PNG Development Group
PNG 1.2

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PNG (Portable Network Graphics) Specification, Version 1.2

For list of authors, see Credits (Chapter 19).

Status of this Document

This is a revision of the PNG 1.0 specification, which has been published as RFC-2083 and as a W3C Recommendation. The revision has been released by the PNG Development Group but has not been approved by any standards body.

The PNG specification is on a standards track under the purview of ISO/IEC JTC 1 SC 24 and is expected to be released eventually as ISO/IEC International Standard 15948. It is the intent of the standards bodies to maintain backward compatibility with this specification. Implementors should periodically check the PNG online resources (see Online Resources, Chapter 16) for the current status of PNG documentation.

Abstract

This document describes PNG (Portable Network Graphics), an extensible file format for the lossless, portable, well-compressed storage of raster images. PNG provides a patent-free replacement for GIF and can also replace many common uses of TIFF. Indexed-color, grayscale, and truecolor images are supported, plus an optional alpha channel. Sample depths range from 1 to 16 bits.

PNG is designed to work well in online viewing applications, such as the World Wide Web, so it is fully streamable with a progressive display option. PNG is robust, providing both full file integrity checking and simple detection of common transmission errors. Also, PNG can store gamma and chromaticity data for improved color matching on heterogeneous platforms.

This specification defines the Internet Media Type “image/png”.

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1 Introduction

The Portable Network Graphics (PNG) format provides a portable, legally unencumbered, well-compressed, well-specified standard for lossless bitmapped image files.

Although the initial motivation for developing PNG was to replace GIF (CompuServe's Graphics Interchange Format), the design provides some useful new features not available in GIF, with minimal cost to developers.

GIF features retained in PNG include:

- Indexed-color images of up to 256 colors.
- Streamability: files can be read and written serially, thus allowing the file format to be used as a communications protocol for on-the-fly generation and display of images.
- Progressive display: a suitably prepared image file can be displayed as it is received over a communications link, yielding a low-resolution image very quickly followed by gradual improvement of detail.
- Transparency: portions of the image can be marked as transparent, creating the effect of a non-rectangular image.
- Ancillary information: textual comments and other data can be stored within the image file.
- Complete hardware and platform independence.
- Effective, 100% lossless compression.

Important new features of PNG, not available in GIF, include:

- Truecolor images of up to 48 bits per pixel.
- Grayscale images of up to 16 bits per pixel.
- Full alpha channel (general transparency masks).
- Image gamma information, which supports automatic display of images with correct brightness/ contrast regardless of the machines used to originate and display the image.
- Reliable, straightforward detection of file corruption.
- Faster initial presentation in progressive display mode.

PNG is designed to be:

- Simple and portable: developers should be able to implement PNG easily.
- Legally unencumbered: to the best knowledge of the PNG authors, no algorithms under legal challenge are used. (Some considerable effort has been spent to verify this.)
- Well compressed: both indexed-color and truecolor images are compressed as effectively as in any other widely used lossless format, and in most cases more effectively.

- Interchangeable: any standard-conforming PNG decoder must read all conforming PNG files.
- Flexible: the format allows for future extensions and private add-ons, without compromising interchangeability of basic PNG.
- Robust: the design supports full file integrity checking as well as simple, quick detection of common transmission errors.

The main part of this specification gives the definition of the file format and recommendations for encoder and decoder behavior. An appendix gives the rationale for many design decisions. Although the rationale is not part of the formal specification, reading it can help implementors understand the design. Cross-references in the main text point to relevant parts of the rationale. Additional appendixes, also not part of the formal specification, provide tutorials on gamma and color theory as well as other supporting material.

The words "must", "required", "should", "recommended", "may", and "optional" in this document are to be interpreted as described in [RFC-2119], which is consistent with their plain English meanings. The word "can" carries the same force as "may".

See Rationale: Why a new file format? (Section 12.1), Why these features? (Section 12.2), Why not these features? (Section 12.3), Why not use format X? (Section 12.4).

Pronunciation

PNG is pronounced "ping".

2 Data Representation

This chapter discusses basic data representations used in PNG files, as well as the expected representation of the image data.

2.1 Integers and byte order

All integers that require more than one byte must be in network byte order: the most significant byte comes first, then the less significant bytes in descending order of significance (MSB LSB for two-byte integers, B3 B2 B1 B0 for four-byte integers). The highest bit (value 128) of a byte is numbered bit 7; the lowest bit (value 1) is numbered bit 0. Values are unsigned unless otherwise noted. Values explicitly noted as signed are represented in two's complement notation.

Unless otherwise stated, four-byte unsigned integers are limited to the range 0 to $2^{31} - 1$ to accommodate languages that have difficulty with unsigned four-byte values. Similarly, four-byte signed integers are limited to the range $-(2^{31} - 1)$ to $2^{31} - 1$ to accommodate languages that have difficulty with the value -2^{31}.

See Rationale: Byte order (Section 12.5).

2.2 Color values

Colors can be represented by either grayscale or RGB (red, green, blue) sample data. Grayscale data represents luminance; RGB data represents calibrated color information (if the cHRM chunk is present) or uncalibrated device-dependent color (if cHRM is absent). All color values range from zero (representing black) to most intense at the maximum value for the sample depth. Note that the maximum value at a given sample depth is $2^{\mathrm{sampledepth}} - 1$, not $2^{\mathrm{sampledepth}}$.

Sample values are not necessarily proportional to light intensity; the gAMA chunk specifies the relationship between sample values and display output intensity, and viewers are strongly encouraged to compensate properly. See Gamma correction (Section 2.7).

Source data with a precision not directly supported in PNG (for example, 5 bit/sample truecolor) must be scaled up to the next higher supported bit depth. This scaling is reversible with no loss of data, and it reduces the number of cases that decoders have to cope with. See Recommendations for Encoders: Sample depth scaling (Section 9.1) and Recommendations for Decoders: Sample depth rescaling (Section 10.4).

2.3 Image layout

Conceptually, a PNG image is a rectangular pixel array, with pixels appearing left-to-right within each scanline, and scanlines appearing top-to-bottom. (For progressive display purposes, the data may actually be transmitted in a different order; see Interlaced data order, Section 2.6.) The size of each pixel is determined by the *bit depth*, which is the number of bits per sample in the image data.

Three types of pixel are supported:

- An *indexed-color* pixel is represented by a single sample that is an index into a supplied palette. The image bit depth determines the maximum number of palette entries, but not the color precision within the palette.
- A *grayscale* pixel is represented by a single sample that is a grayscale level, where zero is black and the largest value for the bit depth is white.
- A *truecolor* pixel is represented by three samples: red (zero = black, max = red) appears first, then green (zero = black, max = green), then blue (zero = black, max = blue). The bit depth specifies the size of each sample, not the total pixel size.

Optionally, grayscale and truecolor pixels can also include an alpha sample, as described in the next section.

Pixels are always packed into scanlines with no wasted bits between pixels. Pixels smaller than a byte never cross byte boundaries; they are packed into bytes with the leftmost pixel in the high-order bits of a byte, the rightmost in the low-order bits. Permitted bit depths and pixel types are restricted so that in all cases the packing is simple and efficient.

PNG permits multi-sample pixels only with 8- and 16-bit samples, so multiple samples of a single pixel are never packed into one byte. All 16-bit samples are stored in network byte order (MSB first).

Scanlines always begin on byte boundaries. When pixels have fewer than 8 bits and the scanline width is not evenly divisible by the number of pixels per byte, the low-order bits in the last byte of each scanline are wasted. The contents of these wasted bits are unspecified.

An additional "filter-type" byte is added to the beginning of every scanline (see Filtering, Section 2.5). The filter-type byte is not considered part of the image data, but it is included in the datastream sent to the compression step.

2.4 Alpha channel

An alpha channel, representing transparency information on a per-pixel basis, can be included in grayscale and truecolor PNG images.

An alpha value of zero represents full transparency, and a value of $2^{\mathrm{bitdepth}} - 1$ represents a fully opaque pixel. Intermediate values indicate partially transparent pixels that can be combined with a background image to yield a composite image. (Thus, alpha is really the degree of opacity of the pixel. But most people refer to alpha as providing transparency information, not opacity information, and we continue that custom here.)

Alpha channels can be included with images that have either 8 or 16 bits per sample, but not with images that have fewer than 8 bits per sample. Alpha samples are represented with the same bit depth used for the image samples. The alpha sample for each pixel is stored immediately following the grayscale or RGB samples of the pixel.

The color values stored for a pixel are not affected by the alpha value assigned to the pixel. This rule is sometimes called "unassociated" or "non-premultiplied" alpha. (Another common technique is to store sample values premultiplied by the alpha fraction; in effect, such an image is already composited against a black background. PNG does *not* use premultiplied alpha.)

Transparency control is also possible without the storage cost of a full alpha channel. In an indexed-color image, an alpha value can be defined for each palette entry. In grayscale and truecolor images, a single pixel value can be identified as being "transparent". These techniques are controlled by the tRNS ancillary chunk type.

If no alpha channel nor tRNS chunk is present, all pixels in the image are to be treated as fully opaque.

Viewers can support transparency control partially, or not at all.

See Rationale: Non-premultiplied alpha (Section 12.8), Recommendations for Encoders: Alpha channel creation (Section 9.4), and Recommendations for Decoders: Alpha channel processing (Section 10.8).

2.5 Filtering

PNG allows the image data to be *filtered* before it is compressed. Filtering can improve the compressibility of the data. The filter step itself does not reduce the size of the data. All PNG filters are strictly lossless.

PNG defines several different filter algorithms, including "None" which indicates no filtering. The filter algorithm is specified for each scanline by a filter-type byte that precedes the filtered scanline in the precompression datastream. An intelligent encoder can switch filters from one scanline to the next. The method for choosing which filter to employ is up to the encoder.

See Filter Algorithms (Chapter 6) and Rationale: Filtering (Section 12.9).

2.6 Interlaced data order

A PNG image can be stored in interlaced order to allow progressive display. The purpose of this feature is to allow images to "fade in" when they are being displayed on-the-fly. Interlacing slightly expands the file size on average, but it gives the user a meaningful display much more rapidly. Note that decoders are required to be able to read interlaced images, whether or not they actually perform progressive display.

With interlace method 0, pixels are stored sequentially from left to right, and scanlines sequentially from top to bottom (no interlacing).

Interlace method 1, known as Adam7 after its author, Adam M. Costello, consists of seven distinct passes over the image. Each pass transmits a subset of the pixels in the image. The pass in which each pixel is transmitted is defined by replicating the following 8-by-8 pattern over the entire image, starting at the upper left corner:

```
1 6 4 6 2 6 4 6
7 7 7 7 7 7 7 7
5 6 5 6 5 6 5 6
7 7 7 7 7 7 7 7
3 6 4 6 3 6 4 6
7 7 7 7 7 7 7 7
5 6 5 6 5 6 5 6
7 7 7 7 7 7 7 7
```

Within each pass, the selected pixels are transmitted left to right within a scanline, and selected scanlines sequentially from top to bottom. For example, pass 2 contains pixels 4, 12, 20, etc. of scanlines 0, 8, 16, etc. (numbering from 0,0 at the upper left corner). The last pass contains the entirety of scanlines 1, 3, 5, etc.

The data within each pass is laid out as though it were a complete image of the appropriate dimensions. For example, if the complete image is 16 by 16 pixels, then pass 3 will contain two scanlines, each containing four pixels. When pixels have fewer than 8 bits, each such scanline is padded as needed to fill an integral number of bytes (see Image layout, Section 2.3). Filtering is done on this reduced image in the usual way, and a filter-type byte is transmitted before each of its scanlines (see Filter Algorithms, Chapter 6). Notice that the transmission order is defined so that all the scanlines transmitted in a pass will have the same number of pixels; this is necessary for proper application of some of the filters.

Caution: If the image contains fewer than five columns or fewer than five rows, some passes will be entirely empty. Encoders and decoders must handle this case correctly. In particular, filter-type bytes are associated only with nonempty scanlines; no filter-type bytes are present in an empty pass.

See Rationale: Interlacing (Section 12.6) and Recommendations for Decoders: Progressive display (Section 10.9).

2.7 Gamma correction

PNG images can specify, via the gAMA chunk, the power function relating the desired display output with the image samples. Display programs are strongly encouraged to use this information, plus information about the display system they are using, to present the image to the viewer in a way that reproduces what the image's original author saw as closely as possible. See Gamma Tutorial (Chapter 13) if you aren't already familiar with gamma issues.

Gamma correction is not applied to the alpha channel, if any. Alpha samples always represent a linear fraction of full opacity.

For high-precision applications, the exact chromaticity of the RGB data in a PNG image can be specified via the cHRM chunk, allowing more accurate color matching than gamma correction alone will provide. If the RGB data conforms to the sRGB specification [sRGB], this can be indicated with the sRGB chunk, enabling even more accurate reproduction. Alternatively, the iCCP chunk can be used to embed an ICC profile [ICC] containing detailed color space information. See Color Tutorial (Chapter 14) if you aren't already familiar with color representation issues.

See Rationale: Why gamma? (Section 12.7), Recommendations for Encoders: Encoder gamma handling (Section 9.2), and Recommendations for Decoders: Decoder gamma handling (Section 10.5).

2.8 Text strings

A PNG file can store text associated with the image, such as an image description or copyright notice. Keywords are used to indicate what each text string represents.

ISO/IEC 8859-1 (Latin-1) is the character set recommended for use in the text strings appearing in tEXt and zTXt chunks [ISO/IEC-8859-1]. It is a superset of 7-bit ASCII. If it is necessary to convey characters outside of the Latin-1 set, the iTXt chunk should be used instead.

Character codes not defined in Latin-1 should not be used in tEXt and zTXt chunks, because they have no platform-independent meaning. If a non-Latin-1 code does appear in a PNG text string, its interpretation will vary across platforms and decoders. Some systems might not even be able to display all the characters in Latin-1, but most modern systems can.

Provision is also made for the storage of compressed text.

See Rationale: Text strings (Section 12.10).

3 File Structure

A PNG file consists of a PNG *signature* followed by a series of *chunks*. This chapter defines the signature and the basic properties of chunks. Individual chunk types are discussed in the next chapter.

3.1 PNG file signature

The first eight bytes of a PNG file always contain the following (decimal) values:

```
137 80 78 71 13 10 26 10
```

This signature indicates that the remainder of the file contains a single PNG image, consisting of a series of chunks beginning with an IHDR chunk and ending with an IEND chunk.

See Rationale: PNG file signature (Section 12.12).

3.2 Chunk layout

Each chunk consists of four parts:

Length
: A 4-byte unsigned integer giving the number of bytes in the chunk's data field. The length counts **only** the data field, **not** itself, the chunk type code, or the CRC. Zero is a valid length. Although encoders and decoders should treat the length as unsigned, its value must not exceed $2^{31} - 1$ bytes.

Chunk Type
: A 4-byte chunk type code. For convenience in description and in examining PNG files, type codes are restricted to consist of uppercase and lowercase ASCII letters (A–Z and a–z, or 65–90 and 97–122 decimal). However, encoders and decoders must treat the codes as fixed binary values, not character strings. For example, it would not be correct to represent the type code IDAT by the EBCDIC equivalents of those letters. Additional naming conventions for chunk types are discussed in the next section.

Chunk Data
: The data bytes appropriate to the chunk type, if any. This field can be of zero length.

CRC
: A 4-byte CRC (Cyclic Redundancy Check) calculated on the preceding bytes in the chunk, including the chunk type code and chunk data fields, but **not** including the length field. The CRC is always present, even for chunks containing no data. See CRC algorithm (Section 3.4).

The chunk data length can be any number of bytes up to the maximum; therefore, implementors cannot assume that chunks are aligned on any boundaries larger than bytes.

Chunks can appear in any order, subject to the restrictions placed on each chunk type. (One notable restriction is that IHDR must appear first and IEND must appear last; thus the IEND chunk serves as an end-of-file marker.) Multiple chunks of the same type can appear, but only if specifically permitted for that type.

