bit, there is no individual mode in RGB ETC2 with punchthrough alpha. In other respects, the opaque blocks are decoded as in RGB ETC2. For the transparent blocks, one index is reserved to represent transparency, and the decoding of the *RGB* channels are also affected. For details, see the corresponding sections.

RGB ETC2 with punchthrough alpha and sRGB encoding is the same as linear RGB ETC2 with punchthrough alpha but the *RGB* channel values should be interpreted as being encoded with the sRGB transfer function.

A texture compressed using any of the ETC texture image formats is described as a number of 4×4 pixel blocks.

Pixel a_1 (see Figure 22.1) of the first block in memory will represent the texture coordinate (u=0, v=0). Pixel a_2 in the second block in memory will be adjacent to pixel m_1 in the first block, etc. until the width of the texture. Then pixel a_3 in the following block (third block in memory for an 8×8 texture) will be adjacent to pixel d_1 in the first block, etc. until the height of the texture.

The data storage for an 8×8 texture using the first, second, third and fourth block if stored in that order in memory would have the texels encoded in the same order as a simple linear format as if the bytes describing the pixels came in the following memory order: a_1 e_1 i_1 m_1 a_2 e_2 i_2 m_2 b_1 f_1 i_1 n_1 b_2 f_2 i_2 n_2 c_1 g_1 k_1 o_1 c_2 g_2 k_2 o_2 d_1 h_1 l_1 p_1 d_2 h_2 l_2 p_2 a_3 e_3 i_3 m_3 a_4 e_4 i_4 m_4 b_3 f_3 i_3 n_3 b_4 f_4 i_4 n_4 c_3 g_3 k_3 o_3 c_4 g_4 k_4 o_4 d_3 h_3 l_3 p_3 d_4 h_4 l_4 p_4.



a_1	e_1	i_1	m_1	a_2	e_2	i_2	m_2
b_1	f_1	j_1	n_1	b_2	f_2	j_2	n_2
c_1	g_1	k_1	o_1	c_2	g_2	k_2	o_2
d_1	h_1	l_1	p_1	d_2	h_2	l_2	p_2
a_3	e_3	i_3	m_3	a_4	e_4	i_4	m_4
b_3	f_3	j_3	n_3	b_4	f_4	j_4	n_4
c_3	g_3	k_3	o_3	c_4	g_4	k_4	o_4
d_3	h_3	l_3	p_3	d_4	h_4	l_4	p_4

Figure 22.1: Pixel layout for an 8×8 texture using four ETC2 compressed blocks

Note how pixel a_3 in the third block is adjacent to pixel d_1 in the first block.

If the width or height of the texture (or a particular mip-level) is not a multiple of four, then padding is added to ensure that the texture contains a whole number of 4×4 blocks in each dimension. The padding does not affect the texel coordinates. For example, the texel shown as a_1 in Figure 22.1 always has coordinates (i=0, j=0). The values of padding texels are irrelevant, e.g., in a 3×3 texture, the texels marked as m_1, n_1, o_1, d_1, h_1, l_1 and p_1 form padding and have no effect on the final texture image.

The number of bits that represent a 4×4 texel block is 64 bits if the format is RGB ETC2, RGB ETC2 with sRGB encoding, RGBA ETC2 with punchthrough alpha, or RGB ETC2 with punchthrough alpha and sRGB encoding.

In those cases the data for a block is stored as a number of bytes, $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7\}$, where byte q_0 is located at the lowest memory address and q_7 at the highest. The 64 bits specifying the block are then represented by the following 64 bit integer:

$$int64bit = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$

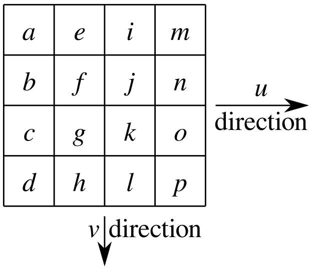
The number of bits that represent a 4×4 texel block is 128 bits if the format is RGBA ETC2 with a linear or sRGB transfer function. In those cases the data for a block is stored as a number of bytes: $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10}, q_{11}, q_{12}, q_{13}, q_{14}, q_{15}\}$, where byte q_0 is located at the lowest memory address and q_{15} at the highest.

This is split into two 64-bit integers, one used for color channel decompression and one for alpha channel decompression:

$$\begin{aligned} int64bit_{Alpha} &= 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7 \\ int64bit_{Color} &= 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_8 + q_9) + q_{10}) + q_{11}) + q_{12}) + q_{13}) + q_{14}) + q_{15} \end{aligned}$$

22.1 Format RGB ETC2

For RGB ETC2, each 64-bit word contains information about a three-channel 4×4 pixel block as shown in Figure 22.2.



a	*e*	*i*	*m*
b	*f*	*j*	*n*
c	*g*	*k*	*o*
d	*h*	*l*	*p*

Figure 22.2: Pixel layout for an ETC2 compressed block

<table>
<tr><td colspan="32"><b>a) Location of bits for mode selection</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td colspan="5">R</td><td colspan="3">R_{d}</td><td colspan="5">G</td><td colspan="3">G_{d}</td><td colspan="5">B</td><td colspan="3">B_{d}</td><td colspan="6">......</td><td>D</td><td>.</td></tr>
<tr><td colspan="32"><b>b) Bit layout for bits 63 through 32 for ‘individual’ mode</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td colspan="4">R</td><td colspan="4">R_2</td><td colspan="4">G</td><td colspan="4">G_2</td><td colspan="4">B</td><td colspan="4">B_2</td><td colspan="3">$table_1$</td><td colspan="3">$table_2$</td><td>0</td><td>F_B</td></tr>
<tr><td colspan="32"><b>c) Bit layout for bits 63 through 32 for ‘differential’ mode</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td colspan="5">R</td><td colspan="3">R_{d}</td><td colspan="5">G</td><td colspan="3">G_{d}</td><td colspan="5">B</td><td colspan="3">B_{d}</td><td colspan="3">$table_1$</td><td colspan="3">$table_2$</td><td>1</td><td>F_B</td></tr>
<tr><td colspan="32"><b>d) Bit layout for bits 63 through 32 for ‘T’ mode</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td colspan="3">...</td><td colspan="2">$R^{3..2}$</td><td>.</td><td colspan="2">$R^{1..0}$</td><td colspan="4">G</td><td colspan="4">B</td><td colspan="4">R_2</td><td colspan="4">G_2</td><td colspan="4">B_2</td><td colspan="2">d_{a}</td><td>1</td><td>d_{b}</td></tr>
<tr><td colspan="32"><b>e) Bit layout for bits 63 through 32 for ‘H’ mode</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td>.</td><td colspan="4">R</td><td colspan="3">$G^{3..1}$</td><td colspan="3">...</td><td>G^0</td><td>B^3</td><td>.</td><td colspan="3">$B^{2..0}$</td><td colspan="4">R_2</td><td colspan="4">G_2</td><td colspan="4">B_2</td><td>d_a</td><td>1</td><td>d_b</td></tr>
<tr><td colspan="32"><b>f) Bit layout for bits 31 through 0 for ‘individual’, ‘differential’, ‘T’ and ‘H’ modes</b></td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>p^1</td><td>o^1</td><td>n^1</td><td>m^1</td><td>l^1</td><td>k^1</td><td>j^1</td><td>i^1</td><td>h^1</td><td>g^1</td><td>f^1</td><td>e^1</td><td>d^1</td><td>c^1</td><td>b^1</td><td>a^1</td><td>p^0</td><td>o^0</td><td>n^0</td><td>m^0</td><td>l^0</td><td>k^0</td><td>j^0</td><td>i^0</td><td>h^0</td><td>g^0</td><td>f^0</td><td>e^0</td><td>d^0</td><td>c^0</td><td>b^0</td><td>a^0</td></tr>
<tr><td colspan="32"><b>g) Bit layout for bits 63 through 0 for ‘planar’ mode</b></td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td>.</td><td colspan="6">R</td><td>G^6</td><td>.</td><td colspan="6">$G^{5..0}$</td><td>B^5</td><td colspan="3">...</td><td colspan="2">$B^{4..3}$</td><td>.</td><td colspan="3">$B^{2..0}$</td><td colspan="5">${R_{\mathrm{h}}}^{5..1}$</td><td>1</td><td>${R_h}^0$</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="7">G_{h}</td><td colspan="6">B_{h}</td><td colspan="6">R_{v}</td><td colspan="7">G_{v}</td><td colspan="6">B_{v}</td></tr>
</table>

Table 22.1: Texel Data format for ETC2 compressed texture formats

The blocks are compressed using one of five different 'modes'. Section a of Table 22.1 shows the bits used for determining the mode used in a given block. First, if the 'differential bit' marked D is set to 0, the 'individual' mode is used. Otherwise, the three 5-bit values R, G and B, and the three 3-bit values R_d, G_d and B_d are examined. R, G and B are treated as integers between 0 and 31 and R_d, G_d and B_d as two's-complement integers between -4 and +3. First, R and R_d are added, and if the sum is not within the interval [0..31], the 'T' mode is selected. Otherwise, if the sum of G and G_d is outside the interval [0..31], the 'H' mode is selected. Otherwise, if the sum of B and B_d is outside of the interval [0..31], the 'planar' mode is selected. Finally, if the D bit is set to 1 and all of the aforementioned sums lie between 0 and 31, the 'differential' mode is selected.

The layout of the bits used to decode the 'individual' and 'differential' modes are shown in section b and section c of Table 22.1, respectively. Both of these modes share several characteristics. In both modes, the 4×4 block is split into two subblocks of either size 2×4 or 4×2. This is controlled by bit 32, which we dub the *flip bit* (F_B in Table 22.1 (b) and (c)). If the *flip bit* is 0, the block is divided into two 2×4 subblocks side-by-side, as shown in Figure 22.3. If the *flip bit* is 1, the block is divided into two 4×2 subblocks on top of each other, as shown in Figure 22.4. In both modes, a *base color* for each subblock is stored, but the way they are stored is different in the two modes:

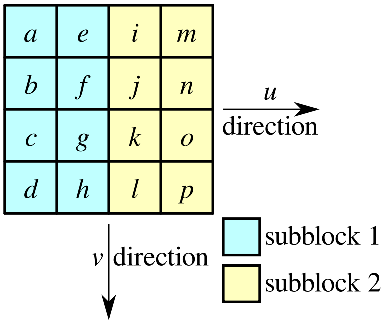


Figure 22.3: Two 2×4-pixel ETC2 subblocks side-by-side

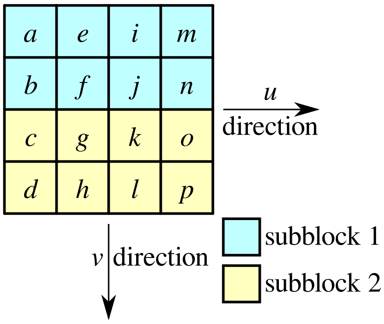


Figure 22.4: Two 4×2-pixel ETC2 subblocks on top of each other

In the 'individual' mode, following the layout shown in section b of Table 22.1, the *base color* for subblock 1 is derived from the codewords R (bits 63..60), G (bits 55..52) and B (bits 47..44). These four bit values are extended to *RGB*:888 by replicating the four higher order bits in the four lower order bits. For instance, if R = 14 = 1110 binary (1110b for short), G = 3 = 0011b and B = 8 = 1000b, then the red component of the *base color* of subblock 1 becomes 11101110b = 238, and the green and blue components become 00110011b = 51 and 10001000b = 136. The *base color* for subblock 2 is decoded the same way, but using the 4-bit codewords R_2 (bits 59..56), G_2 (bits 51..48) and B_2 (bits 43..40) instead. In summary, the *base colors* for the subblocks in the individual mode are:

$$\mathit{base\ color}_{\mathit{subblock1}} = \mathit{extend4to8bits}(R, G, B)$$
$$\mathit{base\ color}_{\mathit{subblock2}} = \mathit{extend4to8bits}(R_2, G_2, B_2)$$

In the ‘differential’ mode, following the layout shown in section c of Table 22.1, the *base color* for subblock 1 is derived from the five-bit codewords R, G and B. These five-bit codewords are extended to eight bits by replicating the top three highest-order bits to the three lowest-order bits. For instance, if R = 28 = 11100b, the resulting eight-bit red color component becomes 11100111b = 231. Likewise, if G = 4 = 00100b and B = 3 = 00011b, the green and blue components become 00100001b = 33 and 00011000b = 24 respectively. Thus, in this example, the *base color* for subblock 1 is (231, 33, 24). The five-bit representation for the *base color* of subblock 2 is obtained by modifying the five-bit codewords R, G and B by the codewords R_{d}, G_{d} and B_{d}. Each of R_{d}, G_{d} and B_{d} is a 3-bit two’s-complement number that can hold values between -4 and +3. For instance, if R = 28 as above, and R_{d} = 100b = y - 4, then the five bit representation for the red color component is 28+(-4) = 24 = 11000b, which is then extended to eight bits to 11000110b = 198. Likewise, if G = 4, G_{d} = 2, B = 3 and B_{d} = 0, the *base color* of subblock 2 will be RGB = 198, 49, 24. In summary, the *base colors* for the subblocks in the ‘differential’ mode are:

$$base\ color_{subblock1} = extend5to8bits(R, G, B)$$
$$base\ color_{subblock2} = extend5to8bits(R + R_{\mathrm{d}}, G + G_{\mathrm{d}}, B + B_{\mathrm{d}})$$

Note that these additions will not under- or overflow, or one of the alternative decompression modes would have been chosen instead of the ‘differential’ mode.

After obtaining the *base color*, the operations are the same for the two modes ‘individual’ and ‘differential’. First a table is chosen using the *table codewords*: For subblock 1, *table codeword 1* is used (bits 39..37), and for subblock 2, *table codeword 2* is used (bits 36..34), see section b or section c of Table 22.1. The *table codeword* is used to select one of eight modifier tables, see Table 22.2. For instance, if the *table codeword* is 010 binary = 2, then the modifier table [-29, -9, 9, 29] is selected for the corresponding sub-block. Note that the values in Table 22.2 are valid for all textures and can therefore be hardcoded into the decompression unit.

Table codeword	Modifier table			
0	-8	-2	2	8
1	-17	-5	5	17
2	-29	-9	9	29
3	-42	-13	13	42
4	-60	-18	18	60
5	-80	-24	24	80
6	-106	-33	33	106
7	-183	-47	47	183

Table 22.2: ETC2 intensity modifier sets for ‘individual’ and ‘differential’ modes

***Pixel index* value**		**Resulting *modifier* value**
MSB	**LSB**	
1	1	-b (large negative value)
1	0	-a (small negative value)
0	0	+a (small positive value)
0	1	+b (large positive value)

Table 22.3: Mapping from pixel index values to modifier values for RGB ETC2 compressed textures

Next, we identify which *modifier* value to use from the modifier table using the two *pixel index* bits. The *pixel index* bits are unique for each pixel. For instance, the *pixel index* for pixel *d* (see Figure 22.2) can be found in bits 19 (most significant bit, MSB), and 3 (least significant bit, LSB), see section f of Table 22.1. Note that the pixel index for a particular texel is always stored in the same bit position, irrespectively of bits *diff bit* and *flip bit*. The *pixel index* bits are decoded using Table 22.3. If, for instance, the *pixel index* bits are 01 binary = 1, and the modifier table [-29, -9, 9, 29] is used, then the *modifier* value selected for that pixel is 29 (see Table 22.3). This *modifier* value is now used to additively modify the *base color*. For example, if we have the *base color* (231, 8, 16), we should add the *modifier* value 29 to all three components: (231+29, 8+29, 16+29) resulting in (260, 37, 45). These values are then clamped to [0..255], resulting in the color (255, 37, 45), and we are finished decoding the texel.

Note

Figure 22.5 shows an example ‘individual mode’ ETC2 block. The two *base colors* are shown as circles, and *modifiers* are applied to each channel to give the ‘paint colors’ selectable by each *pixel index*, shown as small diamonds. Since the same *modifier* is applied to each channel, each *paint color* for a subblock falls on a line (shown dashed) parallel to the grayscale (0, 0, 0) to (255, 255, 255) axis, unless the channels are modified by clamping to the range [0..255].

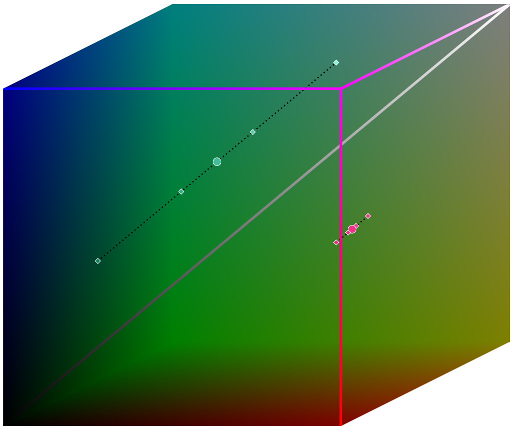


Figure 22.5: ETC2 ‘individual’ mode

In this example, one *base color* is encoded as the 4-bit triple (4, 11, 9), which is expanded by *extend4to8bits* to (68, 187, 153). Modifier table 4 [-60, -18, 18, 60] is selected for this subblock, giving the following *paint colors*:

Modifier	*R*	*G*	*B*
-60	8	127	93
-18	58	169	135
18	86	205	171
60	128	247	213

The other *base color* is encoded as the 4-bit triple (14, 3, 8), which is expanded by *extend4to8bits* to (238, 51, 136). Modifier table 0 [-8, -2, 2, 8] is selected for this subblock, giving the following *paint colors* for the subblock:

Modifier	*R*	*G*	*B*
-8	230	43	128
-2	236	49	134
2	240	53	138
8	246	59	144

In this example, none of the *paint colors* are modified by the process of clipping the channels to the range [0..255]. Since there is no difference in the way the *base colors* are encoded in ‘individual mode’, either *base color* could correspond to either subblock.

Note

Figure 22.6 shows an example 'differential mode' ETC2 block. The two *base colors* are shown as circles; an arrow shows the *base color* of the second subblock (the upper left circle) derived from the first subblock's *base color* (lower right circle). *Modifiers* to the *base colors* give 'paint colors' selectable by each *pixel index*, shown as small diamonds. Since the same *modifier* is applied to each channel, each *paint color* for a subblock falls on a line (shown dashed) parallel to the grayscale (0, 0, 0) to (255, 255, 255) axis, unless channels are modified by clamping to [0..255].

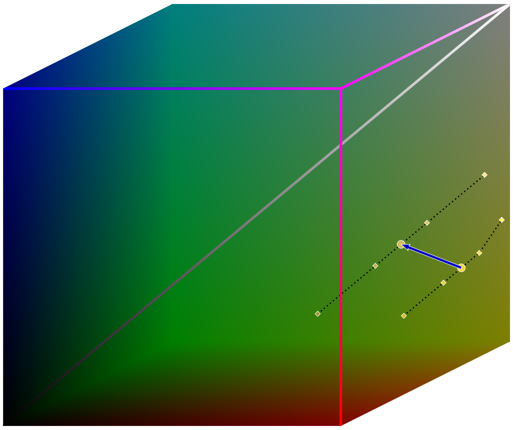


Figure 22.6: ETC2 'differential' mode

Here the first subblock's *base color* is encoded as the 5-bit triple (29, 26, 8), and expanded by *extend5to8bits* to (239, 214, 66). Note that not every color representable in 'individual mode', exists in 'differential mode', or vice-versa.

The *base color* of subblock 2 is the five-bit representation of the *base color* of subblock 1 (29, 26, 8) plus a (R_d, G_d, B_d) offset of (-4, -3, +3), for a new *base color* of (25, 23, 11) - expanded by *extend5to8bits* to (206, 189, 90). The offset cannot exceed the range [0..31] (expanded to [0..255]): this would select the 'T', 'H' or 'planar' modes. For 'differential mode', the *base colors* must be similar in each channel. The two's complement offset gives an asymmetry: we could not swap the subblocks of this example, since a R_d offset of +4 is unrepresentable.

In this example, modifier table 2 [-29, -9, 9, 29] is applied to subblock 1's *base color* of (239, 214, 66):

Modifier	***R***	***G***	***B***
-29	210	185	37
-9	230	205	57
9	248	223	75
29	268	243	95

The last row is clamped to (255, 243, 95), so subblock 1's *paint colors* are not colinear in this example. With *modifiers*, all grays [0..255] are representable. Similarly, modifier table 3 [-42, -13, 13, 42] is applied to the *base color* of subblock 2, (206, 189, 90):

Modifier	***R***	***G***	***B***
-42	164	147	48
-13	193	176	77
13	219	202	103
42	248	231	132

The ‘T’ and ‘H’ compression modes also share some characteristics: both use two *base colors* stored using 4 bits per channel decoded as in the individual mode. Unlike the ‘individual’ mode however, these bits are not stored sequentially, but in the layout shown in section d and section e of Table 22.1. To clarify, in the ‘T’ mode, the two colors are constructed as follows:

$$\begin{aligned}
\textit{base color 1} &= \textit{extend4to8bits}(\,(R^{3..2} \ll 2)\,|\,R^{1..0},\, G,\, B) \\
\textit{base color 2} &= \textit{extend4to8bits}(R_2,\, G_2,\, B_2)
\end{aligned}$$

Here, $\ll$ denotes bit-wise left shift and $|$ denotes bit-wise OR. In the ‘H’ mode, the two colors are constructed as follows:

$$\begin{aligned}
\textit{base color 1} &= \textit{extend4to8bits}(R,\, (G^{3..1} \ll 1)\,|\,G^{0},\, (B^{3} \ll 3)\,|\,B^{2..0}) \\
\textit{base color 2} &= \textit{extend4to8bits}(R_2,\, G_2,\, B_2)
\end{aligned}$$

Both the ‘T’ and ‘H’ modes have four *paint colors* which are the colors that will be used in the decompressed block, but they are assigned in a different manner. In the ‘T’ mode, *paint color 0* is simply the first *base color*, and *paint color 2* is the second *base color*. To obtain the other *paint colors*, a ‘distance’ is first determined, which will be used to modify the luminance of one of the *base colors*. This is done by combining the values d_a and d_b shown in section d of Table 22.1 by $(d_a \ll 1) \mid d_b$, and then using this value as an index into the small look-up table shown in Table 22.4. For example, if d_a is 10 binary and d_b is 1 binary, the *distance index* is 101 binary and the selected ‘distance’ d will be 32. *Paint color 1* is then equal to the second *base color* with the ‘distance’ d added to each channel, and *paint color 3* is the second *base color* with the ‘distance’ d subtracted.

Distance index	**Distance *d***
0	3
1	6
2	11
3	16
4	23
5	32
6	41
7	64

Table 22.4: Distance table for ETC2 ‘T’ and ‘H’ modes

In summary, to determine the four *paint colors* for a ‘T’ block:

$$\begin{aligned}
\textit{paint color 0} &= \textit{base color 1} \\
\textit{paint color 1} &= \textit{base color 2} + (d,d,d) \\
\textit{paint color 2} &= \textit{base color 2} \\
\textit{paint color 3} &= \textit{base color 2} - (d,d,d)
\end{aligned}$$

In both cases, the value of each channel is clamped to within [0..255].

Note

Figure 22.7 shows an example ‘T-mode’ ETC2 block. The two *base colors* are shown as circles, and *modifiers* are applied to *base color 2* to give the other two ‘paint colors’, shown as small diamonds. Since the same *modifier* is applied to each channel, *base color 2* and the two *paint colors* derived from it fall on a line (shown dashed) parallel to the grayscale (0, 0, 0) to (255, 255, 255) axis, unless channels are modified by clamping to [0..255].

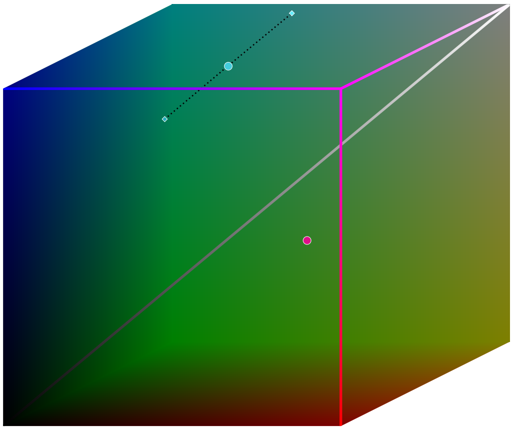


Figure 22.7: ETC2 ‘T’ mode

In this example, the first *base color* is defined as the triple of 4-bit *RGB* values (13, 1, 8), which is expanded by *extend4to8bits* to (221, 17, 136). This becomes *paint color 0*.

The second *base color* is encoded as the triple of 4-bit *RGB* values (4, 12, 13), which is expanded by *extend4to8bits* to (68, 204, 221).

Distance index 5 is used to select a distance value *d* of 32, which is added to and subtracted from the second base color, giving (100, 236, 253) as *paint color 1* and (36, 172, 189) as *paint color 3*. On this occasion, the channels of these *paint colors* are not modified by the process of clamping them to [0..255].

A ‘distance’ value is computed for the ‘H’ mode as well, but doing so is slightly more complex. In order to construct the three-bit index into the distance table shown in Table 22.4, d_a and d_b shown in section e of Table 22.1 are used as the most significant bit and middle bit, respectively, but the least significant bit is computed as (*base color 1* value $\geq$ *base color 2* value), the ‘value’ of a color for the comparison being equal to $(R \ll 16) + (G \ll 8) + B$. Once the ‘distance’ d has been determined for an ‘H’ block, the four *paint colors* will be:

$$\begin{aligned}
\textit{paint color 0} &= \textit{base color 1} + (d,d,d) \\
\textit{paint color 1} &= \textit{base color 1} - (d,d,d) \\
\textit{paint color 2} &= \textit{base color 2} + (d,d,d) \\
\textit{paint color 3} &= \textit{base color 2} - (d,d,d)
\end{aligned}$$

Again, all color components are clamped to within [0..255].

Note

Figure 22.8 shows an example 'H mode' ETC2 block. The two *base colors* are shown as circles, and *modifiers* are applied to each channel to give the 'paint colors' selectable by each *pixel index*, shown as small diamonds. Since the same *modifier* is applied to each channel, each *paint color* falls on a line through the *base color* from which it is derived (shown dashed) parallel to the grayscale (0, 0, 0) to (255, 255, 255) axis, unless the channels are modified by clamping to the range [0..255].

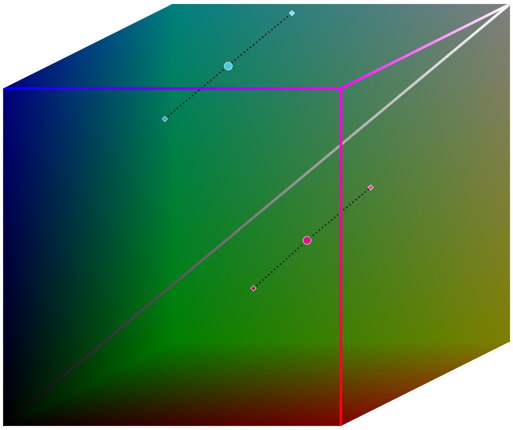


Figure 22.8: ETC2 'H' mode

In this example, the first *base color* is defined as the triple of 4-bit *RGB* values (13, 1, 8), as in the 'T mode' case above. This is expanded by *extend4to8bits* to (221, 17, 136).

The second *base color* is defined as the 4-bit triple (4, 12, 13), which expands to (68, 204, 221).

The block encodes a *distance index* of 5 (this means that *base color 1* must be greater than *base color 2*), corresponding to a distance *d* of 32. This leads to the following *paint colors*:

***Paint color* id**	***Base color***			**Distance**	***Paint color***		
	R	***G***	***B***	***d***	***R***	***G***	***B***
0	221	17	136	+32	253	49	168
1				-32	189	-15	104
2	68	204	221	+32	100	236	253
3				-32	36	172	189

The *G* channel of *paint color 1* is clamped to 0, giving (189, 0, 104). This stops *paint color* 1 being colinear with *paint color 0* and *base color 1*.

Finally, in both the 'T' and 'H' modes, every pixel is assigned one of the four *paint colors* in the same way the four *modifier* values are distributed in 'individual' or 'differential' blocks. For example, to choose a *paint color* for pixel *d*, an index is constructed using bit 19 as most significant bit and bit 3 as least significant bit. Then, if a pixel has index 2, for example, it will be assigned *paint color 2*.

The final mode possible in an RGB ETC2-compressed block is the 'planar' mode. Here, three *base colors* are supplied and used to form a color plane used to determine the color of the individual pixels in the block.

All three *base colors* are stored in *RGB*:676 format, and stored in the manner shown in section g of Table 22.1. The two secondary colors are given the suffix 'h' and 'v', so that the red component of the three colors are R, R_{h} and R_{v}, for example. Some color channels are split into non-consecutive bit-ranges; for example B is reconstructed using B^{5} as the most-significant bit, $B^{4..3}$ as the two following bits, and $B^{2..0}$ as the three least-significant bits.

Once the bits for the *base colors* have been extracted, they must be extended to 8 bits per channel in a manner analogous to the method used for the *base colors* in other modes. For example, the 6-bit blue and red channels are extended by replicating the two most significant of the six bits to the two least significant of the final 8 bits.

With three *base colors* in *RGB*:888 format, the color of each pixel can then be determined as:

$$\begin{aligned}
R(x,y) &= \frac{x\times(R_{\mathrm{h}}-R)}{4.0}+\frac{y\times(R_{\mathrm{v}}-R)}{4.0}+R\\
G(x,y) &= \frac{x\times(G_{\mathrm{h}}-G)}{4.0}+\frac{y\times(G_{\mathrm{v}}-G)}{4.0}+G\\
B(x,y) &= \frac{x\times(B_{\mathrm{h}}-B)}{4.0}+\frac{y\times(B_{\mathrm{v}}-B)}{4.0}+B
\end{aligned}$$

where x and y are values from 0 to 3 corresponding to the pixels coordinates within the block, x being in the u direction and y in the v direction. For example, the pixel g in Figure 22.2 would have $x = 1$ and $y = 2$.

These values are then rounded to the nearest integer (to the larger integer if there is a tie) and then clamped to a value between 0 and 255. Note that this is equivalent to

$$\begin{aligned}
R(x,y) &= \mathit{clamp255}((x\times(R_{\mathrm{h}}-R)+y\times(R_{\mathrm{v}}-R)+4\times R+2)\gg 2)\\
G(x,y) &= \mathit{clamp255}((x\times(G_{\mathrm{h}}-G)+y\times(G_{\mathrm{v}}-G)+4\times G+2)\gg 2)\\
B(x,y) &= \mathit{clamp255}((x\times(B_{\mathrm{h}}-B)+y\times(B_{\mathrm{v}}-B)+4\times B+2)\gg 2)
\end{aligned}$$

where $\mathit{clamp255}(\cdot)$ clamps the value to a number in the range [0..255] and where $\gg$ performs bit-wise right shift.

This specification gives the output for each compression mode in 8-bit integer colors between 0 and 255, and these values all need to be divided by 255 for the final floating point representation.

Note

Figure 22.9 shows an example ‘planar mode’ ETC2 block. The three *base colors* are shown as circles, and the interpolated values are shown as small diamonds.

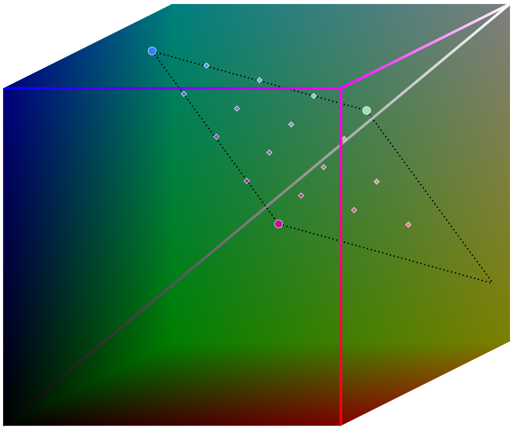


Figure 22.9: ETC2 ‘planar’ mode

In this example, the origin (*R*, *G*, *B*) is encoded as the 6-7-6-bit value (12, 64, 62), which is expanded to (48, 129, 251). The ‘horizontal’ (interpolated by *x*) *base color* (R_h, G_h, B_h) = (50, 5, 37) and ‘vertical’ (interpolated by *y*) *base color* (R_v, G_v, B_v) = (40, 112, 45) expand to (203, 10, 150) and (162, 225, 182) respectively.

The resulting texel colors are then:

x	***y***	***R***	***G***	***B***
0	0	48	129	251
1	0	87	99	226
2	0	126	70	201
3	0	164	40	175
0	1	77	153	234
1	1	115	123	209
2	1	154	94	183
3	1	193	64	158
0	2	105	177	217
1	2	144	147	191
2	2	183	118	166
3	2	221	88	141
0	3	134	201	199
1	3	172	171	174
2	3	211	142	149
3	3	250	112	124

22.2 Format RGB ETC2 with sRGB encoding

Decompression of floating point sRGB values in RGB ETC2 with sRGB encoding follows that of floating point *RGB* values of linear RGB ETC2. The result is sRGB-encoded values between 0.0 and 1.0. The further conversion from an sRGB encoded component *cs* to a linear component *cl* is done according to the formulae in Section 13.3. Assume *cs* is the sRGB component in the range [0, 1].

22.3 Format RGBA ETC2

Each 4×4 block of *RGBA*:8888 information is compressed to 128 bits. To decode a block, the two 64-bit integers $int64bit_{Alpha}$ and $int64bit_{Color}$ are calculated as described in Section 22.1. The *RGB* component is then decoded the same way as for RGB ETC2 (see Section 22.1), using $int64bit_{Color}$ as the *int64bit* codeword.

a) Bit layout in bits 63 through 48															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
base codeword								*multiplier*				*table index*			
b) Bit layout in bits 47 through 0, with pixels as name in Figure 22.2, bits labeled from 0 being the LSB to 47 being the MSB															
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
a_{α}^{2}	a_{α}^{1}	a_{α}^{0}	b_{α}^{2}	b_{α}^{1}	b_{α}^{0}	c_{α}^{2}	c_{α}^{1}	c_{α}^{0}	d_{α}^{2}	d_{α}^{1}	d_{α}^{0}	e_{α}^{2}	e_{α}^{1}	e_{α}^{0}	f_{α}^{2}
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
f_{α}^{1}	f_{α}^{0}	g_{α}^{2}	g_{α}^{1}	g_{α}^{0}	h_{α}^{2}	h_{α}^{1}	h_{α}^{0}	i_{α}^{2}	i_{α}^{1}	i_{α}^{0}	j_{α}^{2}	j_{α}^{1}	j_{α}^{0}	k_{α}^{2}	k_{α}^{1}
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
k_{α}^{0}	l_{α}^{2}	l_{α}^{1}	l_{α}^{0}	m_{α}^{2}	m_{α}^{1}	m_{α}^{0}	n_{α}^{2}	n_{α}^{1}	n_{α}^{0}	o_{α}^{2}	o_{α}^{1}	o_{α}^{0}	p_{α}^{2}	p_{α}^{1}	p_{α}^{0}

Table 22.5: Texel Data format for alpha part of RGBA ETC2 compressed textures

The 64-bits in $int64bit_{Alpha}$ used to decompress the alpha channel are laid out as shown in Table 22.5. The information is split into two parts. The first 16 bits comprise a *base codeword*, a *table codeword* and a *multiplier*, which are used together to compute 8 pixel values to be used in the block. The remaining 48 bits are divided into 16 3-bit indices, which are used to select one of these 8 possible values for each pixel in the block.

Note

The color pixel indices are stored in *a*..*p* order in increasing bit order in a big-endian word representation, with the low bit stored separately from the high bit. However, the alpha indices are stored in *p*..*a* order in increasing bit order in a big-endian word representation, with each bit of each alpha index stored consecutively.

The decoded value of a pixel is a value between 0 and 255 and is calculated the following way:

$$clamp255(base\ codeword + modifier \times multiplier)$$

Equation 22.1: ETC2 base

where $clamp255(\cdot)$ maps values outside the range [0..255] to 0.0 or 255.0.

The *base codeword* is stored in the first 8 bits (bits 63..56) as shown in Table 22.5 part (a). This is the first term in Equation 22.1.

Next, we want to obtain the *modifier*. Bits 51..48 in Table 22.5 part (a) form a 4-bit index used to select one of 16 pre-determined 'modifier tables', shown in Table 22.6.

Table index	**Modifier table**							
0	-3	-6	-9	-15	2	5	8	14
1	-3	-7	-10	-13	2	6	9	12
2	-2	-5	-8	-13	1	4	7	12
3	-2	-4	-6	-13	1	3	5	12
4	-3	-6	-8	-12	2	5	7	11
5	-3	-7	-9	-11	2	6	8	10
6	-4	-7	-8	-11	3	6	7	10
7	-3	-5	-8	-11	2	4	7	10
8	-2	-6	-8	-10	1	5	7	9
9	-2	-5	-8	-10	1	4	7	9
10	-2	-4	-8	-10	1	3	7	9
11	-2	-5	-7	-10	1	4	6	9
12	-3	-4	-7	-10	2	3	6	9
13	-1	-2	-3	-10	0	1	2	9
14	-4	-6	-8	-9	3	5	7	8
15	-3	-5	-7	-9	2	4	6	8

Table 22.6: Intensity modifier sets for RGBA ETC2 alpha component

For example, a *table index* of 13 (1101 binary) means that we should use table [-1, -2 -3, -10, 0, 1, 2, 9]. To select which of these values we should use, we consult the *pixel index* of the pixel we want to decode. As shown in Table 22.5 part (b), bits 47..0 are used to store a 3-bit index for each pixel in the block, selecting one of the 8 possible values. Assume we are interested in pixel *b*. Its pixel index is stored in bits 44..42, with the most significant bit stored in 44 and the least significant bit stored in 42. If the *pixel index* is 011 binary = 3, this means we should take the value 3 from the left in the table, which is -10. This is now our *modifier*, which is the starting point of our second term in the addition.

In the next step we obtain the *multiplier* value; bits 55..52 form a four-bit *multiplier* between 0 and 15. This value should be multiplied with the *modifier*. An encoder is not allowed to produce a *multiplier* of zero, but the decoder should still be able to handle this case (and produce 0 × *modifier* = 0 in that case).