See Rationale: Chunk layout (Section 12.13).

3.3 Chunk naming conventions

Chunk type codes are assigned so that a decoder can determine some properties of a chunk even when it does not recognize the type code. These rules are intended to allow safe, flexible extension of the PNG format, by allowing a decoder to decide what to do when it encounters an unknown chunk. The naming rules are not normally of interest when the decoder does recognize the chunk's type.

Four bits of the type code, namely bit 5 (value 32) of each byte, are used to convey chunk properties. This choice means that a human can read off the assigned properties according to whether each letter of the type code is uppercase (bit 5 is 0) or lowercase (bit 5 is 1). However, decoders should test the properties of an unknown chunk by numerically testing the specified bits; testing whether a character is uppercase or lowercase is inefficient, and even incorrect if a locale-specific case definition is used.

It is worth noting that the property bits are an inherent part of the chunk name, and hence are fixed for any chunk type. Thus, BLOB and bLOb would be unrelated chunk type codes, not the same chunk with different properties. Decoders must recognize type codes by a simple four-byte literal comparison; it is incorrect to perform case conversion on type codes.

The semantics of the property bits are:

Ancillary bit: bit 5 of first byte
: 0 (uppercase) = critical, 1 (lowercase) = ancillary.

  Chunks that are not strictly necessary in order to meaningfully display the contents of the file are known as "ancillary" chunks. A decoder encountering an unknown chunk in which the ancillary bit is 1 can safely ignore the chunk and proceed to display the image. The time chunk (tIME) is an example of an ancillary chunk.

  Chunks that are necessary for successful display of the file's contents are called "critical" chunks. A decoder encountering an unknown chunk in which the ancillary bit is 0 must indicate to the user that the image contains information it cannot safely interpret. The image header chunk (IHDR) is an example of a critical chunk.

Private bit: bit 5 of second byte
: 0 (uppercase) = public, 1 (lowercase) = private.

  A public chunk is one that is part of the PNG specification or is registered in the list of PNG special-purpose public chunk types. Applications can also define private (unregistered) chunks for their own purposes. The names of private chunks must have a lowercase second letter, while public chunks will always be assigned names with uppercase second letters. Note that decoders do not need to test the

private-chunk property bit, since it has no functional significance; it is simply an administrative convenience to ensure that public and private chunk names will not conflict. See Additional chunk types (Section 4.4), and Recommendations for Encoders: Use of private chunks (Section 9.8).

Reserved bit: bit 5 of third byte

Must be 0 (uppercase) in files conforming to this version of PNG.

The significance of the case of the third letter of the chunk name is reserved for possible future expansion. At the present time all chunk names must have uppercase third letters. (Decoders should not complain about a lowercase third letter, however, as some future version of the PNG specification could define a meaning for this bit. It is sufficient to treat a chunk with a lowercase third letter in the same way as any other unknown chunk type.)

Safe-to-copy bit: bit 5 of fourth byte

0 (uppercase) = unsafe to copy, 1 (lowercase) = safe to copy.

This property bit is not of interest to pure decoders, but it is needed by PNG editors (programs that modify PNG files). This bit defines the proper handling of unrecognized chunks in a file that is being modified.

If a chunk's safe-to-copy bit is 1, the chunk may be copied to a modified PNG file whether or not the software recognizes the chunk type, and regardless of the extent of the file modifications.

If a chunk's safe-to-copy bit is 0, it indicates that the chunk depends on the image data. If the program has made *any* changes to *critical* chunks, including addition, modification, deletion, or reordering of critical chunks, then unrecognized unsafe chunks must **not** be copied to the output PNG file. (Of course, if the program **does** recognize the chunk, it can choose to output an appropriately modified version.)

A PNG editor is always allowed to copy all unrecognized chunks if it has only added, deleted, modified, or reordered *ancillary* chunks. This implies that it is not permissible for ancillary chunks to depend on other ancillary chunks.

PNG editors that do not recognize a *critical* chunk must report an error and refuse to process that PNG file at all. The safe/unsafe mechanism is intended for use with ancillary chunks. The safe-to-copy bit will always be 0 for critical chunks.

Rules for PNG editors are discussed further in Chunk Ordering Rules (Chapter 7).

For example, the hypothetical chunk type name bLOb has the property bits:

```
bLOb  <-- 32 bit chunk type code represented in text form
||||
|||+- Safe-to-copy bit is 1 (lowercase letter; bit 5 is 1)
||+-- Reserved bit is 0     (uppercase letter; bit 5 is 0)
|+--- Private bit is 0      (uppercase letter; bit 5 is 0)
+---- Ancillary bit is 1    (lowercase letter; bit 5 is 1)
```

Therefore, this name represents an ancillary, public, safe-to-copy chunk.

See Rationale: Chunk naming conventions (Section 12.14).

3.4 CRC algorithm

Chunk CRCs are calculated using standard CRC methods with pre and post conditioning, as defined by ISO 3309 [ISO-3309] or ITU-T V.42 [ITU-T-V42]. The CRC polynomial employed is

$$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

The 32-bit CRC register is initialized to all 1's, and then the data from each byte is processed from the least significant bit (1) to the most significant bit (128). After all the data bytes are processed, the CRC register is inverted (its ones complement is taken). This value is transmitted (stored in the file) MSB first. For the purpose of separating into bytes and ordering, the least significant bit of the 32-bit CRC is defined to be the coefficient of the x^{31} term.

Practical calculation of the CRC always employs a precalculated table to greatly accelerate the computation. See Sample CRC Code (Chapter 15).

4 Chunk Specifications

This chapter defines the standard types of PNG chunks.

4.1 Critical chunks

All implementations must understand and successfully render the standard critical chunks. A valid PNG image must contain an IHDR chunk, one or more IDAT chunks, and an IEND chunk.

4.1.1 IHDR Image header

The IHDR chunk must appear FIRST. It contains:

```
Width:              4 bytes
Height:             4 bytes
Bit depth:          1 byte
Color type:         1 byte
Compression method: 1 byte
Filter method:      1 byte
Interlace method:   1 byte
```

Width and height give the image dimensions in pixels. They are 4-byte integers. Zero is an invalid value. The maximum for each is $2^{31} - 1$ in order to accommodate languages that have difficulty with unsigned 4-byte values.

Bit depth is a single-byte integer giving the number of bits per sample or per palette index (not per pixel). Valid values are 1, 2, 4, 8, and 16, although not all values are allowed for all color types.

Color type is a single-byte integer that describes the interpretation of the image data. Color type codes represent sums of the following values: 1 (palette used), 2 (color used), and 4 (alpha channel used). Valid values are 0, 2, 3, 4, and 6.

Bit depth restrictions for each color type are imposed to simplify implementations and to prohibit combinations that do not compress well. Decoders must support all valid combinations of bit depth and color type. The allowed combinations are:

Color Type	Allowed Bit Depths	Interpretation
0	1,2,4,8,16	Each pixel is a grayscale sample.
2	8,16	Each pixel is an R,G,B triple.
3	1,2,4,8	Each pixel is a palette index; a PLTE chunk must appear.
4	8,16	Each pixel is a grayscale sample, followed by an alpha sample.
6	8,16	Each pixel is an R,G,B triple, followed by an alpha sample.

The sample depth is the same as the bit depth except in the case of color type 3, in which the sample depth is always 8 bits.

Compression method is a single-byte integer that indicates the method used to compress the image data. At present, only compression method 0 (deflate/inflate compression with a sliding window of at most 32768 bytes) is defined. All standard PNG images must be compressed with this scheme. The compression method field is provided for possible future expansion or proprietary variants. Decoders must check this byte and report an error if it holds an unrecognized code. See Deflate/Inflate Compression (Chapter 5) for details.

Filter method is a single-byte integer that indicates the preprocessing method applied to the image data before compression. At present, only filter method 0 (adaptive filtering with five basic filter types) is defined. As with the compression method field, decoders must check this byte and report an error if it holds an unrecognized code. See Filter Algorithms (Chapter 6) for details.

Interlace method is a single-byte integer that indicates the transmission order of the image data. Two values are currently defined: 0 (no interlace) or 1 (Adam7 interlace). See Interlaced data order (Section 2.6) for details.

4.1.2 PLTE Palette

The PLTE chunk contains from 1 to 256 palette entries, each a three-byte series of the form:

```
Red:   1 byte (0 = black, 255 = red)
Green: 1 byte (0 = black, 255 = green)
Blue:  1 byte (0 = black, 255 = blue)
```

The number of entries is determined from the chunk length. A chunk length not divisible by 3 is an error.

This chunk must appear for color type 3, and can appear for color types 2 and 6; it must not appear for color types 0 and 4. If this chunk does appear, it must precede the first IDAT chunk. There must not be more than one PLTE chunk.

For color type 3 (indexed color), the PLTE chunk is required. The first entry in PLTE is referenced by pixel value 0, the second by pixel value 1, etc. The number of palette entries must not exceed the range that can be represented in the image bit depth (for example, $2^4 = 16$ for a bit depth of 4). It is permissible to have fewer entries than the bit depth would allow. In that case, any out-of-range pixel value found in the image data is an error.

For color types 2 and 6 (truecolor and truecolor with alpha), the PLTE chunk is optional. If present, it provides a suggested set of from 1 to 256 colors to which the truecolor image can be quantized if the viewer cannot display truecolor directly. If neither PLTE nor sPLT is present, such a viewer will need to select colors on its own, but it is often preferable for this to be done once by the encoder. (See Recommendations for Encoders: Suggested palettes, Section 9.5.)

Note that the palette uses 8 bits (1 byte) per sample regardless of the image bit depth specification. In particular, the palette is 8 bits deep even when it is a suggested quantization of a 16-bit truecolor image.

There is no requirement that the palette entries all be used by the image, nor that they all be different.

4.1.3 IDAT Image data

The IDAT chunk contains the actual image data. To create this data:

1. Begin with image scanlines represented as described in Image layout (Section 2.3); the layout and total size of this raw data are determined by the fields of IHDR.
2. Filter the image data according to the filtering method specified by the IHDR chunk. (Note that with filter method 0, the only one currently defined, this implies prepending a filter-type byte to each scanline.)
3. Compress the filtered data using the compression method specified by the IHDR chunk.

The IDAT chunk contains the output datastream of the compression algorithm.

To read the image data, reverse this process.

There can be multiple IDAT chunks; if so, they must appear consecutively with no other intervening chunks. The compressed datastream is then the concatenation of the contents of all the IDAT chunks. The encoder can divide the compressed datastream into IDAT chunks however it wishes. (Multiple IDAT chunks are allowed

so that encoders can work in a fixed amount of memory; typically the chunk size will correspond to the encoder's buffer size.) It is important to emphasize that IDAT chunk boundaries have no semantic significance and can occur at any point in the compressed datastream. A PNG file in which each IDAT chunk contains only one data byte is valid, though remarkably wasteful of space. (For that matter, zero-length IDAT chunks are valid, though even more wasteful.)

See Filter Algorithms (Chapter 6) and Deflate/Inflate Compression (Chapter 5) for details.

4.1.4 IEND Image trailer

The IEND chunk must appear LAST. It marks the end of the PNG datastream. The chunk's data field is empty.

4.2 Ancillary chunks

All ancillary chunks are optional, in the sense that encoders need not write them and decoders can ignore them. However, encoders are encouraged to write the standard ancillary chunks when the information is available, and decoders are encouraged to interpret these chunks when appropriate and feasible.

The standard ancillary chunks are described in the next four sections. This is not necessarily the order in which they would appear in a PNG datastream.

4.2.1 Transparency information

This chunk conveys transparency information in datastreams that do not include a full alpha channel.

4.2.1.1 tRNS Transparency

The tRNS chunk specifies that the image uses simple transparency: either alpha values associated with palette entries (for indexed-color images) or a single transparent color (for grayscale and truecolor images). Although simple transparency is not as elegant as the full alpha channel, it requires less storage space and is sufficient for many common cases.

For color type 3 (indexed color), the tRNS chunk contains a series of one-byte alpha values, corresponding to entries in the PLTE chunk:

```
Alpha for palette index 0:  1 byte
Alpha for palette index 1:  1 byte
...etc...
```

Each entry indicates that pixels of the corresponding palette index must be treated as having the specified alpha value. Alpha values have the same interpretation as in an 8-bit full alpha channel: 0 is fully transparent, 255 is fully opaque, regardless of image bit depth. The tRNS chunk must not contain more alpha values than there are palette entries, but tRNS *can contain fewer values than there are palette entries*. In this case, the alpha value for all remaining palette entries is assumed to be 255. In the common case in which only palette index 0 need be made transparent, only a one-byte tRNS chunk is needed.

For color type 0 (grayscale), the tRNS chunk contains a single gray level value, stored in the format:

`Gray:` 2 bytes, range $0..2^{\text{bitdepth}} - 1$

(If the image bit depth is less than 16, the least significant bits are used and the others are 0.) Pixels of the specified gray level are to be treated as transparent (equivalent to alpha value 0); all other pixels are to be treated as fully opaque (alpha value $2^{\text{bitdepth}} - 1$).

For color type 2 (truecolor), the tRNS chunk contains a single RGB color value, stored in the format:

`Red:` 2 bytes, range $0..2^{\text{bitdepth}} - 1$
`Green:` 2 bytes, range $0..2^{\text{bitdepth}} - 1$
`Blue:` 2 bytes, range $0..2^{\text{bitdepth}} - 1$

(If the image bit depth is less than 16, the least significant bits are used and the others are 0.) Pixels of the specified color value are to be treated as transparent (equivalent to alpha value 0); all other pixels are to be treated as fully opaque (alpha value $2^{\text{bitdepth}} - 1$).

tRNS is prohibited for color types 4 and 6, since a full alpha channel is already present in those cases.

Note: when dealing with 16-bit grayscale or truecolor data, it is important to compare both bytes of the sample values to determine whether a pixel is transparent. Although decoders may drop the low-order byte of the samples for display, this must not occur until after the data has been tested for transparency. For example, if the grayscale level 0x0001 is specified to be transparent, it would be incorrect to compare only the high-order byte and decide that 0x0002 is also transparent.

When present, the tRNS chunk must precede the first IDAT chunk, and must follow the PLTE chunk, if any.

4.2.2 Color space information

These chunks relate the image samples to the desired display intensity.

4.2.2.1 gAMA Image gamma

The gAMA chunk specifies the relationship between the image samples and the desired display output intensity as a power function:

$$\text{sample} = \text{light_out}^{\text{gamma}}$$

Here `sample` and `light_out` are normalized to the range 0.0 (minimum intensity) to 1.0 (maximum intensity). Therefore:

$$\text{sample} = \text{integer_sample}/(2^{\text{bitdepth}} - 1)$$

The gAMA chunk contains:

```
Gamma: 4 bytes
```

The value is encoded as a 4-byte unsigned integer, representing gamma times 100000. For example, a gamma of 1/2.2 would be stored as 45455.

The gamma value has no effect on alpha samples, which are always a linear fraction of full opacity.

If the encoder does not know the image's gamma value, it should not write a gAMA chunk; the absence of a gAMA chunk indicates that the gamma is unknown.

Technically, "desired display output intensity" is not specific enough; one needs to specify the viewing conditions under which the output is desired. For gAMA these are the reference viewing conditions of the sRGB specification [sRGB], which are based on ISO standards [ISO-3664]. Adjusting for different viewing conditions is a complex process normally handled by a Color Management System (CMS). If this adjustment is not performed, the error is usually small. Applications desiring high color fidelity may wish to use an sRGB chunk (see the sRGB chunk specification, Paragraph 4.2.2.3) or an iCCP chunk (see the iCCP chunk specification, Paragraph 4.2.2.4).

If the gAMA chunk appears, it must precede the first IDAT chunk, and it must also precede the PLTE chunk if present. An sRGB chunk or iCCP chunk, when present and recognized, overrides the gAMA chunk.

See Gamma correction (Section 2.7), Recommendations for Encoders: Encoder gamma handling (Section 9.2), and Recommendations for Decoders: Decoder gamma handling (Section 10.5).

4.2.2.2 cHRM Primary chromaticities

Applications that need device-independent specification of colors in a PNG file can use the cHRM chunk to specify the 1931 CIE `x,y` chromaticities of the red, green, and blue primaries used in the image, and the referenced white point. See Color Tutorial (Chapter 14) for more information.

The cHRM chunk contains:

```
White Point x: 4 bytes
White Point y: 4 bytes
Red x:         4 bytes
Red y:         4 bytes
Green x:       4 bytes
Green y:       4 bytes
Blue x:        4 bytes
Blue y:        4 bytes
```

Each value is encoded as a 4-byte unsigned integer, representing the x or y value times 100000. For example, a value of 0.3127 would be stored as the integer 31270.

cHRM is allowed in all PNG files, although it is of little value for grayscale images.

If the encoder does not know the chromaticity values, it should not write a cHRM chunk; the absence of a cHRM chunk indicates that the image's primary colors are device-dependent.

If the cHRM chunk appears, it must precede the first IDAT chunk, and it must also precede the PLTE chunk if present.

An sRGB chunk or iCCP chunk, when present and recognized, overrides the cHRM chunk.

See the sRGB chunk specification (Paragraph 4.2.2.3), the iCCP chunk specification (Paragraph 4.2.2.4), Recommendations for Encoders: Encoder color handling (Section 9.3), and Recommendations for Decoders: Decoder color handling (Section 10.6).

4.2.2.3 sRGB Standard RGB color space

If the sRGB chunk is present, the image samples conform to the sRGB color space [sRGB], and should be displayed using the specified rendering intent as defined by the International Color Consortium [ICC].

The sRGB chunk contains:

```
Rendering intent: 1 byte
```

The following values are defined for the rendering intent:

```
0: Perceptual
1: Relative colorimetric
2: Saturation
3: Absolute colorimetric
```

Perceptual intent is for images preferring good adaptation to the output device gamut at the expense of colorimetric accuracy, like photographs.

Relative colorimetric intent is for images requiring color appearance matching (relative to the output device white point), like logos.

Saturation intent is for images preferring preservation of saturation at the expense of hue and lightness, like charts and graphs.

Absolute colorimetric intent is for images requiring preservation of absolute colorimetry, like proofs (previews of images destined for a different output device).

An application that writes the sRGB chunk should also write a gAMA chunk (and perhaps a cHRM chunk) for compatibility with applications that do not use the sRGB chunk. In this situation, only the following values may be used:

```
gAMA:
Gamma:          45455

cHRM:
White Point x: 31270
White Point y: 32900
Red x:         64000
Red y:         33000
Green x:       30000
Green y:       60000
Blue x:        15000
Blue y:         6000
```

When the sRGB chunk is present, applications that recognize it and are capable of color management [ICC] must ignore the gAMA and cHRM chunks and use the sRGB chunk instead.

Applications that recognize the sRGB chunk but are not capable of full-fledged color management must also ignore the gAMA and cHRM chunks, because the applications already know what values those chunks should contain. The applications must therefore use the values of gAMA and cHRM given above as if they had appeared in gAMA and cHRM chunks.

If the sRGB chunk appears, it must precede the first IDAT chunk, and it must also precede the PLTE chunk if present. The sRGB and iCCP chunks should not both appear.

4.2.2.4 iCCP Embedded ICC profile

If the iCCP chunk is present, the image samples conform to the color space represented by the embedded ICC profile as defined by the International Color Consortium [ICC]. The color space of the ICC profile must be an RGB color space for color images (PNG color types 2, 3, and 6), or a monochrome grayscale color space for grayscale images (PNG color types 0 and 4).

The iCCP chunk contains:

```
Profile name:       1-79 bytes (character string)
Null separator:     1 byte
Compression method: 1 byte
Compressed profile: n bytes
```

The format is like the zTXt chunk. (see the zTXt chunk specification, Paragraph 4.2.3.2). The profile name can be any convenient name for referring to the profile. It is case-sensitive and subject to the same restrictions as the keyword in a text chunk: it must contain only printable Latin-1 [ISO/IEC-8859-1] characters (33–126 and 161–255) and spaces (32), but no leading, trailing, or consecutive spaces. The only value presently defined for the compression method byte is 0, meaning zlib datastream with deflate compression (see Deflate/Inflate Compression, Chapter 5). Decompression of the remainder of the chunk yields the ICC profile.

An application that writes the iCCP chunk should also write gAMA and cHRM chunks that approximate the ICC profile's transfer function, for compatibility with applications that do not use the iCCP chunk.

When the iCCP chunk is present, applications that recognize it and are capable of color management [ICC] should ignore the gAMA and cHRM chunks and use the iCCP chunk instead, but applications incapable of full-fledged color management should use the gAMA and cHRM chunks if present.

A file should contain at most one embedded profile, whether explicit like iCCP or implicit like sRGB.

If the iCCP chunk appears, it must precede the first IDAT chunk, and it must also precede the PLTE chunk if present.

4.2.3 Textual information

The iTXt, tEXt, and zTXt chunks are used for conveying textual information associated with the image. This specification refers to them generically as "text chunks".

Each of the text chunks contains as its first field a keyword that indicates the type of information represented by the text string. The following keywords are predefined and should be used where appropriate:

```
Title            Short (one line) title or caption for image
Author           Name of image's creator
Description      Description of image (possibly long)
Copyright        Copyright notice
Creation Time    Time of original image creation
Software         Software used to create the image
Disclaimer       Legal disclaimer
Warning          Warning of nature of content
Source           Device used to create the image
Comment          Miscellaneous comment; conversion from
                 GIF comment
```

For the Creation Time keyword, the date format defined in section 5.2.14 of RFC 1123 is suggested, but not required [RFC-1123]. Decoders should allow for free-format text associated with this or any other keyword.

Other keywords may be invented for other purposes. Keywords of general interest can be registered with the maintainers of the PNG specification. However, it is also permitted to use private unregistered keywords. (Private keywords should be reasonably self-explanatory, in order to minimize the chance that the same keyword will be used for incompatible purposes by different people.)

The keyword must be at least one character and less than 80 characters long. Keywords are always interpreted according to the ISO/IEC 8859-1 (Latin-1) character set [ISO/IEC-8859-1]. They must contain only printable Latin-1 characters and spaces; that is, only character codes 32–126 and 161–255 decimal are allowed. To reduce the chances for human misreading of a keyword, leading and trailing spaces are forbidden, as are consecutive spaces. Note also that the non-breaking space (code 160) is not permitted in keywords, since it is visually indistinguishable from an ordinary space.

Keywords must be spelled exactly as registered, so that decoders can use simple literal comparisons when looking for particular keywords. In particular, keywords are considered case-sensitive.

Any number of text chunks can appear, and more than one with the same keyword is permissible.

See Recommendations for Encoders: Text chunk processing (Section 9.7) and Recommendations for Decoders: Text chunk processing (Section 10.11).

4.2.3.1 tEXt Textual data

Textual information that the encoder wishes to record with the image can be stored in tEXt chunks. Each tEXt chunk contains a keyword (see above) and a text string, in the format:

```
Keyword:         1-79 bytes (character string)
Null separator: 1 byte
Text:            n bytes (character string)
```

The keyword and text string are separated by a zero byte (null character). Neither the keyword nor the text string can contain a null character. Note that the text string is *not* null-terminated (the length of the chunk is sufficient information to locate the ending). The text string can be of any length from zero bytes up to the maximum permissible chunk size less the length of the keyword and separator.

The text is interpreted according to the ISO/IEC 8859-1 (Latin-1) character set [ISO/IEC-8859-1]. The text string can contain any Latin-1 character. Newlines in the text string should be represented by a single linefeed character (decimal 10); use of other control characters in the text is discouraged.

4.2.3.2 zTXt Compressed textual data

The zTXt chunk contains textual data, just as tEXt does; however, zTXt takes advantage of compression. The zTXt and tEXt chunks are semantically equivalent, but zTXt is recommended for storing large blocks of text.

A zTXt chunk contains:

```
Keyword:            1-79 bytes (character string)
Null separator:     1 byte
Compression method: 1 byte
Compressed text:    n bytes
```

The keyword and null separator are exactly the same as in the tEXt chunk. Note that the keyword is not compressed. The compression method byte identifies the compression method used in this zTXt chunk. The only value presently defined for it is 0 (deflate/inflate compression). The compression method byte is followed by a compressed datastream that makes up the remainder of the chunk. For compression method 0, this datastream adheres to the zlib datastream format (see Deflate/Inflate Compression, Chapter 5). Decompression

of this datastream yields Latin-1 text that is identical to the text that would be stored in an equivalent tEXt chunk.

4.2.3.3 iTXt International textual data

This chunk is semantically equivalent to the tEXt and zTXt chunks, but the textual data is in the UTF-8 encoding of the Unicode character set instead of Latin-1. This chunk contains:

```
Keyword:             1-79 bytes (character string)
Null separator:      1 byte
Compression flag:    1 byte
Compression method:  1 byte
Language tag:        0 or more bytes (character string)
Null separator:      1 byte
Translated keyword:  0 or more bytes
Null separator:      1 byte
Text:                0 or more bytes
```

The keyword is described above.

The compression flag is 0 for uncompressed text, 1 for compressed text. Only the text field may be compressed. The only value presently defined for the compression method byte is 0, meaning zlib datastream with deflate compression. For uncompressed text, encoders should set the compression method to 0 and decoders should ignore it.

The language tag [RFC-1766] indicates the human language used by the translated keyword and the text. Unlike the keyword, the language tag is case-insensitive. It is an ASCII [ISO-646] string consisting of hyphen-separated words of 1–8 letters each (for example: cn, en-uk, no-bok, x-klingon). If the first word is two letters long, it is an ISO language code [ISO-639]. If the language tag is empty, the language is unspecified.

The translated keyword and text both use the UTF-8 encoding of the Unicode character set [ISO/IEC-10646-1], and neither may contain a zero byte (null character). The text, unlike the other strings, is not null-terminated; its length is implied by the chunk length.

Line breaks should not appear in the translated keyword. In the text, a newline should be represented by a single line feed character (decimal 10). The remaining control characters (1–9, 11–31, and 127–159) are discouraged in both the translated keyword and the text. Note that in UTF-8 there is a difference between the *characters* 128–159 (which are discouraged) and the *bytes* 128–159 (which are often necessary).

The translated keyword, if not empty, should contain a translation of the keyword into the language indicated by the language tag, and applications displaying the keyword should display the translated keyword in addition.

4.2.4 Miscellaneous information

These chunks are used for conveying other information associated with the image.

4.2.4.1 bKGD Background color

The bKGD chunk specifies a default background color to present the image against. Note that viewers are not bound to honor this chunk; a viewer can choose to use a different background.

For color type 3 (indexed color), the bKGD chunk contains:

```
Palette index:  1 byte
```

The value is the palette index of the color to be used as background.

For color types 0 and 4 (grayscale, with or without alpha), bKGD contains:

```
Gray:  2 bytes, range 0..2^bitdepth − 1
```

(If the image bit depth is less than 16, the least significant bits are used and the others are 0.) The value is the gray level to be used as background.

For color types 2 and 6 (truecolor, with or without alpha), bKGD contains:

```
Red:   2 bytes, range 0..2^bitdepth − 1
Green: 2 bytes, range 0..2^bitdepth − 1
Blue:  2 bytes, range 0..2^bitdepth − 1
```

(If the image bit depth is less than 16, the least significant bits are used and the others are 0.) This is the RGB color to be used as background.

When present, the bKGD chunk must precede the first IDAT chunk, and must follow the PLTE chunk, if any.

See Recommendations for Decoders: Background color (Section 10.7).

4.2.4.2 pHYs Physical pixel dimensions

The pHYs chunk specifies the intended pixel size or aspect ratio for display of the image. It contains:

```
Pixels per unit, X axis: 4 bytes (unsigned integer)
Pixels per unit, Y axis: 4 bytes (unsigned integer)
Unit specifier:          1 byte
```

The following values are defined for the unit specifier:

```
0: unit is unknown
1: unit is the meter
```

When the unit specifier is 0, the pHYs chunk defines pixel aspect ratio only; the actual size of the pixels remains unspecified.

Conversion note: one inch is equal to exactly 0.0254 meters.

If this ancillary chunk is not present, pixels are assumed to be square, and the physical size of each pixel is unknown.

If present, this chunk must precede the first IDAT chunk.

See Recommendations for Decoders: Pixel dimensions (Section 10.2).

4.2.4.3 sBIT Significant bits

To simplify decoders, PNG specifies that only certain sample depths can be used, and further specifies that sample values should be scaled to the full range of possible values at the sample depth. However, the sBIT chunk is provided in order to store the original number of significant bits. This allows decoders to recover the original data losslessly even if the data had a sample depth not directly supported by PNG. We recommend that an encoder emit an sBIT chunk if it has converted the data from a lower sample depth.

For color type 0 (grayscale), the sBIT chunk contains a single byte, indicating the number of bits that were significant in the source data.

For color type 2 (truecolor), the sBIT chunk contains three bytes, indicating the number of bits that were significant in the source data for the red, green, and blue channels, respectively.

For color type 3 (indexed color), the sBIT chunk contains three bytes, indicating the number of bits that were significant in the source data for the red, green, and blue components of the palette entries, respectively.

For color type 4 (grayscale with alpha channel), the sBIT chunk contains two bytes, indicating the number of bits that were significant in the source grayscale data and the source alpha data, respectively.

For color type 6 (truecolor with alpha channel), the sBIT chunk contains four bytes, indicating the number of bits that were significant in the source data for the red, green, blue, and alpha channels, respectively.

Each depth specified in sBIT must be greater than zero and less than or equal to the sample depth (which is 8 for indexed-color images, and the bit depth given in IHDR for other color types).

A decoder need not pay attention to sBIT: the stored image is a valid PNG file of the sample depth indicated by IHDR. However, if the decoder wishes to recover the original data at its original precision, this can be done by right-shifting the stored samples (the stored palette entries, for an indexed-color image). The encoder must scale the data in such a way that the high-order bits match the original data.

If the sBIT chunk appears, it must precede the first IDAT chunk, and it must also precede the PLTE chunk if present.

See Recommendations for Encoders: Sample depth scaling (Section 9.1) and Recommendations for Decoders: Sample depth rescaling (Section 10.4).

4.2.4.4 sPLT Suggested palette

This chunk can be used to suggest a reduced palette to be used when the display device is not capable of displaying the full range of colors present in the image. If present, it provides a recommended set of colors, with alpha and frequency information, that can be used to construct a reduced palette to which the PNG image can be quantized.

This chunk contains a null-terminated text string that names the palette and a one-byte sample depth, followed by a series of palette entries, each a six-byte or ten-byte series containing five unsigned integers:

```
Palette name:    1-79 bytes (character string)
Null terminator: 1 byte
Sample depth:    1 byte
Red:             1 or 2 bytes
Green:           1 or 2 bytes
Blue:            1 or 2 bytes
Alpha:           1 or 2 bytes
Frequency:       2 bytes
...etc...
```

There can be any number of entries; a decoder determines the number of entries from the remaining chunk length after the sample depth byte. It is an error if this remaining length is not divisible by 6 (if the sPLT sample depth is 8) or by 10 (if the sPLT sample depth is 16). Entries must appear in decreasing order of frequency. There is no requirement that the entries all be used by the image, nor that they all be different.

The palette name can be any convenient name for referring to the palette (for example, “256 color including Macintosh default”, “256 color including Windows-3.1 default”, “Optimal 512”). It may help applications or people to choose the appropriate suggested palette when more than one appears in a PNG file. The palette name is case-sensitive and subject to the same restrictions as a text keyword: it must contain only printable Latin-1 [ISO/IEC-8859-1] characters (33–126 and 161–255) and spaces (32), but no leading, trailing, or consecutive spaces.

The sPLT sample depth must be 8 or 16.