The *modifier* times the *multiplier* now provides the third and final term in the sum in Equation 22.1. The sum is calculated and the value is clamped to the interval [0..255]. The resulting value is the 8-bit output value.

For example, assume a *base codeword* of 103, a *table index* of 13, a *pixel index* of 3 and a *multiplier* of 2. We will then start with the *base codeword* 103 (01100111 binary). Next, a *table index* of 13 selects table [-1, -2, -3, -10, 0, 1, 2, 9], and using a *pixel index* of 3 will result in a *modifier* of -10. The *multiplier* is 2, forming -10 × 2 = -20. We now add this to the base value and get 103 - 20 = 83. After clamping we still get 83 = 01010011 binary. This is our 8-bit output value.

This specification gives the output for each channel in 8-bit integer values between 0 and 255, and these values all need to be divided by 255 to obtain the final floating point representation.

Note that hardware can be effectively shared between the alpha decoding part of this format and that of R11 EAC texture. For details on how to reuse hardware, see Section 22.5.

22.4 Format RGBA ETC2 with sRGB encoding

Decompression of floating point sRGB values in RGBA ETC2 with sRGB encoding follows that of floating point *RGB* values of linear RGBA ETC2. The result is sRGB values between 0.0 and 1.0. The further conversion from an sRGB encoded component *cs* to a linear component *cl* is according to the formula in Section 13.3. Assume *cs* is the sRGB component in the range [0, 1].

The alpha component of RGBA ETC2 with sRGB encoding is done in the same way as for linear RGBA ETC2.

22.5 Format Unsigned R11 EAC

The number of bits to represent a 4×4 texel block is 64 bits. if format is R11 EAC. In that case the data for a block is stored as a number of bytes, $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7\}$, where byte q_0 is located at the lowest memory address and q_7 at the highest. The red component of the 4×4 block is then represented by the following 64-bit integer:

$$\mathit{int64bit} = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$

This 64-bit word contains information about a single-channel 4×4 pixel block as shown in Figure 22.2. The 64-bit word is split into two parts. The first 16 bits comprise a *base codeword*, a *table codeword* and a *multiplier*. The remaining 48 bits are divided into 16 3-bit indices, which are used to select one of the 8 possible values for each pixel in the block, as shown in Table 22.5.

The decoded value is calculated as:

$$\mathit{clamp1}\left((\mathit{base\ codeword} + 0.5) \times \frac{1}{255.875} + \mathit{modifier} \times \mathit{multiplier} \times \frac{1}{255.875}\right)$$

Equation 22.2: Unsigned R11 EAC start

where $\mathit{clamp1}(\cdot)$ maps values outside the range [0.0, 1.0] to 0.0 or 1.0.

We will now go into detail how the decoding is done. The result will be an 11-bit fixed point number where 0 represents 0.0 and 2047 represents 1.0. This is the exact representation for the decoded value. However, some implementations may use, e.g., 16-bits of accuracy for filtering. In such a case the 11-bit value will be extended to 16 bits in a predefined way, which we will describe later.

To get a value between 0 and 2047 we must multiply Equation 22.2 by 2047.0:

$$\mathit{clamp2}\left((\mathit{base\ codeword} + 0.5) \times \frac{2047.0}{255.875} + \mathit{modifier} \times \mathit{multiplier} \times \frac{2047.0}{255.875}\right)$$

where $\mathit{clamp2}(\cdot)$ clamps to the range [0.0, 2047.0].

Since $\frac{2047.0}{255.875}$ is exactly 8.0, the above equation can be written as

$$\mathit{clamp2}(\mathit{base\ codeword} \times 8 + 4 + \mathit{modifier} \times \mathit{multiplier} \times 8)$$

Equation 22.3: Unsigned R11 EAC simple

The *base codeword* is stored in the first 8 bits as shown in Table 22.5 part (a). Bits 63..56 in each block represent an eight-bit integer (*base codeword*) which is multiplied by 8 by shifting three steps to the left. We can add 4 to this value without addition logic by just inserting 100 binary in the last three bits after the shift. For example, if *base codeword* is 129 = 10000001 binary (or 10000001b for short), the shifted value is 10000001000b and the shifted value including the +4 term is 10000001100b = 1036 = 129×8+4. Hence we have summed together the first two terms of the sum in Equation 22.3.

Next, we want to obtain the *modifier*. Bits 51..48 form a 4-bit index used to select one of 16 pre-determined 'modifier tables', shown in Table 22.6. For example, a *table index* of 13 (1101 binary) means that we should use table [-1, -2, -3, -10, 0, 1, 2, 9]. To select which of these values we should use, we consult the *pixel index* of the pixel we want to decode. Bits 47..0 are used to store a 3-bit index for each pixel in the block, selecting one of the 8 possible values. Assume we are interested in pixel *b*. Its pixel indices are stored in bit 44..42, with the most significant bit stored in 44 and the least significant bit stored in 42. If the *pixel index* is 011 binary = 3, this means we should take the value 3 from the left in the table, which is -10. This is now our *modifier*, which is the starting point of our second term in the sum.

In the next step we obtain the *multiplier* value; bits 55..52 form a four-bit *multiplier* between 0 and 15. We will later treat what happens if the *multiplier* value is zero, but if it is nonzero, it should be multiplied with the *modifier*. This product should then be shifted three steps to the left to implement the ×8 multiplication. The result now provides the third and final term in the sum in Equation 22.3. The sum is calculated and the result is clamped to a value in the interval [0..2047]. The resulting value is the 11-bit output value.

For example, assume a *base codeword* of 103, a *table index* of 13, a *pixel index* of 3 and a *multiplier* of 2. We will then first multiply the *base codeword* 103 (01100111b) by 8 by left-shifting it (0110111000b) and then add 4 resulting in 0110111100b = 828 = 103 × 8 + 4. Next, a *table index* of 13 selects table [-1, -2, -3, -10, 0, 1, 2, 9], and using a *pixel index* of 3 will result in a *modifier* of -10. The *multiplier* is nonzero, which means that we should multiply it with the *modifier*, forming -10 × 2 = -20 = 111111101100b. This value should in turn be multiplied by 8 by left-shifting it three steps: 111101100000b = -160. We now add this to the base value and get 828 - 160 = 668. After clamping we still get 668 = 01010011100b. This is our 11-bit output value, which represents the value $\frac{668}{2047} = 0.32633121\ldots$

If the *multiplier* value is zero (i.e., the *multiplier* bits 55..52 are all zero), we should set the *multiplier* to $\frac{1.0}{8.0}$. Equation 22.3 can then be simplified to

$$\mathit{clamp2}(\mathit{base\ codeword} \times 8 + 4 + \mathit{modifier})$$

Equation 22.4: Unsigned R11 EAC simpler

As an example, assume a *base codeword* of 103, a *table index* of 13, a *pixel index* of 3 and a *multiplier* value of 0. We treat the *base codeword* the same way, getting 828 = 103×8+4. The *modifier* is still -10. But the *multiplier* should now be $\frac{1}{8}$, which means that third term becomes $-10 \times \left(\frac{1}{8}\right) \times 8 = -10$. The sum therefore becomes 828-10 = 818. After clamping we still get 818 = 01100110010b, and this is our 11-bit output value, and it represents $\frac{818}{2047} = 0.39960918\ldots$

Some OpenGL ES implementations may find it convenient to use 16-bit values for further processing. In this case, the 11-bit value should be extended using bit replication. An 11-bit value x is extended to 16 bits through $(x \ll 5) + (x \gg 6)$. For example, the value 668 = 01010011100b should be extended to 0101001110001010b = 21386.

In general, the implementation may extend the value to any number of bits that is convenient for further processing, e.g., 32 bits. In these cases, bit replication should be used. On the other hand, an implementation is not allowed to truncate the 11-bit value to less than 11 bits.

Note that the method does not have the same reconstruction levels as the alpha part in the RGBA ETC2 format. For instance, for a *base codeword* of 255 and a *table value* of 0, the alpha part of the RGBA ETC2 format will represent a value of $\frac{(255+0)}{255.0} = 1.0$ exactly. In R11 EAC the same *base codeword* and *table value* will instead represent $\frac{(255.5+0)}{255.875} = 0.99853444\ldots$ That said, it is still possible to decode the alpha part of the RGBA ETC2-format using R11 EAC hardware. This is done by truncating the 11-bit number to 8 bits. As an example, if *base codeword* = 255 and *table value* = 0, we get the 11-bit value (255×8+4+0) = 2044 = 11111111100b, which after truncation becomes the 8-bit value 11111111b = 255 which is exactly the correct value according to RGBA ETC2. Clamping has to be done to [0, 255] after truncation for RGBA ETC2 decoding. Care must also be taken to handle the case when the *multiplier* value is zero. In the 11-bit version, this means multiplying by $\frac{1}{8}$, but in the 8-bit version, it really means multiplication by 0. Thus, the decoder will have to know if it is an RGBA ETC2 texture or an R11 EAC texture to decode correctly, but the hardware can be 100% shared.

As stated above, a *base codeword* of 255 and a *table value* of 0 will represent a value of $\frac{(255.5+0)}{255.875} = 0.99853444\ldots$, and this does not reach 1.0 even though 255 is the highest possible *base codeword*. However, it is still possible to reach a pixel value of 1.0 since a *modifier* other than 0 can be used. Indeed, half of the *modifiers* will often produce a value of 1.0. As an example, assume we choose the *base codeword* 255, a *multiplier* of 1 and the modifier table [-3, -5, -7, -9, 2, 4, 6, 8]. Starting with Equation 22.3,

$$clamp1\left((base\ codeword + 0.5) \times \frac{1}{255.875} + table\ value \times multiplier \times \frac{1}{255.875}\right)$$

we get

$$clamp1\left((255+0.5) \times \frac{1}{255.875} + \begin{bmatrix} -3 & -5 & -7 & -9 & 2 & 4 & 6 & 8 \end{bmatrix} \times \frac{1}{255.875}\right)$$

which equals

$$clamp1\left(\begin{bmatrix} 0.987 & 0.979 & 0.971 & 0.963 & 1.00 & 1.01 & 1.02 & 1.03 \end{bmatrix}\right)$$

or after clamping

$$\begin{bmatrix} 0.987 & 0.979 & 0.971 & 0.963 & 1.00 & 1.00 & 1.00 & 1.00 \end{bmatrix}$$

which shows that several values can be 1.0, even though the base value does not reach 1.0. The same reasoning goes for 0.0.

22.6 Format Unsigned RG11 EAC

The number of bits to represent a 4×4 texel block is 128 bits if the format is RG11 EAC. In that case the data for a block is stored as a number of bytes, $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7, p_0, p_1, p_2, p_3, p_4, p_5, p_6, p_7\}$ where byte q_0 is located at the lowest memory address and p_7 at the highest. The 128 bits specifying the block are then represented by the following two 64 bit integers:

$$int64bit_0 = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$
$$int64bit_1 = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times p_0 + p_1) + p_2) + p_3) + p_4) + p_5) + p_6) + p_7$$

The 64-bit word $int64bit_0$ contains information about the red component of a two-channel 4×4 pixel block as shown in Figure 22.2, and the word $int64bit_1$ contains information about the green component. Both 64-bit integers are decoded in the same way as R11 EAC described in Section 22.5.

22.7 Format Signed R11 EAC

The number of bits to represent a 4×4 texel block is 64 bits if the format is signed R11 EAC. In that case the data for a block is stored as a number of bytes, $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7\}$, where byte q_0 is located at the lowest memory address and q_7 at the highest. The red component of the 4×4 block is then represented by the following 64 bit integer:

$$int64bit = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$

This 64-bit word contains information about a single-channel 4×4 pixel block as shown in Figure 22.2. The 64-bit word is split into two parts. The first 16 bits comprise a *base codeword*, a *table codeword* and a *multiplier*. The remaining 48 bits are divided into 16 3-bit indices, which are used to select one of the 8 possible values for each pixel in the block, as shown in Table 22.5.

The decoded value is calculated as

$$clamp1\left(base\ codeword \times \frac{1}{127.875} + modifier \times multiplier \times \frac{1}{127.875}\right)$$

Equation 22.5: Signed R11 EAC start

where *clamp1*$(\cdot)$ maps values outside the range [-1.0, 1.0] to -1.0 or 1.0. We will now go into detail how the decoding is done. The result will be an 11-bit two's-complement fixed point number where -1023 represents -1.0 and 1023 represents 1.0. This is the exact representation for the decoded value. However, some implementations may use, e.g., 16-bits of accuracy for filtering. In such a case the 11-bit value will be extended to 16 bits in a predefined way, which we will describe later.

To get a value between -1023 and 1023 we must multiply Equation 22.5 by 1023.0:

$$clamp2\left(base\ codeword \times \frac{1023.0}{127.875} + modifier \times multiplier \times \frac{1023.0}{127.875}\right)$$

where *clamp2*$(\cdot)$ clamps to the range [-1023.0, 1023.0]. Since $\frac{1023.0}{127.875}$ is exactly 8, the above formula can be written as:

$$clamp2(base\ codeword \times 8 + modifier \times multiplier \times 8)$$

Equation 22.6: Signed R11 EAC simple

The *base codeword* is stored in the first 8 bits as shown in Table 22.5 part (a). It is a two's-complement value in the range [-127, 127], and where the value -128 is not allowed; however, if it should occur anyway it must be treated as -127. The *base codeword* is then multiplied by 8 by shifting it left three steps. For example the value 65 = 01000001 binary (or 01000001b for short) is shifted to 01000001000b = 520 = 65×8.

Next, we want to obtain the *modifier*. Bits 51..48 form a 4-bit index used to select one of 16 pre-determined 'modifier tables', shown in Table 22.6. For example, a *table index* of 13 (1101 binary) means that we should use table [-1, -2, -3, -10, 0, 1, 2, 9]. To select which of these values we should use, we consult the *pixel index* of the pixel we want to decode. Bits 47..0 are used to store a 3-bit index for each pixel in the block, selecting one of the 8 possible values. Assume we are interested in pixel *b*. Its pixel indices are stored in bit 44..42, with the most significant bit stored in 44 and the least significant bit stored in 42. If the *pixel index* is 011 binary = 3, this means we should take the value 3 from the left in the table, which is -10. This is now our *modifier*, which is the starting point of our second term in the sum.

In the next step we obtain the *multiplier* value; bits 55..52 form a four-bit *multiplier* between 0 and 15. We will later treat what happens if the *multiplier* value is zero, but if it is nonzero, it should be multiplied with the *modifier*. This product should then be shifted three steps to the left to implement the ×8 multiplication. The result now provides the third and final term in the sum in Equation 22.6. The sum is calculated and the result is clamped to a value in the interval [-1023..1023]. The resulting value is the 11-bit output value.

For example, assume a a *base codeword* of 60, a *table index* of 13, a *pixel index* of 3 and a *multiplier* of 2. We start by multiplying the *base codeword* (00111100b) by 8 using bit shift, resulting in (00111100000b) = 480 = 60 × 8. Next, a *table index* of 13 selects table [-1, -2, -3, -10, 0, 1, 2, 9], and using a *pixel index* of 3 will result in a *modifier* of -10. The *multiplier* is nonzero, which means that we should multiply it with the *modifier*, forming -10×2 = -20 = 111111101100b. This value should in turn be multiplied by 8 by left-shifting it three steps: 111101100000b = -160. We now add this to the base value and get 480-160 = 320. After clamping we still get 320 = 00101000000b. This is our 11-bit output value, which represents the value $\frac{320}{1023} = 0.31280547\ldots$.

If the *multiplier* value is zero (i.e., the *multiplier* bits 55..52 are all zero), we should set the *multiplier* to $\frac{1.0}{8.0}$. Equation 22.6 can then be simplified to:

$$clamp2(base\ codeword \times 8 + modifier)$$

Equation 22.7: Signed R11 EAC simpler

As an example, assume a *base codeword* of 65, a *table index* of 13, a *pixel index* of 3 and a *multiplier* value of 0. We treat the *base codeword* the same way, getting 480 = 60×8. The *modifier* is still -10. But the *multiplier* should now be $\frac{1}{8}$, which means that third term becomes $-10 \times \left(\frac{1}{8}\right) \times 8 = -10$. The sum therefore becomes 480-10 = 470. Clamping does not affect the value since it is already in the range [-1023, 1023], and the 11-bit output value is therefore 470 = 00111010110b. This represents $\frac{470}{1023} = 0.45943304\ldots$

Some OpenGL ES implementations may find it convenient to use two's-complement 16-bit values for further processing. In this case, a positive 11-bit value should be extended using bit replication on all the bits except the sign bit. An 11-bit value x is extended to 16 bits through $(x \ll 5)$ + $(x \gg 5)$. Since the sign bit is zero for a positive value, no addition logic is needed for the bit replication in this case. For example, the value 470 = 00111010110b in the above example should be expanded to 0011101011001110b = 15054. A negative 11-bit value must first be made positive before bit replication, and then made negative again:

```
if (result11bit >= 0) {
  result16bit = (result11bit << 5) + (result11bit >> 5);
} else {
  result11bit = -result11bit;
  result16bit = (result11bit << 5) + (result11bit >> 5);
  result16bit = -result16bit;
}
```

Simply bit replicating a negative number without first making it positive will not give a correct result.

In general, the implementation may extend the value to any number of bits that is convenient for further processing, e.g., 32 bits. In these cases, bit replication according to the above should be used. On the other hand, an implementation is not allowed to truncate the 11-bit value to less than 11 bits.

Note that it is not possible to specify a base value of 1.0 or -1.0. The largest possible *base codeword* is +127, which represents $\frac{127}{127.875} = 0.993\ldots$. However, it is still possible to reach a pixel value of 1.0 or -1.0, since the base value is modified by the table before the pixel value is calculated. Indeed, half of the *modifiers* will often produce a value of 1.0. As an example, assume the *base codeword* is +127, the modifier table is [-3, -5, -7, -9, 2, 4, 6, 8] and the *multiplier* is one. Starting with Equation 22.5,

$$\textit{base codeword} \times \frac{1}{127.875} + \textit{modifier} \times \textit{multiplier} \times \frac{1}{127.875}$$

we get

$$\frac{127}{127.875} + \begin{bmatrix} -3 & -5 & -7 & -9 & 2 & 4 & 6 & 8 \end{bmatrix} \times \frac{1}{127.875}$$

which equals

$$\begin{bmatrix} 0.970 & 0.954 & 0.938 & 0.923 & 1.01 & 1.02 & 1.04 & 1.06 \end{bmatrix}$$

or after clamping

$$\begin{bmatrix} 0.970 & 0.954 & 0.938 & 0.923 & 1.00 & 1.00 & 1.00 & 1.00 \end{bmatrix}$$

This shows that it is indeed possible to arrive at the value 1.0. The same reasoning goes for -1.0.

Note also that Equation 22.6/Equation 22.7 are very similar to Equation 22.3/Equation 22.4 in the unsigned version EAC_R11. Apart from the +4, the clamping and the extension to bit sizes other than 11, the same decoding hardware can be shared between the two codecs.

22.8 Format Signed RG11 EAC

The number of bits to represent a 4×4 texel block is 128 bits if the format is signed RG11 EAC. In that case the data for a block is stored as a number of bytes, $\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7, p_0, p_1, p_2, p_3, p_4, p_5, p_6, p_7\}$ where byte q_0 is located at the lowest memory address and p_7 at the highest. The 128 bits specifying the block are then represented by the following two 64 bit integers:

$$\textit{int64bit}_0 = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times q_0 + q_1) + q_2) + q_3) + q_4) + q_5) + q_6) + q_7$$
$$\textit{int64bit}_1 = 256 \times (256 \times (256 \times (256 \times (256 \times (256 \times (256 \times p_0 + p_1) + p_2) + p_3) + p_4) + p_5) + p_6) + p_7$$

The 64-bit word $\textit{int64bit}_0$ contains information about the red component of a two-channel 4×4 pixel block as shown in Figure 22.2, and the word $\textit{int64bit}_1$ contains information about the green component. Both 64-bit integers are decoded in the same way as signed R11 EAC described in Section 22.7.

22.9 Format RGB ETC2 with punchthrough alpha

For RGB ETC2 with punchthrough alpha, each 64-bit word contains information about a four-channel 4×4 pixel block as shown in Figure 22.2.

The blocks are compressed using one of four different ‘modes’. Table 22.7 part (a) shows the bits used for determining the mode used in a given block.

a) Location of bits for mode selection																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
R					R_d			G					G_d			B					B_d			......						Op	.
b) Bit layout for bits 63 through 32 for ‘differential’ mode																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
R					R_d			G					G_d			B					B_d			table_1			table_2			Op	F_B
c) Bit layout for bits 63 through 32 for ‘T’ mode																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
...			$R^{3..2}$		.	$R^{1..0}$		G				B				R_2				G_2				B_2				d_a		Op	d_b
d) Bit layout for bits 63 through 32 for ‘H’ mode																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
.	R				$G^{3..1}$			...			G^0	B^3	.	$B^{2..0}$			R_2				G_2				B_2				d_a	Op	d_b
e) Bit layout for bits 31 through 0 for ‘differential’, ‘T’ and ‘H’ modes																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
p^1	o^1	n^1	m^1	l^1	k^1	j^1	i^1	h^1	g^1	f^1	e^1	d^1	c^1	b^1	a^1	p^0	o^0	n^0	m^0	l^0	k^0	j^0	i^0	h^0	g^0	f^0	e^0	d^0	c^0	b^0	a^0
f) Bit layout for bits 63 through 0 for ‘planar’ mode																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
.	R						G^6	.	$G^{5..0}$						B^5	...			$B^{4..3}$		.	$B^{2..0}$			${R_\text{h}}^{5..1}$					1	${R_\text{h}}^0$
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
G_h							B_h						R_v						G_v							B_v					

Table 22.7: Texel Data format for punchthrough alpha ETC2 compressed texture formats

To determine the mode, the three 5-bit values R, G and B, and the three 3-bit values R_d, G_d and B_d are examined. R, G and B are treated as integers between 0 and 31 and R_d, G_d and B_d as two’s-complement integers between -4 and +3. First, R and R_d are added, and if the sum is not within the interval [0..31], the ‘T’ mode is selected. Otherwise, if the sum of G and G_d is outside the interval [0..31], the ‘H’ mode is selected. Otherwise, if the sum of B and B_d is outside of the interval [0..31], the ‘planar’ mode is selected. Finally, if all of the aforementioned sums lie between 0 and 31, the ‘differential’ mode is selected.

The layout of the bits used to decode the ‘differential’ mode is shown in Table 22.7 part (b). In this mode, the 4×4 block is split into two subblocks of either size 2×4 or 4×2. This is controlled by bit 32, which we dub the *flip bit* (F_B in Table 22.7 (b) and (c)). If the *flip bit* is 0, the block is divided into two 2×4 subblocks side-by-side, as shown in Figure 22.3. If the *flip bit* is 1, the block is divided into two 4×2 subblocks on top of each other, as shown in Figure 22.4. For each subblock, a *base color* is stored.

In the ‘differential’ mode, following the layout shown in Table 22.7 part (b), the *base color* for subblock 1 is derived from the five-bit codewords R, G and B. These five-bit codewords are extended to eight bits by replicating the top three highest-order bits to the three lowest-order bits. For instance, if R = 28 = 11100 binary (11100b for short), the resulting eight-bit red color component becomes 11100111b = 231. Likewise, if G = 4 = 00100b and B = 3 = 00011b, the green and blue components become 00100001b = 33 and 00011000b = 24 respectively. Thus, in this example, the *base color* for subblock 1 is (231, 33, 24). The five bit representation for the *base color* of subblock 2 is obtained by modifying the 5-bit codewords R, G and B by the codewords R_d, G_d and B_d. Each of R_d, G_d and B_d is a 3-bit two’s-complement number that can hold values between -4 and +3. For instance, if R = 28 as above, and R_d = 100b = -4, then the five bit representation for the red color component is 28+(-4)=24 = 11000b, which is then extended to eight bits to 11000110b = 198. Likewise, if $G = 4$, $G_\mathrm{d} = 2$, $B = 3$ and $B_\mathrm{d} = 0$, the *base color* of subblock 2 will be *RGB* = (198, 49, 24). In summary, the *base colors* for the subblocks in the differential mode are:

$$\begin{aligned} base\ color_{subblock1} &= extend5to8bits(R, G, B) \\ base\ color_{subblock2} &= extend5to8bits(R + R_\mathrm{d}, G + G_\mathrm{d}, B + B_\mathrm{d}) \end{aligned}$$

Note that these additions will not under- or overflow, or one of the alternative decompression modes would have been chosen instead of the ‘differential’ mode.

Table codeword	**Modifier table**			
0	-8	-2	2	8
1	-17	-5	5	17
2	-29	-9	9	29
3	-42	-13	13	42
4	-60	-18	18	60
5	-80	-24	24	80
6	-106	-33	33	106
7	-183	-47	47	183

Table 22.8: ETC2 intensity modifier sets for the ‘differential’ if ‘opaque’ (*Op*) is set

Table codeword	**Modifier table**			
0	-8	0	0	8
1	-17	0	0	17
2	-29	0	0	29
3	-42	0	0	42
4	-60	0	0	60
5	-80	0	0	80
6	-106	0	0	106
7	-183	0	0	183

Table 22.9: ETC2 intensity modifier sets for the ‘differential’ if ‘opaque’ (*Op*) is unset

After obtaining the *base color*, a table is chosen using the *table codewords*: For subblock 1, *table codeword 1* is used (bits 39..37), and for subblock 2, *table codeword 2* is used (bits 36..34), see Table 22.7 part (b). The *table codeword* is used to select one of eight modifier tables. If the ‘opaque’-bit (bit 33) is set, Table 22.8 is used. If it is unset, Table 22.9 is used. For instance, if the ‘opaque’-bit is 1 and the *table codeword* is 010 binary = 2, then the modifier table [-29, -9, 9, 29] is selected for the corresponding sub-block. Note that the values in Table 22.8 and Table 22.9 are valid for all textures and can therefore be hardcoded into the decompression unit.

Next, we identify which *modifier* value to use from the modifier table using the two *pixel index* bits. The *pixel index* bits are unique for each pixel. For instance, the *pixel index* for pixel *d* (see Figure 22.2) can be found in bits 19 (most significant bit, MSB), and 3 (least significant bit, LSB), see Table 22.7 part (e). Note that the *pixel index* for a particular texel is always stored in the same bit position, irrespectively of the *flip bit*.

If the ‘opaque’-bit (bit 33) is set, the *pixel index* bits are decoded using Table 22.10. If the ‘opaque’-bit is unset, Table 22.11 will be used instead. If, for instance, the ‘opaque’-bit is 1, and the *pixel index* bits are 01 binary = 1, and the modifier table [-29, -9, 9, 29] is used, then the *modifier* value selected for that pixel is 29 (see Table 22.10). This *modifier* value is now used to additively modify the *base color*. For example, if we have the *base color* (231, 8, 16), we should add the *modifier* value 29 to all three components: (231+29, 8+29, 16+29) resulting in (260, 37, 45). These values are then clamped to [0..255], resulting in the color (255, 37, 45).

***Pixel index* value**		**Resulting *modifier* value**
msb	**lsb**	
1	1	-b (large negative value)
1	0	-a (small negative value)
0	0	+a (small positive value)
0	1	+b (large positive value)

Table 22.10: ETC2 mapping from pixel index values to modifier values when ‘opaque’ bit is set

***Pixel index* value**		**Resulting *modifier* value**
msb	**lsb**	
1	1	-b (large negative value)
1	0	0 (zero)
0	0	0 (zero)
0	1	+b (large positive value)

Table 22.11: ETC2 mapping from pixel index values to modifier values when ‘opaque’ bit is unset

The alpha component is decoded using the ‘opaque’-bit, which is positioned in bit 33 (see Table 22.7 part (b)). If the ‘opaque’-bit is set, alpha is always 255. However, if the ‘opaque’-bit is zero, the alpha-value depends on the pixel indices; if MSB==1 and LSB==0, the alpha value will be zero, otherwise it will be 255. Finally, if the alpha value equals 0, the red, green and blue components will also be zero.

```
if (opaque == 0 && MSB == 1 && LSB == 0) {
  red = 0;
  green = 0;
  blue = 0;
  alpha = 0;
} else {
  alpha = 255;
}
```

Hence *paint color 2* will equal *RGBA* = (0, 0, 0, 0) if opaque = 0.

In the example above, assume that the ‘opaque’-bit was instead 0. Then, since the MSB = 0 and LSB 1, alpha will be 255, and the final decoded *RGBA*-tuple will be (255, 37, 45, 255).

The ‘T’ and ‘H’ compression modes share some characteristics: both use two *base colors* stored using 4 bits per channel. These bits are not stored sequentially, but in the layout shown in Table 22.7 part (c) and Table 22.7 part (d). To clarify, in the ‘T’ mode, the two colors are constructed as follows:

$$\begin{aligned}\textit{base color 1} &= \textit{extend4to8bits}(\,(R^{3..2} \ll 2)\,|\,R^{1..0},\, G,\, B)\\ \textit{base color 2} &= \textit{extend4to8bits}(R_2,\, G_2,\, B_2)\end{aligned}$$

In the ‘H’ mode, the two colors are constructed as follows:

$$\begin{aligned}\textit{base color 1} &= \textit{extend4to8bits}(R,\, (G^{3..1} \ll 1)\,|\,G^{0},\, (B^{3} \ll 3)\,|\,B^{2..0})\\ \textit{base color 2} &= \textit{extend4to8bits}(R_2,\, G_2,\, B_2)\end{aligned}$$

The function *extend4to8bits*(·) just replicates the four bits twice. This is equivalent to multiplying by 17. As an example, *extend4to8bits*(1101b) equals 11011101b = 221.

Both the ‘T’ and ‘H’ modes have four *paint colors* which are the colors that will be used in the decompressed block, but they are assigned in a different manner. In the ‘T’ mode, *paint color 0* is simply the first *base color*, and *paint color 2* is the second *base color*. To obtain the other *paint colors*, a ‘distance’ is first determined, which will be used to modify the luminance of one of the *base colors*. This is done by combining the values d_a and d_b shown in Table 22.7 part (c) by $(d_a \ll 1) \mid d_b$, and then using this value as an index into the small look-up table shown in Table 22.4. For example, if d_a is 10 binary and d_b is 1 binary, the index is 101 binary and the selected distance d will be 32. *Paint color 1* is then equal to the second *base color* with the ‘distance’ d added to each channel, and *paint color 3* is the second *base color* with the ‘distance’ d subtracted. In summary, to determine the four *paint colors* for a ‘T’ block:

$$\begin{aligned}
\textit{paint color 0} &= \textit{base color 1}\\
\textit{paint color 1} &= \textit{base color 2} + (d,d,d)\\
\textit{paint color 2} &= \textit{base color 2}\\
\textit{paint color 3} &= \textit{base color 2} - (d,d,d)
\end{aligned}$$

In both cases, the value of each channel is clamped to within [0..255].

Just as for the differential mode, the *RGB* channels are set to zero if alpha is zero, and the alpha component is calculated the same way:

```
if (opaque == 0 && MSB == 1 && LSB == 0) {
  red = 0;
  green = 0;
  blue = 0;
  alpha = 0;
} else {
  alpha = 255;
}
```

A ‘distance’ value is computed for the ‘H’ mode as well, but doing so is slightly more complex. In order to construct the three-bit index into the distance table shown in Table 22.4, d_a and d_b shown in Table 22.7 part (d) are used as the most significant bit and middle bit, respectively, but the least significant bit is computed as (*base color 1* value $\geq$ *base color 2* value), the ‘value’ of a color for the comparison being equal to $(R \ll 16) + (G \ll 8) + B$. Once the ‘distance’ d has been determined for an ‘H’ block, the four *paint colors* will be:

$$\begin{aligned}
\textit{paint color 0} &= \textit{base color 1} + (d,d,d)\\
\textit{paint color 1} &= \textit{base color 1} - (d,d,d)\\
\textit{paint color 2} &= \textit{base color 2} + (d,d,d)\\
\textit{paint color 3} &= \textit{base color 2} - (d,d,d)
\end{aligned}$$

Yet again, *RGB* is zeroed if alpha is 0 and the alpha component is determined the same way:

```
if (opaque == 0 && MSB == 1 && LSB == 0) {
  red = 0;
  green = 0;
  blue = 0;
  alpha = 0;
} else {
  alpha = 255;
}
```

Hence *paint color 2* will have $R = G = B =$ alpha = 0 if opaque = 0.

Again, all color components are clamped to within [0..255]. Finally, in both the ‘T’ and ‘H’ modes, every pixel is assigned one of the four *paint colors* in the same way the four *modifier* values are distributed in ‘individual’ or ‘differential’ blocks. For example, to choose a *paint color* for pixel d, an index is constructed using bit 19 as most significant bit and bit 3 as least significant bit. Then, if a pixel has index 2, for example, it will be assigned *paint color 2*.

The final mode possible in an RGB ETC2 with punchthrough alpha — compressed block is the ‘planar’ mode. In this mode, the ‘opaque’-bit must be 1 (a valid encoder should not produce an ‘opaque’-bit equal to 0 in the planar mode), but should the ‘opaque’-bit anyway be 0 the decoder should treat it as if it were 1. In the ‘planar’ mode, three *base colors* are supplied and used to form a color plane used to determine the color of the individual pixels in the block.

All three *base colors* are stored in *RGB*:676 format, and stored in the manner shown in Table 22.7 part (f). The two secondary colors are given the suffix ‘h’ and ‘v’, so that the red component of the three colors are R, R_h and R_v, for example. Some color channels are split into non-consecutive bit-ranges; for example B is reconstructed using B^5 as the most-significant bit, $B^{4..3}$ as the two following bits, and $B^{2..0}$ as the three least-significant bits.

Once the bits for the *base colors* have been extracted, they must be extended to 8 bits per channel in a manner analogous to the method used for the *base colors* in other modes. For example, the 6-bit blue and red channels are extended by replicating the two most significant of the six bits to the two least significant of the final 8 bits.

With three *base colors* in *RGB*:888 format, the color of each pixel can then be determined as:

$$\begin{aligned}
R(x,y) &= \frac{x\times(R_\mathrm{h}-R)}{4.0} + \frac{y\times(R_\mathrm{v}-R)}{4.0} + R\\
G(x,y) &= \frac{x\times(G_\mathrm{h}-G)}{4.0} + \frac{y\times(G_\mathrm{v}-G)}{4.0} + G\\
B(x,y) &= \frac{x\times(B_\mathrm{h}-B)}{4.0} + \frac{y\times(B_\mathrm{v}-B)}{4.0} + B\\
A(x,y) &= 255
\end{aligned}$$

where x and y are values from 0 to 3 corresponding to the pixels coordinates within the block, x being in the u direction and y in the v direction. For example, the pixel g in Figure 22.2 would have $x = 1$ and $y = 2$.

These values are then rounded to the nearest integer (to the larger integer if there is a tie) and then clamped to a value between 0 and 255. Note that this is equivalent to

$$\begin{aligned}
R(x,y) &= \mathit{clamp255}((x\times(R_\mathrm{h}-R)+y\times(R_\mathrm{v}-R)+4\times R+2)\gg 2)\\
G(x,y) &= \mathit{clamp255}((x\times(G_\mathrm{h}-G)+y\times(G_\mathrm{v}-G)+4\times G+2)\gg 2)\\
B(x,y) &= \mathit{clamp255}((x\times(B_\mathrm{h}-B)+y\times(B_\mathrm{v}-B)+4\times B+2)\gg 2)\\
A(x,y) &= 255
\end{aligned}$$

where $\mathit{clamp255}(\cdot)$ clamps the value to a number in the range [0..255].

Note that the alpha component is always 255 in the planar mode.

This specification gives the output for each compression mode in 8-bit integer colors between 0 and 255, and these values all need to be divided by 255 for the final floating point representation.

22.10 Format RGB ETC2 with punchthrough alpha and sRGB encoding

Decompression of floating point sRGB values in RGB ETC2 with sRGB encoding and punchthrough alpha follows that of floating point *RGB* values of RGB ETC2 with punchthrough alpha. The result is sRGB values between 0.0 and 1.0. The further conversion from an sRGB encoded component, *cs*, to a linear component, *cl*, is according to the formula in Section 13.3. Assume *cs* is the sRGB component in the range [0, 1]. Note that the alpha component is not gamma corrected, and hence does not use this formula.

Chapter 23

ASTC Compressed Texture Image Formats

This description is derived from the Khronos OES_texture_compression_astc OpenGL extension.

23.1 What is ASTC?

ASTC stands for Adaptive Scalable Texture Compression. The ASTC formats form a family of related compressed texture image formats. They are all derived from a common set of definitions.

ASTC textures may be either 2D or 3D.

ASTC textures may be encoded using either high or low dynamic range. Low dynamic range images may optionally be specified using the sRGB transfer function for the *RGB* channels.

Two sub-profiles (“LDR Profile” and “HDR Profile”) may be implemented, which support only 2D images at low or high dynamic range respectively.

ASTC textures may be encoded as 1, 2, 3 or 4 components, but they are all decoded into *RGBA*. ASTC has a variable block size.

23.2 Design Goals

The design goals for the format are as follows:

- Random access. This is a must for any texture compression format.
- Bit-exact decode. This is a must for conformance testing and reproducibility.
- Suitable for mobile use. The format should be suitable for both desktop and mobile GPU environments. It should be low bandwidth and low in area.
- Flexible choice of bit rate. Current formats only offer a few bit rates, leaving content developers with only coarse control over the size/quality trade-off.
- Scalable and long-lived. The format should support existing *R*, *RG*, *RGB* and *RGBA* image types, and also have high “headroom”, allowing continuing use for several years and the ability to innovate in encoders. Part of this is the choice to include HDR and 3D.
- Feature orthogonality. The choices for the various features of the format are all orthogonal to each other. This has three effects: first, it allows a large, flexible configuration space; second, it makes that space easier to understand; and third, it makes verification easier.
- Best in class at given bit rate. It should beat or match the current best in class for peak signal-to-noise ratio (PSNR) at all bit rates.
- Fast decode. Texel throughput for a cached texture should be one texel decode per clock cycle per decoder. Parallel decoding of several texels from the same block should be possible at incremental cost.
- Low bandwidth. The encoding scheme should ensure that memory access is kept to a minimum, cache reuse is high and memory bandwidth for the format is low.
- Low area. It must occupy comparable die size to competing formats.