The red, green, blue, and alpha samples are either one or two bytes each, depending on the sPLT sample depth, regardless of the image bit depth. The color samples are not premultiplied by alpha, nor are they precomposited against any background. An alpha value of 0 means fully transparent, while an alpha value of 255 (when the sPLT sample depth is 8) or 65535 (when the sPLT sample depth is 16) means fully opaque. The palette samples have the same gamma and chromaticity values as those of the PNG image.

Each frequency value is proportional to the fraction of pixels in the image that are closest to that palette entry in RGBA space, before the image has been composited against any background. The exact scale factor is

chosen by the encoder, but should be chosen so that the range of individual values reasonably fills the range 0 to 65535. It is acceptable to artificially inflate the frequencies for "important" colors such as those in a company logo or in the facial features of a portrait. Zero is a valid frequency meaning the color is "least important" or that it is rarely if ever used. But when all of the frequencies are zero, they are meaningless (nothing may be inferred about the actual frequencies of the colors).

The sPLT chunk can appear for any PNG color type. Note that entries in sPLT can fall outside the color space of the PNG image; for example, in a grayscale PNG, sPLT entries would typically satisfy `R=G=B`, but this is not required. Similarly, sPLT entries can have nonopaque alpha values even when the PNG image does not use transparency.

If sPLT appears, it must precede the first IDAT chunk. There can be multiple sPLT chunks, but if so they must have different palette names.

See Recommendations for Encoders: Suggested palettes (Section 9.5) and Recommendations for Decoders: Suggested-palette and histogram usage (Section 10.10)

4.2.4.5 hIST Palette histogram

The hIST chunk gives the approximate usage frequency of each color in the color palette. A hIST chunk can appear only when a PLTE chunk appears. If a viewer is unable to provide all the colors listed in the palette, the histogram may help it decide how to choose a subset of the colors for display.

The hIST chunk contains a series of 2-byte (16 bit) unsigned integers. There must be exactly one entry for each entry in the PLTE chunk. Each entry is proportional to the fraction of pixels in the image that have that palette index; the exact scale factor is chosen by the encoder.

Histogram entries are approximate, with the exception that a zero entry specifies that the corresponding palette entry is not used at all in the image. It is required that a histogram entry be nonzero if there are any pixels of that color.

When the palette is a suggested quantization of a truecolor image, the histogram is necessarily approximate, since a decoder may map pixels to palette entries differently than the encoder did. In this situation, zero entries should not appear.

The hIST chunk, if it appears, must follow the PLTE chunk, and must precede the first IDAT chunk.

See Rationale: Palette histograms (Section 12.15) and Recommendations for Decoders: Suggested-palette and histogram usage (Section 10.10).

4.2.4.6 tIME Image last-modification time

The tIME chunk gives the time of the last image modification (*not* the time of initial image creation). It contains:

```
Year:   2 bytes (complete; for example, 1995, not 95)
Month:  1 byte (1-12)
Day:    1 byte (1-31)
Hour:   1 byte (0-23)
Minute: 1 byte (0-59)
Second: 1 byte (0-60)     (yes, 60, for leap seconds; not 61,
                           a common error)
```

Universal Time (UTC, also called GMT) should be specified rather than local time.

The tIME chunk is intended for use as an automatically-applied time stamp that is updated whenever the image data is changed. It is recommended that tIME not be changed by PNG editors that do not change the image data. The Creation Time text keyword can be used for a user-supplied time (see the text chunk specification, Paragraph 4.2.3).

4.3 Summary of standard chunks

This table summarizes some properties of the standard chunk types.

Critical chunks (must appear in this order, except PLTE is optional):

Name	Multiple OK?	Ordering constraints
IHDR	No	Must be first
PLTE	No	Before IDAT
IDAT	Yes	Multiple IDATs must be consecutive
IEND	No	Must be last

Ancillary chunks (need not appear in this order):

Name	Multiple OK?	Ordering constraints
cHRM	No	Before PLTE and IDAT
gAMA	No	Before PLTE and IDAT
iCCP	No	Before PLTE and IDAT
sBIT	No	Before PLTE and IDAT
sRGB	No	Before PLTE and IDAT
bKGD	No	After PLTE; before IDAT
hIST	No	After PLTE; before IDAT
tRNS	No	After PLTE; before IDAT
pHYs	No	Before IDAT
sPLT	Yes	Before IDAT
tIME	No	None
iTXt	Yes	None

```
tEXt    Yes     None
zTXt    Yes     None
```

Standard keywords for text chunks:

```
Title            Short (one line) title or caption for image
Author           Name of image's creator
Description      Description of image (possibly long)
Copyright        Copyright notice
Creation Time    Time of original image creation
Software         Software used to create the image
Disclaimer       Legal disclaimer
Warning          Warning of nature of content
Source           Device used to create the image
Comment          Miscellaneous comment; conversion from
                 GIF comment
```

4.4 Additional chunk types

Additional public PNG chunk types are defined in the document "Extensions to the PNG 1.2 Specification, Version 1.2.0" [PNG-EXTENSIONS]. Chunks described there are expected to be less widely supported than those defined in this specification. However, application authors are encouraged to use those chunk types whenever appropriate for their applications. Additional chunk types can be proposed for inclusion in that list by contacting the PNG specification maintainers at png-info@uunet.uu.net or at png-group@w3.org.

New public chunks will be registered only if they are of use to others and do not violate the design philosophy of PNG. Chunk registration is not automatic, although it is the intent of the authors that it be straightforward when a new chunk of potentially wide application is needed. Note that the creation of new critical chunk types is discouraged unless absolutely necessary.

Applications can also use private chunk types to carry data that is not of interest to other applications. See Recommendations for Encoders: Use of private chunks (Section 9.8).

Decoders must be prepared to encounter unrecognized public or private chunk type codes. Unrecognized chunk types must be handled as described in Chunk naming conventions (Section 3.3).

5 Deflate/Inflate Compression

PNG compression method 0 (the only compression method presently defined for PNG) specifies deflate/ inflate compression with a sliding window of at most 32768 bytes. Deflate compression is an LZ77 derivative used in zip, gzip, pkzip, and related programs. Extensive research has been done supporting its patent-free status. Portable C implementations are freely available.

Deflate-compressed datastreams within PNG are stored in the "zlib" format, which has the structure:

```
Compression method/flags code: 1 byte
Additional flags/check bits:   1 byte
Compressed data blocks:        n bytes
Check value:                   4 bytes
```

Further details on this format are given in the zlib specification [RFC-1950].

For PNG compression method 0, the zlib compression method/flags code must specify method code 8 ("deflate" compression) and an LZ77 window size of not more than 32768 bytes. Note that the zlib compression method number is not the same as the PNG compression method number. The additional flags must not specify a preset dictionary. A PNG decoder must be able to decompress any valid zlib datastream that satisfies these additional constraints.

If the data to be compressed contains 16384 bytes or fewer, the encoder can set the window size by rounding up to a power of 2 (256 minimum). This decreases the memory required not only for encoding but also for decoding, without adversely affecting the compression ratio.

The compressed data within the zlib datastream is stored as a series of blocks, each of which can represent raw (uncompressed) data, LZ77-compressed data encoded with fixed Huffman codes, or LZ77-compressed data encoded with custom Huffman codes. A marker bit in the final block identifies it as the last block, allowing the decoder to recognize the end of the compressed datastream. Further details on the compression algorithm and the encoding are given in the deflate specification [RFC-1951].

The check value stored at the end of the zlib datastream is calculated on the uncompressed data represented by the datastream. Note that the algorithm used is not the same as the CRC calculation used for PNG chunk check values. The zlib check value is useful mainly as a cross-check that the deflate and inflate algorithms are implemented correctly. Verifying the chunk CRCs provides adequate confidence that the PNG file has been transmitted undamaged.

In a PNG file, the concatenation of the contents of all the IDAT chunks makes up a zlib datastream as specified above. This datastream decompresses to filtered image data as described elsewhere in this document.

It is important to emphasize that the boundaries between IDAT chunks are arbitrary and can fall anywhere in the zlib datastream. There is not necessarily any correlation between IDAT chunk boundaries and deflate block boundaries or any other feature of the zlib data. For example, it is entirely possible for the terminating zlib check value to be split across IDAT chunks.

In the same vein, there is no required correlation between the structure of the image data (i.e., scanline boundaries) and deflate block boundaries or IDAT chunk boundaries. The complete image data is represented by a single zlib datastream that is stored in some number of IDAT chunks; a decoder that assumes any more than this is incorrect. (Of course, some encoder implementations may emit files in which some of these structures are indeed related. But decoders cannot rely on this.)

PNG also uses zlib datastreams in iTXt, zTXt, and iCCP chunks, where the remainder of the chunk following the compression method byte is a zlib datastream as specified above. Unlike the image data, such datastreams are not split across chunks; each iTXt, zTXt, or iCCP chunk contains an independent zlib datastream.

Additional documentation and portable C code for deflate and inflate are available from the Info-ZIP archives at ftp://ftp.cdrom.com/pub/infozip/.

6 Filter Algorithms

This chapter describes the filter algorithms that can be applied before compression. The purpose of these filters is to prepare the image data for optimum compression.

6.1 Filter types

PNG filter method 0 defines five basic filter types:

```
Type    Name

0       None
1       Sub
2       Up
3       Average
4       Paeth
```

(Note that filter method 0 in IHDR specifies exactly this set of five filter types. If the set of filter types is ever extended, a different filter method number will be assigned to the extended set, so that decoders need not decompress the data to discover that it contains unsupported filter types.)

The encoder can choose which of these filter algorithms to apply on a scanline-by-scanline basis. In the image data sent to the compression step, each scanline is preceded by a filter-type byte that specifies the filter algorithm used for that scanline.

Filtering algorithms are applied to **bytes**, not to pixels, regardless of the bit depth or color type of the image. The filtering algorithms work on the byte sequence formed by a scanline that has been represented as described in Image layout (Section 2.3). If the image includes an alpha channel, the alpha data is filtered in the same way as the image data.

When the image is interlaced, each pass of the interlace pattern is treated as an independent image for filtering purposes. The filters work on the byte sequences formed by the pixels actually transmitted during a pass, and the "previous scanline" is the one previously transmitted in the same pass, not the one adjacent in the complete image. Note that the subimage transmitted in any one pass is always rectangular, but is of smaller width and/or height than the complete image. Filtering is not applied when this subimage is empty.

For all filters, the bytes "to the left of" the first pixel in a scanline must be treated as being zero. For filters that refer to the prior scanline, the entire prior scanline must be treated as being zeroes for the first scanline of an image (or of a pass of an interlaced image).

To reverse the effect of a filter, the decoder must use the decoded values of the prior pixel on the same line, the pixel immediately above the current pixel on the prior line, and the pixel just to the left of the pixel above. This implies that at least one scanline's worth of image data will have to be stored by the decoder at all times. Even though some filter types do not refer to the prior scanline, the decoder will always need to store each scanline as it is decoded, since the next scanline might use a filter that refers to it.

PNG imposes no restriction on which filter types can be applied to an image. However, the filters are not equally effective on all types of data. See Recommendations for Encoders: Filter selection (Section 9.6).

See also Rationale: Filtering (Section 12.9).

6.2 Filter type 0: None

With the `None()` filter, the scanline is transmitted unmodified; it is necessary only to insert a filter-type byte before the data.

6.3 Filter type 1: Sub

The `Sub()` filter transmits the difference between each byte and the value of the corresponding byte of the prior pixel.

To compute the `Sub()` filter, apply the following formula to each byte of the scanline:

```
Sub(x) = Raw(x) - Raw(x-bpp)
```

where `x` ranges from zero to the number of bytes representing the scanline minus one, `Raw()` refers to the raw data byte at that byte position in the scanline, and `bpp` is defined as the number of bytes per complete pixel, rounding up to one. For example, for color type 2 with a bit depth of 16, bpp is equal to 6 (three samples, two bytes per sample); for color type 0 with a bit depth of 2, bpp is equal to 1 (rounding up); for color type 4 with a bit depth of 16, bpp is equal to 4 (two-byte grayscale sample, plus two-byte alpha sample).

Note this computation is done for each **byte**, regardless of bit depth. In a 16-bit image, each MSB is predicted from the preceding MSB and each LSB from the preceding LSB, because of the way that `bpp` is defined.

Unsigned arithmetic modulo 256 is used, so that both the inputs and outputs fit into bytes. The sequence of `Sub` values is transmitted as the filtered scanline.

For all `x < 0`, assume `Raw(x) = 0`.

To reverse the effect of the `Sub()` filter after decompression, output the following value:

```
Sub(x) + Raw(x-bpp)
```

(computed mod 256), where `Raw()` refers to the bytes already decoded.

6.4 Filter type 2: Up

The `Up()` filter is just like the `Sub()` filter except that the pixel immediately above the current pixel, rather than just to its left, is used as the predictor.

To compute the `Up()` filter, apply the following formula to each byte of the scanline:

```
Up(x) = Raw(x) - Prior(x)
```

where x ranges from zero to the number of bytes representing the scanline minus one, `Raw()` refers to the raw data byte at that byte position in the scanline, and `Prior(x)` refers to the unfiltered bytes of the prior scanline.

Note this is done for each **byte**, regardless of bit depth. Unsigned arithmetic modulo 256 is used, so that both the inputs and outputs fit into bytes. The sequence of `Up` values is transmitted as the filtered scanline.

On the first scanline of an image (or of a pass of an interlaced image), assume `Prior(x) = 0` for all x.

To reverse the effect of the `Up()` filter after decompression, output the following value:

```
Up(x) + Prior(x)
```

(computed mod 256), where `Prior()` refers to the decoded bytes of the prior scanline.

6.5 Filter type 3: Average

The `Average()` filter uses the average of the two neighboring pixels (left and above) to predict the value of a pixel.

To compute the `Average()` filter, apply the following formula to each byte of the scanline:

```
Average(x) = Raw(x) - floor((Raw(x-bpp)+Prior(x))/2)
```

where x ranges from zero to the number of bytes representing the scanline minus one, `Raw()` refers to the raw data byte at that byte position in the scanline, `Prior()` refers to the unfiltered bytes of the prior scanline, and `bpp` is defined as for the `Sub()` filter.

Note this is done for each **byte**, regardless of bit depth. The sequence of `Average` values is transmitted as the filtered scanline.

The subtraction of the predicted value from the raw byte must be done modulo 256, so that both the inputs and outputs fit into bytes. However, the sum `Raw(x-bpp)+Prior(x)` must be formed without overflow (using at least nine-bit arithmetic). `floor()` indicates that the result of the division is rounded to the next lower integer if fractional; in other words, it is an integer division or right shift operation.

For all $x < 0$, assume `Raw(x) = 0`. On the first scanline of an image (or of a pass of an interlaced image), assume `Prior(x) = 0` for all x.

To reverse the effect of the `Average()` filter after decompression, output the following value:

```
Average(x) + floor((Raw(x-bpp)+Prior(x))/2)
```

where the result is computed mod 256, but the prediction is calculated in the same way as for encoding. `Raw()` refers to the bytes already decoded, and `Prior()` refers to the decoded bytes of the prior scanline.

6.6 Filter type 4: Paeth

The `Paeth()` filter computes a simple linear function of the three neighboring pixels (left, above, upper left), then chooses as predictor the neighboring pixel closest to the computed value. This technique is due to Alan W. Paeth [PAETH].

To compute the `Paeth()` filter, apply the following formula to each byte of the scanline:

```
Paeth(x) = Raw(x) -
           PaethPredictor(Raw(x-bpp), Prior(x), Prior(x-bpp))
```

where `x` ranges from zero to the number of bytes representing the scanline minus one, `Raw()` refers to the raw data byte at that byte position in the scanline, `Prior()` refers to the unfiltered bytes of the prior scanline, and `bpp` is defined as for the `Sub()` filter.

Note this is done for each **byte**, regardless of bit depth. Unsigned arithmetic modulo 256 is used, so that both the inputs and outputs fit into bytes. The sequence of `Paeth` values is transmitted as the filtered scanline.