Note

There are a number of implementations in the wild which have small inaccuracies in the decoded result. Future hardware should be bit-exact, so software should rely on the behavior documented in this specification.

23.3 Basic Concepts

ASTC is a block-based lossy compression format. The compressed image is divided into a number of blocks of uniform size, which makes it possible to quickly determine which block a given texel resides in.

Each block has a fixed memory footprint of 128 bits, but these bits can represent varying numbers of texels (the block “footprint”).

Note
The term “block footprint” in ASTC refers to the same concept as “compressed texel block dimensions” elsewhere in the Data Format Specification.

Block footprint sizes are not confined to powers-of-two, and are also not confined to be square. They may be 2D, in which case the block dimensions range from 4 to 12 texels, or 3D, in which case the block dimensions range from 3 to 6 texels.

Decoding one texel requires only the data from a single block. This simplifies cache design, reduces bandwidth and improves encoder throughput.

Note
ASTC has multiple types of “mode”, which should not be conflated:

- ASTC has three *operation modes*: sRGB (which is inherently LDR), linear LDR and HDR. These operation modes apply to the entire texture, and are configured by the user or implementation. LDR profile indicates that HDR operation mode is unavailable; otherwise implementations may treat linear LDR operation mode as HDR operation mode if not restricted by other configuration.
- ASTC has three *decode modes*: `decode_float16`, `decode_unorm8` and `decode_rgb9e5`. These decode modes indicate how texels are processed during the decoding operation, and, when available, are configured by the user for the entire texture. Implementations must provide at least the `decode_float16` decode mode.
- ASTC texel blocks have different *block modes*: these allow different combinations of endpoints and other configuration data on a per-block basis.
- ASTC texel blocks have multiple *endpoint modes*: these represent different ways to encode the interpolation endpoints in a texel block. Some *endpoint modes* support HDR values and are collectively known as *HDR endpoint modes*, and others are restricted to the LDR range and are collectively known as *LDR endpoint modes*. *HDR endpoint modes* are decoded as the error color except in *HDR operation mode*.
- Some *HDR endpoint modes* have further configuration *mode bits*.
- An ASTC texel block may optionally operate in *dual-plane mode*, which allows different weights for different endpoint components.

23.4 Block Encoding

To understand how the blocks are stored and decoded, it is useful to start with a simple example, and then introduce additional features.

The simplest block encoding starts by defining two color “endpoints”. The endpoints define two colors, and a number of additional colors are generated by interpolating between them. We can define these colors using 1, 2, 3, or 4 components (usually corresponding to *R*, *RG*, *RGB* and *RGBA* textures), and using low or high dynamic range.

We then store a color interpolant weight for each texel in the image, which specifies how to calculate the color to use. From this, a weighted average of the two endpoint colors is used to generate the intermediate color, which is the returned color for this texel.

There are several different ways of specifying the endpoint colors, and the weights, but once they have been defined, calculation of the texel colors proceeds identically for all of them. Each block is free to choose whichever encoding scheme best represents its color endpoints, within the constraint that all the data fits within the 128 bit block.

For blocks which have a large number of texels (e.g. a 12×12 block), there is not enough space to explicitly store a weight for every texel. In this case, a sparser grid with fewer weights is stored, and interpolation is used to determine the effective weight to be used for each texel position. This allows very low bit rates to be used with acceptable quality. This can also be used to more efficiently encode blocks with low detail, or with strong vertical or horizontal features.

For blocks which have a mixture of disparate colors, a single line in the color space is not a good fit to the colors of the pixels in the original image. It is therefore possible to partition the texels into multiple sets, the pixels within each set having similar colors. For each of these “partitions”, we specify separate endpoint pairs, and choose which pair of endpoints to use for a particular texel by looking up the *partition index* from a partitioning pattern table. In ASTC, this partition table is actually implemented as a function.

The endpoint encoding for each partition is independent.

For blocks which have uncorrelated channels — for example an image with a transparency mask, or an image used as a normal map — it may be necessary to specify two weights for each texel. Interpolation between the components of the endpoint colors can then proceed independently for each “plane” of the image. The assignment of channels to planes is selectable.

Since each of the above options is independent, it is possible to specify any combination of channels, endpoint color encoding, weight encoding, interpolation, multiple partitions and single or dual planes.

Since these values are specified per block, it is important that they are represented with the minimum possible number of bits. As a result, these values are packed together in ways which can be difficult to read, but which are nevertheless highly amenable to hardware decode.

All of the values used as weights and color endpoint values can be specified with a variable number of bits. The encoding scheme used allows a fine-grained trade-off between weight bits and color endpoint bits using “integer sequence encoding”. This can pack adjacent values together, allowing us to use fractional numbers of bits per value.

Finally, a block may be just a single color. This is a so-called “void extent block” and has a special coding which also allows it to identify nearby regions of single color. This may be used to short-circuit fetching of what would be identical blocks, and further reduce memory bandwidth.

23.5 sRGB, Linear LDR and HDR Operation Modes

The decoding process can be simplified if it is known in advance that sRGB output or HDR support is required. This selection is therefore included as part of the global configuration. Implementations must support at least sRGB operation mode, and either or both of linear LDR and HDR operation mode as described in Section 23.24 and Section 23.25; linear LDR operation mode is non-optional unless an implementation supports HDR operation mode and no interface is provided to select between Linear LDR and HDR operation modes. Decoders may not support decode modes other than `decode_float16`, and may substitute HDR operation mode for a requested linear LDR operation mode if not constrained by `decode_unorm8` support.

The operation modes differ in various ways, as shown in Table 23.1.

	sRGB operation mode	**Linear LDR operation mode**	**HDR operation mode**
Endpoint decoding precision	8 bits	16 bits	16 bits
HDR endpoint mode results	Error color	Error color	As decoded

Table 23.1: ASTC differences between sRGB, linear LDR and HDR operation modes

Except in sRGB mode, the type of the values returned by the decoding process for different operation modes is determined by the decode mode as shown in Table 23.2.

Decode mode	**Linear LDR operation mode**	**HDR operation mode**
`decode_float16`	Vector of FP16 values	
`decode_unorm8`	Vector of 8-bit unsigned normalized values	Invalid
`decode_rgb9e5`	Vector using a shared exponent format	

Table 23.2: ASTC decode modes

`decode_float16` returns a value encoded as 16-bit floating point.

`decode_unorm8` returns a value encoded as an unsigned, normalized 8-bit value — that is, the encoded value in the range 0..1.0 is the `unorm` integer value divided by 255.

`decode_rgb9e5` returns an RGB result encoded as a 32-bit value which contains three channel mantissae with a shared exponent, as provided as an example in Section 5.20.4 (and, were it written to memory, described by the example descriptor block Table 11.11).

For sRGB operation mode, the decode mode is ignored, and the decoding always returns a vector of 8-bit unsigned normalized values. To treat the result as linear-light results, the decoded values for R', G' and B' (in the range 0..1) are then converted with the sRGB EOTF.

Using the `decode_unorm8` decoding mode in HDR operation mode gives undefined results.

Note

Some implementations do not provide an explicit way to distinguish linear LDR operation mode from HDR operation mode, and automatically select HDR behavior in `decode_float16` or `decode_rgb9e5` decode modes. Such implementations may still support `decode_unorm8` by implicitly selecting linear LDR operation mode when this decode mode is chosen.

The error color for each operation mode is determined as shown in Table 23.3.

The magenta error color is opaque fully-saturated magenta $(R,G,B,A) = (1.0, 0.0, 1.0, 1.0)$. This has been chosen as it is much more noticeable than black or white, and occurs far less often in valid images.

The *NaNs* error color is a vector of four *NaNs* $(R,G,B,A) = (NaN, NaN, NaN, NaN)$. In this case, the recommended *NaN* value returned is the bit pattern 0xFFFF.

The error color is returned as an informative response to invalid conditions, including invalid block encodings or use of reserved *endpoint modes*. Future, forward-compatible extensions to ASTC may define valid interpretations of these conditions, which will decode to some other color. Therefore, encoders and applications must not rely on invalid encodings as a way of generating the error color.

Decode mode	sRGB operation mode	Linear LDR operation mode	HDR operation mode
`decode_float16`	Magenta	Magenta or *NaNs*	Magenta or *NaNs*
`decode_unorm8`	Magenta	Magenta	Invalid
`decode_rgb9e5`	Magenta	Magenta	Magenta

Table 23.3: ASTC error colors

23.6 Configuration Summary

The global configuration data for the format are as follows:

- Block dimension (2D or 3D)
- Block footprint size
- sRGB, linear LDR or HDR operation mode*
- Decode mode

(*Subject to an implementation implicitly promoting linear LDR operation mode to HDR operation mode.)

The data specified per block are as follows:

- Texel weight grid size
- Texel weight range
- Texel weight values
- Number of partitions
- Partition pattern index
- Color *endpoint modes* (includes LDR or HDR selection)
- Color endpoint data
- Number of planes
- Plane-to-channel assignment

23.7 Decode Procedure

To decode one texel:

```
(Optimization: If within known void-extent, immediately return single color)

Find block containing texel
Read block mode
If void-extent block, store void extent and immediately return single color

For each plane in image
  If block mode requires infill
    Find and decode stored weights adjacent to texel, unquantize and interpolate
  Else
    Find and decode weight for texel, and unquantize

Read number of partitions
If number of partitions > 1
  Read partition table pattern index
  Look up partition number from pattern

Read color endpoint mode and endpoint data for selected partition
Unquantize color endpoints
Interpolate color endpoints using weight (or weights in dual-plane mode)
Return interpolated color
```

23.8 Block Determination and Bit Rates

The block footprint is a global setting for any given texture, and is therefore not encoded in the individual blocks.

For 2D textures, the block footprint's width and height are selectable from a number of predefined sizes, namely 4, 5, 6, 8, 10 and 12 pixels.

For square and nearly-square blocks, this gives the bit rates in Table 23.4.

Footprint		Bit Rate	Increment
Width	Height		
4	4	8.00	125%
5	4	6.40	125%
5	5	5.12	120%
6	5	4.27	120%
6	6	3.56	114%
8	5	3.20	120%
8	6	2.67	105%
10	5	2.56	120%
10	6	2.13	107%
8	8	2.00	125%
10	8	1.60	125%
10	10	1.28	120%
12	10	1.07	120%
12	12	0.89	

Table 23.4: ASTC 2D footprint and bit rates

The "Increment" column indicates the ratio of bit rate against the next lower available rate. A consistent value in this column indicates an even spread of bit rates.

For 3D textures, the block footprint's width, height and depth are selectable from a number of predefined sizes, namely 3, 4, 5, and 6 pixels.

For cubic and near-cubic blocks, this gives the bit rates in Table 23.5.

Block Footprint			Bit Rate	Increment
Width	Height	Depth		
3	3	3	4.74	133%
4	3	3	3.56	133%
4	4	3	2.67	133%
4	4	4	2.00	125%
5	4	4	1.60	125%
5	5	4	1.28	125%
5	5	5	1.02	120%
6	5	5	0.85	120%
6	6	5	0.71	120%
6	6	6	0.59	

Table 23.5: ASTC 3D footprint and bit rates

The full profile supports only those block footprints listed in Table 23.4 and Table 23.5. Other block sizes are not supported.

For images which are not an integer multiple of the block size, additional texels are added to the edges with maximum X and Y (and Z for 3D textures). These texels may be any color, as they will not be accessed.

Although these are not all powers of two, it is possible to calculate block addresses and pixel addresses within the block, for legal image sizes, without undue complexity.

Given an image which is $W \times H \times D$ pixels in size, with block size $w \times h \times d$, the size of the image in blocks is:

$$\mathrm{B_w} = \left\lceil \frac{W}{w} \right\rceil$$

$$\mathrm{B_h} = \left\lceil \frac{H}{h} \right\rceil$$

$$\mathrm{B_d} = \left\lceil \frac{D}{d} \right\rceil$$

For a 3D image built from 2D slices, each 2D slice is a single texel thick, so that for an image which is $W \times H \times D$ pixels in size, with block size $w \times h$, the size of the image in blocks is:

$$\mathrm{B_w} = \left\lceil \frac{W}{w} \right\rceil$$

$$\mathrm{B_h} = \left\lceil \frac{H}{h} \right\rceil$$

$$\mathrm{B_d} = D$$

23.9 Block Layout

Each block in the image is stored as a single 128-bit block in memory. These blocks are laid out in raster order, starting with the block at (0, 0, 0), then ordered sequentially by X, Y and finally Z (if present). They are aligned to 128-bit boundaries in memory.

The bits in the block are labeled in little-endian order — the byte at the lowest address contains bits 0..7. Bit 0 is the least significant bit in the byte.

Each block has the same basic layout, shown in Table 23.6.

127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112
Texel weight data (variable width)												Fill direction →			
111	110	109	108	107	106	105	104	103	102	101	100	99	98	97	96
Texel weight data															
95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80
Texel weight data															
79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64
Texel weight data															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
					More config data										
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
← Fill direction								Color endpoint data							
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
				Extra configuration data											
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Extra			*Part*		*Block mode*										

Table 23.6: ASTC block layout

Since the size of the “texel weight data” field is variable, the positions shown for the “more config data” field and “color endpoint data” field are only representative and not fixed.

The *block mode* field specifies how the Texel Weight Data is encoded.

The *part* field specifies the number of partitions, minus one. If dual-plane mode is enabled, the number of partitions must be 3 or fewer. If 4 partitions are specified, the error color is returned for all texels in the block.

The size and layout of the extra configuration data depends on the number of partitions, and the number of planes in the image, as shown in Table 23.7 and Table 23.8 (only the bottom 32 bits are shown), or whether the texel block is a void-extent block, as described in Section 23.22.

23.9.1 ASTC Single-Partition Encoding

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Color endpoint data															*CEM*
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CEM			0	0	*Block mode*										

Table 23.7: ASTC single-partition block layout

CEM is the *color endpoint mode* field, which determines how the color endpoint data is encoded.

If dual-plane mode is active, the *color component selector* bits appear directly below the weight bits.

23.9.2 ASTC Multi-Partition Encoding

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
			CEM						*Partition index*						
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Partition index			*Part*		*Block mode*										

Table 23.8: ASTC multi-partition block layout

The *partition index* field specifies which partition layout to use. *CEM* is the first 6 bits of *color endpoint mode* information for the various partitions. For *endpoint modes* which require more than 6 bits of *CEM* data, the additional bits appear at a variable position directly beneath the texel weight data.

If dual-plane mode is active, the *color component selector* bits then appear directly below the additional *CEM* bits.

23.9.3 ASTC Void-Extent Block Encoding

The final special case is that if bits [8..0] of the block are “111111100”, then the block is a void-extent block, which has a separate encoding described in Section 23.22.

23.10 Block Mode

The *block mode* field specifies the width, height and depth of the grid of weights, what range of values they use, and whether dual weight planes are present. Since some these are not represented using powers of two (there are 12 possible weight widths, for example), and not all combinations are allowed, this is not a simple bit packing. However, it can be unpacked quickly in hardware.

The weight ranges are encoded using a 3-bit range value ρ, which is interpreted together with a low/high-precision bit P, as shown in Table 23.9. Each weight value is encoded using the specified number of Trits, Quints and Bits. The details of this encoding can be found in Section 23.12.

$\rho^{2..0}$	**Low-precision range (P=0)**				**High-precision range (P=1)**			
	Weight range	**Trits**	**Quints**	**Bits**	**Weight range**	**Trits**	**Quints**	**Bits**
000	Invalid				Invalid			
001	Invalid				Invalid			
010	0..1			1	0..9		1	1
011	0..2	1			0..11	1		2
100	0..3			2	0..15			4
101	0..4		1		0..19		1	2
110	0..5	1		1	0..23	1		3
111	0..7			3	0..31			5

Table 23.9: ASTC weight range encodings

For 2D blocks, the *block mode* field is laid out as shown in Table 23.10.

10	9	8	7	6	5	4	3	2	1	0	W_{width}	W_{height}	Notes
D_P	P	W		H		ρ^0	0	0	ρ^2	ρ^1	W+4	H+2	
D_P	P	W		H		ρ^0	0	1	ρ^2	ρ^1	W+8	H+2	
D_P	P	H		W		ρ^0	1	0	ρ^2	ρ^1	W+2	H+8	
D_P	P	0	H	W		ρ^0	1	1	ρ^2	ρ^1	W+2	H+6	
D_P	P	1	W	H		ρ^0	1	1	ρ^2	ρ^1	W+2	H+2	
D_P	P	0	0	H		ρ^0	ρ^2	ρ^1	0	0	12	H+2	
D_P	P	0	1	W		ρ^0	ρ^2	ρ^1	0	0	W+2	12	
D_P	P	1	1	0	0	ρ^0	ρ^2	ρ^1	0	0	6	10	
D_P	P	1	1	0	1	ρ^0	ρ^2	ρ^1	0	0	10	6	
H		1	0	W		ρ^0	ρ^2	ρ^1	0	0	W+6	H+6	D_P=0, P=0
x	x	1	1	1	1	1	1	1	0	0	-	-	Void-extent
x	x	1	1	1	x	x	x	x	0	0	-	-	Reserved*
x	x	x	x	x	x	x	0	0	0	0	-	-	Reserved

Table 23.10: ASTC 2D *block mode* layout, weight grid width and height

Note that, due to the encoding of the ρ field, as described in the previous page, bits ρ^2 and ρ^1 cannot both be zero, which disambiguates the first five rows from the rest of the table.

Bit positions with a value of x are ignored for purposes of determining if a block is a void-extent block or reserved, but may have defined encodings for specific void-extent blocks.

The penultimate row of Table 23.10 is reserved only if bits [5..2] are not all 1, in which case it encodes a void-extent block (as shown in the previous row).

For 3D blocks, the *block mode* field is laid out as shown in Table 23.11.

10	9	8	7	6	5	4	3	2	1	0	**W$_{\textbf{width}}$**	**W$_{\textbf{height}}$**	**W$_{\textbf{depth}}$**	**Notes**
D_P	P	H		W		ρ^0	D		ρ^2	ρ^1	W+2	H+2	D+2	
H		0	0	D		ρ^0	ρ^2	ρ^1	0	0	6	H+2	D+2	D_P=0, P=0
D		0	1	W		ρ^0	ρ^2	ρ^1	0	0	W+2	6	D+2	D_P=0, P=0
H		1	0	W		ρ^0	ρ^2	ρ^1	0	0	W+2	H+2	6	D_P=0, P=0
D_P	P	1	1	0	0	ρ^0	ρ^2	ρ^1	0	0	6	2	2	
D_P	P	1	1	0	1	ρ^0	ρ^2	ρ^1	0	0	2	6	2	
D_P	P	1	1	1	0	ρ^0	ρ^2	ρ^1	0	0	2	2	6	
x	x	1	1	1	1	1	1	1	0	0	-	-	-	Void-extent
x	x	1	1	1	1	x	x	x	0	0	-	-	-	Reserved*
x	x	x	x	x	x	x	0	0	0	0	-	-	-	Reserved

Table 23.11: ASTC 3D *block mode* layout, weight grid width, height and depth

The D_P bit is set to indicate dual-plane mode. In dual-plane mode, the maximum allowed number of partitions is 3.

The penultimate row of Table 23.11 is reserved only if bits [4..2] are not all 1, in which case it encodes a void-extent block (as shown in the previous row).

The size of the weight grid in each dimension must be less than or equal to the corresponding dimension of the block footprint. If the grid size is greater than the footprint dimension in any axis, then this is an illegal block encoding and all texels will decode to the error color.

23.11 Color Endpoint Mode

If the texel block encodes a single partition, the *color endpoint mode* (*CEM*) field stores one of 16 possible values. Each of these specifies how many raw data values are encoded, and how to convert these raw values into two *RGBA* color endpoints. They can be summarized as shown in Table 23.12.

CEM	**Description**	**Class**
0	LDR Luminance, direct	0
1	LDR Luminance, base+offset	0
2	HDR Luminance, large range	0
3	HDR Luminance, small range	0
4	LDR Luminance+Alpha, direct	1
5	LDR Luminance+Alpha, base+offset	1
6	LDR *RGB*, base+scale	1
7	HDR *RGB*, base+scale	1
8	LDR *RGB*, direct	2
9	LDR *RGB*, base+offset	2
10	LDR *RGB*, base+scale plus two *A*	2
11	HDR *RGB*, direct	2
12	LDR *RGBA*, direct	3
13	LDR *RGBA*, base+offset	3
14	HDR *RGB*, direct + LDR Alpha	3
15	HDR *RGB*, direct + HDR Alpha	3

Table 23.12: ASTC *color endpoint modes*

If the texel block encodes multiple partitions, the *CEM* field is of variable width, from 6 to 14 bits. The lowest 2 bits of the *CEM* field specify how the *endpoint mode* for each partition is calculated as shown in Table 23.13.

Value	**Meaning**
00	All color endpoint pairs are of the same type; a full 4-bit *CEM* is stored in block bits [28..25] and is used for all partitions
01	All endpoint pairs are of class 0 or 1
10	All endpoint pairs are of class 1 or 2
11	All endpoint pairs are of class 2 or 3

Table 23.13: ASTC multi-partition *color endpoint modes*

If the *CEM* selector value in bits [24..23] is not 00, then data layout is as shown in Table 23.14 and Table 23.15.

Part			n	m	l	k	j	i	h	g	
2	…	Weight	M_1								…
3	…	Weight	M_2		M_1		M_0				…
4	…	Weight	M_3		M_2		M_1		M_0		…

Table 23.14: ASTC multi-partition *color endpoint mode* layout

Part	28	27	26	25	24	23
2	M_0		C_1	C_0	*CEM*	
3	M_0	C_2	C_1	C_0	*CEM*	
4	C_3	C_2	C_1	C_0	*CEM*	

Table 23.15: ASTC multi-partition *color endpoint mode* layout (2)

In this view, each partition *i* has two fields. C_i is the class selector bit, choosing between the two possible *CEM* classes (0 indicates the lower of the two classes), and M_i is a two-bit field specifying the low bits of the *color endpoint mode* within that class. The additional bits appear at a variable bit position, immediately below the texel weight data.

The ranges used for the data values are not explicitly specified. Instead, they are derived from the number of available bits remaining after the configuration data and weight data have been specified.

Details of the decoding procedure for Color Endpoints can be found in Section 23.13.

23.12 Integer Sequence Encoding

Both the weight data and the endpoint color data are variable width, and are specified using a sequence of integer values. The range of each value in a sequence (e.g. a color weight) is constrained.

Since it is often the case that the most efficient range for these values is not a power of two, each value sequence is encoded using a technique known as "integer sequence encoding". This allows efficient, hardware-friendly packing and unpacking of values with non-power-of-two ranges.

In a sequence, each value has an identical range. The range is specified in one of the forms shown in Table 23.16 and Table 23.17.

Value range	**MSB encoding**	**LSB encoding**
$0 \ldots 2^n - 1$	-	n-bit value m ($n \leq 8$)
$0 \ldots (3 \times 2^n) - 1$	Base-3 "trit" value t	n-bit value m ($n \leq 6$)
$0 \ldots (5 \times 2^n) - 1$	Base-5 "quint" value q	n-bit value m ($n \leq 5$)

Table 23.16: ASTC range forms

Value range	**Value**	**Block**	**Packed block size**
$0 \ldots 2^n - 1$	m	1	n
$0 \ldots (3 \times 2^n) - 1$	$t \times 2^n + m$	5	$8 + 5 \times n$
$0 \ldots (5 \times 2^n) - 1$	$q \times 2^n + m$	3	$7 + 3 \times n$

Table 23.17: ASTC encoding for different ranges

Since 3^5 is 243, it is possible to pack five trits into 8 bits (which has 256 possible values), so a trit can effectively be encoded as 1.6 bits. Similarly, since 5^3 is 125, it is possible to pack three quints into 7 bits (which has 128 possible values), so a quint can be encoded as 2.33 bits.

The encoding scheme packs the trits or quints, and then interleaves the n additional bits in positions that satisfy the requirements of an arbitrary-length stream. This makes it possible to correctly specify lists of values whose length is not an integer multiple of 3 or 5 values. It also makes it possible to easily select a value at random within the stream.

If there are insufficient bits in the stream to fill the final block, then unused (higher-order) bits are assumed to be 0 when decoding.

To decode the bits for value number i in a sequence of bits b, both indexed from 0, perform the following:

If the range is encoded as n bits per value, then the value is bits $b^{i \times n+n-1..i \times n}$ — a simple multiplexing operation.

If the range is encoded using a trit, then each block contains 5 values (v_0 to v_4), each of which contains a trit (t_0 to t_4) and a corresponding LSB value (m_0 to m_4). The first bit of the packed block is bit $\lfloor \frac{i}{5} \rfloor \times (8+5 \times n)$. The bits in the block are packed as shown in Table 23.18 (in this example, n is 4).

				27	26	25	24	23	22	21	20	19	18	17	16
				T^7	m_4				T^6	T^5	m_3				T^4
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
m_2				T^3	T^2	m_1				T^1	T^0	m_0			

Table 23.18: ASTC trit-based packing

The five trits t_0 to t_4 are obtained by bit manipulations of the 8 bits $T^{7..0}$ as follows:

```
if T[4:2] = 111
    C = { T[7:5], T[1:0] }; t4 = t3 = 2
else
    C = T[4:0]
    if T[6:5] = 11
        t4 = 2; t3 = T[7]
    else
        t4 = T[7]; t3 = T[6:5]

if C[1:0] = 11
    t2 = 2; t1 = C[4]; t0 = { C[3], C[2]&~C[3] }
else if C[3:2] = 11
    t2 = 2; t1 = 2; t0 = C[1:0]
else
    t2 = C[4]; t1 = C[3:2]; t0 = { C[1], C[0]&~C[1] }
```

If the range is encoded using a quint, then each block contains 3 values (v_0 to v_2), each of which contains a quint (q_0 to q_2) and a corresponding LSB value (m_0 to m_2). The first bit of the packed block is bit $\lfloor \frac{i}{3} \rfloor \times (7+3\times n)$.

The bits in the block are packed as described in Table 23.19 and Table 23.20 (in this example, n is 4).

18	17	16
Q^6	Q^5	m_2

Table 23.19: ASTC quint-based packing

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
m_2			Q^4	Q^3	m_1				Q^2	Q^1	Q^0	m_0			

Table 23.20: ASTC quint-based packing (2)

The three quints q_0 to q_2 are obtained by bit manipulations of the 7 bits $Q^{6..0}$ as follows:

```
if Q[2:1] = 11 and Q[6:5] = 00
    q2 = { Q[0], Q[4]&~Q[0], Q[3]&~Q[0] }; q1 = q0 = 4
else
    if Q[2:1] = 11
        q2 = 4; C = { Q[4:3], ~Q[6:5], Q[0] }
    else
        q2 = Q[6:5]; C = Q[4:0]

    if C[2:0] = 101
        q1 = 4; q0 = C[4:3]
    else
        q1 = C[4:3]; q0 = C[2:0]
```

Both these procedures ensure a valid decoding for all 128 possible values (even though a few are duplicates). They can also be implemented efficiently in software using small tables.

Encoding methods are not specified here, although table-based mechanisms work well.

23.13 Endpoint Unquantization

Each color endpoint is specified as a sequence of integers in a given range. These values are packed using integer sequence encoding, as a stream of bits stored from just above the configuration data, and growing upwards.

Once unpacked, the values must be unquantized from their storage range, returning them to a standard range of 0..255.

For bit-only representations with fewer than 8 bits, this is simple bit replication from the most significant bit of the value. For example, the three-bit value `C2 C1 C0` would become `C2 C1 C0 C2 C1 C0 C2 C1` (from most- to least-significant bit).

For trit or quint-based representations, this involves a set of bit manipulations and adjustments to avoid the expense of full-width multipliers. This procedure ensures correct scaling, but scrambles the order of the decoded values relative to the encoded values. This must be compensated for using a table in the encoder.

The initial inputs to the procedure are denoted `A` (9 bits), `B` (9 bits), `C` (9 bits) and `D` (3 bits), and are decoded using the range as described in Table 23.21.

Range	#Trits	#Quints	#Bits	Bit layout	A	B	C	D
0..5	1		1	a	aaaaaaaaa	000000000	204	Trit value
0..9		1	1	a	aaaaaaaaa	000000000	113	Quint value
0..11	1		2	ba	aaaaaaaaa	b000b0bb0	93	Trit value
0..19		1	2	ba	aaaaaaaaa	b0000bb00	54	Quint value
0..23	1		3	cba	aaaaaaaaa	cb000cbcb	44	Trit value
0..39		1	3	cba	aaaaaaaaa	cb0000cbc	26	Quint value
0..47	1		4	dcba	aaaaaaaaa	dcb000dcb	22	Trit value
0..79		1	4	dcba	aaaaaaaaa	dcb0000dc	13	Quint value
0..95	1		5	edcba	aaaaaaaaa	edcb000ed	11	Trit value
0..159		1	5	edcba	aaaaaaaaa	edcb0000e	6	Quint value
0..191	1		6	fedcba	aaaaaaaaa	fedcb000f	5	Trit value

Table 23.21: ASTC color unquantization parameters

These are then processed as follows:

```
unq = D * C + B;
unq = unq ^ A;
unq = (A & 0x80) | (unq >> 2);
```

Note that the multiply in the first line is nearly trivial as it only needs to multiply by 0, 1, 2, 3 or 4.

23.14 Endpoint Interpretation

The decoding method used depends on the *color endpoint mode* (*CEM*) field, which specifies how many values are used to represent the endpoint.

The *CEM* field also specifies how to take the *n* unquantized color endpoint values v_0 to v_{n-1} and convert them into two *RGBA* color endpoints e_0 and e_1.

The methods can be summarized as shown in Table 23.22.

CEM	Range	Description	*n*
0	LDR	Luminance, direct	2
1	LDR	Luminance, base+offset	2
2	HDR	Luminance, large range	2
3	HDR	Luminance, small range	2
4	LDR	Luminance+Alpha, direct	4
5	LDR	Luminance+Alpha, base+offset	4
6	LDR	*RGB*, base+scale	4
7	HDR	*RGB*, base+scale	4
8	LDR	*RGB*, direct	6
9	LDR	*RGB*, base+offset	6
10	LDR	*RGB*, base+scale plus two *A*	6
11	HDR	*RGB*	6
12	LDR	*RGBA*, direct	8
13	LDR	*RGBA*, base+offset	8
14	HDR	*RGB* + LDR Alpha	8
15	HDR	*RGB* + HDR Alpha	8

Table 23.22: ASTC LDR color endpoint values by mode

Color endpoint mode 14 is special in that the alpha values are interpolated linearly, but the color components are interpolated logarithmically. This is the only *color endpoint* mode with mixed-mode operation, and will return the error color if encountered in LDR *operation mode*.

23.14.1 LDR Endpoint Decoding

Decode the different LDR *endpoint modes* as follows:

23.14.1.1 LDR Endpoint Mode 0: Luminance, direct

```
e0 = (v0, v0, v0, 0xFF);
e1 = (v1, v1, v1, 0xFF);
```

23.14.1.2 LDR Endpoint Mode 1: Luminance, base+offset

```
L0 = (v0 >> 2) | (v1 & 0xC0);
L1 = L0 + (v1 & 0x3F);
if (L1 > 0xFF) { L1 = 0xFF; }
e0 = (L0, L0, L0, 0xFF);
e1 = (L1, L1, L1, 0xFF);
```

23.14.1.3 LDR Endpoint Mode 4: Luminance+Alpha,direct

```
e0 = (v0, v0, v0, v2);
e1 = (v1, v1, v1, v3);
```

23.14.1.4 LDR Endpoint Mode 5: Luminance+Alpha, base+offset

```
bit_transfer_signed( v1, v0 );
bit_transfer_signed( v3, v2 );
e0 = (v0, v0, v0, v2);
e1 = (v0 + v1, v0 + v1, v0 + v1, v2 + v3);
clamp_unorm8( e0 );
clamp_unorm8( e1 );
```

23.14.1.5 LDR Endpoint Mode 6 *RGB*, base+scale

```
e0 = (v0 * v3 >> 8, v1 * v3 >> 8, v2 * v3 >> 8, 0xFF);
e1 = (v0, v1, v2, 0xFF);
```

23.14.1.6 LDR Endpoint Mode 8: *RGB*, Direct

```
s0 = v0 + v2 + v4;
s1 = v1 + v3 + v5;
if (s1 >= s0) {
    e0 = (v0, v2, v4, 0xFF);
    e1 = (v1, v3, v5, 0xFF);
} else {
    e0 = blue_contract( v1, v3, v5, 0xFF );
    e1 = blue_contract( v0, v2, v4, 0xFF );
}
```

23.14.1.7 LDR Endpoint Mode 9: *RGB*, base+offset

```
bit_transfer_signed( v1, v0 );
bit_transfer_signed( v3, v2 );
bit_transfer_signed( v5, v4 );
if (v1 + v3 + v5 >= 0) {
    e0 = (v0, v2, v4, 0xFF);
    e1 = (v0 + v1, v2 + v3, v4 + v5, 0xFF);
} else {
    e0 = blue_contract( v0 + v1, v2 + v3, v4 + v5, 0xFF );
    e1 = blue_contract( v0, v2, v4, 0xFF );
}
clamp_unorm8( e0 );
clamp_unorm8( e1 );
```

23.14.1.8 LDR Endpoint Mode 10: *RGB*, base+scale plus two *A*

```
e0 = (v0 * v3 >> 8, v1 * v3 >> 8, v2 * v3 >> 8, v4);
e1 = (v0, v1, v2, v5);
```

23.14.1.9 LDR Endpoint Mode 12: *RGBA*, direct

```
s0 = v0 + v2 + v4;
s1 = v1 + v3 + v5;
if (s1 >= s0) {
    e0 = (v0, v2, v4, v6);
    e1 = (v1, v3, v5, v7);
} else {
    e0 = blue_contract( v1, v3, v5, v7 );
    e1 = blue_contract( v0, v2, v4, v6 );
}
```

23.14.1.10 LDR Endpoint Mode 13: *RGBA*, base+offset

```
bit_transfer_signed( v1, v0 );
bit_transfer_signed( v3, v2 );
bit_transfer_signed( v5, v4 );
bit_transfer_signed( v7, v6 );
if (v1 + v3 + v5 >= 0) {
    e0 = (v0, v2, v4, v6);
    e1 = (v0 + v1, v2 + v3, v4 + v5, v6 + v7);
} else {
    e0 = blue_contract( v0 + v1, v2 + v3, v4 + v5, v6 + v7 );
    e1 = blue_contract( v0, v2, v4, v6 );
}
clamp_unorm8( e0 ); clamp_unorm8( e1 );
```

The `bit_transfer_signed()` procedure transfers a bit from one value (*a*) to another (*b*). Initially, both *a* and *b* are in the range 0..255. After calling this procedure, *a*'s range becomes -32..31, and *b* remains in the range 0..255. Note that, as is often the case, this is easier to express in hardware than in C:

```
bit_transfer_signed( int& a, int& b )
{
    b >>= 1;
    b |= a & 0x80;
    a >>= 1;
    a &= 0x3F;
    if ((a & 0x20) != 0) { a -= 0x40; }
}
```

The `blue_contract()` procedure is used to give additional precision to *RGB* colors near gray:

```
color blue_contract( int r, int g, int b, int a )
{
    color c;
    c.r = (r + b) >> 1;
    c.g = (g + b) >> 1;
    c.b = b;
    c.a = a;
    return c;
}
```

The `clamp_unorm8()` procedure is used to clamp a color into 8-bit unsigned normalized fixed-point range:

```
void clamp_unorm8( color c )
{
    if (c.r < 0) { c.r = 0; } else if (c.r > 255) { c.r = 255; }
    if (c.g < 0) { c.g = 0; } else if (c.g > 255) { c.g = 255; }
    if (c.b < 0) { c.b = 0; } else if (c.b > 255) { c.b = 255; }
    if (c.a < 0) { c.a = 0; } else if (c.a > 255) { c.a = 255; }
}
```

23.14.2 HDR Endpoint Decoding

For *HDR endpoint modes*, color values are represented in a 12-bit pseudo-logarithmic representation.

23.14.2.1 HDR Endpoint Mode 2

Endpoint mode 2 represents luminance-only data with a large range. It encodes using two values (v_0, v_1). The complete decoding procedure is as follows:

```
if (v1 >= v0) {
    y0 = (v0 << 4);
    y1 = (v1 << 4);
} else {
    y0 = (v1 << 4) + 8;
    y1 = (v0 << 4) - 8;
}
// Construct RGBA result (0x780 is 1.0f)
e0 = (y0, y0, y0, 0x780);
e1 = (y1, y1, y1, 0x780);
```

23.14.2.2 HDR Endpoint Mode 3

Endpoint mode 3 represents luminance-only data with a small range. It packs the bits for a base luminance value, together with an offset, into two values (v_0, v_1), according to Table 23.23.

Value	7	6	5	4	3	2	1	0
$\mathbf{v_0}$	M	$L^{6..0}$						
$\mathbf{v_1}$	$X^{3..0}$				$d^{3..0}$			

Table 23.23: ASTC HDR endpoint mode 3 value layout

The bit field marked as X allocates different bits to L or d depending on the value of the mode bit M.

The complete decoding procedure is as follows:

```
// Check mode bit and extract.
if ((v0 & 0x80) !=0) {
    y0 = ((v1 & 0xE0) << 4) | ((v0 & 0x7F) << 2);
    d  =  (v1 & 0x1F) << 2;
} else {
    y0 = ((v1 & 0xF0) << 4) | ((v0 & 0x7F) << 1);
    d  =  (v1 & 0x0F) << 1;
}

// Add delta and clamp
y1 = y0 + d;
if (y1 > 0xFFF) { y1 = 0xFFF; }

// Construct RGBA result (0x780 is 1.0f)
e0 = (y0, y0, y0, 0x780);
e1 = (y1, y1, y1, 0x780);
```

23.14.2.3 HDR Endpoint Mode 7

Endpoint mode 7 packs the bits for a base *RGB* value, a scale factor, and some mode bits into the four values (v_0, v_1, v_2, v_3), as shown in Table 23.24.

Value	7	6	5	4	3	2	1	0
v_0	$\mathrm{M}^{3..2}$		$R^{5..0}$					
v_1	M^1	X^0	X^1	$G^{4..0}$				
v_2	M^0	X^2	X^3	$B^{4..0}$				
v_3	X^4	X^5	X^6	$\mathrm{S}^{4..0}$				

Table 23.24: ASTC HDR endpoint mode 7 value layout

The mode bits M^0 to M^3 are a packed representation of an endpoint bit mode, together with the major component index. For modes 0 to 4, the component (red, green, or blue) with the largest magnitude is identified, and the values swizzled to ensure that it is decoded from the red channel.

The endpoint bit mode is used to determine the number of bits assigned to each component of the endpoint, and the destination of each of the extra bits X^0 to X^6, as shown in Table 23.25.

	Number of bits					**Destination of extra bits**						
Mode	***R***	***G***	***B***	**S**		$\mathbf{X^0}$	$\mathbf{X^1}$	$\mathbf{X^2}$	$\mathbf{X^3}$	$\mathbf{X^4}$	$\mathbf{X^5}$	$\mathbf{X^6}$
0	11	5	5	7		R^9	R^8	R^7	R^{10}	R^6	S^6	S^5
1	11	6	6	5		R^8	G^5	R^7	B^5	R^6	R^{10}	R^9
2	10	5	5	8		R^9	R^8	R^7	R^6	S^7	S^6	S^5
3	9	6	6	7		R^8	G^5	R^7	B^5	R^6	S^6	S^5
4	8	7	7	6		G^6	G^5	B^6	B^5	R^6	R^7	S^5
5	7	7	7	7		G^6	G^5	B^6	B^5	R^6	S^6	S^5

Table 23.25: ASTC HDR mode 7 endpoint bit mode

As noted before, this appears complex when expressed in C, but much easier to achieve in hardware: bit masking, extraction, shifting and assignment usually ends up as a single wire or multiplexer.

The complete decoding procedure is as follows:

```
// Extract mode bits and unpack to major component and mode.
int majcomp; int mode; int modeval = ((v0&0xC0)>>6) | ((v1&0x80)>>5) | ((v2&0x80)>>4);

if ((modeval & 0xC) != 0xC) {
    majcomp = modeval >> 2; mode = modeval & 3;
} else if (modeval != 0xF) {
    majcomp = modeval & 3;  mode = 4;
} else {
    majcomp = 0; mode = 5;
}

// Extract low-order bits of r, g, b, and s.
int red  = v0 & 0x3f; int green = v1 & 0x1f;
int blue = v2 & 0x1f; int scale = v3 & 0x1f;

// Extract high-order bits, which may be assigned depending on mode
int x0 = (v1 >> 6) & 1; int x1 = (v1 >> 5) & 1; int x2 = (v2 >> 6) & 1;
int x3 = (v2 >> 5) & 1; int x4 = (v3 >> 7) & 1; int x5 = (v3 >> 6) & 1;
int x6 = (v3 >> 5) & 1;

// Now move the high-order xs into the right place.
int ohm = 1 << mode;
if (ohm & 0x30) { green |= x0 << 6; }
if (ohm & 0x3A) { green |= x1 << 5; }
if (ohm & 0x30) { blue |= x2 << 6; }
if (ohm & 0x3A) { blue |= x3 << 5; }
if (ohm & 0x3D) { scale |= x6 << 5; }
if (ohm & 0x2D) { scale |= x5 << 6; }
if (ohm & 0x04) { scale |= x4 << 7; }
if (ohm & 0x3B) { red |= x4 << 6; }
if (ohm & 0x04) { red |= x3 << 6; }
if (ohm & 0x10) { red |= x5 << 7; }
if (ohm & 0x0F) { red |= x2 << 7; }
if (ohm & 0x05) { red |= x1 << 8; }
if (ohm & 0x0A) { red |= x0 << 8; }
if (ohm & 0x05) { red |= x0 << 9; }
if (ohm & 0x02) { red |= x6 << 9; }
if (ohm & 0x01) { red |= x3 << 10; }
if (ohm & 0x02) { red |= x5 << 10; }

// Shift the bits to the top of the 12-bit result.
static const int shamts[6] = { 1, 1, 2, 3, 4, 5 };
int shamt = shamts[mode];
red <<= shamt; green <<= shamt; blue <<= shamt; scale <<= shamt;

// Minor components are stored as differences
if (mode != 5) { green = red - green; blue = red - blue; }

// Swizzle major component into place
if (majcomp == 1) { swap( red, green ); }
if (majcomp == 2) { swap( red, blue ); }

// Clamp output values, set alpha to 1.0
e1.r = clamp( red, 0, 0xFFF );
e1.g = clamp( green, 0, 0xFFF );
e1.b = clamp( blue, 0, 0xFFF );
e1.alpha = 0x780;
e0.r = clamp( red - scale, 0, 0xFFF );
e0.g = clamp( green - scale, 0, 0xFFF );
e0.b = clamp( blue - scale, 0, 0xFFF );
e0.alpha = 0x780;
```

23.14.2.4 HDR Endpoint Mode 11

Mode 11 specifies two *RGB* values, which it calculates from a number of bitfields (a, b_0, b_1, c, d_0 and d_1) which are packed together with some mode bits into the six values (v_0, v_1, v_2, v_3, v_4, v_5) as shown in Table 23.26.

Value	7	6	5	4	3	2	1	0
$\mathbf{v_0}$	$a^{7..0}$							
$\mathbf{v_1}$	m_0	a^8	$c^{5..0}$					
$\mathbf{v_2}$	m_1	X^0	${b_0}^{5..0}$					
$\mathbf{v_3}$	m_2	X^1	${b_1}^{5..0}$					
$\mathbf{v_4}$	mj_0	X^2	X^4	${d_0}^{4..0}$				
$\mathbf{v_5}$	mj_1	X^3	X^5	${d_1}^{4..0}$				

Table 23.26: ASTC HDR mode 11 value layout

If the major component bits $mj^{1..0}$ are both 1, then the *RGB* values are specified directly by Table 23.27.

Value	7	6	5	4	3	2	1	0
$\mathbf{v_0}$	${R_0}^{11..4}$							
$\mathbf{v_1}$	${R_1}^{11..4}$							
$\mathbf{v_2}$	${G_0}^{11..4}$							
$\mathbf{v_3}$	${G_1}^{11..4}$							
$\mathbf{v_4}$	1	${B_0}^{11..5}$						
$\mathbf{v_5}$	1	${B_1}^{11..5}$						

Table 23.27: ASTC HDR mode 11 direct value layout

The mode bits $m^{2..0}$ specify the bit allocation for the different values, and the destinations of the extra bits X^0 to X^5 as shown in Table 23.28.

	Number of bits					**Destination of extra bits**					
Mode	**a**	**b**	**c**	**d**		$\mathbf{X^0}$	$\mathbf{X^1}$	$\mathbf{X^2}$	$\mathbf{X^3}$	$\mathbf{X^4}$	$\mathbf{X^5}$
0	9	7	6	7		${b_0}^6$	${b_1}^6$	${d_0}^6$	${d_1}^6$	${d_0}^5$	${d_1}^5$
1	9	8	6	6		${b_0}^6$	${b_1}^6$	${b_0}^7$	${b_1}^7$	${d_0}^5$	${d_1}^5$
2	10	6	7	7		a^9	c^6	${d_0}^6$	${d_1}^6$	${d_0}^5$	${d_1}^5$
3	10	7	7	6		${b_0}^6$	${b_1}^6$	a^9	c^6	${d_0}^5$	${d_1}^5$
4	11	8	6	5		${b_0}^6$	${b_1}^6$	${b_0}^7$	${b_1}^7$	a^9	a^{10}
5	11	6	7	6		a^9	a^{10}	c^7	c^6	${d_0}^5$	${d_1}^5$
6	12	7	7	5		${b_0}^6$	${b_1}^6$	a^{11}	c^6	a^9	a^{10}
7	12	6	7	6		a^9	a^{10}	a^{11}	c^6	${d_0}^5$	${d_1}^5$

Table 23.28: ASTC HDR mode 11 endpoint bit mode

The complete decoding procedure is as follows:

```
// Find major component
int majcomp = ((v4 & 0x80) >> 7) | ((v5 & 0x80) >> 6);

// Deal with simple case first
if (majcomp == 3) {
    e0 = (v0 << 4, v2 << 4, (v4 & 0x7f) << 5, 0x780);
    e1 = (v1 << 4, v3 << 4, (v5 & 0x7f) << 5, 0x780);
    return;
}

// Decode mode, parameters.
int mode = ((v1&0x80)>>7) | ((v2&0x80)>>6) | ((v3&0x80)>>5);
int va  = v0 | ((v1 & 0x40) << 2);
int vb0 = v2 & 0x3f; int vb1 = v3 & 0x3f;
int vc  = v1 & 0x3f;
int vd0 = v4 & 0x7f; int vd1 = v5 & 0x7f;

// Assign top bits of vd0, vd1.
static const int dbitstab[8] = {7,6,7,6,5,6,5,6};
vd0 = signextend( vd0, dbitstab[mode] );
vd1 = signextend( vd1, dbitstab[mode] );

// Extract and place extra bits
int x0 = (v2 >> 6) & 1;
int x1 = (v3 >> 6) & 1;
int x2 = (v4 >> 6) & 1;
int x3 = (v5 >> 6) & 1;
int x4 = (v4 >> 5) & 1;
int x5 = (v5 >> 5) & 1;

int ohm = 1 << mode;
if (ohm & 0xA4) { va |= x0 << 9; }
if (ohm & 0x08) { va |= x2 << 9; }
if (ohm & 0x50) { va |= x4 << 9; }
if (ohm & 0x50) { va |= x5 << 10; }
if (ohm & 0xA0) { va |= x1 << 10; }
if (ohm & 0xC0) { va |= x2 << 11; }
if (ohm & 0x04) { vc |= x1 << 6; }
if (ohm & 0xE8) { vc |= x3 << 6; }
if (ohm & 0x20) { vc |= x2 << 7; }
if (ohm & 0x5B) { vb0 |= x0 << 6; }
if (ohm & 0x5B) { vb1 |= x1 << 6; }
if (ohm & 0x12) { vb0 |= x2 << 7; }
if (ohm & 0x12) { vb1 |= x3 << 7; }

// Now shift up so that major component is at top of 12-bit value
int shamt = (modeval >> 1) ^ 3;
va <<= shamt; vb0 <<= shamt; vb1 <<= shamt;
vc <<= shamt; vd0 <<= shamt; vd1 <<= shamt;

e1.r = clamp( va, 0, 0xFFF );
e1.g = clamp( va - vb0, 0, 0xFFF );
e1.b = clamp( va - vb1, 0, 0xFFF );
e1.alpha = 0x780;
e0.r = clamp( va - vc, 0, 0xFFF );
e0.g = clamp( va - vb0 - vc - vd0, 0, 0xFFF );
e0.b = clamp( va - vb1 - vc - vd1, 0, 0xFFF );
e0.alpha = 0x780;

if (majcomp == 1)      { swap( e0.r, e0.g ); swap( e1.r, e1.g ); }
else if (majcomp == 2) { swap( e0.r, e0.b ); swap( e1.r, e1.b ); }
```

23.14.2.5 HDR Endpoint Mode 14

Endpoint mode 14 specifies two *RGBA* values, using the eight values (v_0, v_1, v_2, v_3, v_4, v_5, v_6, v_7). First, the *RGB* values are decoded from (v_0..v_5) using the method from endpoint mode 11, then the alpha values are filled in from v_6 and v_7:

```
// Decode RGB as for mode 11
(e0, e1) = decode_mode_11( v0, v1, v2, v3, v4, v5 );

// Now fill in the alphas
e0.alpha = v6;
e1.alpha = v7;
```

Note that in this *endpoint mode*, the alpha values are interpreted (and interpolated) as 8-bit unsigned normalized values, as in the LDR modes. This is the only *HDR endpoint mode* that exhibits this behavior.

23.14.2.6 HDR Endpoint Mode 15

Endpoint mode 15 specifies two *RGBA* values, using the eight values (v_0, v_1, v_2, v_3, v_4, v_5, v_6, v_7). First, the *RGB* values are decoded from (v_0..v_5) using the method from endpoint mode 11. The alpha values are stored in values v_6 and v_7 as a mode and two values which are interpreted according to the mode *M*, as shown in Table 23.29.

Value	7	6	5	4	3	2	1	0
$\mathbf{v_6}$	M^0	$A^{6..0}$						
$\mathbf{v_7}$	M^1	$B^{6..0}$						

Table 23.29: ASTC HDR mode 15 alpha value layout

The alpha values are decoded from v_6 and v_7 as follows:

```
// Decode RGB as for endpoint mode 11
(e0, e1) = decode_mode_11( v0, v1, v2, v3, v4, v5 );

// Extract mode bits
mode = ((v6 >> 7) & 1) | ((v7 >> 6) & 2);
v6 &= 0x7F;
v7 &= 0x7F;

if (mode == 3) {
    // Directly specify alphas
    e0.alpha = v6 << 5;
    e1.alpha = v7 << 5;
} else {
    // Transfer bits from v7 to v6 and sign extend v7.
    v6 |= (v7 << (mode + 1)) & 0x780;
    v7 &= (0x3F >> mode);
    v7 ^= 0x20 >> mode;
    v7 -= 0x20 >> mode;
    v6 <<= (4 - mode);
    v7 <<= (4 - mode);

    // Add delta and clamp
    v7 += v6;
    v7 = clamp( v7, 0, 0xFFF );
    e0.alpha = v6;
    e1.alpha = v7;
}
```

Note that in this *endpoint mode*, the alpha values are interpreted (and interpolated) as 12-bit HDR values, and are interpolated as for any other HDR component.

23.15 Weight Decoding

The weight information is stored as a stream of bits, growing downwards from the most significant bit in the block. Bit *n* in the stream is thus bit 127-*n* in the block.

For each position in the weight grid, a value (in the specified range) is packed into the stream. These are ordered in a raster pattern starting from position (0,0,0), with the X dimension increasing fastest, and the Z dimension increasing slowest. If dual-plane mode is selected, both weights are emitted together for each position, plane 0 first, then plane 1.

23.16 Weight Unquantization

Each weight plane is specified as a sequence of integers in a given range. These values are packed using integer sequence encoding.

Once unpacked, the values must be unquantized from their storage range, returning them to a standard range of 0..64. The procedure for doing so is similar to the color endpoint unquantization.

First, we unquantize the actual stored weight values to the range 0..63.

For bit-only representations of fewer than 5 bits, this is simple bit replication from the most significant bit of the value. For example, a 3-bit weight `C2 C1 C0` becomes the 5-bit value `C2 C1 C0 C2 C1` (from most- to least-significant bit).

For trit or quint-based representations, this involves a set of bit manipulations and adjustments to avoid the expense of full-width multipliers.

For representations with no additional bits, the results are as shown in Table 23.30.

Range	0	1	2	3	4
0..2	0	32	63	-	-
0..4	0	16	32	47	63

Table 23.30: ASTC weight unquantization values

For other values, we calculate the initial inputs to a bit manipulation procedure. These are denoted `A` (7 bits), `B` (7 bits), `C` (7 bits), and `D` (3 bits) and are decoded using the range as shown in Table 23.31.

Range	#Trits	#Quints	#Bits	Bit layout	A	B	C	D
0..5	1		1	a	aaaaaaa	0000000	50	Trit value
0..9		1	1	a	aaaaaaa	0000000	28	Quint value
0..11	1		2	ba	aaaaaaa	b000b0b	23	Trit value
0..19		1	2	ba	aaaaaaa	b0000b0	13	Quint value
0..23	1		3	cba	aaaaaaa	cb000cb	11	Trit value

Table 23.31: ASTC weight unquantization parameters

These are then processed as follows:

```
unq = D * C + B;
unq = unq ^ A;
unq = (A & 0x20) | (unq >> 2);
```

Note that the multiply in the first line is nearly trivial as it only needs to multiply by 0, 1, 2, 3 or 4.

As a final step, for all types of value, the range is expanded from 0..63 up to 0..64 as follows:

```
if (unq > 32) { unq += 1; }
```

This allows the implementation to use 64 as a divisor during interpolation, which is much easier than using 63.

23.17 Weight Infill

After unquantization, the weights are subject to weight selection and infill. The infill method is used to calculate the weight for a texel position, based on the weights in the stored weight grid array (which may be a different size). The procedure below must be followed exactly, to ensure bit exact results.

The block size is specified as three dimensions along the s, t and r axes ($\mathrm{B_s}$, $\mathrm{B_t}$, $\mathrm{B_r}$). Texel coordinates within the block ($\mathrm{b_s}$, $\mathrm{b_t}$, $\mathrm{b_r}$) can have values from 0 to one less than the block dimension in that axis. For each block dimension, we compute scale factors (D_s, D_t, D_r):

$$D_s = \left\lfloor \frac{\left(1024 + \left\lfloor \frac{\mathrm{B_s}}{2} \right\rfloor\right)}{(\mathrm{B_s} - 1)} \right\rfloor$$

$$D_t = \left\lfloor \frac{\left(1024 + \left\lfloor \frac{\mathrm{B_t}}{2} \right\rfloor\right)}{(\mathrm{B_t} - 1)} \right\rfloor$$

$$D_r = \left\lfloor \frac{\left(1024 + \left\lfloor \frac{\mathrm{B_r}}{2} \right\rfloor\right)}{(\mathrm{B_r} - 1)} \right\rfloor$$

Since the block dimensions are constrained, these are easily looked up in a table. These scale factors are then used to scale the ($\mathrm{b_s}$, $\mathrm{b_t}$, $\mathrm{b_r}$) coordinates to a homogeneous coordinate ($\mathrm{c_s}$, $\mathrm{c_t}$, $\mathrm{c_r}$):

```
cs = Ds * bs;
ct = Dt * bt;
cr = Dr * br;
```

This homogeneous coordinate ($\mathrm{c_s}$, $\mathrm{c_t}$, $\mathrm{c_r}$) is then scaled again to give a coordinate ($\mathrm{g_s}$, $\mathrm{g_t}$, $\mathrm{g_r}$) in the weight-grid space. The weight-grid is of size ($\mathrm{W_{width}}$, $\mathrm{W_{height}}$, $\mathrm{W_{depth}}$), as specified in the *block mode* field (Table 23.10 and Table 23.11):

```
gs = (cs * (Wwidth - 1) + 32) >> 6;
gt = (ct * (Wheight - 1) + 32) >> 6;
gr = (cr * (Wdepth - 1) + 32) >> 6;
```

The resulting coordinates may be in the range 0..176. These are interpreted as 4:4 unsigned fixed point numbers in the range 0.0 .. 11.0.

If we label the integral parts of these ($\mathrm{j_s}$, $\mathrm{j_t}$, $\mathrm{j_r}$) and the fractional parts ($\mathrm{f_s}$, $\mathrm{f_t}$, $\mathrm{f_r}$), then:

```
js = gs >> 4; fs = gs & 0x0F;
jt = gt >> 4; ft = gt & 0x0F;
jr = gr >> 4; fr = gr & 0x0F;
```

These values are then used to interpolate between the stored weights. This process differs for 2D and 3D.

For 2D, bilinear interpolation is used:

```
v0 = js + jt * Wwidth;
p00 = decode_weight( v0 );
p01 = decode_weight( v0 + 1 );
p10 = decode_weight( v0 + Wwidth );
p11 = decode_weight( v0 + Wwidth + 1 );
```

The function `decode_weight(n)` decodes the n^{th} weight in the stored weight stream. The values $\mathrm{p_{00}}$ to $\mathrm{p_{11}}$ are the weights at the corner of the square in which the texel position resides. These are then weighted using the fractional position to produce the effective weight i as follows:

```
w11 = (fs * ft + 8) >> 4;
w10 = ft - w11;
w01 = fs - w11;
w00 = 16 - fs - ft + w11;
i = (p00 * w00 + p01 * w01 + p10 * w10 + p11 * w11 + 8) >> 4;
```

$f_s > f_t$	$f_t > f_r$	$f_s > f_r$	s_1	s_2	w_0	w_1	w_2	w_3
True	True	*True*	1	W_{width}	$16 - f_s$	$f_s - f_t$	$f_t - f_r$	f_r
False	*True*	True	W_{width}	1	$16 - f_t$	$f_t - f_s$	$f_s - f_r$	f_r
True	False	True	1	$W_{width} \times W_{height}$	$16 - f_s$	$f_s - f_r$	$f_r - f_t$	f_t
True	*False*	False	$W_{width} \times W_{height}$	1	$16 - f_r$	$f_r - f_s$	$f_s - f_t$	f_t
False	True	False	W_{width}	$W_{width} \times W_{height}$	$16 - f_t$	$f_t - f_r$	$f_r - f_s$	f_s
False	False	*False*	$W_{width} \times W_{height}$	W_{width}	$16 - f_r$	$f_r - f_t$	$f_t - f_s$	f_s

Table 23.32: ASTC simplex interpolation parameters

For 3D, simplex interpolation is used as it is cheaper than a naïve trilinear interpolation. First, we pick some parameters for the interpolation based on comparisons of the fractional parts of the texel position as shown in Table 23.32.

Italicized test results are implied by the others. The effective weight *i* is then calculated as:

```
v0 = js + jt * Wwidth + jr * Wwidth * Wheight;
p0 = decode_index( v0 );
p1 = decode_index( v0 + s1 );
p2 = decode_index( v0 + s1 + s2 );
p3 = decode_index( v0 + Wwidth * Wheight + Wwidth + 1 );
i = (p0 * w0 + p1 * w1 + p2 * w2 + p3 * w3 + 8) >> 4;
```

23.18 Weight Application

Once the effective weight *i* for the texel has been calculated, the color endpoints are interpolated and expanded.

23.18.1 *LDR endpoint modes*

For *LDR endpoint modes*, each color component C is calculated from the corresponding 8-bit endpoint components C_0 and C_1 as follows:

If sRGB conversion is not enabled, C_0 and C_1 are first expanded to 16 bits by bit replication:

```
C0 = (C0 << 8) | C0;
C1 = (C1 << 8) | C1;
```

If sRGB conversion is enabled, C_0 and C_1 are expanded to 16 bits differently, as follows:

```
C0 = (C0 << 8) | 0x80;
C1 = (C1 << 8) | 0x80;
```

C_0 and C_1 are then interpolated to produce a UNORM16 result C:

```
C = floor( (C0 * (64 - i) + C1 * i + 32) / 64 );
```

If sRGB conversion is not enabled and the decode mode is `decode_float16`, then if C = 65535 the final result is 1.0 (0x3C00); otherwise C is divided by 65536 and the infinite-precision result of the division is converted to FP16 with round-to-zero semantics.

If sRGB conversion is not enabled and the decode mode is `decode_unorm8`, then the top 8 bits of the interpolation result for the *R*, *G*, *B* and *A* channels are used as the final result.

If sRGB conversion is not enabled and the decode mode is `decode_rgb9e5`, then the final result is a combination of the (UNORM16) values of C for the three color components (C_r, C_g and C_b) computed as follows:

```
int lz = clz17( Cr | Cg | Cb | 1 );
if (Cr == 65535) {
    Cr = 65536;
    lz = 0;
}
if (Cg == 65535) {
    Cg = 65536;
    lz = 0;
}
if (Cb == 65535) {
    Cb = 65536;
    lz = 0;
}
Cr <<= lz;
Cg <<= lz;
Cb <<= lz;
Cr = (Cr >> 8) & 0x1FF;
Cg = (Cg >> 8) & 0x1FF;
Cb = (Cb >> 8) & 0x1FF;
uint32_t exponent = 16 - lz;
uint32_t texel = (exponent << 27) | (Cb << 18) | Cg << 9) | Cr;
```

The `clz17()` function counts leading zeroes in a 17-bit value.

If sRGB conversion is enabled, then the decoding mode is ignored and the top 8 bits of the interpolation result for the *R*, *G* and *B* channels are treated as an unsigned, normalized 8-bit value to be converted with the sRGB EOTF. The top 8 bits of the *A* channel are used directly as the final unsigned, normalized 8-bit result.

23.18.2 *HDR endpoint modes*

For *HDR endpoint modes*, color values are represented in a 12-bit pseudo-logarithmic representation, and interpolation occurs in a piecewise-approximate logarithmic manner as follows:

In sRGB and Linear LDR operation modes, the error color is returned.

In *HDR endpoint modes*, the color components from each endpoint, C_0 and C_1, are initially shifted left 4 bits to become 16-bit integer values and these are interpolated in the same way as LDR. The 16-bit value C is then decomposed into the top five bits, E, and the bottom 11 bits M, which are then processed and recombined with E to form the final value C_f:

```
C = floor( (C0 * (64 - i) + C1 * i + 32) / 64 );
E = (C & 0xF800) >> 11;
M = C & 0x7FF;

if (M < 512) {
    Mt = 3 * M;
} else if (M >= 1536) {
    Mt = 5 * M - 2048;
} else {
    Mt = 4 * M - 512;
}

Cf = (E << 10) + (Mt >> 3);
```

This interpolation is a considerably closer approximation to a logarithmic space than simple 16-bit interpolation.

This final value C_f is interpreted as an IEEE FP16 value. If the result is +Inf or NaN, it is converted to the bit pattern 0x7BFF, which is the largest representable finite value.

If the decode mode is `decode_rgb9e5`, then the final result is a combination of the (IEEE FP16) values of $\mathrm{C_f}$ for the three color components (C_r, C_g and C_b) computed as follows:

```
if (Cr > 0x7c00) {
    Cr = 0;
} else if (Cr == 0x7c00) {
    Cr = 0x7bff;
}
if (Cg > 0x7c00) {
    Cg = 0;
} else if (Cg == 0x7c00) {
    Cg = 0x7bff;
}
if (Cb > 0x7c00) {
    Cb = 0;
} else if (Cb == 0x7c00) {
    Cb = 0x7bff;
}

int Re = (Cr >> 10) & 0x1F;
int Ge = (Cg >> 10) & 0x1F;
int Be = (Cb >> 10) & 0x1F;
int Rex = Re == 0 ? 1 : Re;
int Gex = Ge == 0 ? 1 : Ge;
int Bex = Be == 0 ? 1 : Be;
int Xm = ((Cr | Cg | Cb) & 0x200) >> 9;
int Xe = Re | Ge | Be;
uint32_t rshift, gshift, bshift, expo;

if (Xe == 0) {
    expo = rshift = gshift = bshift = Xm;
} else if (Re >= Ge && Re >= Be) {
    expo = Rex + 1;
    rshift = 2;
    gshift = Rex - Gex + 2;
    bshift = Rex - Bex + 2;
} else if (Ge >= Be) {
    expo = Gex + 1;
    rshift = Gex - Rex + 2;
    gshift = 2;
    bshift = Gex - Bex + 2;
} else {
    expo = Bex + 1;
    rshift = Bex - Rex + 2;
    gshift = Bex - Gex + 2;
    bshift = 2;
}

int Rm = (Cr & 0x3FF) | (Re == 0 ? 0 : 0x400);
int Gm = (Cg & 0x3FF) | (Ge == 0 ? 0 : 0x400);
int Bm = (Cb & 0x3FF) | (Be == 0 ? 0 : 0x400);
Rm = (Rm >> rshift) & 0x1FF;
Gm = (Gm >> gshift) & 0x1FF;
Bm = (Bm >> bshift) & 0x1FF;

uint32_t texel = (expo << 27) | (Bm << 18) | (Gm << 9) | (Rm << 0);
```

23.19 Dual-Plane Decoding

If dual-plane mode is disabled, all of the endpoint components are interpolated using the same weight value.

If dual-plane mode is enabled, two weights are stored with each texel. One component is then selected to use the second weight for interpolation, instead of the first weight. The first weight is then used for all other components.

The component to treat specially is indicated using the 2-bit *Color Component Selector* (*CCS*) field as shown in Table 23.33.

Value	Weight 0	Weight 1
0	*GBA*	*R*
1	*RBA*	*G*
2	*RGA*	*B*
3	*RGB*	*A*

Table 23.33: ASTC dual plane *color component selector* values

The *CCS* bits are stored at a variable position directly below the weight bits and any additional *CEM* bits.

23.20 Partition Pattern Generation

When multiple partitions are active, each texel position is assigned a *partition index*. This *partition index* is calculated using a seed (the partition pattern index), the texel's *x*, *y*, *z* position within the block, and the number of partitions. An additional argument, `small_block`, is set to 1 if the number of texels in the block is less than 31, otherwise it is set to 0.

This function is specified in terms of *x*, *y* and *z* in order to support 3D textures. For 2D textures and texture slices, *z* will always be 0.

The full partition selection algorithm is as follows:

```
int select_partition( int seed, int x, int y, int z,
                      int partitioncount, int small_block )
{
    if (small_block) {
        x <<= 1;
        y <<= 1;
        z <<= 1;
    }
    seed += (partitioncount - 1) * 1024;
    uint32_t rnum = hash52( seed );
    uint8_t seed1  =  rnum        & 0xF;
    uint8_t seed2  = (rnum >>  4) & 0xF;
    uint8_t seed3  = (rnum >>  8) & 0xF;
    uint8_t seed4  = (rnum >> 12) & 0xF;
    uint8_t seed5  = (rnum >> 16) & 0xF;
    uint8_t seed6  = (rnum >> 20) & 0xF;
    uint8_t seed7  = (rnum >> 24) & 0xF;
    uint8_t seed8  = (rnum >> 28) & 0xF;
    uint8_t seed9  = (rnum >> 18) & 0xF;
    uint8_t seed10 = (rnum >> 22) & 0xF;
    uint8_t seed11 = (rnum >> 26) & 0xF;
    uint8_t seed12 = ((rnum >> 30) | (rnum << 2)) & 0xF;

    seed1  *= seed1;    seed2  *= seed2;
    seed3  *= seed3;    seed4  *= seed4;
    seed5  *= seed5;    seed6  *= seed6;
    seed7  *= seed7;    seed8  *= seed8;
    seed9  *= seed9;    seed10 *= seed10;
    seed11 *= seed11;   seed12 *= seed12;

    int sh1, sh2, sh3;
    if (seed & 1) {
        sh1 = (seed & 2 ? 4 : 5);
        sh2 = (partitioncount == 3 ? 6 : 5);
    } else {
        sh1 = (partitioncount == 3 ? 6 : 5);
        sh2 = (seed & 2 ? 4 : 5);
    }
    sh3 = (seed & 0x10) ? sh1 : sh2;

    seed1 >>= sh1; seed2  >>= sh2; seed3  >>= sh1; seed4  >>= sh2;
    seed5 >>= sh1; seed6  >>= sh2; seed7  >>= sh1; seed8  >>= sh2;
    seed9 >>= sh3; seed10 >>= sh3; seed11 >>= sh3; seed12 >>= sh3;

    int a = seed1 * x + seed2 * y + seed11 * z + (rnum >> 14);
    int b = seed3 * x + seed4 * y + seed12 * z + (rnum >> 10);
    int c = seed5 * x + seed6 * y + seed9  * z + (rnum >>  6);
    int d = seed7 * x + seed8 * y + seed10 * z + (rnum >>  2);

    a &= 0x3F; b &= 0x3F; c &= 0x3F; d &= 0x3F;

    if (partitioncount < 4) { d = 0; }
    if (partitioncount < 3) { c = 0; }

    if (a >= b && a >= c && a >= d) { return 0; }
    else if (b >= c && b >= d) { return 1; }
    else if (c >= d) { return 2; }
    else { return 3; }
}
```

As has been observed before, the bit selections are much easier to express in hardware than in C.

The seed is expanded using a hash function `hash52()`, which is defined as follows:

```
uint32_t hash52( uint32_t p )
{
    p ^= p >> 15;  p -= p << 17;  p += p << 7; p += p <<  4;
    p ^= p >>  5;  p += p << 16;  p ^= p >> 7; p ^= p >> 3;
    p ^= p <<  6;  p ^= p >> 17;
    return p;
}
```

This assumes that all operations act on 32-bit values

23.21 Data Size Determination

The size of the data used to represent color endpoints is not explicitly specified. Instead, it is determined from the *block mode* and number of partitions as follows:

```
config_bits = 17;
if (num_partitions > 1) {
    if (single_CEM) { config_bits = 29; }
    else { config_bits = 25 + 3 * num_partitions; }
}

num_weights = Wwidth * Wheight * Wdepth; // size of weight grid

if (dual_plane) {
    config_bits += 2;
    num_weights *= 2;
}

weight_bits = ceil( num_weights * 8 * trits_in_weight_range / 5 ) +
              ceil( num_weights * 7 * quints_in_weight_range / 3 ) +
              num_weights * bits_in_weight_range;

remaining_bits = 128 - config_bits - weight_bits;

num_CEM_pairs = base_CEM_class + 1 + count_bits( extra_CEM_bits );
```

The *CEM* value range is then looked up from a table indexed by remaining bits and `num_CEM_pairs`. This table is initialized such that the range is as large as possible, consistent with the constraint that the number of bits required to encode `num_CEM_pairs` pairs of values is not more than the number of remaining bits.

An equivalent iterative algorithm would be:

```
num_CEM_values = num_CEM_pairs*2;

for(range = each possible CEM range in descending order of size)
{
    CEM_bits = ceil( num_CEM_values * 8 * trits_in_CEM_range / 5 ) +
               ceil( num_CEM_values * 7 * quints_in_CEM_range / 3 ) +
               num_CEM_values * bits_in_CEM_range;

    if (CEM_bits <= remaining_bits) { break; }
}
return range;
```

In cases where this procedure results in unallocated bits, these bits are not read by the decoding process and can have any value.

23.22 Void-Extent Blocks

A void-extent block is a block encoded with a single color. It also specifies some additional information about the extent of the single-color area beyond this block, which can optionally be used by a decoder to reduce or prevent redundant block fetches. Void-extent blocks must be supported, but void extents may not be checked.

In the HDR case, if the decode mode is `decode_rgb9e5`, then any negative color component values are set to 0 before conversion to the shared exponent format (as described in Section 23.18).

The layout of a 2D void-extent block is as shown in Table 23.34.

127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112
Block color A component$^{15..0}$															
111	110	109	108	107	106	105	104	103	102	101	100	99	98	97	96
Block color B component$^{15..0}$															
95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80
Block color G component$^{15..0}$															
79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64
Block color R component$^{15..0}$															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
Void-extent maximum t coordinate$^{12..0}$													Min t coord$^{12..10}$		
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Void-extent minimum t coordinate$^{9..0}$										Void-extent maximum s coordinate$^{12..7}$					
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Void-extent maximum s coordinate$^{5..0}$							Void-extent minimum s coordinate$^{12..4}$								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Minimum s coordinate$^{3..0}$				1	1	D	1	1	1	1	1	1	1	0	0

Table 23.34: ASTC 2D void-extent block layout overview

The layout of a 3D void-extent block is as shown in Table 23.35.

Bit 9 is the Dynamic Range flag, which indicates the format in which colors are stored. A 0 value indicates LDR, and a 1 indicates HDR.

For LDR encodings the color components are stored in the same UNORM16 format as the output of the interpolator. The values stored here directly provide the LDR values of C defined in Section 23.18. These values follow the same post-interpolator path as non-void-extent LDR blocks, with regards to handling of sRGB conversion and decoding modes.

For HDR encodings the color components are stored as FP16 values. The values stored here directly provide the HDR values of C_f defined in Section 23.18. These values follow the same post-interpolator path as non-void-extent HDR blocks, with regards to handling of decoding modes.

If a void-extent block with HDR values is decoded in LDR operation mode, then the result will be the error color, opaque magenta, for all texels within the block.

In the HDR case, if the color component values are infinity or NaN, this will result in undefined behavior. As usual, this must not lead to an API's interruption or termination.

Bits 10 and 11 are reserved and must be 1.

The minimum and maximum coordinate values are treated as unsigned integers and then normalized into the range 0..1 (by dividing by 2^{13}-1 or 2^{9}-1, for 2D and 3D respectively). The maximum values for each dimension must be greater than the corresponding minimum values, unless they are all all-1s.

If all the coordinates are all-1s, then the void extent is ignored, and the block is simply a constant-color block.

The existence of single-color blocks with void extents must not produce results different from those obtained if these single-color blocks are defined without void-extents. Any situation in which the results would differ is invalid. Results from invalid void extents are undefined.

<table>
<tr><td>127</td><td>126</td><td>125</td><td>124</td><td>123</td><td>122</td><td>121</td><td>120</td><td>119</td><td>118</td><td>117</td><td>116</td><td>115</td><td>114</td><td>113</td><td>112</td></tr>
<tr><td colspan="16">Block color A component$^{15..0}$</td></tr>
<tr><td>111</td><td>110</td><td>109</td><td>108</td><td>107</td><td>106</td><td>105</td><td>104</td><td>103</td><td>102</td><td>101</td><td>100</td><td>99</td><td>98</td><td>97</td><td>96</td></tr>
<tr><td colspan="16">Block color B component$^{15..0}$</td></tr>
<tr><td>95</td><td>94</td><td>93</td><td>92</td><td>91</td><td>90</td><td>89</td><td>88</td><td>87</td><td>86</td><td>85</td><td>84</td><td>83</td><td>82</td><td>81</td><td>80</td></tr>
<tr><td colspan="16">Block color G component$^{15..0}$</td></tr>
<tr><td>79</td><td>78</td><td>77</td><td>76</td><td>75</td><td>74</td><td>73</td><td>72</td><td>71</td><td>70</td><td>69</td><td>68</td><td>67</td><td>66</td><td>65</td><td>64</td></tr>
<tr><td colspan="16">Block color R component$^{15..0}$</td></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td></tr>
<tr><td colspan="9">Void-extent maximum r coordinate$^{8..0}$</td><td colspan="7">Void-extent minimum r coordinate$^{8..2}$</td></tr>
<tr><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td colspan="2">Min r coord$^{1..0}$</td><td colspan="9">Void-extent maximum t coordinate$^{8..0}$</td><td colspan="5">Void-extent min t coordinate$^{8..4}$</td></tr>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td></tr>
<tr><td colspan="4">Minimum t coordinate$^{3..0}$</td><td colspan="9">Void-extent minimum s coordinate$^{8..0}$</td><td colspan="3">Min s coord$^{8..6}$</td></tr>
<tr><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="6">Void-extent minimum s coordinate$^{5..0}$</td><td>D</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
</table>

Table 23.35: ASTC 3D void-extent block layout overview

If a void-extent appears in a MIPmap level other than the most detailed one, then the extent will apply to all of the more detailed levels too. This allows decoders to avoid sampling more detailed MIPmaps.