The `PaethPredictor()` function is defined by the following pseudocode:

```
function PaethPredictor (a, b, c)
begin
     ; a = left, b = above, c = upper left
     p := a + b - c        ; initial estimate
     pa := abs(p - a)      ; distances to a, b, c
     pb := abs(p - b)
     pc := abs(p - c)
     ; return nearest of a,b,c,
     ; breaking ties in order a,b,c.
     if pa <= pb AND pa <= pc then return a
     else if pb <= pc then return b
     else return c
end
```

The calculations within the `PaethPredictor()` function must be performed exactly, without overflow. Arithmetic modulo 256 is to be used only for the final step of subtracting the function result from the target byte value.

Note that the order in which ties are broken is critical and must not be altered. The tie break order is: pixel to the left, pixel above, pixel to the upper left. (This order differs from that given in Paeth's article.)

For all `x` $<$ `0`, assume `Raw(x) = 0` and `Prior(x) = 0`. On the first scanline of an image (or of a pass of an interlaced image), assume `Prior(x) = 0` for all `x`.

To reverse the effect of the `Paeth()` filter after decompression, output the following value:

```
Paeth(x) + PaethPredictor(Raw(x-bpp), Prior(x), Prior(x-bpp))
```

(computed mod 256), where `Raw()` and `Prior()` refer to bytes already decoded. Exactly the same `PaethPredictor()` function is used by both encoder and decoder.

7 Chunk Ordering Rules

To allow new chunk types to be added to PNG, it is necessary to establish rules about the ordering requirements for all chunk types. Otherwise a PNG editing program cannot know what to do when it encounters an unknown chunk.

We define a "PNG editor" as a program that modifies a PNG file and wishes to preserve as much as possible of the ancillary information in the file. Two examples of PNG editors are a program that adds or modifies text chunks, and a program that adds a suggested palette to a truecolor PNG file. Ordinary image editors are not PNG editors in this sense, because they usually discard all unrecognized information while reading in an image. (Note: we strongly encourage programs handling PNG files to preserve ancillary information whenever possible.)

As an example of possible problems, consider a hypothetical new ancillary chunk type that is safe-to-copy and is required to appear after PLTE if PLTE is present. If our program to add a suggested PLTE does not recognize this new chunk, it may insert PLTE in the wrong place, namely after the new chunk. We could prevent such problems by requiring PNG editors to discard all unknown chunks, but that is a very unattractive solution. Instead, PNG requires ancillary chunks not to have ordering restrictions like this.

To prevent this type of problem while allowing for future extension, we put some constraints on both the behavior of PNG editors and the allowed ordering requirements for chunks.

7.1 Behavior of PNG editors

The rules for PNG editors are:

- When copying an unknown unsafe-to-copy ancillary chunk, a PNG editor must not move the chunk relative to any critical chunk. It can relocate the chunk freely relative to other ancillary chunks that occur between the same pair of critical chunks. (This is well defined since the editor must not add, delete, modify, or reorder critical chunks if it is preserving unknown unsafe-to-copy chunks.)
- When copying an unknown safe-to-copy ancillary chunk, a PNG editor must not move the chunk from before IDAT to after IDAT or vice versa. (This is well defined because IDAT is always present.) Any other reordering is permitted.
- When copying a *known* ancillary chunk type, an editor need only honor the specific chunk ordering rules that exist for that chunk type. However, it can always choose to apply the above general rules instead.
- PNG editors must give up on encountering an unknown critical chunk type, because there is no way to be certain that a valid file will result from modifying a file containing such a chunk. (Note that

simply discarding the chunk is not good enough, because it might have unknown implications for the interpretation of other chunks.)

These rules are expressed in terms of copying chunks from an input file to an output file, but they apply in the obvious way if a PNG file is modified in place.

See also Chunk naming conventions (Section 3.3).

7.2 Ordering of ancillary chunks

The ordering rules for an ancillary chunk type cannot be any stricter than this:

- Unsafe-to-copy chunks can have ordering requirements relative to critical chunks.
- Safe-to-copy chunks can have ordering requirements relative to IDAT.

The actual ordering rules for any particular ancillary chunk type may be weaker. See for example the ordering rules for the standard ancillary chunk types (Summary of standard chunks, Section 4.3).

Decoders must not assume more about the positioning of any ancillary chunk than is specified by the chunk ordering rules. In particular, it is never valid to assume that a specific ancillary chunk type occurs with any particular positioning relative to other ancillary chunks. (For example, it is unsafe to assume that your private ancillary chunk occurs immediately before IEND. Even if your application always writes it there, a PNG editor might have inserted some other ancillary chunk after it. But you can safely assume that your chunk will remain somewhere between IDAT and IEND.)

7.3 Ordering of critical chunks

Critical chunks can have arbitrary ordering requirements, because PNG editors are required to give up if they encounter unknown critical chunks. For example, IHDR has the special ordering rule that it must always appear first. A PNG editor, or indeed any PNG-writing program, must know and follow the ordering rules for any critical chunk type that it can emit.

8 Miscellaneous Topics

8.1 File name extension

On systems where file names customarily include an extension signifying file type, the extension ".png" is recommended for PNG files. Lowercase ".png" is preferred if file names are case-sensitive.

8.2 Internet media type

The Internet Assigned Numbers Authority (IANA) has registered "image/png" as the Internet Media Type for PNG [RFC-2045], [RFC-2048]. For robustness, decoders may choose to also support the interim media type "image/x-png" that was in use before registration was complete.

8.3 Macintosh file layout

In the Apple Macintosh system, the following conventions are recommended:

- The four-byte file type code for PNG files is "PNGf". (This code has been registered with Apple for PNG files.) The creator code will vary depending on the creating application.
- The contents of the data fork must be a PNG file exactly as described in the rest of this specification.
- The contents of the resource fork are unspecified. It may be empty or may contain application-dependent resources.
- When transferring a Macintosh PNG file to a non-Macintosh system, only the data fork should be transferred.

8.4 Multiple-image extension

PNG itself is strictly a single-image format. However, it may be necessary to store multiple images within one file; for example, this is needed to convert GIF animation files. The PNG Development Group has defined and approved a multiple-image format based on PNG, called "Multiple-image Network Graphics (MNG)" [MNG]. This is considered a separate file format and has a different signature. PNG-supporting applications may or may not choose to support the multiple-image format.

See Rationale: Why not these features? (Section 12.3).

8.5 Security considerations

A PNG file or datastream is composed of a collection of explicitly typed "chunks". Chunks whose contents are defined by the specification could actually contain anything, including malicious code. But there is no known risk that such malicious code could be executed on the recipient's computer as a result of decoding the PNG image.

The possible security risks associated with private chunk types and future chunk types cannot be specified at this time. Security issues will be considered when evaluating chunks proposed for registration as public chunks. There is no additional security risk associated with unknown or unimplemented chunk types, because such chunks will be ignored, or at most be copied into another PNG file.

The text chunks contain keywords and data that is meant to be displayed as plain text. The iCCP, sPLT, and some public "extension" chunks contain keywords meant to be displayed as plain text. It is possible that if a decoder displays such text without filtering out control characters, especially the ESC (escape) character, certain systems or terminals could behave in undesirable and insecure ways. We recommend that decoders filter out control characters to avoid this risk; see Recommendations for Decoders: Text chunk processing (Section 10.11).

Every chunk begins with a length field, making it easier to write decoders invulnerable to fraudulent chunks that attempt to overflow buffers. The CRC at the end of every chunk provides a robust defense against accidentally corrupted data. Also, the PNG signature bytes provide early detection of common file transmission errors.

A decoder that fails to check CRCs could be subject to data corruption. The only likely consequence of such corruption is incorrectly displayed pixels within the image. Worse things might happen if the CRC of the IHDR chunk is not checked and the width or height fields are corrupted. See Recommendations for Decoders: Error checking (Section 10.1).

A poorly written decoder might be subject to buffer overflow, because chunks can be extremely large, up to $2^{31} - 1$ bytes long. But properly written decoders will handle large chunks without difficulty.

9 Recommendations for Encoders

This chapter gives some recommendations for encoder behavior. The only absolute requirement on a PNG encoder is that it produce files that conform to the format specified in the preceding chapters. However, best results will usually be achieved by following these recommendations.

9.1 Sample depth scaling

When encoding input samples that have a sample depth that cannot be directly represented in PNG, the encoder must scale the samples up to a sample depth that is allowed by PNG. The most accurate scaling method is the linear equation

```
output = ROUND(input * MAXOUTSAMPLE / MAXINSAMPLE)
```

where the input samples range from `0` to `MAXINSAMPLE` and the outputs range from `0` to `MAXOUTSAMPLE` (which is $2^{\mathrm{sampledepth}} - 1$).

A close approximation to the linear scaling method can be achieved by "left bit replication", which is shifting the valid bits to begin in the most significant bit and repeating the most significant bits into the open bits. This method is often faster to compute than linear scaling. As an example, assume that 5-bit samples are being scaled up to 8 bits. If the source sample value is 27 (in the range from 0–31), then the original bits are:

```
4 3 2 1 0
---------
1 1 0 1 1
```

Left bit replication gives a value of 222:

```
7 6 5 4 3  2 1 0
---------------
1 1 0 1 1  1 1 0
|=======|  |===|
    |      Leftmost Bits Repeated to Fill Open Bits
    |
Original Bits
```

which matches the value computed by the linear equation. Left bit replication usually gives the same value as linear scaling and is never off by more than one.

A distinctly less accurate approximation is obtained by simply left-shifting the input value and filling the low order bits with zeroes. This scheme cannot reproduce white exactly, since it does not generate an all-ones maximum value; the net effect is to darken the image slightly. This method is not recommended in general, but it does have the effect of improving compression, particularly when dealing with greater-than-eight-bit sample depths. Since the relative error introduced by zero-fill scaling is small at high sample depths, some encoders may choose to use it. Zero-fill must **not** be used for alpha channel data, however, since many decoders will special-case alpha values of all zeroes and all ones. It is important to represent both those values exactly in the scaled data.

When the encoder writes an sBIT chunk, it is required to do the scaling in such a way that the high-order bits of the stored samples match the original data. That is, if the sBIT chunk specifies a sample depth of `S`, the high-order `S` bits of the stored data must agree with the original `S`-bit data values. This allows decoders to recover the original data by shifting right. The added low-order bits are not constrained. Note that all the above scaling methods meet this restriction.

When scaling up source data, it is recommended that the low-order bits be filled consistently for all samples; that is, the same source value should generate the same sample value at any pixel position. This improves compression by reducing the number of distinct sample values. However, this is not a requirement, and some encoders may choose not to follow it. For example, an encoder might instead dither the low-order bits, improving displayed image quality at the price of increasing file size.

In some applications the original source data may have a range that is not a power of 2. The linear scaling equation still works for this case, although the shifting methods do not. It is recommended that an sBIT chunk not be written for such images, since sBIT suggests that the original data range was exactly $0..2^{\mathrm{S}} - 1$.

9.2 Encoder gamma handling

See Gamma Tutorial (Chapter 13) if you aren't already familiar with gamma issues.

Encoders capable of full-fledged color management [ICC] will perform more sophisticated calculations than those described here, and they may choose to use the iCCP chunk. Encoders that know that their image samples conform to the sRGB specification [sRGB] should use the sRGB chunk and not perform gamma handling. Otherwise, this section applies.

The encoder has two gamma-related decisions to make. First, it must decide how to transform whatever image samples it has into the image samples that will go into the PNG file. Second, it must decide what value to write into the gAMA chunk.

The rule for the second decision is simply to write whatever value will cause a decoder to do what you want. See Recommendations for Decoders: Decoder gamma handling (Section 10.5).

The first decision depends on the nature of the image samples and their precision. If the samples represent light intensity in floating-point or high-precision integer form (perhaps from a computer image renderer), then the encoder may perform "gamma encoding" (applying a power function with exponent less than 1) before quantizing the data to integer values for output to the file. This results in fewer banding artifacts at a given sample depth, or allows smaller samples while retaining the same visual quality. An intensity level expressed as a floating-point value in the range 0 to 1 can be converted to a file image sample by

$$\text{sample} = \text{intensity}^{\text{encoding_exponent}}$$
$$\text{integer_sample} = \text{ROUND}(\text{sample} * (2^{\text{bitdepth}} - 1))$$

If the intensity in the equation is the desired display output intensity, then the encoding exponent is the gamma value to be written to the file, by the definition of gAMA (See the gAMA chunk specification, Paragraph 4.2.2.1). But if the intensity available to the encoder is the original scene intensity, another transformation may be needed. Sometimes the displayed image should have higher contrast than the original image; in other words, the end-to-end transfer function from original scene to display output should have an exponent greater than 1. In this case,

```
gamma = encoding_exponent / end_to_end_exponent
```

If you don't know whether the conditions under which the original image was captured (or calculated) warrant such a contrast change, you may assume that display intensities are proportional to original scene intensities; in other words, the end-to-end exponent is 1, so gamma and the encoding exponent are equal.

If the image is being written to a file only, the encoder is free to choose the encoding exponent. Choosing a value that causes the gamma value in the gAMA chunk to be 1/2.2 is often a reasonable choice because it minimizes the work for a decoder displaying on a typical video monitor.

Some image renderers may simultaneously write the image to a PNG file and display it on-screen. The displayed pixels should be appropriate for the display system, so that the user sees a proper representation of the intended scene.

If the renderer wants to write the displayed sample values to the PNG file, avoiding a separate gamma encoding step for file output, then the renderer should approximate the transfer function of the display system by a power function, and write the reciprocal of the exponent into the gAMA chunk. This will allow a PNG decoder to reproduce what the file's originator saw on screen during rendering.

However, it is equally reasonable for a renderer to compute displayed pixels appropriate for the display device, and to perform separate gamma encoding for file storage, arranging to have a value in the gAMA chunk more appropriate to the future use of the image.

Computer graphics renderers often do not perform gamma encoding, instead making sample values directly proportional to scene light intensity. If the PNG encoder receives intensity samples that have already been quantized into integers, there is no point in doing gamma encoding on them; that would just result in further loss of information. The encoder should just write the sample values to the PNG file. This does not imply that the gAMA chunk should contain a gamma value of 1.0, because the desired end-to-end transfer function from scene intensity to display output intensity is not necessarily linear. The desired gamma value is probably not far from 1.0, however. It may depend on whether the scene being rendered is a daylight scene or an indoor scene, etc.

When the sample values come directly from a piece of hardware, the correct gamma value can in principle be inferred from the transfer function of the hardware and the lighting conditions of the scene. In the case of video digitizers ("frame grabbers"), the samples are probably in the sRGB color space, because the sRGB specification was designed to be compatible with video standards. Image scanners are less predictable. Their output samples may be proportional to the input light intensity because CCD (charge coupled device) sensors themselves are linear, or the scanner hardware may have already applied a power function designed to compensate for dot gain in subsequent printing (an exponent of about 0.57), or the scanner may have corrected the samples for display on a monitor. The device documentation might describe the transformation performed, or might describe the target display or printer for the image data (which might be configurable). You can also scan a calibrated target and use calibration software to determine the behavior of the device. Remember that gamma relates file samples to desired display output, not to scanner input.

File format converters generally should not attempt to convert supplied images to a different gamma. Store the data in the PNG file without conversion, and deduce the gamma value from information in the source file if possible. Gamma alteration at file conversion time causes re-quantization of the set of intensity levels that are represented, introducing further roundoff error with little benefit. It's almost always better to just copy the sample values intact from the input to the output file.

If the source file format describes the gamma characteristic of the image, a file format converter is strongly encouraged to write a PNG gAMA chunk. Note that some file formats specify the exponent of the function mapping file samples to display output rather than the other direction. If the source file's gamma value is greater than 1.0, it is probably a display system exponent, and you should use its reciprocal for the PNG gamma. If the source file format records the relationship between image samples and something other than display output, then deducing the PNG gamma value will be more complex.

Regardless of how an image was originally created, if an encoder or file format converter knows that the image has been displayed satisfactorily using a display system whose transfer function can be approximated by a power function with exponent `display_exponent`, then the image can be marked as having the gamma value:

```
gamma = 1 / display_exponent
```

It's better to write a gAMA chunk with an approximately right value than to omit the chunk and force PNG decoders to guess at an appropriate gamma.

On the other hand, if the encoder has no way to infer the gamma value, then it is better to omit the gAMA chunk entirely. If the image gamma has to be guessed at, leave it to the decoder to do the guessing.

Gamma does not apply to alpha samples; alpha is always represented linearly.

See also Recommendations for Decoders: Decoder gamma handling (Section 10.5).

9.3 Encoder color handling

See Color Tutorial (Chapter 14) if you aren't already familiar with color issues.

Encoders capable of full-fledged color management [ICC] will perform more sophisticated calculations than those described here, and they may choose to use the iCCP chunk. Encoders that know that their image samples conform to the sRGB specification [sRGB] are strongly encouraged to use the sRGB chunk. Otherwise, this section applies.

If it is possible for the encoder to determine the chromaticities of the source display primaries, or to make a strong guess based on the origin of the image or the hardware running it, then the encoder is strongly encouraged to output the cHRM chunk. If it does so, the gAMA chunk should also be written; decoders can do little with cHRM if gAMA is missing.

Video created with recent video equipment probably uses the CCIR 709 primaries and D65 white point [ITU-R-BT709], which are:

	R	G	B	White
x	0.640	0.300	0.150	0.3127
y	0.330	0.600	0.060	0.3290

An older but still very popular video standard is SMPTE-C [SMPTE-170M]:

	R	G	B	White
x	0.630	0.310	0.155	0.3127
y	0.340	0.595	0.070	0.3290

The original NTSC color primaries have not been used in decades. Although you may still find the NTSC numbers listed in standards documents, you won't find any images that actually use them.

Scanners that produce PNG files as output should insert the filter chromaticities into a cHRM chunk.

In the case of hand-drawn or digitally edited images, you have to determine what monitor they were viewed on when being produced. Many image editing programs allow you to specify what type of monitor you are using. This is often because they are working in some device-independent space internally. Such programs have enough information to write valid cHRM and gAMA chunks, and should do so automatically.

If the encoder is compiled as a portion of a computer image renderer that performs full-spectral rendering, the monitor values that were used to convert from the internal device-independent color space to RGB should be written into the cHRM chunk. Any colors that are outside the gamut of the chosen RGB device should be clipped or otherwise constrained to be within the gamut; PNG does not store out-of-gamut colors.

If the computer image renderer performs calculations directly in device-dependent RGB space, a cHRM chunk should not be written unless the scene description and rendering parameters have been adjusted to

look good on a particular monitor. In that case, the data for that monitor (if known) should be used to construct a cHRM chunk.

There are often cases where an image's exact origins are unknown, particularly if it began life in some other format. A few image formats store calibration information, which can be used to fill in the cHRM chunk. For example, all PhotoCD images use the CCIR 709 primaries and D65 white point, so these values can be written into the cHRM chunk when converting a PhotoCD file. PhotoCD also uses the SMPTE-170M transfer function. (PhotoCD can store colors outside the RGB gamut, so the image data will require gamut mapping before writing to PNG format.) TIFF 6.0 files can optionally store calibration information, which if present should be used to construct the cHRM chunk. GIF and most other formats do not store any calibration information.

It is **not** recommended that file format converters attempt to convert supplied images to a different RGB color space. Store the data in the PNG file without conversion, and record the source primary chromaticities if they are known. Color space transformation at file conversion time is a bad idea because of gamut mismatches and rounding errors. As with gamma conversions, it's better to store the data losslessly and incur at most one conversion when the image is finally displayed.

See also Recommendations for Decoders: Decoder color handling (Section 10.6).

9.4 Alpha channel creation

The alpha channel can be regarded either as a mask that temporarily hides transparent parts of the image, or as a means for constructing a non-rectangular image. In the first case, the color values of fully transparent pixels should be preserved for future use. In the second case, the transparent pixels carry no useful data and are simply there to fill out the rectangular image area required by PNG. In this case, fully transparent pixels should all be assigned the same color value for best compression.

Image authors should keep in mind the possibility that a decoder will ignore transparency control. Hence, the colors assigned to transparent pixels should be reasonable background colors whenever feasible.

For applications that do not require a full alpha channel, or cannot afford the price in compression efficiency, the tRNS transparency chunk is also available.

If the image has a known background color, this color should be written in the bKGD chunk. Even decoders that ignore transparency may use the bKGD color to fill unused screen area.

If the original image has premultiplied (also called "associated") alpha data, convert it to PNG's non-premultiplied format by dividing each sample value by the corresponding alpha value, then multiplying by the maximum value for the image bit depth, and rounding to the nearest integer. In valid premultiplied data, the sample values never exceed their corresponding alpha values, so the result of the division should always be in the range 0 to 1. If the alpha value is zero, output black (zeroes).

9.5 Suggested palettes

Suggested palettes can appear as sPLT chunks in any PNG file, or as a PLTE chunk in truecolor PNG files. In either case, the suggested palette is not an essential part of the image data, but it may be used to present the image on indexed-color display hardware. Suggested palettes are of no interest to viewers running on truecolor hardware.

When sPLT is used to provide a suggested palette, it is recommended that the encoder use the frequency fields to indicate the relative importance of the palette entries, rather than leave them all zero (meaning undefined). The frequency values are most easily computed as "nearest neighbor" counts, that is, the approximate usage of each RGBA palette entry if no dithering is applied. (These counts will often be available for free as a consequence of developing the suggested palette.) Because the suggested palette includes transparency information, it should be computed for the uncomposited image.

Even for indexed-color images, sPLT can be used to define alternative reduced palettes for viewers that are unable to display all the colors present in the PLTE chunk.

An older method for including a suggested palette in a truecolor PNG file uses the PLTE chunk. If this method is used, the histogram (frequencies) should appear in a separate hIST chunk. Also, PLTE does not include transparency information, so for images of color type 6 (truecolor with alpha channel), it is recommended that a bKGD chunk appear and that the palette and histogram be computed with reference to the image as it would appear after compositing against the specified background color. This definition is necessary to ensure that useful palette entries are generated for pixels having fractional alpha values. The resulting palette will probably be useful only to viewers that present the image against the same background color. It is recommended that PNG editors delete or recompute the palette if they alter or remove the bKGD chunk in an image of color type 6.

For images of color type 2 (truecolor without alpha channel), it is recommended that PLTE and hIST be computed with reference to the RGB data only, ignoring any transparent-color specification. If the file uses transparency (has a tRNS chunk), viewers can easily adapt the resulting palette for use with their intended background color. They need only replace the palette entry closest to the tRNS color with their background color (which may or may not match the file's bKGD color, if any).

If PLTE appears without bKGD in an image of color type 6, the circumstances under which the palette was computed are unspecified.

For providing suggested palettes, sPLT is more flexible than PLTE in the following ways:

- With sPLT, there can be multiple suggested palettes. A decoder may choose an appropriate palette based on name or number of entries.
- In an RGBA (color type 6) PNG, PLTE represents a palette already composited against the bKGD color, so it is useful only for display against that background color. The sPLT chunk provides an uncomposited palette, which is useful for display against backgrounds of the decoder's choice.
- Since sPLT is a noncritical chunk, a PNG editor can add or modify suggested palettes without being forced to discard unknown unsafe-to-copy chunks.

- Whereas sPLT is allowed in PNG files of color types 0, 3, and 4 (grayscale and indexed), PLTE cannot be used to provide reduced palettes in these cases.
- More than 256 entries can appear in sPLT.

An encoder that uses sPLT may choose to write a PLTE/hIST suggested palette as well, for backward compatibility with decoders that do not recognize sPLT.

9.6 Filter selection

For images of color type 3 (indexed color), filter type 0 (None) is usually the most effective. Note that color images with 256 or fewer colors should almost always be stored in indexed color format; truecolor format is likely to be much larger.

Filter type 0 is also recommended for images of bit depths less than 8. For low-bit-depth grayscale images, it may be a net win to expand the image to 8-bit representation and apply filtering, but this is rare.

For truecolor and grayscale images, any of the five filters may prove the most effective. If an encoder uses a fixed filter, the Paeth filter is most likely to be the best.

For best compression of truecolor and grayscale images, we recommend an adaptive filtering approach in which a filter is chosen for each scanline. The following simple heuristic has performed well in early tests: compute the output scanline using all five filters, and select the filter that gives the smallest sum of absolute values of outputs. (Consider the output bytes as signed differences for this test.) This method usually outperforms any single fixed filter choice. However, it is likely that much better heuristics will be found as more experience is gained with PNG.

Filtering according to these recommendations is effective on interlaced as well as noninterlaced images.

9.7 Text chunk processing

A nonempty keyword *must* be provided for each text chunk (iTXt, tEXt, or zTXt). The generic keyword "Comment" can be used if no better description of the text is available. If a user-supplied keyword is used, be sure to check that it meets the restrictions on keywords.

Text stored in tEXt or zTXt chunks is expected to use the Latin-1 character set. Encoders should provide character code remapping if the local system's character set is not Latin-1. Encoders wishing to store characters not defined in Latin-1 should use the iTXt chunk.

Encoders should discourage the creation of single lines of text longer than 79 characters, in order to facilitate easy reading.

It is recommended that text items less than 1K (1024 bytes) in size should be output using uncompressed text chunks. In particular, it is recommended that the text associated with basic title and author keywords should always be output with uncompressed chunks. Lengthy disclaimers, on the other hand, are ideal candidates for compression.

Placing large text chunks after the image data (after IDAT) can speed up image display in some situations, since the decoder won't have to read over the text to get to the image data. But it is recommended that small text chunks, such as the image title, appear before IDAT.

9.8 Use of private chunks

Applications can use PNG private chunks to carry information that need not be understood by other applications. Such chunks must be given names with lowercase second letters, to ensure that they can never conflict with any future public chunk definition. Note, however, that there is no guarantee that some other application will not use the same private chunk name. If you use a private chunk type, it is prudent to store additional identifying information at the beginning of the chunk data.

Use an ancillary chunk type (lowercase first letter), not a critical chunk type, for all private chunks that store information that is not absolutely essential to view the image. Creation of private critical chunks is discouraged because they render PNG files unportable. Such chunks should not be used in publicly available software or files. If private critical chunks are essential for your application, it is recommended that one appear near the start of the file, so that a standard decoder need not read very far before discovering that it cannot handle the file.

If you want others outside your organization to understand a chunk type that you invent, contact the maintainers of the PNG specification to submit a proposed chunk name and definition for addition to the list of special-purpose public chunks (see Additional chunk types, Section 4.4). Note that a proposed public chunk name (with uppercase second letter) must not be used in publicly available software or files until registration has been approved.

If an ancillary chunk contains textual information that might be of interest to a human user, you should **not** create a special chunk type for it. Instead use a text chunk and define a suitable keyword. That way, the information will be available to users not using your software.

Keywords in text chunks should be reasonably self-explanatory, since the idea is to let other users figure out what the chunk contains. If of general usefulness, new keywords can be registered with the maintainers of the PNG specification. But it is permissible to use keywords without registering them first.

9.9 Private type and method codes

This specification defines the meaning of only some of the possible values of some fields. For example, only compression method 0 and filter types 0 through 4 are defined. Numbers greater than 127 must be used when inventing experimental or private definitions of values for any of these fields. Numbers below 128 are reserved for possible future public extensions of this specification. Note that use of private type codes may render a file unreadable by standard decoders. Such codes are strongly discouraged except for experimental purposes, and should not appear in publicly available software or files.

10 Recommendations for Decoders

This chapter gives some recommendations for decoder behavior. The only absolute requirement on a PNG decoder is that it successfully read any file conforming to the format specified in the preceding chapters. However, best results will usually be achieved by following these recommendations.

10.1 Error checking

To ensure early detection of common file-transfer problems, decoders should verify that all eight bytes of the PNG file signature are correct. (See Rationale: PNG file signature, Section 12.12.) A decoder can have additional confidence in the file's integrity if the next eight bytes are an IHDR chunk header with the correct chunk length.

Unknown chunk types must be handled as described in Chunk naming conventions (Section 3.3). An unknown chunk type is *not* to be treated as an error unless it is a critical chunk.

It is strongly recommended that decoders should verify the CRC on each chunk.

In some situations it is desirable to check chunk headers (length and type code) before reading the chunk data and CRC. The chunk type can be checked for plausibility by seeing whether all four bytes are ASCII letters (codes 65–90 and 97–122); note that this need be done only for unrecognized type codes. If the total file size is known (from file system information, HTTP protocol, etc), the chunk length can be checked for plausibility as well.

If CRCs are not checked, dropped/added data bytes or an erroneous chunk length can cause the decoder to get out of step and misinterpret subsequent data as a chunk header. Verifying that the chunk type contains letters is an inexpensive way of providing early error detection in this situation.

For known-length chunks such as IHDR, decoders should treat an unexpected chunk length as an error. Future extensions to this specification will not add new fields to existing chunks; instead, new chunk types will be added to carry new information.

Unexpected values in fields of known chunks (for example, an unexpected compression method in the IHDR chunk) must be checked for and treated as errors. However, it is recommended that unexpected field values be treated as fatal errors only in *critical* chunks. An unexpected value in an ancillary chunk can be handled by ignoring the whole chunk as though it were an unknown chunk type. (This recommendation assumes that the chunk's CRC has been verified. In decoders that do not check CRCs, it is safer to treat any unexpected value as indicating a corrupted file.)

10.2 Pixel dimensions

Non-square pixels can be represented (see the pHYs chunk), but viewers are not required to account for them; a viewer can present any PNG file as though its pixels are square.

Conversely, viewers running on display hardware with non-square pixels are strongly encouraged to rescale images for proper display.

10.3 Truecolor image handling

To achieve PNG's goal of universal interchangeability, decoders are required to accept all types of PNG image: indexed-color, truecolor, and grayscale. Viewers running on indexed-color display hardware need to be able to reduce truecolor images to indexed format for viewing. This process is usually called "color quantization".

A simple, fast way of doing this is to reduce the image to a fixed palette. Palettes with uniform color spacing ("color cubes") are usually used to minimize the per-pixel computation. For photograph-like images, dithering is recommended to avoid ugly contours in what should be smooth gradients; however, dithering introduces graininess that can be objectionable.

The quality of rendering can be improved substantially by using a palette chosen specifically for the image, since a color cube usually has numerous entries that are unused in any particular image. This approach requires more work, first in choosing the palette, and second in mapping individual pixels to the closest available color. PNG allows the encoder to supply suggested palettes, but not all encoders will do so, and the suggested palettes may be unsuitable in any case (they may have too many or too few colors). High-quality viewers will therefore need to have a palette selection routine at hand. A large lookup table is usually the most feasible way of mapping individual pixels to palette entries with adequate speed.

Numerous implementations of color quantization are available. The PNG reference implementation, libpng, includes code for the purpose.

10.4 Sample depth rescaling

Decoders may wish to scale PNG data to a lesser sample depth (data precision) for display. For example, 16-bit data will need to be reduced to 8-bit depth for use on most present-day display hardware. Reduction of 8-bit data to 5-bit depth is also common.

The most accurate scaling is achieved by the linear equation

```
output = ROUND(input * MAXOUTSAMPLE / MAXINSAMPLE)
```

where

$$\text{MAXINSAMPLE} = 2^{\text{sampledepth}} - 1$$
$$\text{MAXOUTSAMPLE} = 2^{\text{desired_sampledepth}} - 1$$

A slightly less accurate conversion is achieved by simply shifting right by `sampledepth - desired_sampledepth` places. For example, to reduce 16-bit samples to 8-bit, one need only discard the low-order byte. In many situations the shift method is sufficiently accurate for display purposes, and it is certainly much faster. (But if gamma correction is being done, sample rescaling can be merged into the gamma correction lookup table, as is illustrated in Decoder gamma handling, Section 10.5.)

When an sBIT chunk is present, the original pre-PNG data can be recovered by shifting right to the sample depth specified by sBIT. Note that linear scaling will not necessarily reproduce the original data, because the encoder is not required to have used linear scaling to scale the data up. However, the encoder is required to have used a method that preserves the high-order bits, so shifting always works. This is the only case in which shifting might be said to be more accurate than linear scaling.