If the more detailed MIPmap level is not a constant color in this region, then the block may be marked as constant color, but without a void extent, as detailed above.

If a void-extent extends to the edge of a texture, then filtered texture colors may not be the same color as that specified in the block, due to texture border colors, wrapping, or cube face wrapping.

Care must be taken when updating or extracting partial image data that void-extents in the image do not become invalid.

23.23 Illegal Encodings

In ASTC, there is a variety of ways to encode an illegal block. Decoders are required to recognize all illegal blocks and emit the standard error color value upon encountering an illegal block.

Here is a comprehensive list of situations that represent illegal block encodings:

- The *block mode* specified is one of the block modes explicitly listed as Reserved.
- A 2D void-extent block that has any of the reserved bits not set to 1.
- A *block mode* has been specified that would require more than 64 weights total.
- A *block mode* has been specified that would require more than 96 bits for integer sequence encoding of the weight grid.
- A *block mode* has been specified that would require fewer than 24 bits for integer sequence encoding of the weight grid.
- The size of the weight grid exceeds the size of the block footprint in any dimension.
- *Color endpoint modes* have been specified such that the color integer sequence encoding would require more than 18 integers.
- The number of bits available for color endpoint encoding after all the other fields have been counted is less than $\left\lceil \frac{13 \times C}{5} \right\rceil$ where C is the number of color endpoint integers (this would restrict color integers to a range smaller than 0..5, which is not supported).
- Dual-weight mode is enabled for a block with 4 partitions.
- Void-extent blocks where the low coordinate for some texture axis is greater than or equal to the high coordinate.

Note also that, in LDR operation mode, a block which has both HDR and LDR *endpoint modes* assigned to different partitions is not an error block. Only those texels which belong to the HDR partition will result in the error color. Texels belonging to a LDR partition will be decoded as normal.

23.24 LDR Profile Support

In order to ease verification and accelerate adoption, an LDR-only subset of the full ASTC specification has been made available.

Implementations of this LDR Profile must satisfy the following requirements:

- All textures with valid encodings for LDR Profile must decode identically using either a LDR Profile, HDR Profile, or Full Profile decoder.
- All features included only in the HDR Profile or Full Profile must be treated as reserved in the LDR Profile, and return the error color on decoding.
- Any sequence of API calls valid for the LDR Profile must also be valid for the HDR Profile or Full Profile and return identical results when given a texture encoded for the LDR Profile.

The feature subset for the LDR profile is:

- 2D textures only.
- Only those block sizes listed in Table 23.4 are supported.
- sRGB and linear LDR operation modes only.
- Only *LDR endpoint modes* must be supported, namely modes 0, 1, 4, 5, 6, 8, 9, 10, 12, 13.
- Decoding from a HDR endpoint results in the error color.
- LDR, 2D void-extent blocks must be supported.

23.25 HDR Profile Support

In order to ease verification and accelerate adoption, a second subset of the full ASTC specification has been made available, known as the HDR profile.

Implementations of the HDR Profile must satisfy the following requirements:

- The HDR profile is a superset of the LDR profile and therefore all valid LDR encodings must decode identically using a HDR profile decoder.
- All textures with valid encodings for HDR Profile must decode identically using either a HDR Profile or Full Profile decoder.
- All features included only in the Full Profile must be treated as reserved in the HDR Profile, and return the error color on decoding.
- Any sequence of API calls valid for the HDR Profile must also be valid for the Full Profile and return identical results when given a texture encoded for the HDR Profile.

The feature subset for the HDR profile is:

- 2D textures only.
- Only those block sizes listed in Table 23.4 are supported.
- All *endpoint modes* must be supported.
- 2D void-extent blocks must be supported.

Chapter 24

PVRTC Compressed Texture Image Formats

This description is derived from the PVRTC Texture Compression User Guide, part of the PowerVR Documentation.

24.1 PVRTC Overview

PVRTC is PowerVR's family of proprietary texture compression schemes, providing compression of color data at 4 or 2 bits per pixel (4/2bpp).

There are two generations of PVRTC: PVRTC1 and PVRTC2. Both support 4bpp and 2bpp compression ratios. They are broadly similar, but PVRTC2 adds additional features to the format. Both primarily use an interpolation and modulation scheme to compress texture data wherein texel values are encoded as two low-resolution images, $\mathbf{A_{Low}}$ and $\mathbf{B_{Low}}$, along with a full-resolution, low bit-precision modulation signal, $\mathbf{M_{Sig}}$, to combine those images.

More information on the specifics of the PVRTC1 compression technique can be found in the "Graphics Hardware 2003" paper Texture Compression using Low-Frequency Signal Modulation.

In PVRTC, images are described in terms of 64-bit little-endian words, each of which contains a pixel from each of the low-resolution images, $\mathbf{A_{Low}}$ and $\mathbf{B_{Low}}$, and a subset of the modulation data, $\mathbf{M_{Sig}}$, corresponding to either a 4×4 or 8×4 set of pixels. Unlike traditional block-based formats, PVRTC uses adjacent data-words to reconstruct the original image.

If combined with this encoding scheme, the sRGB EOTF is applied to the unquantized version of the R', G' and B' channels (that is, $R_{out} = EOTF_{sRGB}\left(\frac{R'}{255}\right)$, etc.) at the end of the texel decode process, but the A channel is interpreted linearly.

24.2 Format PVRTC1 4bpp

For PVRTC1 4bpp, each 64-bit word $W_{X,Y}$ at block coordinates (X,Y) contains the modulation information for a 4×4 block of texels beginning at image pixels $(4 \times X, 4 \times Y)$, and a color sample for each low-resolution image which influences an overlapping 7×7 texel region of the final output, with each sample centered on output pixel $((4 \times X) + 2, (4 \times Y) + 2)$. Nearly every texel position requires data from a set of 2×2 data words in order to be decoded: the low-resolution encoded images are bilinearly interpolated to, in effect, generate a pair of full-resolution images prior to modulation, and this interpolation requires examining multiple data words in the compressed image data.

The dimensions of PVRTC1 images must be powers of two. Any mip level of a texture must comprise at least two words of PVRTC data in each dimension; for example, a texture of 16×4 texels is represented by 4×2 PVRTC words of 4×4 texels each. Some (particularly software) implementations are further constrained to square images. If a texture (or a particular mip-level) is smaller than the size of the block of texels described by one word in any dimension, reconstruction of an image occurs as if fetching the upper-left most texels from the region covered by those words.

24.2.1 PVRTC1 4bpp word encoding

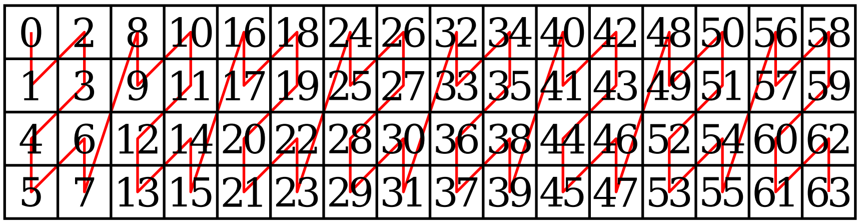
Each data word contains two colors and a set of modulation data describing how to interpolate between them for each pixel position in the original image. A flag M describes how the modulation data should be interpreted, and each color contains a bit to describe whether it contains alpha data.

Bits 64..32: Color data and flags																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Color B																**Color A**															M
Bits 31..0: Modulation data bits [1..0] for pixel offset (x, y)																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3,3		2,3		1,3		0,3		3,2		2,2		1,2		0,2		3,1		2,1		1,1		0,1		3,0		2,0		1,0		0,0	

Table 24.1: Texel Data format for PVRTC1 4bpp compressed texture formats

24.2.2 PVRTC1 4bpp word offset calculation

Data words in PVRTC1 formats are stored in a reflected Morton order, as shown in the figure below, where each cell corresponds to the index of a 64-bit word $W_{X,Y}$:



0	2	8	10	16	18	24	26	32	34	40	42	48	50	56	58
1	3	9	11	17	19	25	27	33	35	41	43	49	51	57	59
4	6	12	14	20	22	28	30	36	38	44	46	52	54	60	62
5	7	13	15	21	23	29	31	37	39	45	47	53	55	61	63

Figure 24.1: Reflected Morton Order 16×4-block image

Expressing each of the X and Y indices as an array of bits, the index of a particular PVRTC word can be found by interleaving the bits of the X and Y indices as follows:

Let Xb be the number of bits used to express X — i.e. $Xb = \log_2\left(\max\left(\left\lceil \frac{width}{4} \right\rceil, 2\right)\right)$.

Let Yb be the number of bits used to express Y — i.e. $Yb = \log_2\left(\max\left(\left\lceil \frac{height}{4} \right\rceil, 2\right)\right)$.

Then:

$$\textit{Reflected Morton order offset } W_{X,Y} = \begin{cases} X^{Xb} \ldots X^{\mathrm{n}} \ldots X^{Yb+1} X^{Yb} Y^{Yb} \ldots X^{\mathrm{m}} Y^{\mathrm{m}} \ldots X^0 Y^0, & \text{width} \geq \text{height} \\ Y^{Yb} \ldots Y^{\mathrm{n}} \ldots Y^{Xb+1} X^{Xb} Y^{Xb} \ldots X^{\mathrm{m}} Y^{\mathrm{m}} \ldots X^0 Y^0, & \text{width} < \text{height} \end{cases}$$

That is, to form the word offset, bits of X and Y are interleaved, with bits from Y in the lower of each interleaved pair. These bits are interleaved up to the number of bits needed to represent the largest possible X or Y, for whichever of *width* and *height* is smaller. Any remaining bits from X or Y, for whichever of *width* and *height* is larger, are appended to the offset bit pattern.

For example, Figure 24.1 represents a 64×16-texel image represented by 16×4 = 64 words of 64 bits. The largest possible X value in this example is $\frac{64}{4} - 1 = 15$; the largest possible Y value in this example is $\frac{16}{4} - 1 = 3$. The bottom four bits of the word offset are composed by interleaving the bottom two bits of Y and the bottom two bits of X (with Y in the lowest bit). Bits 5..4 of the word offset are derived from bits 3..2 of X, since no further bits are required to represent Y.

In this case, the word at X=13, Y=2, $W_{13,2}$=54 is constructed as follows:

X	**1**	**1**	**0**		**1**		= 13
$W_{13,2}$	**1**	**1**	**0**	*1*	**1**	*0*	= 54
Y			*1*		*0*		= 2

Table 24.2: Calculation of reflected Morton word offset for 13,2

Where *wordWidth* and *wordHeight* are the image width and height in units of 4×4 areas encoded by words:

$$\begin{aligned} wordWidth &= \max\left(\left\lceil \frac{width}{4} \right\rceil, 2\right) \\ wordHeight &= \max\left(\left\lceil \frac{height}{4} \right\rceil, 2\right) \end{aligned}$$

the word offset for $X = \left\lfloor \frac{x}{4} \right\rfloor$ and $Y = \left\lfloor \frac{y}{4} \right\rfloor$ can be calculated iteratively as follows:

```
uint32_t reflectedMortonOffset(const uint32_t X,
                               const uint32_t Y,
                               const uint32_t wordWidth,
                               const uint32_t wordHeight)
{
    const uint32_t minDim = (wordWidth <= wordHeight) ? wordWidth : wordHeight;
    uint32_t offset = 0, shift = 0, mask;

    // Tests XY bounds AND that Width and Height != 0
    assert(X < wordWidth && Y < wordHeight);

    // Must be (non-zero) powers of 2
    assert((wordWidth  & (wordWidth  - 1)) == 0 && wordWidth >= 2);
    assert((wordHeight & (wordHeight - 1)) == 0 && wordHeight >= 2);

    for (mask = 1; mask < minDim; mask <<= 1)
    {
        offset |= (((Y & mask) | ((X & mask) <<  1))) << shift;
        shift++;
    }

    // At least one of X or Y will have run out of MSBs
    offset |= ((X | Y) >> shift) << (shift * 2);

    return offset;
}
```

24.2.3 PVRTC1 4bpp color reconstruction samples

Each data word encodes a color sample value from each of the two low-resolution images, with the (X, Y) position of the block corresponding to the (X_{Low}, Y_{Low}) position of the colors in the low-resolution images. The image colors for a given pixel position (x, y) are reconstructed using the words containing the four nearest color samples: $W_{X_{Low},Y_{Low}}$, $W_{X_{Low}+1,Y_{Low}}$, $W_{X_{Low},Y_{Low}+1}$ and $W_{X_{Low}+1,Y_{Low}+1}$, where X_{Low} and Y_{Low} are derived as follows:

$$X_{Low} = \left\lfloor \frac{x-2}{4} \right\rfloor \qquad Y_{Low} = \left\lfloor \frac{y-2}{4} \right\rfloor$$

Note

Figure 24.2 shows a grid of pixels with (*x* = 0, *y* = 0) at top left. Each word $W_{X_{Mod},Y_{Mod}}$ holds modulation values for a 4×4 texel region $\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$, as described in Section 24.2.5, where $X_{Mod} = \lfloor \frac{x}{4} \rfloor$ and $Y_{Mod} = \lfloor \frac{y}{4} \rfloor$.

For $X_{Low} = \left\lfloor \frac{x-2}{4} \right\rfloor$ and $Y_{Low} = \left\lfloor \frac{y-2}{4} \right\rfloor$, color reconstruction for the pixels shaded in Figure 24.2 requires data from the words $W_{X_{Low},Y_{Low}}$ through $W_{X_{Low}+1,Y_{Low}+1}$; the pixels for which these these words hold modulation values are shown as $\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$ through $\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}+1}$, outlined in red.

All pixels within the region contained by the dashed outline have the same values for X_{Low} and Y_{Low}. The remaining shaded pixels have different calculated X_{Low} and/or Y_{Low} values, but due to Equation 24.1, no contribution is required from additional words.

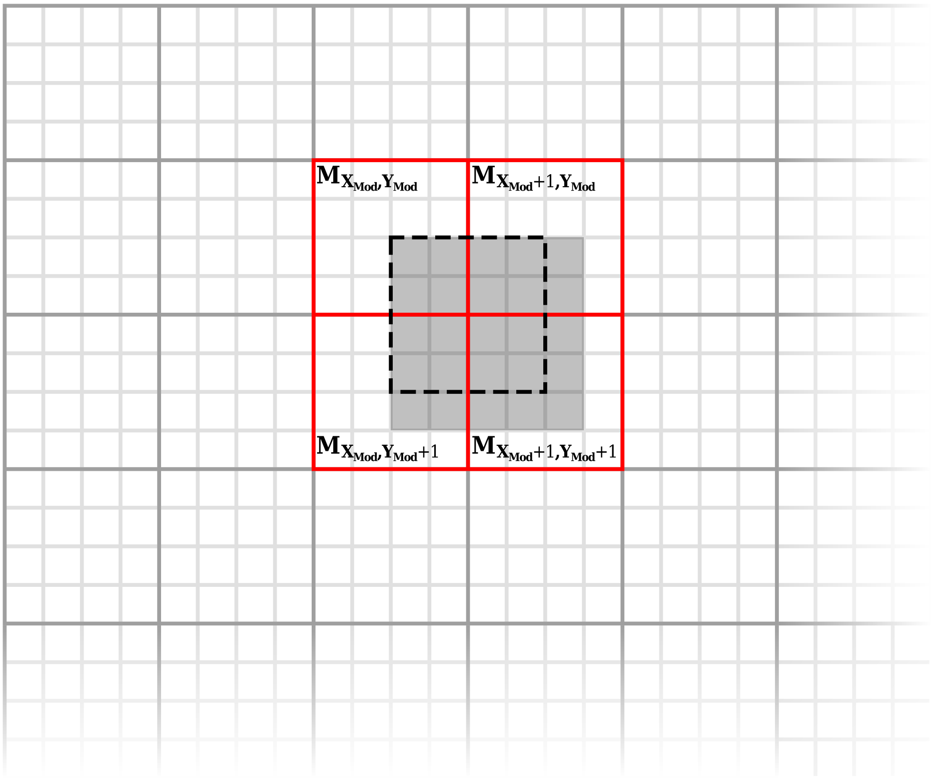

$\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$
$\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}}$
$\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}+1}$
$\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}+1}$

Figure 24.2: PVRTC1 image reconstruction

The texture data words are wrapped toroidally, such that the “nearest” sample may exist on the opposite side of the image.

Note

For example, sampling a pixel in any corner of the image results in the words in all four corners being examined — or sampling a pixel at the bottom of the image will result in words from the top of the image being examined, as shown in Figure 24.3. In this example, the nearest samples “below” the shaded pixels in regions $\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}},\mathbf{Y}_{\mathbf{Mod}}}$ and $\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}}+1,\mathbf{Y}_{\mathbf{Mod}}}$ the row of words at the top of the image, and the nearest samples “above” the shaded pixels in regions $\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}},\mathbf{Y}_{\mathbf{Mod}}+1}$ and $\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}}+1,\mathbf{Y}_{\mathbf{Mod}}+1}$ are in words $W_{X_{Low},Y_{Low}}$ and $W_{X_{Low}+1,Y_{Low}}$ at the bottom of the image.

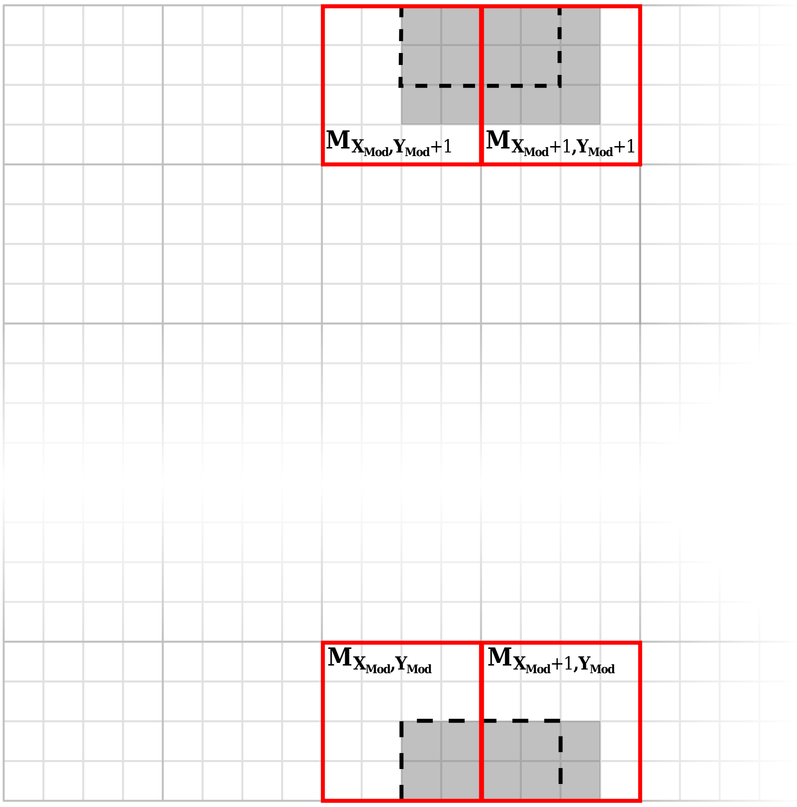

$\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}},\mathbf{Y}_{\mathbf{Mod}}+1}$
$\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}}+1,\mathbf{Y}_{\mathbf{Mod}}+1}$
$\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}},\mathbf{Y}_{\mathbf{Mod}}}$
$\mathbf{M}_{\mathbf{X}_{\mathbf{Mod}}+1,\mathbf{Y}_{\mathbf{Mod}}}$

Figure 24.3: PVRTC1 image reconstruction (wrapping)

In modern decoder implementations, if the texture width or height is a single texel block or smaller, both “wrapped” color reconstruction samples will come from the same PVRTC word, much as in PVRTC2. For example an 8×4-texel image in PVRTC1 4bpp will be described by the color reconstruction samples in the first and third PVRTC words, with the second and fourth (required by the minimum wordHeight of two texel blocks) purely acting as padding.

In older implementations, the color reconstructions samples are retrieved from the padding PVRTC words. Some encoders might have used this to allow a single 4×4 texture to use eight reconstruction samples for extra flexibility, with six samples coming from the padding words — but only the two samples from the first texel block would be accessed on a modern decoder. For consistency, therefore, padding PVRTC words used to increase the width or height to two PVRTC words should be encoded with the same color reconstruction sample values as the adjacent non-padding texel blocks.

24.2.4 PVRTC1 4bpp image reconstruction

The layout of color data in PVRTC word depends on the value of the opacity flag *Op*, stored in the most-significant bit of the color. If *Op* is 1, then the color is treated as opaque (no alpha data), and if *Op* is 0, the color has alpha data and may be translucent. The exact data layout of each color is described below:

<table>
<tr><th colspan="16">Color B — opaque color mode (opacity flag <i>Op</i> = 1)</th></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td></tr>
<tr><td>1</td><td colspan="5">Red</td><td colspan="5">Green</td><td colspan="5">Blue</td></tr>
<tr><th colspan="16">Color B — translucent color mode (opacity flag <i>Op</i> = 0)</th></tr>
<tr><td>63</td><td>62</td><td>61</td><td>60</td><td>59</td><td>58</td><td>57</td><td>56</td><td>55</td><td>54</td><td>53</td><td>52</td><td>51</td><td>50</td><td>49</td><td>48</td></tr>
<tr><td>0</td><td colspan="3">Alpha</td><td colspan="4">Red</td><td colspan="4">Green</td><td colspan="4">Blue</td></tr>
<tr><th colspan="16">Color A — opaque color mode (opacity flag <i>Op</i> = 1)</th></tr>
<tr><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td>1</td><td colspan="5">Red</td><td colspan="5">Green</td><td colspan="4">Blue</td><td><i>M</i></td></tr>
<tr><th colspan="16">Color A — translucent color mode (opacity flag <i>Op</i> = 0)</th></tr>
<tr><td>47</td><td>46</td><td>45</td><td>44</td><td>43</td><td>42</td><td>41</td><td>40</td><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td></tr>
<tr><td>0</td><td colspan="3">Alpha</td><td colspan="4">Red</td><td colspan="4">Green</td><td colspan="3">Blue</td><td><i>M</i></td></tr>
</table>

Table 24.3: Data layout of color segments in a PVRTC1 word

The **Color A** values and **Color B** values for each word are bilinearly interpolated by a factor of 4 in both dimensions, resulting in a pair of color values from two virtual images, **Image A** and **Image B**. This upscale operation is performed by treating each color as an *ARGB*:4555 format, and generating results in an *ARGB*:8888 format. Any *R*, *G*, or *B* channel in each color with fewer than 5 bits is initially expanded via bit replication:

- a 3-bit channel, $\mathrm{C}^2\mathrm{C}^1\mathrm{C}^0$ becomes $\mathrm{C}^2\mathrm{C}^1\mathrm{C}^0\mathrm{C}^2\mathrm{C}^1$
- a 4-bit channel, $\mathrm{C}^3\mathrm{C}^2\mathrm{C}^1\mathrm{C}^0$ becomes $\mathrm{C}^3\mathrm{C}^2\mathrm{C}^1\mathrm{C}^0\mathrm{C}^3$

The 3-bit alpha channel values are expanded to 4 bits by zero padding:

- $A^2A^1A^0$ becomes $A^2A^1A^0 0$

If the color is *opaque*, then the alpha channel is expanded to the 4-bit value, 0b1111.

For each channel *C* of each color (**Color A** and **Color B**), the interpolation proceeds as follows:

- For low-resolution image color channel $\mathbf{C_{X_{Low},Y_{Low}}}$ stored in word $W_{X_{Low},Y_{Low}}$:
  - X_{Low} = $\left\lfloor \frac{x-2}{4} \right\rfloor$, as described above.
  - Y_{Low} = $\left\lfloor \frac{y-2}{4} \right\rfloor$, as described above.
- Using relative coordinates:
  - $x_r = (x-2) - \left(4 \times \left\lfloor \frac{x-2}{4} \right\rfloor\right) = (x-2) - (4 \times X_{Low})$
  - $y_r = (y-2) - \left(4 \times \left\lfloor \frac{y-2}{4} \right\rfloor\right) = (y-2) - (4 \times Y_{Low})$
- Coordinates wrap at the edges of the image (but see Section 24.2.3 for small images).
- An interpolation is performed which is mathematically equivalent to Equation 24.1.

$$\begin{aligned} C_{x,y} = {} & \left(\mathbf{C_{X_{Low},Y_{Low}}} \times (4-x_r) \times (4-y_r)\right) + \left(\mathbf{C_{X_{Low}+1,Y_{Low}}} \times x_r \times (4-y_r)\right) \\ & + \left(\mathbf{C_{X_{Low},Y_{Low}+1}} \times (4-x_r) \times y_r\right) + \left(\mathbf{C_{X_{Low}+1,Y_{Low}+1}} \times x_r \times y_r\right) \end{aligned}$$

Equation 24.1: PVRTC1 4bpp color channel interpolation

Note

The colors of **Image A** and **Image B** at $(x = (4 \times X_{Low} + 2),\ y = (4 \times Y_{Low} + 2))$ are exactly the corresponding colors that word $W_{X_{Low},Y_{Low}}$ encodes. Texels in the same column as a texel block such that $x_r = 0$ are not influenced by the color samples from words $W_{X_{Low}+1,Y_{Low}}$ and $W_{X_{Low}+1,Y_{Low}+1}$. Texels in the same row as a texel block such that $y_r = 0$ are not influenced by the color samples from words $W_{X_{Low},Y_{Low}+1}$ and $W_{X_{Low}+1,Y_{Low}+1}$. Therefore a single color sample at $C_{x,y}$ influences the interpolated color of all texels in the 7×7 region from $C_{x-3,y-3}$ to $C_{x+3,y+3}$ centered on the color sample.

Any 2×2 quad of texel values can be evaluated from a single set of four adjacent texel blocks. This means that the number of texel blocks accessed during bilinear filtering is no worse than the worst case of the self-contained texel blocks of other schemes.

For the red, green and blue channels, $C_{x,y}$ is a 5.4-bit fixed-point value whose bit pattern can be converted to an 8-bit normalized value, i.e. UNORM, as **Image {A,B}**$\{R,G,B\}_{x,y} = \left\lfloor \frac{C_{x,y}}{2} \right\rfloor + \left\lfloor \frac{C_{x,y}}{64} \right\rfloor$.

For the alpha channel, $C_{x,y}$ is a 4.4-bit fixed-point value whose bit pattern can be converted to an 8-bit normalized value as **Image {A,B}**$\{A\}_{x,y} = C_{x,y} + \left\lfloor \frac{C_{x,y}}{16} \right\rfloor$.

24.2.5 PVRTC1 4bpp color modulation

The final image is created by linearly interpolating between the **Image A** and **Image B** texels, using the modulation data for each pixel to determine the weighting. The modulation information is retrieved from word $W_{X_{Mod},Y_{Mod}}$ where $X_{Mod} = \left\lfloor \frac{x}{4} \right\rfloor$ and $Y_{Mod} = \left\lfloor \frac{y}{4} \right\rfloor$. The weight for the interpolation is derived from the 2 bits of the modulation data corresponding to the relevant pixel offset (x_{offset} = x - (4 × X_{Mod}), y_{offset} = y - (4 × Y_{Mod})), depending on the value of modulation flag M.

Standard bilinear (M = 0)		**Punch-through** (M = 1)		
Modulation bits	**Weight**	**Modulation bits**	**Weight**	**Alpha**
00	0	00	0	Normal
01	3	01	4	
10	5	10		“Punch-through”
11	8	11	8	Normal

Table 24.4: Modulation weights for PVRTC1 4bpp

$$Final\ color_{x,y} = \left\lfloor \frac{(\textbf{Image A}_{x,y} \times (8 - weight)) + (\textbf{Image B}_{x,y} \times weight)}{8} \right\rfloor$$

Equation 24.2: PVRTC image modulation

If punch-through mode is selected, and the modulation bits for a given pixel have a value of 0b10, the alpha value of the resulting color is 0x00. This is irrespective of the presence or values of any alpha channel in the input colors.

Note

For punch-through pixels, the *RGB* components are 50:50 blends of the corresponding pixels in the upscaled images. For this reason, with PVRTC1 4bpp, it is advised to not use pre-multiplied alpha textures, and to change the color of fully transparent areas to the average of the local neighborhood. PVRTexTool provides “alpha bleed” functionality to modify fully-transparent areas appropriately.

24.3 Format PVRTC1 2bpp

PVRTC1 2bpp has the same broad data layout as PVRTC1 4bpp, but instead uses an 8×4 bilinear upscale. It retains the constraint that images must have dimensions that are powers of two, with a minimum word width and height of two.

24.3.1 PVRTC1 2bpp word offset calculation

The inputs to the Morton order encoding for 2bpp mode are:

Let Xb be the number of bits used to express X — i.e. $Xb = \log_2\left(\max\left(\left\lceil\frac{width}{8}\right\rceil, 2\right)\right)$.

Let Yb be the number of bits used to express Y — i.e. $Yb = \log_2\left(\max\left(\left\lceil\frac{height}{4}\right\rceil, 2\right)\right)$.

24.3.2 PVRTC1 2bpp image reconstruction

For each channel C of each color (**Color A** and **Color B**), the interpolation proceeds as follows:

- For low-resolution image color channel $\mathbf{C}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$ stored in word $W_{X_{Low},Y_{Low}}$:
  - $X_{Low} = \left\lfloor\frac{x-4}{8}\right\rfloor$
  - $Y_{Low} = \left\lfloor\frac{y-2}{4}\right\rfloor$
- Using relative coordinates:
  - $x_r = (x-4) - \left(8 \times \left\lfloor\frac{x-4}{8}\right\rfloor\right) = (x-4) - (8 \times X_{Low})$
  - $y_r = (y-2) - \left(4 \times \left\lfloor\frac{y-2}{4}\right\rfloor\right) = (y-2) - (4 \times Y_{Low})$
- Coordinates wrap at the edges of the image (but see Section 24.2.3 for which words contain the color reconstruction samples for small images).
- An interpolation is performed which is mathematically equivalent to Equation 24.3.

$$C_{x,y} = \left(\mathbf{C}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}} \times (8-x_r) \times (4-y_r)\right) + \left(\mathbf{C}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}} \times x_r \times (4-y_r)\right)$$
$$+ \left(\mathbf{C}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1} \times (8-x_r) \times y_r\right) + \left(\mathbf{C}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1} \times x_r \times y_r\right)$$

Equation 24.3: PVRTC1 2bpp color channel interpolation

For the red, green and blue channels, $C_{x,y}$ is a 5.5-bit fixed-point value whose bit pattern can be converted to an 8-bit normalized value as **Image {A,B}**$\{R,G,B\}_{x,y} = \left\lfloor\frac{C_{x,y}}{4}\right\rfloor + \left\lfloor\frac{C_{x,y}}{128}\right\rfloor$.

For the alpha channel, $C_{x,y}$ is a 4.5-bit fixed-point value whose bit pattern can be converted to an 8-bit normalized value as **Image {A,B}**$\{A\}_{x,y} = \left\lfloor\frac{C_{x,y}}{2}\right\rfloor + \left\lfloor\frac{C_{x,y}}{32}\right\rfloor$.

24.3.3 PVRTC1 2bpp color modulation

The modulation data, retrieved from word $W_{X,Y}$ where $X_{Mod} = \left\lfloor \frac{x}{8} \right\rfloor$ and $Y_{Mod} = \left\lfloor \frac{y}{4} \right\rfloor$, are interpreted differently in order to accommodate the additional pixels. Each word holds the modulation data which corresponds to pixels that have offsets ($x_{offset} = x - 8 \times X_{Mod}$, $y_{offset} = y - 4 \times Y_{Mod}$).

In PVRTC1 2bpp, rather than changing the weight values as in PVRTC1 4bpp, the modulation flag M in bit 32 affects the modulation data layout. Optional flags in bit 0 and bit 20 of the modulation data may further affect the layout:

Bits 64..32: Color data and flags																															
Identical to PVRTC1 4bpp																															
Bits 31..0: Modulation data: direct encoding, 1 bit per pixel (modulation flag M = 0) for pixel offset (x, y)																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
7,3	6,3	5,3	4,3	3,3	2,3	1,3	0,3	7,2	6,2	5,2	4,2	3,2	2,2	1,2	0,2	7,1	6,1	5,1	4,1	3,1	2,1	1,1	0,1	7,0	6,0	5,0	4,0	3,0	2,0	1,0	0,0
Bits 31..0: Modulation data, checkerboard-interpolated encoding, samples for pixel offset (x, y), bits[1..0] (modulation flag M = 1, bit 0 flag = 0)																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
7,3		5,3		3,3		1,3		6,2		4,2		2,2		0,2		7,1		5,1		3,1		1,1		6,0		4,0		2,0		0,0	0
Bits 31..0: Modulation data, horizontally- or vertically-interpolated encoding, samples for pixel offset (x, y) (modulation flag M = 1, bit 0 flag = 1)																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
7,3		5,3		3,3		1,3		6,2		4,2	*F*	2,2		0,2		7,1		5,1		3,1		1,1		6,0		4,0		2,0		0,0	1

Table 24.5: Texel Data format for PVRTC1 2bpp compressed texture formats

If the modulation flag M is set to 0, each pixel only has a single bit of modulation data. The selected color is **Image A** for modulation data bit = 0, and **Image B** for modulation data bit = 1.

Modulation flag value *M*	**Mode**
0	Standard Bilinear, 1bpp modulation
1	Standard Bilinear, interpolated modulation

Table 24.6: Modulation modes for PVRTC1 2bpp

If the modulation flag M is set to 1, the pixels with 2-bit stored values have modulation weights equal to those of PVRTC1 4bpp for modulation mode 0, as shown in Table 24.4; to get translucent data, the **Color A** and **Color B** must be set accordingly.

The modulation data for the pixel at 0,0 (and when $\text{bit}_0 = 1$, the pixel at 2,4) is treated as if the value was duplicated — so the single-bit 0 encoding becomes 0b00, and 1 becomes 0b11, such that the texels always correspond to **Image A** or **Image B**.

For pixels without stored modulation data, bit_0 and flag F in bit 20 determine how they are reconstructed:

- If bit_0 is 0, the value is the mean of the weights of the four horizontally- and vertically-adjacent pixels, rounded to the nearest integer: $weight_{x,y} = \left\lfloor \frac{w(md(x-1,y)) + w(md(x,y-1)) + w(md(x+1,y)) + w(md(x,y+1)) + 2}{4} \right\rfloor$.
- If bit_0 is 1, and flag F is 1, the value is the mean of the weights of the two vertically-adjacent pixels, rounded to the nearest integer: $weight_{x,y} = \left\lfloor \frac{w(md(x,y-1)) + w(md(x,y+1)) + 1}{2} \right\rfloor$.
- If bit_0 is 1, and flag F is 0, the value is the mean of the weights from the horizontally-adjacent pixels, rounded to the nearest integer: $weight_{x,y} = \left\lfloor \frac{w(md(x-1,y)) + w(md(x+1,y)) + 1}{2} \right\rfloor$.

where *md(x,y)* is the modulation data for texel offset (x, y) and $w()$ is the weighting described in Table 24.4 for $M = 0$.

If an adjacent pixel's modulation value is not present in the current word, the value is obtained from the adjacent PVRTC word which does contain that pixel's modulation data, with the position wrapping to the other side of the image if necessary.

This weight is then applied to Equation 24.2.

24.4 Format PVRTC2 4bpp

PVRTC2 is the second revision of the PVRTC compression scheme, and shares most of its layout and interpretation. The PVRTC2 sections document the differences between the formats.

PVRTC2 images may have logical dimensions of any size greater than zero. If the logical size of the image is not a multiple of the interpolation size, the stored format uses the next-larger multiple. Any padding texels added by this resize are not accessed when reconstructing the image.

PVRTC2 words are not laid out in a reflected Morton order, instead they are laid out in a standard linear order.

The layout of PVRTC2 data words is very similar to that of PVRTC1, though there are two main differences:

- There is only a single opacity flag *Op* that affects both colors, rather than per-color flags.
- A *hard transition* flag *H* is included to aid representing color discontinuities, or diverse color distributions.

Bits 64..32: Color data and flags																															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Op	**Color B**															*H*	**Color A**														*M*
Bits 31..0: Modulation data bits [1..0] for pixel offset (*x*, *y*) — identical to PVRTC1 4bpp																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3,3		2,3		1,3		0,3		3,2		2,2		1,2		0,2		3,1		2,1		1,1		0,1		3,0		2,0		1,0		0,0	

Table 24.7: Texel Data format for PVRTC2 4bpp compressed texture formats

Color B — opaque color mode (opacity flag *Op* = 1)															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
1	Red					Green					Blue				
Color B — translucent color mode (opacity flag *Op* = 0)															
63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
0	Alpha			Red				Green				Blue			
Color A — opaque color mode (opacity flag *Op* = 1)															
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
H	Red					Green					Blue				*M*
Color A — translucent color mode (opacity flag *Op* = 0)															
47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
H	Alpha			Red				Green				Blue			*M*

Table 24.8: Data layout of color segments in a PVRTC2 word

There is one change to the interpretation of the color data relative to PVRTC1: as there is only one opacity flag for each PVRTC2 data word, to allow a local area to span the full alpha gamut when in translucent mode, **Color B**'s 3-bit alpha channel is expanded to four bits as $A^2A^1A^0 1$, instead of $A^2A^1A^0 0$.

24.4.1 Hard transition flag

The bilinear interpolation scheme of PVRTC1 usually works well as most areas of natural image textures are reasonably ‘continuous’. However at the boundaries of non-tiling textures, around sub-textures in texture atlases, or in some areas of hand-drawn graphics, this assumption can break down. To address these issues, PVRTC2 includes the *hard transition flag*, H.

Since it can be assumed that such discontinuities are more likely to be centered on boundaries of multiples of 4×4 texel regions, the hard transition flag H changes the behavior of the entire red-dotted region shown in Figure 24.4. This is a subset of the logical 4×4 pixel regions $\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$ through $\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}+1}$ that correspond to the modulation data stored in 64-bit data words $W_{X_{Mod},Y_{Mod}}$ through $W_{X_{Mod}+1,Y_{Mod}+1}$. The flag H for this hard transition region is stored in $W^{47}_{X_{Mod},Y_{Mod}}$.

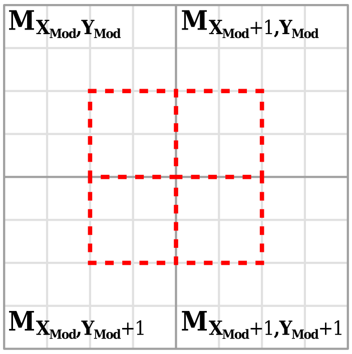

$\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$
$\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}}$
$\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}+1}$
$\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}+1}$

Figure 24.4: PVRTC2 hard transition subsets

The hard transition region is further subdivided into four smaller subregions, shown with the dotted 2×2 texel outlines in Figure 24.4, where it intersects the pixel regions $\mathbf{M}_{\mathbf{X_{Mod}},\mathbf{Y_{Mod}}}$ through $\mathbf{M}_{\mathbf{X_{Mod}}+1,\mathbf{Y_{Mod}}+1}$. The hard transition flag H, coupled with the relevant modulation flag M for the texel subregion, determines how the colors for each reconstructed pixel in the subregion are evaluated, as summarized in the table below.

Modulation flag M	**Hard transition flag** H	**Mode**
0	0	Standard bilinear
1	0	Punch-through alpha
0	1	Non-interpolated
1	1	Local palette

Table 24.9: Modulation modes for PVRTC2 4bpp

In ‘standard bilinear’ the modulation behaves as described for PVRTC1 4bpp.

In ‘punch-through alpha’, the modulation behaves in almost the same manner as the equivalent mode as for PVRTC1 4bpp except that for texels marked as ‘punch-through’; i.e. using the 2-bit encoding 0b10, the output texel is set to transparent black, which may be better suited to pre-multiplied texture formats.

The remaining two modes are described below.

24.4.2 Non-interpolated

In the non-interpolated mode, the **A** and **B** base colors are not bilinearly interpolated in the affected regions. Instead, the colors for the word encapsulating each particular pixel are used directly, in the sense that the stored colors are expanded, where necessary, via bit replication to an *ARGB*:4555 format and then again, by a second bit replication, to *ARGB*:8888. The modulation encodings are interpreted in the same manner as for the “standard bilinear” weights, and the colors blended, as before, with Equation 24.2.

24.4.3 Local palette mode

In local palette mode, the hard transition region is no longer reconstructed by interpolating the upscaled images. Instead, the eight distinct colors from each surrounding word make up a local palette from which colors are selected.

Denoting **Color B** and **Color A** from words $W_{X_{Low},Y_{Low}}$ through $W_{X_{Low}+1,Y_{Low}+1}$ as described above, the following colors are available: $\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$, $\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$, $\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$, $\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$, $\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$, $\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$, $\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$ and $\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$.

Whilst 8 distinct colors exist in each of those four words, only two bits of modulation data are available for each pixel. Subsequently, each pixel at offset $(x_r = (x-2)-(4\times X_{Low}), y_r = (y-2)-(4\times Y_{Low}))$ relative to start of the hard transition region has access to a subset of the palette as follows:

Modulation bits	**0,0**	**1,0**	**2,0**	**3,0**
0	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$
1	$\left\lfloor\frac{5\times\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}+3\times\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}}{8}\right\rfloor$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$
2	$\left\lfloor\frac{3\times\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}+5\times\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}}{8}\right\rfloor$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
3	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
Modulation bits	**0,1**	**1,1**	**2,1**	**3,1**
0	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$
1	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$
2	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
3	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
Modulation bits	**0,2**	**1,2**	**2,2**	**3,2**
0	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$
1	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$
2	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
3	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$
Modulation bits	**0,3**	**1,3**	**2,3**	**3,3**
0	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$
1	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}+1}$
2	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{A}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$
3	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}},\mathbf{Y_{Low}}+1}$	$\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$

Table 24.10: Color mappings in local palette mode for PVRTC2 4bpp

Note

The entry for offset 0,0 is interpolated as per PVRTC's standard bilinear filtering mode. It will thus only use colors from word $W_{X_{Low},Y_{Low}}$.

The local palette mode shares with the other modes of PVRTC2 the property that the column $x_r = 0$ has no contribution from words $W_{X_{Low}+1,Y_{Low}}$ and $W_{X_{Low}+1,Y_{Low}+1}$, and that row $y_r = 0$ has no contribution from words $W_{X_{Low},Y_{Low}+1}$ and $W_{X_{Low}+1,Y_{Low}+1}$. Therefore any 2×2 quad of texel values, required for example by bilinear filtering, can be evaluated from a single set of four adjacent texel blocks.

- The modulation values correspond to the same entry in the list for each pixel above. For instance, a modulation value of 3 (bit pattern 11) for pixel position 0,1 (which is offset 2,3 relative to the top left of block P) would correspond to color $\mathbf{B}_{\mathbf{X_{Low}}+1,\mathbf{Y_{Low}}}$ being selected.
- The stored color values are first expanded, *where necessary*, to *ARGB*:4555 (via bit replication for *R*, *G*, or *B* and via padding for Alpha) and then from 4555 to *ARGB*:8888, again by bit replication. For example,
  - A three-bit alpha value for **Color A**, $A^2A^1A^0$, is initially mapped to $A^2A^1A^00$, and then to $A^2A^1A^00\,A^2A^1A^00$
  - A four-bit color value, $C^3C^2C^1C^0$, is first mapped to $C^3C^2C^1C^0C^3$ and then subsequently to $C^3C^2C^1C^0C^3C^3C^2C^1$

24.5 Format PVRTC2 2bpp

PVRTC2 2bpp data layout has color data laid out identically to PVRTC2 4bpp, and modulation data equivalent to PVRTC1 2bpp. The only difference between the PVRTC1 and PVRTC2 variants is the addition of the hard transition flag *H* and the single opacity flag *Op*, as specified in the PVRTC2 4bpp format.

Bits 63-32: Color data and flags
Identical to PVRTC2 4bpp
Bits 31-0: Modulation data
Identical to PVRTC1 2bpp

Table 24.11: Texel Data format for PVRTC2 2bpp compressed texture formats

Color values are interpreted in the same manner as for the PVRTC2 4bpp format.

The 2bpp variation of PVRTC2 is slightly simpler than the 4bpp, in that it only uses the non-interpolated mode — no local palette mode exists.

Modulation flag *M*	**Hard transition** *H*	Mode
0	0	Standard bilinear, 1bpp modulation
1	0	Standard bilinear, interpolated modulation
0	1	Non-interpolated, 1bpp modulation
1	1	Non-interpolated, interpolated modulation

Table 24.12: Modulation modes for PVRTC2 2bpp

If the hard transition flag *H* for PVRTC2 2bpp is equal to 0, the format is interpreted in the same manner as the PVRTC1 2bpp format.

When the hard transition flag *H* for PVRTC2 2bpp is equal to 1, the initial bilinear interpolation of block colors across the hard transition region is skipped as for PVRTC2 4bpp. Subsequently, the format is interpreted in the same way as the PVRTC1 2bpp format.

Note

When interpreting modulation data in the interpolated modulation mode, the hard transition flag has no effect on this — the modulation values are always interpolated across PVRTC words.

Chapter 25

Universal ASTC Compressed Texture Images

UASTC was created by Rich Geldreich, who has placed the design in the public domain.

25.1 Introduction

UASTC is a 19-mode 4×4 pixel LDR-only subset of the ASTC specification with a simpler 128-bit block format. It can be quickly, losslessly transcoded to the standard ASTC block format, quickly transcoded to BC7 with very low quality loss (within around .75-1.5 *RGB* dB PSNR), or re-encoded to high quality ETC1, ETC1 with A8, or BC1-5 with a small amount of per-pixel work. There are 9 opaque modes, 1 solid-color mode, and 9 modes with alpha support. These UASTC modes each map to one of 6 BC7 modes (all except 0 and 4).

UASTC is the first high quality universal (or virtual) block-based texture format that supports block partitioning along with the ability to be efficiently transcoded to multiple GPU texture formats. Transcoding can either be done using the CPU or with a GPU compute shader. Transcoding UASTC to ASTC and BC7 do not involve any pixel-level operations. UASTC's fields directly correspond to ASTC's fields whenever possible.

The UASTC block format has hint bits to accelerate UASTC transcoding to various texture formats. There are up to two BC1 hint bits per block which direct the UASTC→BC1 transcoder to reuse the UASTC endpoint and/or weight indices (appropriately mapped) for faster real-time compression. On average ~60% of UASTC blocks don't need PCA, and ~30% don't need real-time BC1 encoding at all. There are also hint bits to accelerate transcoding to high quality ETC1 and ETC2 EAC A8.

25.2 Bitstream format

Bits are described in order from the start of the block (the first byte's least-significant bit) working "down" towards bit 127. Each block may contain the following fields, the exact layout of which depends on the *Mode Index* value.

- **MODE** Value that defines the block's layout and decoding strategy.
- ***R*, *G*, *B*, and *A*** Solid color value (only for *Mode Index* 8).
- **BC1H0 and BC1H1** BC1 transcoding acceleration hints. See Transcoding to BC1 for details.
- **ETC*** ETC1/EAC transcoding acceleration hints. See Transcoding to ETC for details.
- **CSEL** Color Component Selector field. Indicates which color channel uses the second set of interpolation weights (only for dual-plane modes).
- **PAT** Index into a mode-specific partition pattern table. There are three tables and 60 total partition patterns.
- **ET[]** Packed endpoint trits values. Depending on the *Mode Index*, there could be 0, 2, or 4 **ET** elements.

- **EQ[]** Packed endpoint quints values. Depending on the *Mode Index*, there could be 0, 2, or 4 **EQ** elements.
- ***RL0*, *RH0*, *RL1*, *RH1*, *RL2*, *RH2*** Red endpoint bits.
- ***GL0*, *GH0*, *GL1*, *GH1*, *GL2*, *GH2*** Green endpoint bits.
- ***BL0*, *BH0*, *BL1*, *BH1*, *BL2*, *BH2*** Blue endpoint bits.
- ***AL0*, *AH0*, *AL1*, *AH1*** Alpha endpoint bits.
- ***LL0*, *LH0*, *LL1*, *LH1*** Luminance endpoint bits.
- **WEIGHTS0[i] and WEIGHTS1[i]** Weight indices for planes 0 and 1, texel i = 4 × y + x. WEIGHTS1 is present only in dual-plane modes. Each array has 16 elements.

Note

Just like BC7, the first weight index of each subset's "anchor" pixel always has a most-significant bit of 0, so these weights can be encoded with one fewer bit than the others. In dual-plane modes (which are always one subset), the first two weight indices must have a most-significant bit of 0.

Unassigned bits must be zero.

25.3 Mode Index

A Huffman-coded mode field is always first and is stored starting at bit 0 of the block (bit 0 of byte 0); it takes from 2 to 7 bits. The *Mode Index* range is [0..19]. The last *Mode Index* (19) is reserved for possible future expansion and should be decoded to the error color (255, 0, 255, 255). The encoding of each *Mode Index* is defined in Table 25.1.

Mode Bits	*Mode Value*	**Encoding Bit Length**	*Mode Index*
xxxxx00	0x00	2	11
xxxx010	0x02	3	10
xxxx110	0x06	3	12
xxx0001	0x01	4	0
xxx1001	0x09	4	18
xx00011	0x03	5	3
xx00111	0x07	5	7
xx01011	0x0B	5	5
xx01101	0x0D	5	14
xx01111	0x0F	5	9
xx10011	0x13	5	4
xx10111	0x17	5	8
xx11011	0x1B	5	6
xx11101	0x1D	5	2
xx11111	0x1F	5	13
x010101	0x15	6	16
x100101	0x25	6	17
x110101	0x35	6	1
0000101	0x05	7	15
1000101	0x45	7	19

Table 25.1: UASTC *Mode Index* encoding

If the *Mode Bits* do not match any *Mode Index* value, the block is invalid and decodes to the error color (255, 0, 255, 255).

25.4 Solid color blocks

Blocks representing solid color use *Mode Index* 8 and are encoded in the consecutive bit allocations shown from top to bottom in Table 25.2, starting at the least significant bit in the block.

Value	**Bits**
MODE	5 (= 0x17)
R	8
G	8
B	8
A	8
ETC1D	1
ETC1I	3
ETC1S	2
ETC1R	5
ETC1G	5
ETC1B	5

Table 25.2: UASTC bit interpretations for solid color blocks

If ETC1D is 0, indicating that the corresponding ETC1 block encoding would use individual rather than differential blocks, the unused top bit of each of ETC1R, ETC1G, and ETC1B should be set to 0.

25.5 Interpolated blocks

Interpolated blocks have different layouts depending on the *Mode Index*.

25.5.1 Configuration

The assignment of bits to configuration values in each blockmode is shown in Table 25.3. For table values read top to bottom, the corresponding number of bits are stored consecutively in the block, starting with the least-significant bit.

Mode Index	**Value**	**Bits**
0..7, 9..18	MODE	2-7
0..7, 9..18	BC1H0	1
0..7, 9, 13..18	BC1H1	1
0..7, 9..18	ETC1F	1
0..7, 9..18	ETC1D	1
0..7, 9..18	ETCI0	3
0..7, 9..18	ETCI1	3
0..9, 13..18	ETCBI	5
9..17	ETC2T	4
9..17	ETC2M	4
3	PAT	4
2, 4, 7, 9, 16	PAT	5
6, 11, 13	CSEL	2

Table 25.3: Block configuration bits

25.5.2 Endpoint bits

The bits which encode endpoints immediately follow the configuration bits.

25.5.2.1 *num_ebits*

The number of bits, *num_ebits*, used to encode endpoints depends on the decoded *Mode Index* value as shown in Table 25.4.

Mode Index	0	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18
num_ebits	6	8	4	2	3	8	5	3	4	4	4	6	8	8	8	8	8	5

Table 25.4: Endpoint bits for each mode

25.5.2.2 Endpoint encoding

The assignment of bits to endpoint values in each block mode is shown in Table 25.5 and Table 25.6. For table values read top to bottom, the corresponding number of bits are stored consecutively in the block, starting with the least-significant bit after the configuration bits.

Mode Index	**Value**	**Bits**	***Mode Index***	**Value**	**Bits**	***Mode Index***	**Value**	**Bits**	***Mode Index***	**Value**	**Bits**
4, 6, 7	EQ[0]	7	0	ET[0]	8	3	ET[0]	8	10..12	ET[0]	8
4, 6, 7	EQ[1]	7	0	ET[1]	2	3	ET[1]	8	10..12	ET[1]	5
4, 7	EQ[2]	7				3	ET[2]	8			
4, 7	EQ[3]	7				3	ET[3]	5			

Table 25.5: Block endpoint description prefix

Mode Index	**Value**	**Bits**	***Mode Index***	**Value**	**Bits**
0..7, 9..14, 18	*RL0*	*num_ebits*	15..17	*LL0*	*num_ebits*
0..7, 9..14, 18	*RH0*	*num_ebits*	15..17	*LH0*	*num_ebits*
0..7, 9..14, 18	*GL0*	*num_ebits*			
0..7, 9..14, 18	*GH0*	*num_ebits*			
0..7, 9..14, 18	*BL0*	*num_ebits*			
0..7, 9..14, 18	*BH0*	*num_ebits*			
9..14	*AL0*	*num_ebits*	15..17	*AL0*	*num_ebits*
9..14	*AH0*	*num_ebits*	15..17	*AH0*	*num_ebits*
2..4, 7, 9	*RL1*	*num_ebits*	16	*LL1*	*num_ebits*
2..4, 7, 9	*RH1*	*num_ebits*	16	*LH1*	*num_ebits*
2..4, 7, 9	*GL1*	*num_ebits*			
2..4, 7, 9	*GH1*	*num_ebits*			
2..4, 7, 9	*BL1*	*num_ebits*			
2..4, 7, 9	*BH1*	*num_ebits*			
3	*RL2*	*num_ebits*			
3	*RH2*	*num_ebits*			
3	*GL2*	*num_ebits*			
3	*GH2*	*num_ebits*			
3	*BL2*	*num_ebits*			
3	*BH2*	*num_ebits*			
9	*AL1*	*num_ebits*	16	*AL1*	*num_ebits*
9	*AH1*	*num_ebits*	16	*AH1*	*num_ebits*

Table 25.6: Block endpoint description suffix

25.5.3 Weights

Weight values are stored per texel, and indicate an interpolation between the corresponding endpoints. This section immediately follows the endpoint bits. Weights are stored in raster order: increasing x order most frequently, then increasing y order.

25.5.3.1 *num_wbits*

The value of *num_wbits* depends on the *Mode Index* as shown in Table 25.7.

Mode Index	0	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18
num_wbits	4	2	3	2	2	3	2	2	2	4	2	3	1	2	4	2	2	5

Table 25.7: UASTC weight bits for each mode

25.5.3.2 *anchor_indices*

As in the *index bits* of BC7, one bit of the weight value of one texel can be treated as implicit by swapping the weight values as required. The texel chosen is at the *anchor_index* for the pattern.

When *Mode Index* is 2, 4, 9, or 16, the value of *anchor_indices* depends on the value encoded in *PAT* as shown in Table 25.8.

PAT	0	1	2	3	4	5	6	7	8	9
anchor_indices	0,2	0,3	1,0	0,3	7,0	0,2	3,0	7,0	0,11	2,0
PAT	10	11	12	13	14	15	16	17	18	19
anchor_indices	0,7	11,0	3,0	8,0	0,4	12,0	1,0	8,0	0,1	0,2
PAT	20	21	22	23	24	25	26	27	28	29
anchor_indices	0,4	8,0	1,0	0,2	4,0	0,1	4,0	1,0	4,0	1,0

Table 25.8: UASTC anchor indices for the first and second partition for *Mode Indices* 2, 4, 9, and 16

When *Mode Index* is 3, the value of *anchor_indices* depends on the value encoded in *PAT* as shown in Table 25.9.

PAT	0	1	2	3	4	5	6	7	8	9	10
anchor_indices	0,8,10	8,0,12	4,0,12	8,0,4	3,0,2	0,1,3	0,2,1	1,9,0	1,2,0	4,0,8	0,6,2

Table 25.9: UASTC anchor indices for the first, second, and third partition for *Mode Index* 3

When *Mode Index* is 7, the value of *anchor_indices* depends on the value encoded in *PAT* as shown in Table 25.10.

PAT	0	1	2	3	4	5	6	7	8	9
anchor_indices	0,4	0,2	2,0	0,7	8,0	0,1	0,3	0,1	2,0	0,1
PAT	10	11	12	13	14	15	16	17	18	
anchor_indices	0,8	2,0	0,1	0,7	12,0	2,0	9,0	0,2	4,0	

Table 25.10: UASTC anchor indices for the first and second partition for *Mode Index* 7

Note that the *anchor_indices* correspond to the first texel of each partition in raster order. The texels corresponding to *anchor_indices* are highlit in Table 25.26, Table 25.27 and Table 25.28.

If the value encoded in *PAT* is greater than the maximum value listed in the corresponding tables for these formats, no further processing is performed and the block must be decoded to the error color (255, 0, 255, 255).

In other modes, the (single) *anchor index* is always 0.

25.5.3.3 Weight encoding

The assignment of bits to weight values in each block mode is shown in Table 25.11. For table values read top to bottom, the corresponding number of bits are stored consecutively in the block, starting with the least-significant bit after the configuration bits.

for (i = 0; i < 16; i++) {		Value	Bits
	Mode Index $\in$ 0-7, 9-18 i $\in$ *anchor_indices*	WEIGHTS0[i]	*num_wbits* - 1
	Mode Index $\in$ 6,11,13,17 i $\in$ *anchor_indices*	WEIGHTS1[i]	*num_wbits* - 1
	Mode Index $\in$ 0-7, 9-18 i $\notin$ *anchor_indices*	WEIGHTS0[i]	*num_wbits*
	Mode Index $\in$ 6,11,13,17 i $\notin$ *anchor_indices*	WEIGHTS1[i]	*num_wbits*
}			

Table 25.11: UASTC weight bit assignment

25.6 UASTC mode encoding summary (informative)

A summary of the bit allocations in each UASTC mode can be found in Table 25.12 through Table 25.17. Most mode encodings are followed by weight values of an indicated number of bits per texel, the arrangement of which may depend on the *PAT* field. Dual-plane modes are indicated by “×2” in the weight description. Note that one bit per partition is reclaimed from the weights according to the *anchor_indices*. Any unassigned bits (following the weights, if present) are set to 0.

Mode Index	11	10	12	0	18	3	7	5	14	9
0	0	0	0	1	1	1	1	1	1	1
1	0	1	1	0	0	1	1	1	0	1
2	BC1H0	0	1	0	0	0	1	0	1	1
3	ETC1F	BC1H0	BC1H0	0	1	0	0	1	1	1
4	ETC1D	ETC1F	ETC1F	BC1H0	BC1H0	0	0	0	0	0
5	ETCI0^{0}	ETC1D	ETC1D	BC1H1	BC1H1	BC1H0	BC1H0	BC1H0	BC1H0	BC1H0
6	ETCI0^{1}	ETCI0^{0}	ETCI0^{0}	ETC1F	ETC1F	BC1H1	BC1H1	BC1H1	BC1H1	BC1H1
7	ETCI0^{2}	ETCI0^{1}	ETCI0^{1}	ETC1D	ETC1D	ETC1F	ETC1F	ETC1F	ETC1F	ETC1F
8	ETCI1^{0}	ETCI0^{2}	ETCI0^{2}	ETCI0^{0}	ETCI0^{0}	ETC1D	ETC1D	ETC1D	ETC1D	ETC1D
9	ETCI1^{1}	ETCI1^{0}	ETCI1^{0}	ETCI0^{1}	ETCI0^{1}	ETCI0^{0}	ETCI0^{0}	ETCI0^{0}	ETCI0^{0}	ETCI0^{0}
10	ETCI1^{2}	ETCI1^{1}	ETCI1^{1}	ETCI0^{2}	ETCI0^{2}	ETCI0^{1}	ETCI0^{1}	ETCI0^{1}	ETCI0^{1}	ETCI0^{1}
11	ETC2T^{0}	ETCI1^{2}	ETCI1^{2}	ETCI1^{0}	ETCI1^{0}	ETCI0^{2}	ETCI0^{2}	ETCI0^{2}	ETCI0^{2}	ETCI0^{2}
12	ETC2T^{1}	ETC2T^{0}	ETC2T^{0}	ETCI1^{1}	ETCI1^{1}	ETCI1^{0}	ETCI1^{0}	ETCI1^{0}	ETCI1^{0}	ETCI1^{0}
13	ETC2T^{2}	ETC2T^{1}	ETC2T^{1}	ETCI1^{2}	ETCI1^{2}	ETCI1^{1}	ETCI1^{1}	ETCI1^{1}	ETCI1^{1}	ETCI1^{1}
14	ETC2T^{3}	ETC2T^{2}	ETC2T^{2}	ETCBI^{0}	ETCBI^{0}	ETCI1^{2}	ETCI1^{2}	ETCI1^{2}	ETCI1^{2}	ETCI1^{2}
15	ETC2M^{0}	ETC2T^{3}	ETC2T^{3}	ETCBI^{1}	ETCBI^{1}	ETCBI^{0}	ETCBI^{0}	ETCBI^{0}	ETCBI^{0}	ETCBI^{0}
16	ETC2M^{1}	ETC2M^{0}	ETC2M^{0}	ETCBI^{2}	ETCBI^{2}	ETCBI^{1}	ETCBI^{1}	ETCBI^{1}	ETCBI^{1}	ETCBI^{1}
17	ETC2M^{2}	ETC2M^{1}	ETC2M^{1}	ETCBI^{3}	ETCBI^{3}	ETCBI^{2}	ETCBI^{2}	ETCBI^{2}	ETCBI^{2}	ETCBI^{2}
18	ETC2M^{3}	ETC2M^{2}	ETC2M^{2}	ETCBI^{4}	ETCBI^{4}	ETCBI^{3}	ETCBI^{3}	ETCBI^{3}	ETCBI^{3}	ETCBI^{3}
19	CSEL^{0}	ETC2M^{3}	ETC2M^{3}	ET[0]^{0}	$RL0^{0}$	ETCBI^{4}	ETCBI^{4}	ETCBI^{4}	ETCBI^{4}	ETCBI^{4}
20	CSEL^{1}	ET[0]^{0}	ET[0]^{0}	ET[0]^{1}	$RL0^{1}$	PAT^{0}	PAT^{0}	$RL0^{0}$	ETC2T^{0}	ETC2T^{0}
21	ET[0]^{0}	ET[0]^{1}	ET[0]^{1}	ET[0]^{2}	$RL0^{2}$	PAT^{1}	PAT^{1}	$RL0^{1}$	ETC2T^{1}	ETC2T^{1}
22	ET[0]^{1}	ET[0]^{2}	ET[0]^{2}	ET[0]^{3}	$RL0^{3}$	PAT^{2}	PAT^{2}	$RL0^{2}$	ETC2T^{2}	ETC2T^{2}
23	ET[0]^{2}	ET[0]^{3}	ET[0]^{3}	ET[0]^{4}	$RL0^{4}$	PAT^{3}	PAT^{3}	$RL0^{3}$	ETC2T^{3}	ETC2T^{3}
24	ET[0]^{3}	ET[0]^{4}	ET[0]^{4}	ET[0]^{5}	$RH0^{0}$	ET[0]^{0}	PAT^{4}	$RL0^{4}$	ETC2M^{0}	ETC2M^{0}
25	ET[0]^{4}	ET[0]^{5}	ET[0]^{5}	ET[0]^{6}	$RH0^{1}$	ET[0]^{1}	EQ[0]^{0}	$RL0^{5}$	ETC2M^{1}	ETC2M^{1}
26	ET[0]^{5}	ET[0]^{6}	ET[0]^{6}	ET[0]^{7}	$RH0^{2}$	ET[0]^{2}	EQ[0]^{1}	$RL0^{6}$	ETC2M^{2}	ETC2M^{2}
27	ET[0]^{6}	ET[0]^{7}	ET[0]^{7}	ET[1]^{0}	$RH0^{3}$	ET[0]^{3}	EQ[0]^{2}	$RL0^{7}$	ETC2M^{3}	ETC2M^{3}
28	ET[0]^{7}	ET[1]^{0}	ET[1]^{0}	ET[1]^{1}	$RH0^{4}$	ET[0]^{4}	EQ[0]^{3}	$RH0^{0}$	$RL0^{0}$	PAT^{0}
29	ET[1]^{0}	ET[1]^{1}	ET[1]^{1}	$RL0^{0}$	$GL0^{0}$	ET[0]^{5}	EQ[0]^{4}	$RH0^{1}$	$RL0^{1}$	PAT^{1}
30	ET[1]^{1}	ET[1]^{2}	ET[1]^{2}	$RL0^{1}$	$GL0^{1}$	ET[0]^{6}	EQ[0]^{5}	$RH0^{2}$	$RL0^{2}$	PAT^{2}
31	ET[1]^{2}	ET[1]^{3}	ET[1]^{3}	$RL0^{2}$	$GL0^{2}$	ET[0]^{7}	EQ[0]^{6}	$RH0^{3}$	$RL0^{3}$	PAT^{3}
32	ET[1]^{3}	ET[1]^{4}	ET[1]^{4}	$RL0^{3}$	$GL0^{3}$	ET[1]^{0}	EQ[1]^{0}	$RH0^{4}$	$RL0^{4}$	PAT^{4}
33	ET[1]^{4}	$RL0^{0}$	$RL0^{0}$	$RL0^{4}$	$GL0^{4}$	ET[1]^{1}	EQ[1]^{1}	$RH0^{5}$	$RL0^{5}$	$RL0^{0}$

Table 25.12: UASTC mode encoding bits 0..33 (1/2)

Mode Index	11	10	12	0	18	3	7	5	14	9
34	$RL0^{0}$	$RL0^{1}$	$RL0^{1}$	$RL0^{5}$	$GH0^{0}$	ET[1]^{2}	EQ[1]^{2}	$RH0^{6}$	$RL0^{6}$	$RL0^{1}$
35	$RL0^{1}$	$RL0^{2}$	$RL0^{2}$	$RH0^{0}$	$GH0^{1}$	ET[1]^{3}	EQ[1]^{3}	$RH0^{7}$	$RL0^{7}$	$RL0^{2}$
36	$RL0^{2}$	$RL0^{3}$	$RL0^{3}$	$RH0^{1}$	$GH0^{2}$	ET[1]^{4}	EQ[1]^{4}	$GL0^{0}$	$RH0^{0}$	$RL0^{3}$
37	$RL0^{3}$	$RH0^{0}$	$RL0^{4}$	$RH0^{2}$	$GH0^{3}$	ET[1]^{5}	EQ[1]^{5}	$GL0^{1}$	$RH0^{1}$	$RH0^{0}$
38	$RH0^{0}$	$RH0^{1}$	$RL0^{5}$	$RH0^{3}$	$GH0^{4}$	ET[1]^{6}	EQ[1]^{6}	$GL0^{2}$	$RH0^{2}$	$RH0^{1}$
39	$RH0^{1}$	$RH0^{2}$	$RH0^{0}$	$RH0^{4}$	$BL0^{0}$	ET[1]^{7}	EQ[2]^{0}	$GL0^{3}$	$RH0^{3}$	$RH0^{2}$
40	$RH0^{2}$	$RH0^{3}$	$RH0^{1}$	$RH0^{5}$	$BL0^{1}$	ET[2]^{0}	EQ[2]^{1}	$GL0^{4}$	$RH0^{4}$	$RH0^{3}$
41	$RH0^{3}$	$GL0^{0}$	$RH0^{2}$	$GL0^{0}$	$BL0^{2}$	ET[2]^{1}	EQ[2]^{2}	$GL0^{5}$	$RH0^{5}$	$GL0^{0}$
42	$GL0^{0}$	$GL0^{1}$	$RH0^{3}$	$GL0^{1}$	$BL0^{3}$	ET[2]^{2}	EQ[2]^{3}	$GL0^{6}$	$RH0^{6}$	$GL0^{1}$
43	$GL0^{1}$	$GL0^{2}$	$RH0^{4}$	$GL0^{2}$	$BL0^{4}$	ET[2]^{3}	EQ[2]^{4}	$GL0^{7}$	$RH0^{7}$	$GL0^{2}$
44	$GL0^{2}$	$GL0^{3}$	$RH0^{5}$	$GL0^{3}$	$BH0^{0}$	ET[2]^{4}	EQ[2]^{5}	$GH0^{0}$	$GL0^{0}$	$GL0^{3}$
45	$GL0^{3}$	$GH0^{0}$	$GL0^{0}$	$GL0^{4}$	$BH0^{1}$	ET[2]^{5}	EQ[2]^{6}	$GH0^{1}$	$GL0^{1}$	$GH0^{0}$
46	$GH0^{0}$	$GH0^{1}$	$GL0^{1}$	$GL0^{5}$	$BH0^{2}$	ET[2]^{6}	EQ[3]^{0}	$GH0^{2}$	$GL0^{2}$	$GH0^{1}$
47	$GH0^{1}$	$GH0^{2}$	$GL0^{2}$	$GH0^{0}$	$BH0^{3}$	ET[2]^{7}	EQ[3]^{1}	$GH0^{3}$	$GL0^{3}$	$GH0^{2}$
48	$GH0^{2}$	$GH0^{3}$	$GL0^{3}$	$GH0^{1}$	$BH0^{4}$	ET[3]^{0}	EQ[3]^{2}	$GH0^{4}$	$GL0^{4}$	$GH0^{3}$
49	$GH0^{3}$	$BL0^{0}$	$GL0^{4}$	$GH0^{2}$	Wt$^{0..4}$	ET[3]^{1}	EQ[3]^{3}	$GH0^{5}$	$GL0^{5}$	$BL0^{0}$
50	$BL0^{0}$	$BL0^{1}$	$GL0^{5}$	$GH0^{3}$	:	ET[3]^{2}	EQ[3]^{4}	$GH0^{6}$	$GL0^{6}$	$BL0^{1}$
51	$BL0^{1}$	$BL0^{2}$	$GH0^{0}$	$GH0^{4}$		ET[3]^{3}	EQ[3]^{5}	$GH0^{7}$	$GL0^{7}$	$BL0^{2}$
52	$BL0^{2}$	$BL0^{3}$	$GH0^{1}$	$GH0^{5}$		ET[3]^{4}	EQ[3]^{6}	$BL0^{0}$	$GH0^{0}$	$BL0^{3}$
53	$BL0^{3}$	$BH0^{0}$	$GH0^{2}$	$BL0^{0}$		$RL0^{0}$	$RL0^{0}$	$BL0^{1}$	$GH0^{1}$	$BH0^{0}$
54	$BH0^{0}$	$BH0^{1}$	$GH0^{3}$	$BL0^{1}$		$RL0^{1}$	$RL0^{1}$	$BL0^{2}$	$GH0^{2}$	$BH0^{1}$
55	$BH0^{1}$	$BH0^{2}$	$GH0^{4}$	$BL0^{2}$		$RH0^{0}$	$RL0^{2}$	$BL0^{3}$	$GH0^{3}$	$BH0^{2}$
56	$BH0^{2}$	$BH0^{3}$	$GH0^{5}$	$BL0^{3}$		$RH0^{1}$	$RH0^{0}$	$BL0^{4}$	$GH0^{4}$	$BH0^{3}$
57	$BH0^{3}$	$AL0^{0}$	$BL0^{0}$	$BL0^{4}$		$GL0^{0}$	$RH0^{1}$	$BL0^{5}$	$GH0^{5}$	$AL0^{0}$
58	$AL0^{0}$	$AL0^{1}$	$BL0^{1}$	$BL0^{5}$		$GL0^{1}$	$RH0^{2}$	$BL0^{6}$	$GH0^{6}$	$AL0^{1}$
59	$AL0^{1}$	$AL0^{2}$	$BL0^{2}$	$BH0^{0}$		$GH0^{0}$	$GL0^{0}$	$BL0^{7}$	$GH0^{7}$	$AL0^{2}$
60	$AL0^{2}$	$AL0^{3}$	$BL0^{3}$	$BH0^{1}$		$GH0^{1}$	$GL0^{1}$	$BH0^{0}$	$BL0^{0}$	$AL0^{3}$
61	$AL0^{3}$	$AH0^{0}$	$BL0^{4}$	$BH0^{2}$		$BL0^{0}$	$GL0^{2}$	$BH0^{1}$	$BL0^{1}$	$AH0^{0}$
62	$AH0^{0}$	$AH0^{1}$	$BL0^{5}$	$BH0^{3}$		$BL0^{1}$	$GH0^{0}$	$BH0^{2}$	$BL0^{2}$	$AH0^{1}$
63	$AH0^{1}$	$AH0^{2}$	$BH0^{0}$	$BH0^{4}$		$BH0^{0}$	$GH0^{1}$	$BH0^{3}$	$BL0^{3}$	$AH0^{2}$
64	$AH0^{2}$	$AH0^{3}$	$BH0^{1}$	$BH0^{5}$		$BH0^{1}$	$GH0^{2}$	$BH0^{4}$	$BL0^{4}$	$AH0^{3}$
65	$AH0^{3}$	Wt$^{0..3}$	$BH0^{2}$	Wt$^{0..3}$		$RL1^{0}$	$BL0^{0}$	$BH0^{5}$	$BL0^{5}$	$RL1^{0}$
66	Wt$^{0..1}\times$2	:	$BH0^{3}$	:		$RL1^{1}$	$BL0^{1}$	$BH0^{6}$	$BL0^{6}$	$RL1^{1}$
67	:		$BH0^{4}$			$RH1^{0}$	$BL0^{2}$	$BH0^{7}$	$BL0^{7}$	$RL1^{2}$

Table 25.13: UASTC mode encoding bits 34..67 (1/2)