When comparing pixel values to tRNS chunk values to detect transparent pixels, it is necessary to do the comparison exactly. Therefore, transparent pixel detection must be done before reducing sample precision.

10.5 Decoder gamma handling

See Gamma Tutorial (Chapter 13) if you aren't already familiar with gamma issues.

Decoders capable of full-fledged color management [ICC] will perform more sophisticated calculations than what is described here. Otherwise, this section applies.

For an image display program to produce correct tone reproduction, it is necessary to take into account the relationship between file samples and display output, and the transfer function of the display system. This can be done by calculating

$$\text{sample} = \text{integer_sample}/(2^{\text{bitdepth}} - 1.0)$$
$$\text{display_output} = \text{sample}^{(1.0/\text{gamma})}$$

```
display_input = inverse_display_transfer(display_output)
framebuf_sample = ROUND(display_input * MAX_FRAMEBUF_SAMPLE)
```

where `integer_sample` is the sample value from the file, `framebuf_sample` is the value to write into the frame buffer, and `MAX_FRAMEBUF_SAMPLE` is the maximum value of a frame buffer sample (255 for 8-bit, 31 for 5-bit, etc). The first line converts an integer sample into a normalized 0-to-1 floating-point value, the second converts to a value proportional to the desired display output intensity, the third accounts for the display system's transfer function, and the fourth converts to an integer frame buffer sample.

A step could be inserted between the second and third to adjust `display_output` to account for the difference between the actual viewing conditions and the reference viewing conditions. However, this adjustment requires accounting for veiling glare, black mapping, and color appearance models, none of which can be well approximated by power functions. The calculations are not described here. If viewing conditions are ignored, the error will usually be small.

Typically, the display transfer function can be approximated by a power function with exponent `display_exponent`, in which case the second and third lines can be merged into

$$\begin{aligned}\text{display_input} &= \text{sample}^{(1.0/(\text{gamma}*\text{display_exponent}))} \\ &= \text{sample}^{\text{decoding_exponent}}\end{aligned}$$

so as to perform only one power calculation. For color images, the entire calculation is performed separately for R, G, and B values.

The value of gamma can be taken directly from the gAMA chunk. Alternatively, an application may wish to allow the user to adjust the appearance of the displayed image by influencing the value of gamma. For example, the user could manually set a parameter called `user_exponent` that defaults to 1.0, and the application could set

```
gamma = gamma_from_file / user_exponent
decoding_exponent = 1.0 / (gamma * display_exponent)
      = user_exponent / (gamma_from_file * display_exponent)
```

The user would set `user_exponent` greater than 1 to darken the mid-level tones, or less than 1 to lighten them.

It is *not* necessary to perform transcendental math for every pixel. Instead, compute a lookup table that gives the correct output value for every possible sample value. This requires only 256 calculations per image (for 8-bit accuracy), not one or three calculations per pixel. For an indexed-color image, a one-time correction of the palette is sufficient, unless the image uses transparency and is being displayed against a nonuniform background.

If floating-point calculations are not possible, gamma correction tables can be computed using integer arithmetic and a precomputed table of logarithms. Example code appears in the "Extensions to the PNG Specification" document [PNG-EXTENSIONS].

When the incoming image has unknown gamma (gAMA, sRGB, and iCCP all absent), choose a likely default gamma value, but allow the user to select a new one if the result proves too dark or too light. The default gamma can depend on other knowledge about the image, like whether it came from the Internet or from the local system.

In practice, it is often difficult to determine what value of the display exponent should be used. In systems with no built-in gamma correction, the display exponent is determined entirely by the CRT (cathode ray tube). Assume a CRT exponent of 2.2 unless detailed calibration measurements of this particular CRT are available.

Many modern frame buffers have lookup tables that are used to perform gamma correction, and on these systems the display exponent value should be the exponent of the lookup table and CRT combined. You may not be able to find out what the lookup table contains from within an image viewer application, so you may have to ask the user what the display system's exponent is. Unfortunately, different manufacturers use different ways of specifying what should go into the lookup table, so interpretation of the system "gamma" value is system-dependent. The Gamma Tutorial (Chapter 13) gives some examples.

The response of real displays is actually more complex than can be described by a single number (the display exponent). If actual measurements of the monitor's light output as a function of voltage input are available, the third and fourth lines of the computation above can be replaced by a lookup in these measurements, to find the actual frame buffer value that most nearly gives the desired brightness.

10.6 Decoder color handling

See Color Tutorial (Chapter 14) if you aren't already familiar with color issues.

In many cases, decoders will treat image data in PNG files as device-dependent RGB data and display it without modification (except for appropriate gamma correction). This provides the fastest display of PNG images. But unless the viewer uses exactly the same display hardware as the original image author used, the colors will not be exactly the same as the original author saw, particularly for darker or near-neutral colors. The cHRM chunk provides information that allows closer color matching than that provided by gamma correction alone.

Decoders can use the cHRM data to transform the image data from RGB to CIE XYZ and thence into a perceptually linear color space such as CIE LAB. They can then partition the colors to generate an optimal palette, because the geometric distance between two colors in CIE LAB is strongly related to how different those colors appear (unlike, for example, RGB or XYZ spaces). The resulting palette of colors, once transformed back into RGB color space, could be used for display or written into a PLTE chunk.

Decoders that are part of image processing applications might also transform image data into CIE LAB space for analysis.

In applications where color fidelity is critical, such as product design, scientific visualization, medicine, architecture, or advertising, decoders can transform the image data from source RGB to the display RGB space of the monitor used to view the image. This involves calculating the matrix to go from source RGB to XYZ and the matrix to go from XYZ to display RGB, then combining them to produce the overall transformation. The decoder is responsible for implementing gamut mapping.

Decoders running on platforms that have a Color Management System (CMS) can pass the image data, gAMA, and cHRM values to the CMS for display or further processing.

Decoders that provide color printing facilities can use the facilities in Level 2 PostScript to specify image data in calibrated RGB space or in a device-independent color space such as XYZ. This will provide better color fidelity than a simple RGB to CMYK conversion. The PostScript Language Reference manual [POSTSCRIPT] gives examples. Such decoders are responsible for implementing gamut mapping between source RGB (specified in the cHRM chunk) and the target printer. The PostScript interpreter is then responsible for producing the required colors.

Decoders can use the cHRM data to calculate an accurate grayscale representation of a color image. Conversion from RGB to gray is simply a case of calculating the Y (luminance) component of XYZ, which is a weighted sum of the R, G, and B values. The weights depend on the monitor type, i.e., the values in the cHRM chunk. Decoders may wish to do this for PNG files with no cHRM chunk. In that case, a reasonable default would be the CCIR 709 primaries [ITU-R-BT709]. Do *not* use the original NTSC primaries, unless you really do have an image color-balanced for such a monitor. Few monitors ever used the NTSC primaries, so such images are probably nonexistent these days.

10.7 Background color

The background color given by bKGD will typically be used to fill unused screen space around the image, as well as any transparent pixels within the image. (Thus, bKGD is valid and useful even when the image does not use transparency.) If no bKGD chunk is present, the viewer will need to make its own decision about a suitable background color.

Viewers that have a specific background against which to present the image (such as Web browsers) should ignore the bKGD chunk, in effect overriding bKGD with their preferred background color or background image.

The background color given by bKGD is not to be considered transparent, even if it happens to match the color given by tRNS (or, in the case of an indexed-color image, refers to a palette index that is marked as transparent by tRNS). Otherwise one would have to imagine something "behind the background" to composite against. The background color is either used as background or ignored; it is not an intermediate layer between the PNG image and some other background.

Indeed, it will be common that bKGD and tRNS specify the same color, since then a decoder that does not implement transparency processing will give the intended display, at least when no partially-transparent pixels are present.

10.8 Alpha channel processing

In the most general case, the alpha channel can be used to composite a foreground image against a background image; the PNG file defines the foreground image and the transparency mask, but not the background image. Decoders are *not* required to support this most general case. It is expected that most will be able to support compositing against a single background color, however.

The equation for computing a composited sample value is

```
output = alpha * foreground + (1-alpha) * background
```

where the alpha value and the input and output sample values are expressed as fractions in the range 0 to 1. This computation should be performed with intensity samples (not gamma-encoded samples). For color images, the computation is done separately for R, G, and B samples.

The following code illustrates the general case of compositing a foreground image over a background image. It assumes that you have the original pixel data available for the background image, and that output is to a frame buffer for display. Other variants are possible; see the comments below the code. The code allows the sample depths and gamma values of foreground and background images to be different, and not necessarily suited to the display system. Don't assume everything is the same without checking.

This code is standard C, with line numbers added for reference in the comments below:

```
01  int foreground[4];  /* image pixel: R, G, B, A */
02  int background[3];  /* background pixel: R, G, B */
03  int fbpix[3];       /* frame buffer pixel */
04  int fg_maxsample;   /* foreground max sample */
05  int bg_maxsample;   /* background max sample */
06  int fb_maxsample;   /* frame buffer max sample */
07  int ialpha;
08  float alpha, compalpha;
09  float gamfg, linfg, gambg, linbg, comppix, gcvideo;
```

```
    /* Get max sample values in data and frame buffer */
10  fg_maxsample = (1 << fg_sample_depth) - 1;
11  bg_maxsample = (1 << bg_sample_depth) - 1;
12  fb_maxsample = (1 << frame_buffer_sample_depth) - 1;
    /*
     * Get integer version of alpha.
     * Check for opaque and transparent special cases;
     * no compositing needed if so.
     *
     * We show the whole gamma decode/correct process in
     * floating point, but it would more likely be done
     * with lookup tables.
     */
13  ialpha = foreground[3];

14  if (ialpha == 0) {
        /*
         * Foreground image is transparent here.
         * If the background image is already in the frame
         * buffer, there is nothing to do.
         */
15      ;
16  } else if (ialpha == fg_maxsample) {
        /*
         * Copy foreground pixel to frame buffer.
         */
17      for (i = 0; i < 3; i++) {
18          gamfg = (float) foreground[i] / fg_maxsample;
19          linfg = pow(gamfg, 1.0/fg_gamma);
20          comppix = linfg;
21          gcvideo = pow(comppix, 1.0/display_exponent);
22          fbpix[i] = (int) (gcvideo * fb_maxsample + 0.5);
23      }
24  } else {
        /*
         * Compositing is necessary.
         * Get floating-point alpha and its complement.
         * Note: alpha is always linear; gamma does not
         * affect it.
         */
25      alpha = (float) ialpha / fg_maxsample;
26      compalpha = 1.0 - alpha;

27      for (i = 0; i < 3; i++) {
            /*
             * Convert foreground and background to
             * floating point, then undo gamma encoding.
             */
28          gamfg = (float) foreground[i] / fg_maxsample;
```

```
29          linfg = pow(gamfg, 1.0/fg_gamma);
30          gambg = (float) background[i] / bg_maxsample;
31          linbg = pow(gambg, 1.0/bg_gamma);
            /*
             * Composite.
             */
32          comppix = linfg * alpha + linbg * compalpha;
            /*
             * Gamma correct for display.
             * Convert to integer frame buffer pixel.
             */
33          gcvideo = pow(comppix, 1.0/display_exponent);
34          fbpix[i] = (int) (gcvideo * fb_maxsample + 0.5);
35      }
36  }
```

Variations:

1. If output is to another PNG image file instead of a frame buffer, lines 21, 22, 33, and 34 should be changed to be something like:

   ```
   /*
    * Gamma encode for storage in output file.
    * Convert to integer sample value.
    */
   gamout = pow(comppix, outfile_gamma);
   outpix[i] = (int) (gamout * out_maxsample + 0.5);
   ```

   Also, it becomes necessary to process background pixels when alpha is zero, rather than just skipping pixels. Thus, line 15 will need to be replaced by copies of lines 17–23, but processing background instead of foreground pixel values.

2. If the sample depths of the output file, foreground file, and background file are all the same, and the three gamma values also match, then the no-compositing code in lines 14–23 reduces to nothing more than copying pixel values from the input file to the output file if alpha is one, or copying pixel values from background to output file if alpha is zero. Since alpha is typically either zero or one for the vast majority of pixels in an image, this is a great savings. No gamma computations are needed for most pixels.

3. When the sample depths and gamma values all match, it may appear attractive to skip the gamma decoding and encoding (lines 28–31, 33–34) and just perform line 32 using gamma-encoded sample values. Although this doesn't hurt image quality too badly, the time savings are small if alpha values of zero and one are special-cased as recommended here.

4. If the original pixel values of the background image are no longer available, only processed frame buffer pixels left by display of the background image, then lines 30 and 31 need to extract intensity from the frame buffer pixel values using code like:

```
/*
 * Convert frame buffer value into intensity sample.
 */
gcvideo = (float) fbpix[i] / fb_maxsample;
linbg = pow(gcvideo, display_exponent);
```

However, some roundoff error can result, so it is better to have the original background pixels available if at all possible.

5. Note that lines 18–22 are performing exactly the same gamma computation that is done when no alpha channel is present. So, if you handle the no-alpha case with a lookup table, you can use the same lookup table here. Lines 28–31 and 33–34 can also be done with (different) lookup tables.

6. Of course, everything here can be done in integer arithmetic. Just be careful to maintain sufficient precision all the way through.

Note: in floating-point arithmetic, no overflow or underflow checks are needed, because the input sample values are guaranteed to be between 0 and 1, and compositing always yields a result that is in between the input values (inclusive). With integer arithmetic, some roundoff-error analysis might be needed to guarantee no overflow or underflow.

When displaying a PNG image with full alpha channel, it is important to be able to composite the image against some background, even if it's only black. Ignoring the alpha channel will cause PNG images that have been converted from an associated-alpha representation to look wrong. (Of course, if the alpha channel is a separate transparency mask, then ignoring alpha is a useful option: it allows the hidden parts of the image to be recovered.)

Even if the decoder author does not wish to implement true compositing logic, it is simple to deal with images that contain only zero and one alpha values. (This is implicitly true for grayscale and truecolor PNG files that use a tRNS chunk; for indexed-color PNG files, it is easy to check whether tRNS contains any values other than 0 and 255.) In this simple case, transparent pixels are replaced by the background color, while others are unchanged.

If a decoder contains only this much transparency capability, it should deal with a full alpha channel by converting it to a binary alpha channel, either by treating all nonzero alpha values as fully opaque or by dithering. Neither approach will yield very good results for images converted from associated-alpha formats, but it's better than doing nothing. Dithering full alpha to binary alpha is very much like dithering grayscale to black-and-white, except that all fully transparent and fully opaque pixels should be left unchanged by the dither.

10.9 Progressive display

When receiving images over slow transmission links, decoders can improve perceived performance by displaying interlaced images progressively. This means that as each pass is received, an approximation to the complete image is displayed based on the data received so far. One simple yet pleasing effect can be obtained by expanding each received pixel to fill a rectangle covering the yet-to-be-transmitted pixel positions below and to the right of the received pixel. This process can be described by the following pseudocode:

```
Starting_Row [1..7] =  { 0, 0, 4, 0, 2, 0, 1 }
Starting_Col [1..7] =  { 0, 4, 0, 2, 0, 1, 0 }
Row_Increment [1..7] = { 8, 8, 8, 4, 4, 2, 2 }
Col_Increment [1..7] = { 8, 8, 4, 4, 2, 2, 1 }
Block_Height [1..7] =  { 8, 8, 4, 4, 2, 2, 1 }
Block_Width [1..7] =   { 8, 4, 4, 2, 2, 1, 1 }

pass := 1
while pass <= 7
begin
    row := Starting_Row[pass]

    while row < height
    begin
        col := Starting_Col[pass]

        while col < width
        begin
            visit (row, col,
                   min (Block_Height[pass], height - row),
                   min (Block_Width[pass], width - col))
            col := col + Col_Increment[pass]
        end
        row := row + Row_Increment[pass]
    end

    pass := pass + 1
end
```

Here, the function `visit(row,column,height,width)` obtains the next transmitted pixel and paints a rectangle of the specified height and width, whose upper-left corner is at the specified row and column, using the color indicated by the pixel. Note that row and column are measured from 0,0 at the upper left corner.