Mode Index	11	10	12	0	18	3	7	5	14	9
68			$BH0^{5}$			$RH1^{1}$	$BH0^{0}$	$\mathrm{Wt}^{0..2}$	$BH0^{0}$	$RL1^{3}$
69			$AL0^{0}$			$GL1^{0}$	$BH0^{1}$		$BH0^{1}$	$RH1^{0}$
70			$AL0^{1}$			$GL1^{1}$	$BH0^{2}$		$BH0^{2}$	$RH1^{1}$
71			$AL0^{2}$			$GH1^{0}$	$RL1^{0}$		$BH0^{3}$	$RH1^{2}$
72			$AL0^{3}$			$GH1^{1}$	$RL1^{1}$		$BH0^{4}$	$RH1^{3}$
73			$AL0^{4}$			$BL1^{0}$	$RL1^{2}$		$BH0^{5}$	$GL1^{0}$
74			$AL0^{5}$			$BL1^{1}$	$RH1^{0}$		$BH0^{6}$	$GL1^{1}$
75			$AH0^{0}$			$BH1^{0}$	$RH1^{1}$		$BH0^{7}$	$GL1^{2}$
76			$AH0^{1}$			$BH1^{1}$	$RH1^{2}$		$AL0^{0}$	$GL1^{3}$
77			$AH0^{2}$			$RL2^{0}$	$GL1^{0}$		$AL0^{1}$	$GH1^{0}$
78			$AH0^{3}$			$RL2^{1}$	$GL1^{1}$		$AL0^{2}$	$GH1^{1}$
79			$AH0^{4}$			$RH2^{0}$	$GL1^{2}$		$AL0^{3}$	$GH1^{2}$
80			$AH0^{5}$			$RH2^{1}$	$GH1^{0}$		$AL0^{4}$	$GH1^{3}$
81			$\mathrm{Wt}^{0..2}$			$GL2^{0}$	$GH1^{1}$		$AL0^{5}$	$BL1^{0}$
82			:			$GL2^{1}$	$GH1^{2}$		$AL0^{6}$	$BL1^{1}$
83						$GH2^{0}$	$BL1^{0}$		$AL0^{7}$	$BL1^{2}$
84						$GH2^{1}$	$BL1^{1}$		$AH0^{0}$	$BL1^{3}$
85						$BL2^{0}$	$BL1^{2}$		$AH0^{1}$	$BH1^{0}$
86						$BL2^{1}$	$BH1^{0}$		$AH0^{2}$	$BH1^{1}$
87						$BH2^{0}$	$BH1^{1}$		$AH0^{3}$	$BH1^{2}$
88						$BH2^{1}$	$BH1^{2}$		$AH0^{4}$	$BH1^{3}$
89						$\mathrm{Wt}^{0..1}$	$\mathrm{Wt}^{0..1}$		$AH0^{5}$	$AL1^{0}$
90						:	:		$AH0^{6}$	$AL1^{1}$
91									$AH0^{7}$	$AL1^{2}$
92									$\mathrm{Wt}^{0..1}$	$AL1^{3}$
93									:	$AH1^{0}$
94										$AH1^{1}$
95										$AH1^{2}$
96										$AH1^{3}$
97										$\mathrm{Wt}^{0..1}$
98										:

Table 25.14: UASTC mode encoding bits 68..98 (1/2)

Mode Index	4	8	6	2	13	16	17	1	15	19
0	1	1	1	1	1	1	1	1	1	1
1	1	1	1	0	1	0	0	0	0	0
2	0	1	0	1	1	1	1	1	1	1
3	0	0	1	1	1	0	0	0	0	0
4	1	1	1	1	1	1	0	1	0	0
5	BC1H0	R^{0}	BC1H0	BC1H0	BC1H0	0	1	1	0	0
6	BC1H1	R^{1}	BC1H1	BC1H1	BC1H1	BC1H0	BC1H0	BC1H0	0	1
7	ETC1F	R^{2}	ETC1F	ETC1F	ETC1F	BC1H1	BC1H1	BC1H1	BC1H0	
8	ETC1D	R^{3}	ETC1D	ETC1D	ETC1D	ETC1F	ETC1F	ETC1F	BC1H1	
9	ETCI0^{0}	R^{4}	ETCI0^{0}	ETCI0^{0}	ETCI0^{0}	ETC1D	ETC1D	ETC1D	ETC1F	
10	ETCI0^{1}	R^{5}	ETCI0^{1}	ETCI0^{1}	ETCI0^{1}	ETCI0^{0}	ETCI0^{0}	ETCI0^{0}	ETC1D	
11	ETCI0^{2}	R^{6}	ETCI0^{2}	ETCI0^{2}	ETCI0^{2}	ETCI0^{1}	ETCI0^{1}	ETCI0^{1}	ETCI0^{0}	
12	ETCI1^{0}	R^{7}	ETCI1^{0}	ETCI1^{0}	ETCI1^{0}	ETCI0^{2}	ETCI0^{2}	ETCI0^{2}	ETCI0^{1}	
13	ETCI1^{1}	G^{0}	ETCI1^{1}	ETCI1^{1}	ETCI1^{1}	ETCI1^{0}	ETCI1^{0}	ETCI1^{0}	ETCI0^{2}	
14	ETCI1^{2}	G^{1}	ETCI1^{2}	ETCI1^{2}	ETCI1^{2}	ETCI1^{1}	ETCI1^{1}	ETCI1^{1}	ETCI1^{0}	
15	ETCBI^{0}	G^{2}	ETCBI^{0}	ETCBI^{0}	ETCBI^{0}	ETCI1^{2}	ETCI1^{2}	ETCI1^{2}	ETCI1^{1}	
16	ETCBI^{1}	G^{3}	ETCBI^{1}	ETCBI^{1}	ETCBI^{1}	ETCBI^{0}	ETCBI^{0}	ETCBI^{0}	ETCI1^{2}	
17	ETCBI^{2}	G^{4}	ETCBI^{2}	ETCBI^{2}	ETCBI^{2}	ETCBI^{1}	ETCBI^{1}	ETCBI^{1}	ETCBI^{0}	
18	ETCBI^{3}	G^{5}	ETCBI^{3}	ETCBI^{3}	ETCBI^{3}	ETCBI^{2}	ETCBI^{2}	ETCBI^{2}	ETCBI^{1}	
19	ETCBI^{4}	G^{6}	ETCBI^{4}	ETCBI^{4}	ETCBI^{4}	ETCBI^{3}	ETCBI^{3}	ETCBI^{3}	ETCBI^{2}	
20	PAT^{0}	G^{7}	CSEL^{0}	PAT^{0}	ETC2T^{0}	ETCBI^{4}	ETCBI^{4}	ETCBI^{4}	ETCBI^{3}	
21	PAT^{1}	B^{0}	CSEL^{1}	PAT^{1}	ETC2T^{1}	ETC2T^{0}	ETC2T^{0}	$RL0^{0}$	ETCBI^{4}	
22	PAT^{2}	B^{1}	EQ[0]^{0}	PAT^{2}	ETC2T^{2}	ETC2T^{1}	ETC2T^{1}	$RL0^{1}$	ETC2T^{0}	
23	PAT^{3}	B^{2}	EQ[0]^{1}	PAT^{3}	ETC2T^{3}	ETC2T^{2}	ETC2T^{2}	$RL0^{2}$	ETC2T^{1}	
24	PAT^{4}	B^{3}	EQ[0]^{2}	PAT^{4}	ETC2M^{0}	ETC2T^{3}	ETC2T^{3}	$RL0^{3}$	ETC2T^{2}	
25	EQ[0]^{0}	B^{4}	EQ[0]^{3}	$RL0^{0}$	ETC2M^{1}	ETC2M^{0}	ETC2M^{0}	$RL0^{4}$	ETC2T^{3}	
26	EQ[0]^{1}	B^{5}	EQ[0]^{4}	$RL0^{1}$	ETC2M^{2}	ETC2M^{1}	ETC2M^{1}	$RL0^{5}$	ETC2M^{0}	
27	EQ[0]^{2}	B^{6}	EQ[0]^{5}	$RL0^{2}$	ETC2M^{3}	ETC2M^{2}	ETC2M^{2}	$RL0^{6}$	ETC2M^{1}	
28	EQ[0]^{3}	B^{7}	EQ[0]^{6}	$RL0^{3}$	CSEL^{0}	ETC2M^{3}	ETC2M^{3}	$RL0^{7}$	ETC2M^{2}	
29	EQ[0]^{4}	A^{0}	EQ[1]^{0}	$RH0^{0}$	CSEL^{1}	PAT^{0}	$LL0^{0}$	$RH0^{0}$	ETC2M^{3}	
30	EQ[0]^{5}	A^{1}	EQ[1]^{1}	$RH0^{1}$	$RL0^{0}$	PAT^{1}	$LL0^{1}$	$RH0^{1}$	$LL0^{0}$	
31	EQ[0]^{6}	A^{2}	EQ[1]^{2}	$RH0^{2}$	$RL0^{1}$	PAT^{2}	$LL0^{2}$	$RH0^{2}$	$LL0^{1}$	
32	EQ[1]^{0}	A^{3}	EQ[1]^{3}	$RH0^{3}$	$RL0^{2}$	PAT^{3}	$LL0^{3}$	$RH0^{3}$	$LL0^{2}$	
33	EQ[1]^{1}	A^{4}	EQ[1]^{4}	$GL0^{0}$	$RL0^{3}$	PAT^{4}	$LL0^{4}$	$RH0^{4}$	$LL0^{3}$	

Table 25.15: UASTC mode encoding bits 0..33 (2/2)

Mode Index	4	8	6	2	13	16	17	1	15	19
34	EQ[1]^{2}	A^{5}	EQ[1]^{5}	$GL0^{1}$	$RL0^{4}$	$LL0^{0}$	$LL0^{5}$	$RH0^{5}$	$LL0^{4}$	
35	EQ[1]^{3}	A^{6}	EQ[1]^{6}	$GL0^{2}$	$RL0^{5}$	$LL0^{1}$	$LL0^{6}$	$RH0^{6}$	$LL0^{5}$	
36	EQ[1]^{4}	A^{7}	$RL0^{0}$	$GL0^{3}$	$RL0^{6}$	$LL0^{2}$	$LL0^{7}$	$RH0^{7}$	$LL0^{6}$	
37	EQ[1]^{5}	ETC1D	$RL0^{1}$	$GH0^{0}$	$RL0^{7}$	$LL0^{3}$	$LH0^{0}$	$GL0^{0}$	$LL0^{7}$	
38	EQ[1]^{6}	ETC1I^{0}	$RL0^{2}$	$GH0^{1}$	$RH0^{0}$	$LL0^{4}$	$LH0^{1}$	$GL0^{1}$	$LH0^{0}$	
39	EQ[2]^{0}	ETC1I^{1}	$RL0^{3}$	$GH0^{2}$	$RH0^{1}$	$LL0^{5}$	$LH0^{2}$	$GL0^{2}$	$LH0^{1}$	
40	EQ[2]^{1}	ETC1I^{2}	$RL0^{4}$	$GH0^{3}$	$RH0^{2}$	$LL0^{6}$	$LH0^{3}$	$GL0^{3}$	$LH0^{2}$	
41	EQ[2]^{2}	ETC1S^{0}	$RH0^{0}$	$BL0^{0}$	$RH0^{3}$	$LL0^{7}$	$LH0^{4}$	$GL0^{4}$	$LH0^{3}$	
42	EQ[2]^{3}	ETC1S^{1}	$RH0^{1}$	$BL0^{1}$	$RH0^{4}$	$LH0^{0}$	$LH0^{5}$	$GL0^{5}$	$LH0^{4}$	
43	EQ[2]^{4}	ETC1R^{0}	$RH0^{2}$	$BL0^{2}$	$RH0^{5}$	$LH0^{1}$	$LH0^{6}$	$GL0^{6}$	$LH0^{5}$	
44	EQ[2]^{5}	ETC1R^{1}	$RH0^{3}$	$BL0^{3}$	$RH0^{6}$	$LH0^{2}$	$LH0^{7}$	$GL0^{7}$	$LH0^{6}$	
45	EQ[2]^{6}	ETC1R^{2}	$RH0^{4}$	$BH0^{0}$	$RH0^{7}$	$LH0^{3}$	$AL0^{0}$	$GH0^{0}$	$LH0^{7}$	
46	EQ[3]^{0}	ETC1R^{3}	$GL0^{0}$	$BH0^{1}$	$GL0^{0}$	$LH0^{4}$	$AL0^{1}$	$GH0^{1}$	$AL0^{0}$	
47	EQ[3]^{1}	ETC1R^{4}	$GL0^{1}$	$BH0^{2}$	$GL0^{1}$	$LH0^{5}$	$AL0^{2}$	$GH0^{2}$	$AL0^{1}$	
48	EQ[3]^{2}	ETC1G^{0}	$GL0^{2}$	$BH0^{3}$	$GL0^{2}$	$LH0^{6}$	$AL0^{3}$	$GH0^{3}$	$AL0^{2}$	
49	EQ[3]^{3}	ETC1G^{1}	$GL0^{3}$	$RL1^{0}$	$GL0^{3}$	$LH0^{7}$	$AL0^{4}$	$GH0^{4}$	$AL0^{3}$	
50	EQ[3]^{4}	ETC1G^{2}	$GL0^{4}$	$RL1^{1}$	$GL0^{4}$	$AL0^{0}$	$AL0^{5}$	$GH0^{5}$	$AL0^{4}$	
51	EQ[3]^{5}	ETC1G^{3}	$GH0^{0}$	$RL1^{2}$	$GL0^{5}$	$AL0^{1}$	$AL0^{6}$	$GH0^{6}$	$AL0^{5}$	
52	EQ[3]^{6}	ETC1G^{4}	$GH0^{1}$	$RL1^{3}$	$GL0^{6}$	$AL0^{2}$	$AL0^{7}$	$GH0^{7}$	$AL0^{6}$	
53	$RL0^{0}$	ETC1B^{0}	$GH0^{2}$	$RH1^{0}$	$GL0^{7}$	$AL0^{3}$	$AH0^{0}$	$BL0^{0}$	$AL0^{7}$	
54	$RL0^{1}$	ETC1B^{1}	$GH0^{3}$	$RH1^{1}$	$GH0^{0}$	$AL0^{4}$	$AH0^{1}$	$BL0^{1}$	$AH0^{0}$	
55	$RL0^{2}$	ETC1B^{2}	$GH0^{4}$	$RH1^{2}$	$GH0^{1}$	$AL0^{5}$	$AH0^{2}$	$BL0^{2}$	$AH0^{1}$	
56	$RH0^{0}$	ETC1B^{3}	$BL0^{0}$	$RH1^{3}$	$GH0^{2}$	$AL0^{6}$	$AH0^{3}$	$BL0^{3}$	$AH0^{2}$	
57	$RH0^{1}$	ETC1B^{4}	$BL0^{1}$	$GL1^{0}$	$GH0^{3}$	$AL0^{7}$	$AH0^{4}$	$BL0^{4}$	$AH0^{3}$	
58	$RH0^{2}$		$BL0^{2}$	$GL1^{1}$	$GH0^{4}$	$AH0^{0}$	$AH0^{5}$	$BL0^{5}$	$AH0^{4}$	
59	$GL0^{0}$		$BL0^{3}$	$GL1^{2}$	$GH0^{5}$	$AH0^{1}$	$AH0^{6}$	$BL0^{6}$	$AH0^{5}$	
60	$GL0^{1}$		$BL0^{4}$	$GL1^{3}$	$GH0^{6}$	$AH0^{2}$	$AH0^{7}$	$BL0^{7}$	$AH0^{6}$	
61	$GL0^{2}$		$BH0^{0}$	$GH1^{0}$	$GH0^{7}$	$AH0^{3}$	Wt$^{0..1}$×2	$BH0^{0}$	$AH0^{7}$	
62	$GH0^{0}$		$BH0^{1}$	$GH1^{1}$	$BL0^{0}$	$AH0^{4}$	:	$BH0^{1}$	Wt$^{0..3}$	
63	$GH0^{1}$		$BH0^{2}$	$GH1^{2}$	$BL0^{1}$	$AH0^{5}$		$BH0^{2}$	:	
64	$GH0^{2}$		$BH0^{3}$	$GH1^{3}$	$BL0^{2}$	$AH0^{6}$		$BH0^{3}$		
65	$BL0^{0}$		$BH0^{4}$	$BL1^{0}$	$BL0^{3}$	$AH0^{7}$		$BH0^{4}$		
66	$BL0^{1}$		Wt$^{0..1}$×2	$BL1^{1}$	$BL0^{4}$	$LL1^{0}$		$BH0^{5}$		
67	$BL0^{2}$		:	$BL1^{2}$	$BL0^{5}$	$LL1^{1}$		$BH0^{6}$		
68	$BH0^{0}$			$BL1^{3}$	$BL0^{6}$	$LL1^{2}$		$BH0^{7}$		

Table 25.16: UASTC mode encoding bits 34..68 (2/2)

Mode Index	4	8	6	2	13	16	17	1	15	19
69	$BH0^{1}$			$BH1^{0}$	$BL0^{7}$	$LL1^{3}$		Wt$^{0..1}$		
70	$BH0^{2}$			$BH1^{1}$	$BH0^{0}$	$LL1^{4}$		:		
71	$RL1^{0}$			$BH1^{2}$	$BH0^{1}$	$LL1^{5}$				
72	$RL1^{1}$			$BH1^{3}$	$BH0^{2}$	$LL1^{6}$				
73	$RL1^{2}$			Wt$^{0..2}$	$BH0^{3}$	$LL1^{7}$				
74	$RH1^{0}$			:	$BH0^{4}$	$LH1^{0}$				
75	$RH1^{1}$				$BH0^{5}$	$LH1^{1}$				
76	$RH1^{2}$				$BH0^{6}$	$LH1^{2}$				
77	$GL1^{0}$				$BH0^{7}$	$LH1^{3}$				
78	$GL1^{1}$				$AL0^{0}$	$LH1^{4}$				
79	$GL1^{2}$				$AL0^{1}$	$LH1^{5}$				
80	$GH1^{0}$				$AL0^{2}$	$LH1^{6}$				
81	$GH1^{1}$				$AL0^{3}$	$LH1^{7}$				
82	$GH1^{2}$				$AL0^{4}$	$AL1^{0}$				
83	$BL1^{0}$				$AL0^{5}$	$AL1^{1}$				
84	$BL1^{1}$				$AL0^{6}$	$AL1^{2}$				
85	$BL1^{2}$				$AL0^{7}$	$AL1^{3}$				
86	$BH1^{0}$				$AH0^{0}$	$AL1^{4}$				
87	$BH1^{1}$				$AH0^{1}$	$AL1^{5}$				
88	$BH1^{2}$				$AH0^{2}$	$AL1^{6}$				
89	Wt$^{0..1}$				$AH0^{3}$	$AL1^{7}$				
90	:				$AH0^{4}$	$AH1^{0}$				
91					$AH0^{5}$	$AH1^{1}$				
92					$AH0^{6}$	$AH1^{2}$				
93					$AH0^{7}$	$AH1^{3}$				
94					Wt$^{0}\times 2$	$AH1^{4}$				
95					:	$AH1^{5}$				
96						$AH1^{6}$				
97						$AH1^{7}$				
98						Wt$^{0..1}$				
99						:				

Table 25.17: UASTC mode encoding bits 69..99 (2/2)

25.7 Decoding process

Decoding starts with parsing *Mode Index* to determine whether the block contains solid color (*Mode Index* 8) or interpolated values.

25.7.1 Solid color blocks

8-bit values for ***R***, ***G***, ***B***, and ***A*** are used for all 16 pixels of the block.

25.7.2 Interpolated blocks

Decoding interpolated blocks involves several steps: extracting endpoints, restoring interpolation weights, and interpolating pixel values.

25.7.2.1 Extracting endpoints

8-bit endpoint values are extracted and unquantized from encoded endpoint bits (denoted as ***RL0***, ***RH0***, etc. in the bitstream) and packed **ET** or **EQ** values (when present).

25.7.2.2 Unpacking Trits

When present, **ET** fields contain trit values for each encoded endpoint packed in the same order as endpoints. Trits (values of [0..2] range) are used when *Mode Index* is 0, 3, 10, 11, or 12. Each **ET** value contains up to 5 trits packed as:

```
ET = trit4 * 81 + trit3 * 27 + trit2 * 9 + trit1 * 3 + trit0
```

When the number of endpoint values isn't a multiple of 5, the final **ET** value contains fewer packed values. For example, trits for *Mode Index* 0 would be packed as:

```
ET[0] = tritBL0 * 81 + tritGH0 * 27 + tritGL0 * 9 + tritRH0 * 3 + tritRL0
ET[1] = tritBH0
```

Trit values could be unpacked by sequential modulus and division operations or equivalent precomputed lookup tables:

```
trit0 = ET % 3; trit1 = (ET % 9) / 3; trit2 = (ET % 27) / 9;
trit3 = (ET % 81) / 27; trit4 = (ET % 243) / 81;
```

Implementations should be resilient to ET bytes containing 243..255, which are mapped to 0..12 by the above equations.

25.7.2.3 Unpacking Quints

When present, **EQ** fields contain quint values for each encoded endpoint packed in the same order as endpoints. Quints (values of [0..4] range) are used when *Mode Index* is 4, 6, or 7. Each **EQ** value contains 3 quints packed as:

```
EQ = quint2 * 25 + quint1 * 5 + quint0
```

Quint values could be unpacked by sequential modulus and division operations or equivalent precomputed lookup tables:

```
quint0 = EQ % 5; quint1 = (ET % 25) / 5; quint2 = (EQ % 125) / 25;
```

Implementations should be resilient to EQ bit fields containing 125..127, which are mapped to 0..2 by the above equations.

25.7.2.4 Unquantizing endpoints

Each endpoint value is defined by its trit/quint value (if present) and remaining *num_ebits* bits. It must be unquantized to [0..255] range before being used for interpolation.

For modes that use only endpoint bits (i.e., their bitstream does not contain **ET** or **EQ** fields, for example *Mode Index* 18), unquantization is performed by replicating endpoint bits from the most significant bit of the value to the total length of 8. For example, 5-bit `abcde` value must be dequantized to `abcdeabc` 8-bit value.

Modes that use **ET** (trits) or **EQ** (quints) must be unquantized using one of the following approaches:

- Using ASTC Endpoint Unquantization. UASTC *Mode Indices* map to ASTC ranges as defined by Table 25.18.

UASTC *Mode Index*	0	3	4	6	7	10	11	12
Row in Table 23.21	0..191	0..11	0..39	0..159	0..39	0..47	0..47	0..191

Table 25.18: UASTC endpoint unquantization mapping

- Constructing an intermediate value by shifting unpacked trit/quint left *num_ebits* bits, logically OR in the endpoint bits and looking up the dequantized value using one of the following precomputed data in Table 25.19, Table 25.20, Table 25.21, Table 25.22, and Table 25.23. Note that, after unquantization, the order of values is different.

For example, a *Mode Index* 7 endpoint with a quint value of 4 and endpoint bits value of 2 would yield (4 << 3) | 2 == 34. The 34-th element of the relevant unquantization data is {9, 58}. This means that the 8-bit endpoint value is 58/255 scaled from 9/39 (because there are 40 quantized values total for this mode).

(*trit* << 2) | *bits*	0	1	2	3	4	5	6	7	8	9	10	11
Value /11	0	11	3	8	1	10	4	7	2	9	5	6
Value /255	0	255	69	186	23	232	92	163	46	209	116	139

Table 25.19: UASTC unquantization data for *Mode Index* 3 (12 values)

(*quint* << 3) | *bits*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Value / 39	0	39	5	34	10	29	15	24	1	38	6	33	11	28	16	23	2	37	7	32
Value / 255	0	255	32	223	65	190	97	158	6	249	39	216	71	184	104	151	13	242	45	210
(*quint* << 3) | *bits*	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Value / 39	12	27	17	22	3	36	8	31	13	26	18	21	4	35	9	30	14	25	19	20
Value / 255	78	177	110	145	19	236	52	203	84	171	117	138	26	229	58	197	91	164	123	132

Table 25.20: UASTC unquantization data for *Mode Indices* 4 and 7 (40 values)

25.7.2.5 Deriving missing *RGBA* values

For *Mode Indices* 15, 16, and 17, *RGB* endpoint values are derived from ***L**** unquantized values as

RL0* = *GL0* = *BL0* = *LL0

RH0* = *GH0* = *BH0* = *LH0

For *Mode Index* 16 only:

RL1* = *GL1* = *BL1* = *LL1

RH1* = *GH1* = *BH1* = *LH1

For *Mode Indices* 0..7, and 18, all *Alpha* endpoint values must be set to 255.

(*trit* << 4) | *bits*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value / 47	0	47	3	44	6	41	9	38	12	35	15	32	18	29	21	26
Value / 255	0	255	16	239	32	223	48	207	65	190	81	174	97	158	113	142
(*trit* << 4) | *bits*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Value / 47	1	46	4	43	7	40	10	37	13	34	16	31	19	28	22	25
Value / 255	5	250	21	234	38	217	54	201	70	185	86	169	103	152	119	136
(*trit* << 4) | *bits*	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Value / 47	2	45	5	42	8	39	11	36	14	33	17	30	20	27	23	24
Value / 255	11	244	27	228	43	212	59	196	76	179	92	163	108	147	124	131

Table 25.21: UASTC unquantization data for *Mode Indices* 10 and 11 (48 values)

(*quint* << 5) | *bits*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value / 159	0	159	5	154	10	149	15	144	{20	139	25	134	30	129	35	124
Value / 255	0	255	8	247	16	239	24	231	32	223	40	215	48	207	56	199
(*quint* << 5) | *bits*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Value / 159	40	119	45	114	50	109	55	104	60	99	65	94	70	89	75	84
Value / 255	64	191	72	183	80	175	88	167	96	159	104	151	112	143	120	135
(*quint* << 5) | *bits*	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Value / 159	1	158	6	153	11	148	16	143	21	138	26	133	31	128	36	123
Value / 255	1	254	9	246	17	238	25	230	33	222	41	214	49	206	57	198
(*quint* << 5) | *bits*	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Value / 159	41	118	46	113	51	108	56	103	61	98	66	93	71	88	76	83
Value / 255	65	190	73	182	81	174	89	166	97	158	105	150	113	142	121	134
(*quint* << 5) | *bits*	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
Value / 159	2	157	7	152	12	147	17	142	22	137	27	132	32	127	37	122
Value / 255	3	252	11	244	19	236	27	228	35	220	43	212	51	204	59	196
(*quint* << 5) | *bits*	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Value / 159	42	117	47	112	52	107	57	102	62	97	67	92	72	87	77	82
Value / 255	67	188	75	180	83	172	91	164	99	156	107	148	115	140	123	132
(*quint* << 5) | *bits*	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
Value / 159	3	156	8	151	13	146	18	141	23	136	28	131	33	126	38	121
Value / 255	4	251	12	243	20	235	28	227	36	219	44	211	52	203	60	195
(*quint* << 5) | *bits*	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
Value / 159	43	116	48	111	53	106	58	101	63	96	68	91	73	86	78	81
Value / 255	68	187	76	179	84	171	92	163	100	155	108	147	116	139	124	131
(*quint* << 5) | *bits*	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
Value / 159	4	155	9	150	14	145	19	140	24	135	29	130	34	125	39	120
Value / 255	6	249	14	241	22	233	30	225	38	217	46	209	54	201	62	193
(*quint* << 5) | *bits*	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
Value / 159	44	115	49	110	54	105	59	100	64	95	69	90	74	85	79	80
Value / 255	70	185	78	177	86	169	94	161	102	153	110	145	118	137	126	129

Table 25.22: UASTC unquantization data for *Mode Index* 6 (160 values)

(*trit* << 6) | *bits*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value / 191	0	191	3	188	6	185	9	182	12	179	15	176	18	173	21	170
Value / 255	0	255	4	251	8	247	12	243	16	239	20	235	24	231	28	227
(*trit* << 6) | *bits*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Value / 191	24	167	27	164	30	161	33	158	36	155	39	152	42	149	45	146
Value / 255	32	223	36	219	40	215	44	211	48	207	52	203	56	199	60	195
(*trit* << 6) | *bits*	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Value / 191	48	143	51	140	54	137	57	134	60	131	63	128	66	125	69	122
Value / 255	64	191	68	187	72	183	76	179	80	175	84	171	88	167	92	163
(*trit* << 6) | *bits*	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Value / 191	72	119	75	116	78	113	81	110	84	107	87	104	90	101	93	98
Value / 255	96	159	100	155	104	151	108	147	112	143	116	139	120	135	124	131
(*trit* << 6) | *bits*	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
Value / 191	1	190	4	187	7	184	10	181	13	178	16	175	19	172	22	169
Value / 255	1	254	5	250	9	246	13	242	17	238	21	234	25	230	29	226
(*trit* << 6) | *bits*	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Value / 191	25	166	28	163	31	160	34	157	37	154	40	151	43	148	46	145
Value / 255	33	222	37	218	41	214	45	210	49	206	53	202	57	198	61	194
(*trit* << 6) | *bits*	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
Value / 191	49	142	52	139	55	136	58	133	61	130	64	127	67	124	70	121
Value / 255	65	190	69	186	73	182	77	178	81	174	85	170	89	166	93	162
(*trit* << 6) | *bits*	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
Value / 191	73	118	76	115	79	112	82	109	85	106	88	103	91	100	94	97
Value / 255	97	158	101	154	105	150	109	146	113	142	117	138	121	134	125	130
(*trit* << 6) | *bits*	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
Value / 191	2	189	5	186	8	183	11	180	14	177	17	174	20	171	23	168
Value / 255	2	253	6	249	10	245	14	241	18	237	22	233	26	229	30	225
(*trit* << 6) | *bits*	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
Value / 191	26	165	29	162	32	159	35	156	38	153	41	150	44	147	47	144
Value / 255	34	221	38	217	42	213	46	209	50	205	54	201	58	197	62	193
(*trit* << 6) | *bits*	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175
Value / 191	50	141	53	138	56	135	59	132	62	129	65	126	68	123	71	120
Value / 255	66	189	70	185	74	181	78	177	82	173	86	169	90	165	94	161
(*trit* << 6) | *bits*	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
Value / 191	74	117	77	114	80	111	83	108	86	105	89	102	92	99	95	96
Value / 255	98	157	102	153	106	149	110	145	114	141	118	137	122	133	126	129

Table 25.23: UASTC unquantization data for *Mode Indices* 0 and 12 (192 values)

25.7.2.6 Unquantizing weights

Weights are stored with 1..5 bits. They must be dequantized to 6-bit interpolation values. This could be done with either of these approaches:

- Using ASTC Weights Unquantization. UASTC *num_wbits* values refer to bit-only representations, and so are expanded to 6-bit values by bit replication, then have the final `if (unq > 32) { unq +=1;}` step applied.
- Using precomputed data to get unquantized weights directly, as shown in Table 25.24.

num_wbits	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	64														
2	0	21	43	64												
3	0	9	18	27	37	46	55	64								
4	0	4	8	12	17	21	25	29	35	39	43	47	52	56	60	64
5	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
num_wbits	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64

Table 25.24: UASTC unquantization values for weight expansion

25.7.2.7 Decoding pixel values

To decode each pixel's 8-bit *RGBA* value, the decoder needs to have dequantized endpoints, weights, and parsed configuration data as described in the sections above.

The final value of each color channel is computed as a weighted sum of the block's endpoints.

25.7.2.8 One subset, single plane

This process is applied to blocks with *Mode Indices* 0, 1, 5, 10, 12, 14, 15, and 18.

First, unquantized endpoint values are expanded to 16 bits. If sRGB conversion is not enabled, this is performed by bit replication. If sRGB conversion is enabled, channels are expanded by left-shifting each value 8 bits and logically ORing 0x80.

```
RL0 = (RL0 << 8) | (is_srgb ? 0x80 : RL0)
RH0 = (RH0 << 8) | (is_srgb ? 0x80 : RH0)
GL0 = (GL0 << 8) | (is_srgb ? 0x80 : GL0)
GH0 = (GH0 << 8) | (is_srgb ? 0x80 : GH0)
BL0 = (BL0 << 8) | (is_srgb ? 0x80 : BL0)
BH0 = (BH0 << 8) | (is_srgb ? 0x80 : BH0)
AL0 = (AL0 << 8) | (is_srgb ? 0x80 : AL0)
AH0 = (AH0 << 8) | (is_srgb ? 0x80 : AH0)
```

Then, the final values are computed as follows:

```
C = ((CL * (64 - W) + CH * W + 32) >> 6) >> 8
```

Note that this description corresponds to conversion to ASTC and then extracting the color channels as described for decode mode `decode_unorm8` in Section 23.18 of ASTC.

`CL` and `CH` are 4-component *RGBA* endpoints, `W` is an unquantized 6-bit weight value taken from the `WEIGHTS0` array, and `C` is the resulting pixel value.

25.7.2.9 One subset, dual plane

This process is applied to blocks with *Mode Indices* 6, 11, 13, and 17.

Decoding proceeds as in the previous section with the only difference being that one color channel uses weights from the `WEIGHTS1` array. The selection of that channel is based on the following rules.

For blocks with *Mode Indices* 6, 11, and 13, the separately-interpolated channel is selected based on the value of the **CSEL** field as shown in Table 25.25.

CSEL	WEIGHTS0	WEIGHTS1
0	*G*, *B*, *A*	*R*
1	*R*, *B*, *A*	*G*
2	*R*, *G*, *A*	*B*
3	*R*, *G*, *B*	*A*

Table 25.25: UASTC **CSEL** field

Note that since *Mode Index* 6 Alpha endpoints are always 255, decoders could safely ignore WEIGHTS1 values when encountering such blocks with **CSEL** value of 3.

For blocks with *Mode Index* 17, the separately-interpolated channel is always Alpha.

25.7.2.10 Two subsets

This process is applied to blocks with *Mode Indices* 2, 4, 7, 9, and 16.

These blocks have 2 sets of endpoint values and the partition pattern index (PAT) defines which set each pixel belongs to.

For blocks with *Mode Index* 7, there are 19 total partition patterns, with the partition indices for each pixel defined in Table 25.26.

0				1				2				3				4			
0	0	0	0	***0***	0	***1***	0	***1***	1	***0***	0	***0***	0	0	0	***1***	1	1	1
1	1	1	1	0	0	1	0	1	1	0	0	0	0	0	***1***	1	1	1	1
0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	***0***	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1
5				6				7				8				9			
0	***1***	0	0	***0***	0	0	***1***	***0***	***1***	1	1	***1***	1	***0***	0	***0***	***1***	1	1
0	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	1	1	1
0	1	0	0	1	1	1	1	0	0	1	1	0	0	1	1	0	0	0	0
0	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0
10				11				12				13				14			
0	0	0	0	***1***	1	***0***	0	***0***	***1***	1	1	***0***	0	0	0	***1***	1	1	1
0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	***1***	1	1	1	1
1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
1	1	1	0	1	1	0	0	0	0	0	0	1	1	1	1	***0***	1	1	0
15				16				17				18							
1	1	***0***	0	***1***	1	1	1	***0***	0	***1***	1	***1***	1	1	1				
1	1	0	0	1	1	1	1	0	1	1	0	***0***	1	1	1				
1	1	0	0	1	***0***	0	0	1	1	0	0	0	0	0	0				
1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0				

Table 25.26: Partition table for 2-subset *Mode Index* 7, with the 4×4 block of values for each PAT value

For other blocks (with *Mode Indices* 2, 4, 9, and 16), there are 30 total partition patterns and the partition indices for each pixel are defined in Table 25.27.

0				1				2				3				4				5			
0	0	***1***	1	***0***	0	0	***1***	***1***	***0***	0	0	***0***	0	0	***1***	***1***	1	1	1	***0***	0	***1***	1
0	0	1	1	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1	***0***	0	1	1	1
0	0	1	1	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1	0	0	1	1	1
0	0	1	1	0	0	0	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1
6				7				8				9				10				11			
1	1	1	***0***	***1***	1	1	1	***0***	0	0	0	***1***	1	***0***	0	***0***	0	0	0	***1***	1	1	1
1	1	0	0	1	1	1	***0***	0	0	0	0	1	0	0	0	0	0	0	***1***	1	1	1	1
1	0	0	0	1	1	0	0	0	0	0	***1***	0	0	0	0	0	1	1	1	1	1	1	***0***
0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1	0	0	0
12				13				14				15				16				17			
1	1	1	***0***	***1***	1	1	1	***0***	0	0	0	***1***	1	1	1	***1***	***0***	0	0	***1***	1	1	1
1	0	0	0	1	1	1	1	***1***	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
0	0	0	0	***0***	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	***0***	1	1	1
0	0	0	0	0	0	0	0	1	1	1	1	***0***	0	0	0	1	1	1	1	0	0	0	1
18				19				20				21				22				23			
0	***1***	1	1	***0***	0	***1***	1	***0***	0	0	0	***1***	1	1	1	***1***	***0***	0	0	***0***	0	***1***	1
0	0	1	1	0	0	0	1	***1***	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1
0	0	0	1	0	0	0	0	1	1	0	0	***0***	1	1	1	1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
24				25				26				27				28				29			
1	1	1	1	***0***	***1***	1	0	***1***	1	1	1	***1***	***0***	1	0	***1***	1	1	1	***1***	***0***	0	1
0	1	1	1	0	1	1	0	***0***	0	0	0	1	0	1	0	***0***	0	0	0	0	0	1	1
0	1	1	1	0	1	1	0	0	0	0	0	1	0	1	0	1	1	1	1	0	1	1	0
0	0	1	1	0	1	1	0	1	1	1	1	1	0	1	0	0	0	0	0	1	1	0	0

Table 25.27: Partition table for 2-subset *Mode Indices* 2, 4, 9, and 16, with the 4×4 block of values for each PAT value

Decoding proceeds as in Section 25.7.2.8 with the only difference being that pixels belonging to the second subset use the second set of endpoint values (***RL1***, ***RH1***, ***GL1***, ***GH1***, ***BL1***, ***BH1***, ***AL1***, and ***AH1***).

25.7.2.11 Three subsets

This process is applied to blocks with *Mode Index* 3.

These blocks have 3 sets of endpoint values and partition pattern index (PAT) defines to which set each pixel belongs.

There are 11 total partition patterns, for which the partition indices for each pixel are defined in Table 25.28.

0				1				2				3				4				5			
0	0	0	0	***1***	1	1	1	***1***	1	1	1	***1***	1	1	1	***1***	1	***2***	***0***	***0***	***1***	1	***2***
0	0	0	0	1	1	1	1	***0***	0	0	0	***2***	2	2	2	1	1	2	0	0	1	1	2
1	1	***2***	2	***0***	0	0	0	0	0	0	0	***0***	0	0	0	1	1	2	0	0	1	1	2
1	1	2	2	***2***	2	2	2	***2***	2	2	2	0	0	0	0	1	1	2	0	0	1	1	2
6				7				8				9				10							
0	***2***	***1***	1	***2***	***0***	0	0	***2***	***0***	***1***	2	***1***	1	1	1	***0***	0	***2***	2				
0	2	1	1	2	0	0	0	2	0	1	2	***0***	0	0	0	0	0	***1***	1				
0	2	1	1	2	***1***	1	1	2	0	1	2	***2***	2	2	2	0	0	1	1				
0	2	1	1	2	1	1	1	2	0	1	2	1	1	1	1	0	0	2	2				

Table 25.28: Partition table for 3-subset *Mode Index* 3, with the 4×4 block of values for each PAT value

Decoding proceeds as in the previous section section with the only difference being that pixels belonging to the third subset use the third set of endpoint values (***RL2***, ***RH2***, ***GL2***, ***GH2***, ***BL2***, ***BH2***, ***AL2***, and ***AH2***).

25.8 Transcoding UASTC blocks to other compressed formats

To take advantage of hardware texture decoders, UASTC blocks can be transcoded to natively-supported compressed texture formats. Regardless of the target format, transcoding always starts with parsing the UASTC block as described in the Bitstream format section above.

25.8.1 Transcoding to ASTC

Transcoding UASTC to ASTC is always a 100% lossless operation. Only 4×4 LDR ASTC blocks are supported as transcode targets.

25.8.1.1 Solid color blocks

Mode Index 8 UASTC blocks correspond to void-extent ASTC blocks. The following rules apply:

8-bit UASTC *RGBA* values are extended to 16-bit by bit replication before being written to the ASTC block:

```
Rastc = (R << 8) | R
Gastc = (G << 8) | G
Bastc = (B << 8) | B
Aastc = (A << 8) | A
```

The ASTC Dynamic Range flag must be set to 0.

All minimum and maximum void-extent coordinate bits must be set to 1.

25.8.1.2 Interpolated blocks

Each UASTC *Mode Index* corresponds to a fixed set of ASTC configuration parameters, including endpoint range, as defined in Table 25.29. When the block contains multiple subsets, all endpoint pairs use the same CEM.

UASTC *Mode Index*	**ASTC Mode**	**Weight Range**	**Endpoint Range**	**Subsets**	**ASTC CEM**
0	578	0..15	0..191	1	8 (Direct *RGB*)
1	66	0..3	0..255	1	8 (Direct *RGB*)
2	83	0..7	0..15	2	8 (Direct *RGB*)
3	66	0..3	0..11	3	8 (Direct *RGB*)
4	66	0..3	0..39	2	8 (Direct *RGB*)
5	83	0..7	0..255	1	8 (Direct *RGB*)
6	1090 (Dp)	0..3	0..159	1	8 (Direct *RGB*)
7	66	0..3	0..39	2	8 (Direct *RGB*)
9	66	0..3	0..15	2	12 (Direct *RGBA*)
10	578	0..15	0..47	1	12 (Direct *RGBA*)
11	1090 (Dp)	0..3	0..47	1	12 (Direct *RGBA*)
12	83	0..7	0..191	1	12 (Direct *RGBA*)
13	1089 (Dp)	0..1	0..255	1	12 (Direct *RGBA*)
14	66	0..3	0..255	1	12 (Direct *RGBA*)
15	578	0..15	0..255	1	4 (Direct *LA*)
16	66	0..3	0..255	2	4 (Direct *LA*)
17	1090 (Dp)	0..3	0..255	1	4 (Direct *LA*)
18	595	0..31	0..31	1	8 (Direct *RGB*)

Table 25.29: UASTC to ASTC configuration mapping

UASTC endpoints and weights require only repacking (and reordering in some cases, see below) when transcoded to ASTC. No per-pixel processing or full block decoding is needed.

25.8.1.3 Multi-subset blocks

For each UASTC partition pattern there is a seed value for ASTC partition generator that produces the same pattern in the ASTC decoder. That seed value (ASTC Partition Index) is derived from UASTC ***PAT*** value.

When UASTC *Mode Index* is 2, 4, 9, or 16, the value of ASTC Partition Index depends on ***PAT*** as shown in Table 25.30.

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9
ASTC Partition Index	28	20	16	29	91	9	107	72	149	204
UASTC *PAT*	10	11	12	13	14	15	16	17	18	19
ASTC Partition Index	50	114	496	17	78	39	252	828	43	156
UASTC *PAT*	20	21	22	23	24	25	26	27	28	29
ASTC Partition Index	116	210	476	273	684	359	246	195	694	524

Table 25.30: ASTC Partition Index for UASTC ***PAT*** values in *Mode Indices* 2, 4, 9, or 16

When the UASTC *Mode Index* is 3, the value of the ASTC Partition Index depends on ***PAT*** as shown in Table 25.31.

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9	10
ASTC Partition Index	260	74	32	156	183	15	745	0	335	902	254

Table 25.31: ASTC Partition Index for UASTC ***PAT*** values in *Mode Index* 3

When the UASTC *Mode Index* is 7, the value of ASTC Partition Index depends on ***PAT*** as shown in Table 25.32.

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9
ASTC Partition Index	36	48	61	137	161	183	226	281	302	307
UASTC *PAT*	10	11	12	13	14	15	16	17	18	
ASTC Partition Index	479	495	593	594	605	799	812	988	993	

Table 25.32: ASTC Partition Index for UASTC ***PAT*** values in *Mode Index* 7

25.8.1.4 Endpoints

UASTC endpoint pairs must be repacked according to ASTC BISE specification by interleaving bits with trits or quints. When the CEM value is 8 or 12, transcoders must ensure that the order of each endpoint pair does not cause Blue Contraction by swapping low and high values and inverting weights.

```
if (RLi + GLi + BLi > RHi + GHi + BHi) {
    swap(RLi, RHi);
    swap(GLi, GHi);
    swap(GLi, GHi);

    foreach (w in weights) {
        w = max_weight_index - w;
    }
}
```

25.8.1.5 Weights

UASTC weight values must be packed in reverse bit order starting from the end of the ASTC block as described in Section 23.15. Transcoded ASTC blocks always use a 4×4 grid of weights.

Note that UASTC weight ranges do not use trits or quints.

25.8.1.6 Dual-plane blocks

For *RGB* and *RGBA* dual-plane blocks (*Mode Indices* 6, 11, and 13), the *CCS* value is set directly from **CSEL** UASTC field.

For *LA* dual-plane blocks (*Mode Index* 17), the *CCS* value must be set to 3.

25.8.2 Transcoding to BC7

Transcoding UASTC to BC7 is nearly a lossless operation. The primary source of loss is mapping UASTC endpoints to BC7 endpoints. This is done using a simple scale with optional optimal p-bit computation. The UASTC weight indices are either copied as-is, or converted to the closest corresponding BC7 weight indices using a lookup table. The partition patterns are lossless, the weight tables are the same for 2/3-bits and very similar for 4-bits, and the endpoint interpolation method is nearly the same (16-bits in UASTC, 8-bits with BC7, and both formats use [0, 64] weights with rounding in the linear interpolation).

25.8.2.1 Solid color blocks

Mode Index 8 UASTC blocks should be transcoded to BC7 mode 5 or mode 6 as follows:

To encode a solid-color block using BC7 mode 5, each two-bit pixel index IB in the BC7 texel block should be set to the two-bit value 1, indicating a 6-bit weight of 21. The endpoints *E* for the BC7 texel block should then be selected for each channel *C* as follows:

$$E_0 = C \gg 1$$

$$E_1 = \begin{cases} (C \gg 1) + 1, & C < 128 \,\&\&\, C \text{ is odd} \\ (C \gg 1) - 1, & C > 127 \,\&\&\, C \text{ is even} \\ C \gg 1, & \text{otherwise} \end{cases}$$

The alpha channel for BC7 mode 5 is described with 8 bits, so both alpha endpoints can be set to exactly the 8-bit value encoded in the UASTC solid color block, and the secondary index bits IB_2 can be set to 0.

To encode a solid-color block using BC7 mode 6, each four-bit pixel index in the BC7 texel block should be set to the four-bit value 7, indicating a 6-bit weight of 30. If more channels contain 255 than contain 0, *EPB₀*, and *EPB₁* should be set to 1; otherwise *EPB₀* and *EPB₁* should be set to 0.

The endpoints *E* for the BC7 texel block should then be selected for each channel *C* as follows:

$$E_0 = C \gg 1$$

$$E_1 = \begin{cases} (C \gg 1) + 1, & EPB_{0,1} = 0 \,\&\&\, C \text{ is odd} \\ (C \gg 1) - 1, & EPB_{0,1} = 1 \,\&\&\, C \text{ is even} \\ C \gg 1, & \text{otherwise} \end{cases}$$

For both modes, other choices of endpoints and weights are also capable of encoding the same values; the approaches shown above are recommended for consistency. Note that it is not possible to represent channels of both 255 and 0 concurrently using BC7 mode 6 due to both weights and *EPB* values being shared between channels, so these cases will require the use of BC7 mode 5 to record values exactly. In other cases, the use of BC7 mode 6 is considered preferable for further image compression.

25.8.2.2 Interpolated blocks

Each UASTC *Mode Index* maps to a single BC7 mode. Depending on the block's configuration, transcoders may need to convert partition indices, scale and/or invert weights, swap endpoint pairs, and swap color channels. For BC7 modes with p-bits, transcoders also need to compute their optimal values. Table 25.33 provides a high-level overview of these steps, and subsequent sections describe each of them in detail.

UASTC *Mode Index*	BC7 Mode	Subsets	Weights scale	Weights order	BC7 EP bits	P-bits
0	6	single	copy	copy	7777	endpoint
1	3	1-to-2	copy	check anchors	7770	endpoint
2	1	2-to-2	copy	check anchors	6660	subset
3	2	3-to-3	copy	check anchors	5550	no
4	3	2-to-2	copy	check anchors	7770	endpoint
5	6	single	3-to-4	copy	7777	endpoint
6	5	single	copy	copy	7778	no
7	2	2-to-3	copy	check anchors	5550	no
9	7	2-to-2	copy	check anchors	5555	endpoint
10	6	single	copy	copy	7777	endpoint
11	5	single	copy	copy	7778	no
12	6	single	3-to-4	copy	7777	endpoint
13	5	single	1-to-2	copy	7778	no
14	6	single	2-to-4	copy	7777	endpoint
15	6	single	copy	copy	7777	endpoint
16	7	2-to-2	copy	check anchors	5555	endpoint
17	5	single	copy	copy	7778	no
18	6	single	5-to-4	copy	7777	endpoint

Table 25.33: UASTC to BC7 mode mapping

Note

Solid color (*RGB*) UASTC modes 0, 5, and 18 are transcoded to *RGBA* BC7 mode 6; minimizing the overall error when choosing EP bits may result in BC7 values that are incompletely opaque (*Alpha* = 254).

25.8.2.3 Multi-subset blocks

For each UASTC partition pattern there is a BC7 partition index that, combined with endpoint pairs reordering, produces the same pattern in the BC7 decoder. That partition index depends on the UASTC ***PAT*** value.

When UASTC *Mode Index* is 1, the value of BC7 partition index must be 0 and single UASTC endpoint pair must be replicated to both BC7 endpoint pairs.

When UASTC *Mode Index* is 2, 4, 9, or 16, the value of BC7 partition index and subset order depends on ***PAT*** as shown in Table 25.34.

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9
BC7 partition index	0	1	2	3	4	5	6	7	8	9
BC7 subset order	{0,1}	{0,1}	{1,0}	{0,1}	{1,0}	{0,1}	{1,0}	{1,0}	{0,1}	{1,0}
UASTC *PAT*	10	11	12	13	14	15	16	17	18	19
BC7 partition index	10	11	12	13	14	15	17	18	19	20
BC7 subset order	{0,1}	{1,0}	{1,0}	{1,0}	{0,1}	{1,0}	{1,0}	{1,0}	{0,1}	{0,1}
UASTC *PAT*	20	21	22	23	24	25	26	27	28	29
BC7 partition index	21	22	23	24	25	26	29	32	33	52
BC7 subset order	{0,1}	{1,0}	{1,0}	{0,1}	{1,0}	{0,1}	{1,0}	{1,0}	{1,0}	{1,0}

Table 25.34: BC7 partition index and subset order for UASTC ***PAT*** values in *Mode Indices* 2, 4, 9, or 16

When UASTC *Mode Index* is 3, the value of BC7 partition index and subset order depends on ***PAT*** as shown in Table 25.35.

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9	10
BC7 partition index	4	8	9	10	11	12	13	20	35	36	57
BC7 subset order	{0,1,2}	{1,0,2}	{1,0,2}	{1,2,0}	{1,2,0}	{0,1,2}	{0,2,1}	{2,0,1}	{2,0,1}	{1,0,2}	{0,1,2}

Table 25.35: BC7 partition index and subset order for UASTC ***PAT*** values in *Mode Index* 3

For example, UASTC *Mode Index* 3, ***PAT*** 8 has 3 endpoint pairs and maps to BC7 partition 35 with order {1, 2, 0}. This means that BC7 subset 0 must use UASTC subset 1, BC7 subset 1 must use UASTC subset 2, and BC7 subset 2 must use UASTC subset 0.

When UASTC *Mode Index* is 7, the value of BC7 partition index and subset order depends on ***PAT*** as shown in Table 25.36. (These are 3-subset BC7 partitions, but only 2 subsets from those patterns are used by setting two of the BC7 endpoint pairs to the same values.)

UASTC *PAT*	0	1	2	3	4	5	6	7	8	9
BC7 partition index	10	11	0	2	8	13	1	33	40	20
BC7 subset order	{0,1,0}	{0,1,0}	{1,0,0}	{0,1,0}	{1,0,1}	{0,1,0}	{0,1,1}	{0,1,1}	{1,0,0}	{0,1,0}
UASTC *PAT*	10	11	12	13	14	15	16	17	18	
BC7 partition index	21	58	3	32	59	34	20	14	31	
BC7 subset order	{0,0,1}	{1,0,0}	{0,0,1}	{0,1,1}	{1,1,0}	{1,0,0}	{1,1,0}	{0,1,0}	{1,0,0}	

Table 25.36: BC7 partition index and subset order for UASTC ***PAT*** values in *Mode Index* 7

25.8.2.4 Endpoints

UASTC endpoints must be unquantized to 8-bit range as described in Section 25.7.2.4.

For BC7 modes without p-bits (2 and 5), unquantized endpoint values must be scaled to the target number of BC7 endpoint bits (5 or 7 respectively).

The following equations must be used (with integer division):

```
bc7_5bit_ep = (uastc_ep * 31 + 127) / 255
bc7_7bit_ep = (uastc_ep * 127 + 127) / 255
```

For all other modes, unquantized values must first be normalized to [0.0, 1.0] floating-point range by dividing them by 255.0. Optimal BC7 quantized endpoint colors and p-bits must be computed using the functions included below.

25.8.2.5 Common helpers

- **clamp(int x, int min, int max)** Clamps integer x to the [min, max] inclusive range.
- **squaref(float x)** Returns x * x floating-point value.
- **(int)(float x)** Casts floating-point x value to integer, discarding the fractional part.

25.8.2.6 Subset P-bits computation

This routine computes optimal p-bit value per subset (used only in BC7 mode 1).

Inputs (for each subset):

- **xl[3] and xh[3]** Floating-point *RGB* endpoint values ([0.0, 1.0]).

Outputs (for each subset):

- **bestMinColor[3]** and **bestMaxColor[3]** Quantized 6-bit *RGB* values.
- **bestPbit** P-bit value.

Helpers:

- **clamp(int x, int min, int max)** Clamps integer x to the [min, max] inclusive range.
- **squaref(float x)** Returns x * x floating-point value.
- **(int)(float x)** Casts floating-point x value to integer, discarding the fractional part.

```
float best_err = 1e+9f;

for (int p = 0; p < 2; p++)
{
    uint8_t xMinColor[3], xMaxColor[3], scaledLow[3], scaledHigh[3];
    for (size_t c = 0; c < 3; c++)
    {
        xMinColor[c] = clamp(((int)((xl[c] * 127.0 - p) / 2.0f + .5f)) * 2 + p,
                             p, 126 + p);
        xMaxColor[c] = clamp(((int)((xh[c] * 127.0 - p) / 2.0f + .5f)) * 2 + p,
                             p, 126 + p);

        scaledLow[c] = (xMinColor[c] << 1) | (xMinColor[c] >> 6);
        scaledHigh[c] = (xMaxColor[c] << 1) | (xMaxColor[c] >> 6)
    }

    float err = 0.0;
    for (size_t i = 0; i < 3; i++)
    {
        err += squaref((scaledLow[i] / 255.0f) - xl[i]) +
               squaref((scaledHigh[i] / 255.0f) - xh[i]);
    }

    if (err < best_err)
    {
        best_err = err;
        bestPbit = p;
        for (size_t j = 0; j < 3; j++)
        {
            bestMinColor[j] = xMinColor[j] >> 1;
            bestMaxColor[j] = xMaxColor[j] >> 1;
        }
    }
}
```

25.8.2.7 Endpoint P-bits computation

This routine computes 2 optimal p-bit values per endpoint pair per subset (BC7 modes 3, 6, and 7).

Constants:

BC7 Mode	comps	comp_bits
3	3	7
6	4	7
7	4	5

Inputs (for each subset):

- **xl[comps]** and **xh[comps]** Floating-point *RGB(A)* endpoint values ([0.0, 1.0]).

Outputs (for each subset):

- **bestMinColor[comps]** and **bestMaxColor[comps]** Quantized *RGB(A)* values.
- **bestPbits[2]** P-bits to pack into BC7 output.

```
const uint32_t total_bits = comp_bits + 1;
const int iscalep = (1 << total_bits) - 1;
const float scalep = (float)iscalep;

float best_err0 = 1e+9f;
float best_err1 = 1e+9f;

for (int p = 0; p < 2; p++)
{
    uint8_t xMinColor[comps], xMaxColor[comps], scaledLow[comps], scaledHigh[comps];
    for (size_t c = 0; c < comps; c++)
    {
        xMinColor[c] =
            (uint8_t)(clamp(((int)((xl[c] * scalep - p) / 2.0f + .5f)) * 2 + p,
                            p, iscalep - 1 + p));
        xMaxColor[c] =
            (uint8_t)(clamp(((int)((xh[c] * scalep - p) / 2.0f + .5f)) * 2 + p,
                            p, iscalep - 1 + p));

        scaledLow[c] = (xMinColor[c] << (8 - total_bits));
        scaledLow[c] |= (scaledLow[c] >> total_bits);

        scaledHigh[c] = (xMaxColor[c] << (8 - total_bits));
        scaledHigh[c] |= (scaledHigh[c] >> total_bits);
    }

    float err0 = 0.0, err1 = 0.0;
    for (size_t i = 0; i < comps; i++)
    {
        err0 += squaref(scaledLow[i] - xl[i] * 255.0f);
        err1 += squaref(scaledHigh[i] - xh[i] * 255.0f);
    }

    if (err0 < best_err0)
    {
        best_err0 = err0;
        bestPbits[0] = p;

        for (size_t i = 0; i < comps; i++)
        {
            bestMinColor[i] = xMinColor[i] >> 1;
        }
    }

    if (err1 < best_err1)
    {
        best_err1 = err1;
        best_pbits[1] = p;

        for (size_t i = 0; i < comps; i++)
        {
            bestMaxColor[i] = xMaxColor[i] >> 1;
        }
    }
}
```

25.8.2.8 Weights

For most UASTC *Mode Indices*, weight indices can be copied to BC7 indices as-is.

Implementations must respect “anchor” indices for multi-subset BC7 modes and swap low/high endpoint values and invert weight indices accordingly.

Although UASTC *Mode Index* 1 has only one subset, its BC7 counterpart (mode 3) has two subsets, so implementations may need to swap duplicated endpoints and invert weights for the second subset.

When the number of bits per weight index is different between a given UASTC *Mode Index* and BC7 mode, the mappings in Table 25.37 apply.

UASTC 1-bit (*Mode Index* 13) to BC7 2-bit (mode 5)								
UASTC weight	0	1						
BC7 weight	0	3						
UASTC 2-bit (*Mode Index* 14) to BC7 4-bit (mode 6)								
UASTC weight	0	1	2	3				
BC7 weight	0	5	10	15				
UASTC 3-bit (*Mode Index* 5 and 12) to BC7 4-bit (mode 6)								
UASTC weight	0	1	2	3	4	5	6	7
BC7 weight	0	2	4	6	9	11	13	15
UASTC 5-bit (*Mode Index* 18) to BC7 4-bit (mode 6)								
UASTC weight	0	1	2	3	4	5	6	7
BC7 weight	0	0	1	1	2	2	3	3
UASTC weight	8	9	10	11	12	13	14	15
BC7 weight	4	4	5	5	6	6	6	7
UASTC weight	16	17	18	19	20	21	22	23
BC7 weight	8	9	9	9	10	10	11	11
UASTC weight	24	25	26	27	28	29	30	31
BC7 weight	12	12	13	13	14	14	15	15

Table 25.37: UASTC mapping for BC7 weights with different bit counts

25.8.2.9 Dual-plane blocks

UASTC dual-plane blocks are transcoded to BC7 mode 5 and utilize BC7 rotation bits to select which channel uses the second set of weights.

For *RGB* and *RGBA* dual-plane blocks (UASTC *Mode Indices* 6, 11, and 13), the value of the rotation bits depends on the **CSEL** UASTC field. The channel that uses the second set of weights must be swapped with alpha (within an endpoint pair) as per the BC7 specification.

CSEL	BC7 RB	Channel
0	1	*Red*
1	2	*Green*
2	3	*Blue*
3	0	*Alpha*

Table 25.38: UASTC to BC7 component selection

For *LA* dual-plane blocks (*Mode Index* 17) BC7 rotation bits must be set to 0; no channel swapping is needed.

25.8.3 Transcoding to ETC formats

UASTC blocks contain various hints to speedup transcoding to some ETC formats. Namely:

- **UASTC to ETC1 RGB**

  Note
  To transcode UASTC alpha channel into a separate ETC1 texture (for example, to provide *RGBA* data to older hardware), transcoders would need to determine optimal ETC1 parameters themselves. For solid-color blocks, this could be easily accelerated with a pre-computed lookup table.

- **UASTC to ETC2 *RGBA* (ETC1 *RGB* + ETC2 *Alpha*)**

  Note
  There are no hints for ETC2-only color modes (“T”, “H”, or planar).

  Note
  Transcoding non-solid UASTC *RGB* data to ETC2/EAC R11 (or RG11) blocks requires full-block re-encoding.

25.8.3.1 Solid color blocks

For solid-color UASTC blocks, ETC1 *RGB* transcode hints directly follow the 32-bit *RGBA* block color.

- **ETC1D** Color mode (0 - individual, 1 - differential).
- **ETC1I** Intensity table index. Must be used for both ETC1 subblocks.
- **ETC1S** Pixel index value to use for all 16 pixels.
- **ETC1R**, **ETC1G**, and **ETC1B** Pre-computed *RGB* value, pre-quantized to 5 bits for differential color mode, or to 4 bits for individual color mode. In individual color mode, a transcoder must ignore the unused top bit of each channel encoding that is used to pad the representation to 5 bits.

A transcoder must copy these values to the appropriate fields of the ETC1 block. For differential color mode, color delta bits must be set to 0. For individual color mode, pre-computed *RGB* values must be used for both base colors.

When transcoding to ETC2 RGBA, following rules apply for the ETC2 Alpha block.

- **Base codeword** Copy from *A* UASTC field.
- **Multiplier** 1.
- **Table index** 13.
- **All pixel indices** 4.

25.8.3.2 Interpolated blocks

For interpolated UASTC blocks, ETC1 *RGB* transcode hints include:

- **ETC1F** Flip bit (0 - side-by-side, 1 - top-to-bottom).
- **ETC1D** Color mode (0 - individual, 1 - differential).
- **ETCI0** Table codeword 1.
- **ETCI1** Table codeword 2.
- **ETCBI** An optional field indicating how to bias each ETC1’s subset’s computed block color.

The UASTC block must first be unpacked to pixels. After this, the only expensive work required to transcode to ETC1 is computing the subblock average colors and the pixel indices.

Subblock colors

To compute each subblock's quantized block color for individual color mode:

1. Compute each subblock's average pixel color and quantize it to 4-bits/component, with rounding. This could be done by summing 8 color values and computing (for each channel, with integer division):

   ```
   (sum * 15 + 1020) / (8 * 255)
   ```

2. For UASTC modes that have an **ETCBI** field, apply the ETC1 bias (as defined by the function below) to the result of the previous step.
3. Write the updated subblock colors to the ETC1 block.

To compute each subblock's quantized block color for differential color mode:

1. Compute each subblock's average pixel color and quantize it to 5-bits/component, with rounding. This could be done by summing 8 color values and computing (for each channel, with integer division):

   ```
   (sum * 31 + 1020) / (8 * 255)
   ```

2. For UASTC modes that have an **ETCBI** field, apply the ETC1 bias (as defined by the function below) to the result of the previous step.
3. Compute the difference between the updated subblock colors `(color2 -color1)` and clamp it to a [-4, 3] 3-bit range.
4. Write the subblock color and the delta to the ETC1 block.

Applying ETCBI

Inputs (for each subblock):

- **subblock** Subblock index. Either 0 or 1.
- **limit** Maximum quantized color value. 31 for differential color mode, 15 for individual color mode.
- **bias** UASTC **ETCBI** field value.
- **blockColor[3]** Quantized average subblock *RGB* color.

Outputs (for each subblock):

- **blockColor[3]** Biased subblock color value.

```
for (uint32_t c = 0; c < 3; c++)
{
    int delta = 0;

    switch (bias)
    {
    case 2: delta = subblock ? 0 : ((c == 0) ? -1 : 0); break;
    case 5: delta = subblock ? 0 : ((c == 1) ? -1 : 0); break;
    case 6: delta = subblock ? 0 : ((c == 2) ? -1 : 0); break;

    case 7: delta = subblock ? 0 : ((c == 0) ? 1 : 0); break;
    case 11: delta = subblock ? 0 : ((c == 1) ? 1 : 0); break;
    case 15: delta = subblock ? 0 : ((c == 2) ? 1 : 0); break;

    case 18: delta = subblock ? ((c == 0) ? -1 : 0) : 0; break;
    case 19: delta = subblock ? ((c == 1) ? -1 : 0) : 0; break;
    case 20: delta = subblock ? ((c == 2) ? -1 : 0) : 0; break;

    case 21: delta = subblock ? ((c == 0) ? 1 : 0) : 0; break;
    case 24: delta = subblock ? ((c == 1) ? 1 : 0) : 0; break;
    case 8: delta = subblock ? ((c == 2) ? 1 : 0) : 0; break;

    case 10: delta = -2; break;

    case 27: delta = subblock ? 0 : -1; break;
    case 28: delta = subblock ? -1 : 1; break;
    case 29: delta = subblock ? 1 : 0; break;
    case 30: delta = subblock ? -1 : 0; break;
    case 31: delta = subblock ? 0 : 1; break;

    default:
        static const int s_divs[3] = { 1, 3, 9 };
        delta = ((bias / s_divs[c]) % 3) - 1;
        break;
    }

    int v = block_color[c];
    if (v == 0)
    {
        v = (delta == -2) ? 3 : (delta + 1);
    }
    else if (v == limit)
    {
        v += (delta - 1);
    }
    else
    {
        v += delta;
        if ((v < 0) || (v > limit))
            v = (v - delta) - delta;
    }

    block_color[c] = (uint8_t)v;
}
```

25.8.3.3 Pixel indices

The last step is computing the pixel indices. This is done by comparing decoded pixel values with 4-color palette that is fixed for each subblock.

To accelerate this step, transcoders may compute the errors in a luma space with *RGB* component weights of (1, 1, 1) for linearly-encoded textures and of (54, 183, 19) for sRGB-encoded textures.

25.8.3.4 ETC2/EAC *alpha* transcoding

For UASTC *RGB* blocks (that have fully-opaque alpha), ETC2/EAC Alpha blocks must be encoded as:

- **Base codeword** 255.
- **Multiplier** 1.
- **Table index** 13.
- **All pixel indices** 4.

UASTC *RGBA* modes contain two ETC2/EAC Alpha hints to accelerate transcoding of the alpha values:

- **ETC2T** Table index.
- **ETC2M** Multiplier.
  - **ETC2M** cannot be zero. In such a case, the block is invalid and must be decoded to the error color.
- When the *alpha* value is the same for all pixels of the block and ETC2* hints are not used (see step 1 below), the encoder must still set **ETC2T** and **ETC2M** fields to 13 and 1 respectively.

Steps for transcoding the *alpha* channel:

1. Compute minimum and maximum values of the block's *alpha*. If they are equal to each other (i.e. all pixels of the block have the same alpha value), the transcoding is done and the ETC2/EAC Alpha parameters are the same as for opaque blocks with the only difference that *base codeword* must be set to the block's alpha value.
2. Compute the *base codeword* by finding the approximate center of the range of alpha values for the hinted table index:

   ```
   baseAlpha = roundf(minAlpha + (maxAlpha - minAlpha) * c)
   ```

   Where c is the floating-point value based on the table index:

Table index	0	1	2	3	4	5	6	7
Float value	15/29	13/25	13/25	13/25	12/23	11/21	11/21	11/21
Table index	8	9	10	11	12	13	14	15
Float value	10/19	10/19	10/19	10/19	10/19	10/19	9/17	9/17

3. For each pixel, compute the pixel index that would yield lowest error with all other block parameters set (table index, base value, and multiplier).
4. Write all computed values to the ETC2/EAC Alpha block.

25.8.4 Transcoding to BC1-5 formats

Only BC1 (without 3-color mode) and *RGB* parts of BC2/BC3 transcode targets could be accelerated by using UASTC hints (BC1H0 and BC1H1).

BC4/BC5 and the *alpha* part of BC3 always require pixel-level re-encoding.

Using BC1 hints

Most UASTC modes have **BC1H0** and/or **BC1H1** hint bits. When set, they signal that some steps of a typical BC1 encoding process could be skipped.

When the **BC1H0** bit is present and set:

- The first subset's endpoints can be scaled to BC1 range (5, 6, 5), as in (using integer division):

  ```
  R_bc1 = max((_R_ * 31 + 127) / 255, 31)
  G_bc1 = max((_G_ * 63 + 127) / 255, 63)
  B_bc1 = max((_B_ * 31 + 127) / 255, 31)
  ```

  Other subsets (when present) can be ignored. Note that endpoints may need to be swapped to avoid the BC1 3-color mode.

- The first plane's weight indices can be mapped to BC1 2-bit codes. The second plane weights (when present) are ignored. Note that the order of BC1 codes does not follow the order of actual interpolation weights, see the exact mappings in Table 25.39.

- This skips the expensive PCA and least-squares steps. Transcoders aiming at high quality may choose to ignore this hint.

When the **BC1H1** bit is present and set:

- The first plane's weight indices can be mapped to BC1 2-bit codes. The second plane weights (when present) are ignored. Note that the order of BC1 codes does not follow the order of actual interpolation weights, see the exact mappings in Table 25.39.

- Transcoders have to compute optimal endpoint values with pixel codes fixed. This skips the expensive PCA step.

<table>
<tr><th colspan="9">UASTC 1-bit weight indices to BC1 codes</th></tr>
<tr><td>UASTC weight</td><td>0</td><td>1</td><td colspan="6"></td></tr>
<tr><td>BC1 code</td><td>0</td><td>1</td><td colspan="6"></td></tr>
<tr><th colspan="9">UASTC 2-bit weight indices to BC1 codes</th></tr>
<tr><td>UASTC weight</td><td>0</td><td>1</td><td>2</td><td>3</td><td colspan="4"></td></tr>
<tr><td>BC1 code</td><td>0</td><td>2</td><td>3</td><td>1</td><td colspan="4"></td></tr>
<tr><th colspan="9">UASTC 3-bit weight indices to BC1 codes</th></tr>
<tr><td>UASTC weight</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>BC1 code</td><td>0</td><td>0</td><td>2</td><td>2</td><td>3</td><td>3</td><td>1</td><td>1</td></tr>
<tr><th colspan="9">UASTC 4-bit weight indices to BC1 codes</th></tr>
<tr><td>UASTC weight</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>BC1 code</td><td>0</td><td>0</td><td>0</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>UASTC weight</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>BC1 code</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>1</td><td>1</td><td>1</td></tr>
<tr><th colspan="9">UASTC 5-bit weight indices to BC1 codes</th></tr>
<tr><td>UASTC weight</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>BC1 code</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>2</td></tr>
<tr><td>UASTC weight</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>BC1 code</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>UASTC weight</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td></tr>
<tr><td>BC1 code</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>UASTC weight</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td>BC1 code</td><td>3</td><td>3</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Table 25.39: UASTC mapping weight indices to BC1 codes

Part V

References and contributors

Chapter 26

External references

IEEE754-2008 - IEEE standard for floating-point arithmetic

IEEE Std 754-2019 https://doi.org/10.1109/IEEESTD.2019.8766229 July, 2019.

ISO/IEC 60559:2020 https://www.iso.org/standard/80985.html

CIE Colorimetry - Part 3: CIE tristimulus values

ISO/CIE 11664-3:2019 https://www.iso.org/standard/74165.html

ITU-R BT.601 Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios

http://www.itu.int/rec/R-REC-BT.601/en

ITU-R BT.709 Parameter values for the HDTV standards for production and international programme exchange

https://www.itu.int/rec/R-REC-BT.709/en

ITU-R BT.2020 Parameter values for ultra-high definition television systems for production and international programme exchange

http://www.itu.int/rec/R-REC-BT.2020/en

ITU-R BT.2100 Image parameter values for high dynamic range television for use in production and international programme exchange

http://www.itu.int/rec/R-REC-BT.2100/en

JPEG File Interchange Format (JFIF)

https://www.itu.int/rec/T-REC-T.871/en

Legacy version:

https://www.w3.org/Graphics/JPEG/jfif3.pdf

ITU-R BT.1886: Reference electro-optical transfer function for flat panel displays used in HDTV studio production

https://www.itu.int/rec/R-REC-BT.1886/en

ITU-R BT.2087 Colour conversion from Recommendation ITU-R BT.709 to Recommendation ITU-R BT.2020

http://www.itu.int/rec/R-REC-BT.2087/en

ITU-R BT.2390 High dynamic range television for production and international programme exchange

https://www.itu.int/pub/R-REP-BT.2390-11-2023+

ITU-R BT.470 Conventional analogue television systems

https://www.itu.int/rec/R-REC-BT.470/en

Note
BT.470-6 contains descriptions of analog broadcast systems. BT.470-7 deprecates this description in favor of BT.1700.

Note
Although this specification is written in English, the countries in Appendix 1 appear to be listed in alphabetical order as they would have been written in French.

ITU-R BT.472-3: Video-frequency characteristics of a television system to be used for the international exchange of programmes between countries that have adopted 625-line colour or monochrome systems

http://www.itu.int/rec/R-REC-BT.472/en

ITU-R BT.1700: Characteristics of composite video signals for conventional analogue television systems

https://www.itu.int/rec/R-REC-BT.1700/en

Note
This specification includes SMTPE170M-2004 (which describes NTSC) along with PAL and NTSC.

ITU-R BT.2043: Analogue television systems currently in use throughout the world

https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-BT.2043-2004-PDF-E.pdf

Note
Although this specification is written in English, the countries appear to be listed in alphabetical order as they would have been written in French.

SMPTE 170m Composite analog video signal — NTSC for studio applications

https://pub.smpte.org/pub/st170/st0170-2004_stable2010.pdf

SMPTE 170m-2004 is freely available as part of ITU-R BT.1700 at:

https://www.itu.int/rec/R-REC-BT.1700/en

FCC 73.682 - TV transmission standards

https://www.govinfo.gov/app/details/CFR-2001-title47-vol4/CFR-2001-title47-vol4-sec73-682

ST 240:1999 - SMPTE Standard - For Television — 1125-Line High-Definition Production Systems — Signal Parameters

Formerly known as SMPTE240M - interim HDTV standard prior to international agreement on BT.709.

https://www.normsplash.com/SMPTE/146382533/SMPTE-ST-240

(Apparently no longer available from SMPTE or IEEE.)

(See also https://pub.smpte.org/pub/st260/st0260-1999_stable2004.pdf.)

IEC/4WD 61966-2-1: Colour measurement and management in multimedia systems and equipment - part 2-1: default RGB colour space - sRGB

https://webstore.iec.ch/publication/6169 (specification)

http://www.w3.org/Graphics/Color/srgb

IEC 61966-2-2:2003: Multimedia systems and equipment — Colour measurement and management — Part 2-2: Colour management — Extended RGB colour space — scRGB

https://www.iso.org/standard/35876.html

http://www.color.org/chardata/rgb/scrgb.xalter

A working draft is freely available at https://web.archive.org/web/20110725185444/http://www.colour.org/tc8-05/Docs/-colorspace/61966-2-2NPa.pdf.

http://www.color.org/sycc.pdf - sYCC (the $Y'C_BC_R$ variant of sRGB)

DCI P3 color space

- SMPTE 428-1: D-Cinema Distribution Master — Image Characteristics
- SMPTE EG 432-1: Digital Source Processing — Color Processing for D-Cinema
- SMPTE RP 431-2: D-Cinema Quality — Reference Projector and Environment See https://www.smpte.org/blog/-understanding-standards-digital-cinema-format.

The latest versions are available from the SMPTE store.

https://developer.apple.com/reference/coregraphics/cgcolorspace/1408916-displayp3 describes Apple's Display P3 color space.

Academy Color Encoding System

http://www.oscars.org/science-technology/sci-tech-projects/aces/aces-documentation

The international standard for ACES, SMPTE ST 2065-1:2012 - Academy Color Encoding Specification (ACES), is available from the SMPTE.

TB-2014-004: Informative Notes on SMPTE ST 2065-1 – Academy Color Encoding Specification (ACES) is freely available and contains a draft of the international standard.

ACEScc — A Logarithmic Encoding of ACES Data for use within Color Grading Systems

ACEScct — A Quasi-Logarithmic Encoding of ACES Data for use within Color Grading Systems

Sony S-Log

S-Log description from archive.org

S-Log 2 description from archive.org

S-Log3 description

(Sony no longer seems to host these public documents.)

Adobe RGB (1998)

https://www.adobe.com/digitalimag/pdfs/AdobeRGB1998.pdf

https://www.adobe.com/digitalimag/adobergb.html

Windows Media Foundation YUV

https://docs.microsoft.com/en-us/windows/win32/medfound/recommended-8-bit-yuv-formats-for-video-rendering

Chapter 27

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