If the decoder is merging the received image with a background image, it may be more convenient just to paint the received pixel positions; that is, the `visit()` function sets only the pixel at the specified row and column, not the whole rectangle. This produces a "fade-in" effect as the new image gradually replaces the old. An advantage of this approach is that proper alpha or transparency processing can be done as each pixel is replaced. Painting a rectangle as described above will overwrite background-image pixels that may be needed later, if the pixels eventually received for those positions turn out to be wholly or partially transparent. Of course, this is a problem only if the background image is not stored anywhere offscreen.

10.10 Suggested-palette and histogram usage

For viewers running on indexed-color hardware trying to display a truecolor image, or an indexed-color image whose palette is too large for the framebuffer, the encoder may have provided one or more suggested palettes in sPLT chunks. If one of them is found to be suitable, based on its size and perhaps its name, the

decoder can use that palette. Note that suggested palettes with a sample depth different from what the decoder needs can be converted using sample depth rescaling (See Recommendations for Decoders: Sample depth rescaling, Section 10.4).

When the background is a solid color, the decoder should composite the image and the suggested palette against that color, then quantize the resulting image to the resulting RGB palette. When the image uses transparency and the background is not a solid color, no suggested palette is likely to be useful.

For truecolor images, a suggested palette might also be provided in a PLTE chunk. If the image has a tRNS chunk and the background is a solid color, the viewer can adapt the suggested paletted for use with this background color. To do this, replace the palette entry closest to the tRNS color with the background color, or just add a palette entry for the background color if the viewer can handle more colors than there are palette entries.

For images of color type 6 (truecolor with alpha channel), any PLTE chunk should have been designed for display of the image against a uniform background of the color specified by bKGD. Viewers should probably ignore the palette if they intend to use a different background, or if the bKGD chunk is missing. Viewers can use the suggested palette for display against a different background than it was intended for, but the results may not be very good.

If the viewer presents a transparent truecolor image against a background that is more complex than a single color, it is unlikely that the PLTE chunk will be optimal for the composite image. In this case it is best to perform a truecolor compositing step on the truecolor PNG image and background image, then color-quantize the resulting image.

In truecolor PNG files, if both PLTE and sPLT appear, the decoder can choose from among the palettes suggested by both, bearing in mind the different transparency semantics mentioned above.

The frequencies in sPLT and hIST chunks are useful when the viewer cannot provide as many colors as are used in the palette. If the viewer is short only a few colors, it is usually adequate to drop the least-used colors from the palette. To reduce the number of colors substantially, it's best to choose entirely new representative colors, rather than trying to use a subset of the existing palette. This amounts to performing a new color quantization step; however, the existing palette and frequencies can be used as the input data, thus avoiding a scan of the image data.

If no suggested palettes are provided, a decoder can develop its own, at the cost of an extra pass over the image data. Alternatively, a default palette (probably a color cube) can be used.

See also Recommendations for Encoders: Suggested palettes (Section 9.5).

10.11 Text chunk processing

If practical, decoders should have a way to display to the user all text chunks found in the file. Even if the decoder does not recognize a particular text keyword, the user might be able to understand it.

Text in the tEXt and zTXt chunks is not supposed to contain any characters outside the ISO 8859-1 (Latin-1) character set (that is, no codes 0–31 or 127–159), except for the newline character (decimal 10). But decoders

might encounter such characters anyway. Some of these characters can be safely displayed (e.g., TAB, FF, and CR, decimal 9, 12, and 13, respectively), but others, especially the ESC character (decimal 27), could pose a security hazard because unexpected actions may be taken by display hardware or software. To prevent such hazards, decoders should not attempt to directly display any non-Latin-1 characters (except for newline and perhaps TAB, FF, CR) encountered in a tEXt or zTXt chunk. Instead, ignore them or display them in a visible notation such as "\nnn". See Security considerations (Section 8.5).

Even though encoders are supposed to represent newlines as LF, it is recommended that decoders not rely on this; it's best to recognize all the common newline combinations (CR, LF, and CR-LF) and display each as a single newline. TAB can be expanded to the proper number of spaces needed to arrive at a column multiple of 8.

Decoders running on systems with non-Latin-1 character set encoding should provide character code remapping so that Latin-1 characters are displayed correctly. Some systems may not provide all the characters defined in Latin-1. Mapping unavailable characters to a visible notation such as "\nnn" is a good fallback. In particular, character codes 127–255 should be displayed only if they are printable characters on the decoding system. Some systems may interpret such codes as control characters; for security, decoders running on such systems should not display such characters literally.

Decoders should be prepared to display text chunks that contain any number of printing characters between newline characters, even though encoders are encouraged to avoid creating lines in excess of 79 characters.

11 Glossary

a^b

Exponentiation; `a` raised to the power `b`. Note that zero raised to any positive power is zero.

Alpha

A value representing a pixel's degree of transparency. The more transparent a pixel, the less it hides the background against which the image is presented. In PNG, alpha is really the degree of opacity: zero alpha represents a completely transparent pixel, maximum alpha represents a completely opaque pixel. But most people refer to alpha as providing transparency information, not opacity information, and we continue that custom here.

Ancillary chunk

A chunk that provides additional information. A decoder can still produce a meaningful image, though not necessarily the best possible image, without processing the chunk.

Bit depth

The number of bits per palette index (in indexed-color PNGs) or per sample (in other color types). This is the same value that appears in IHDR.

Byte

Eight bits; also called an octet.

Channel
The set of all samples of the same kind within an image; for example, all the blue samples in a truecolor image. (The term "component" is also used, but not in this specification.) A sample is the intersection of a channel and a pixel.

Chromaticity
A pair of values `x,y` that precisely specify a color, except for the brightness information.

Chunk
A section of a PNG file. Each chunk has a type indicated by its chunk type name. Most types of chunks also include some data. The format and meaning of the data within the chunk are determined by the type name.

CIE
International Commission on Illumination (Commission Internationale de l'Éclairage).

CIE XYZ
A device-independent color space in which each component is the sum of a weighted power distribution over the visible spectrum. The Y component is luminence (see below).

CIE LAB
A perceptually linear color space.

Composite
As a verb, to form an image by merging a foreground image and a background image, using transparency information to determine where the background should be visible. The foreground image is said to be "composited against" the background.

CRC
Cyclic Redundancy Check. A CRC is a type of check value designed to catch most transmission errors. A decoder calculates the CRC for the received data and compares it to the CRC that the encoder calculated, which is appended to the data. A mismatch indicates that the data was corrupted in transit.

Critical chunk
A chunk that must be understood and processed by the decoder in order to produce a meaningful image from a PNG file.

CRT
Cathode Ray Tube: a common type of computer display hardware.

Datastream
A sequence of bytes. This term is used rather than "file" to describe a byte sequence that is only a portion of a file. We also use it to emphasize that a PNG image might be generated and consumed "on-the-fly", never appearing in a stored file at all.

Deflate
The name of the compression algorithm used in standard PNG files, as well as in zip, gzip,

pkzip, and other compression programs. Deflate is a member of the LZ77 family of compression methods.

Filter
A transformation applied to image data in hopes of improving its compressibility. PNG uses only lossless (reversible) filter algorithms.

Frame buffer
The final digital storage area for the image shown by a computer display. Software causes an image to appear onscreen by loading it into the frame buffer.

Gamma
Informally, a measure of the brightness of mid-level tones in an image. Outside this specification, the term "gamma" is often used as the exponent of a power function that is the transfer function of any stage(s) of an imaging pipeline:

$$\mathrm{output} = \mathrm{input}^{\mathrm{gamma}}$$

where both input and output are scaled to the range 0 to 1. Within this specification, gamma refers specifically to the function from display output to image samples.

Grayscale
An image representation in which each pixel is represented by a single sample value representing overall luminance (on a scale from black to white). PNG also permits an alpha sample to be stored for each pixel of a grayscale image.

Indexed color
An image representation in which each pixel is represented by a single sample that is an index into a palette or lookup table. The selected palette entry defines the actual color of the pixel.

Intensity
Power per unit area of light entering or leaving a surface. It is often normalized to the range 0 to 1 by dividing by a maximum intensity.

Lossless compression
Any method of data compression that guarantees the original data can be reconstructed exactly, bit-for-bit.

Lossy compression
Any method of data compression that reconstructs the original data approximately, rather than exactly.

LSB
Least Significant Byte of a multi-byte value.

Luminance
Perceived brightness, or grayscale level, of a color. Luminance and chromaticity together fully define a perceived color.

LUT
Look Up Table. In general, a table used to transform data. In frame buffer hardware, a LUT can be used to map indexed-color pixels into a selected set of truecolor values, or to perform gamma correction. In software, a LUT can be used as a fast way of implementing any one-variable mathematical function.

MSB
Most Significant Byte of a multi-byte value.

Palette
The set of colors available in an indexed-color image. In PNG, a palette is an array of colors defined by red, green, and blue samples. (Alpha values can also be defined for palette entries, via the tRNS chunk.)

Pixel
The information stored for a single grid point in the image. The complete image is a rectangular array of pixels.

PNG editor
A program that modifies a PNG file and preserves ancillary information, including chunks that it does not recognize. Such a program must obey the rules given in Chunk Ordering Rules (Chapter 7).

Sample
A single number in the image data; for example, the red value of a pixel. A pixel is composed of one or more samples. When discussing physical data layout (in particular, in Image layout, Section 2.3), we use "sample" to mean a number stored in the image array. It would be more precise but much less readable to say "sample or palette index" in that context. Elsewhere in the specification, "sample" means a color value or alpha value. In the indexed-color case, these are palette entries not palette indexes.

Sample depth
The precision, in bits, of color values and alpha values. In indexed-color PNGs the sample depth is always 8 by definition of the PLTE chunk. In other color types it is the same as the bit depth.

Scanline
One horizontal row of pixels within an image.

Truecolor
An image representation in which pixel colors are defined by storing three samples for each pixel, representing red, green, and blue intensities respectively. PNG also permits an alpha sample to be stored for each pixel of a truecolor image.

White point
The chromaticity of a computer display's nominal white value.

zlib
A particular format for data that has been compressed using deflate-style compression. Also

the name of a library implementing this method. PNG implementations need not use the zlib library, but they must conform to its format for compressed data.

12 Appendix: Rationale

(This appendix is not part of the formal PNG specification.)

This appendix gives the reasoning behind some of the design decisions in PNG. Many of these decisions were the subject of considerable debate. The authors freely admit that another group might have made different decisions; however, we believe that our choices are defensible and consistent.

12.1 Why a new file format?

Does the world really need yet another graphics format? We believe so. GIF is no longer freely usable, but no other commonly used format can directly replace it, as is discussed in more detail below. We might have used an adaptation of an existing format, for example GIF with an unpatented compression scheme. But this would require new code anyway; it would not be all that much easier to implement than a whole new file format. (PNG is designed to be simple to implement, with the exception of the compression engine, which would be needed in any case.) We feel that this is an excellent opportunity to design a new format that fixes some of the known limitations of GIF.

12.2 Why these features?

The features chosen for PNG are intended to address the needs of applications that previously used the special strengths of GIF. In particular, GIF is well adapted for online communications because of its streamability and progressive display capability. PNG shares those attributes.

We have also addressed some of the widely known shortcomings of GIF. In particular, PNG supports truecolor images. We know of no widely used image format that losslessly compresses truecolor images as effectively as PNG does. We hope that PNG will make use of truecolor images more practical and widespread.

Some form of transparency control is desirable for applications in which images are displayed against a background or together with other images. GIF provided a simple transparent-color specification for this purpose. PNG supports a full alpha channel as well as transparent-color specifications. This allows both highly flexible transparency and compression efficiency.

Robustness against transmission errors has been an important consideration. For example, images transferred across the Internet are often mistakenly processed as text, leading to file corruption. PNG is designed so that such errors can be detected quickly and reliably.

PNG has been expressly designed not to be completely dependent on a single compression technique. Although deflate/inflate compression is mentioned in this document, PNG would still exist without it.

12.3 Why not these features?

Some features have been deliberately omitted from PNG. These choices were made to simplify implementation of PNG, promote portability and interchangeability, and make the format as simple and foolproof as possible for users. In particular:

- There is no uncompressed variant of PNG. It is possible to store uncompressed data by using only uncompressed deflate blocks (a feature normally used to guarantee that deflate does not make incompressible data much larger). However, PNG software must support full deflate/inflate; any software that does not is not compliant with the PNG standard. The two most important features of PNG—portability and compression—are absolute requirements for online applications, and users demand them. Failure to support full deflate/inflate compromises both of these objectives.
- There is no lossy compression in PNG. Existing formats such as JFIF (JPEG File Interchange Format) already handle lossy compression well. Furthermore, available lossy compression methods, e.g., the JPEG (Joint Photographic Experts Group) algorithm, are far from foolproof—a poor choice of quality level can ruin an image. To avoid user confusion and unintentional loss of information, we feel it is best to keep lossy and lossless formats strictly separate. Also, lossy compression is complex to implement. Adding JPEG support to a PNG decoder might significantly increase its size, causing some decoders to omit support for the feature, which would erode our goal of interchangeability.
- There is no support for CMYK (Cyan, Magenta, Yellow, blacK) or other unusual color spaces. Again, this is in the name of promoting portability. CMYK, in particular, is far too device-dependent to be useful as a portable image representation.
- There is no standard chunk for thumbnail views of images. In discussions with software vendors who use thumbnails in their products, it has become clear that most would not use a "standard" thumbnail chunk. For one thing, every vendor has a different idea of what the dimensions and characteristics of a thumbnail ought to be. Also, some vendors keep thumbnails in separate files to accommodate varied image formats; they are not going to stop doing that simply because of a thumbnail chunk in one new format. Proprietary chunks containing vendor-specific thumbnails appear to be more practical than a common thumbnail format.

It is worth noting that private extensions to PNG could easily add these features. We will not, however, include them as part of the basic PNG standard.

PNG also does not support multiple images in one file. This restriction is a reflection of the reality that many applications do not need and will not support multiple images per file. In any case, single images are a fundamentally different sort of object from sequences of images. Rather than make false promises of interchangeability, we have drawn a clear distinction between single-image and multi-image formats. PNG is a single-image format. (But see Multiple-image extension, Section 8.4.)

12.4 Why not use format X?

We considered numerous existing formats before deciding to develop PNG. None could meet the requirements that we felt were important for PNG.

GIF is no longer suitable as a universal standard because of legal entanglements. Although just replacing GIF's compression method would avoid that problem, GIF does not support truecolor images, alpha channels, or gamma correction. The spec has more subtle problems too. Only a small subset of the GIF89 spec is actually portable across a variety of implementations, but there is no codification of the most portable part of the spec.

TIFF (the Tagged Image File Format) is far too complex to meet our goals of simplicity and interchangeability. Defining a TIFF subset would meet that objection, but would frustrate users making the reasonable assumption that a file saved as TIFF from their existing software would load into a program supporting our flavor of TIFF. Furthermore, TIFF is not designed for stream processing, has no provision for progressive display, and does not currently provide any good, legally unencumbered, lossless compression method.

IFF has also been suggested, but is not suitable in detail: available image representations are too machine-specific or not adequately compressed. The overall chunk structure of IFF is a useful concept that PNG has liberally borrowed from, but we did not attempt to be bit-for-bit compatible with IFF chunk structure. Again this is due to detailed issues, notably the fact that IFF FORMs are not designed to be serially writable.

Lossless JPEG is not suitable because it does not provide for the storage of indexed-color images. Furthermore, its lossless truecolor compression is often inferior to that of PNG.

12.5 Byte order

It has been asked why PNG uses network byte order. We have selected one byte ordering and used it consistently. Which order in particular is of little relevance, but network byte order has the advantage that routines to convert to and from it are already available on any platform that supports TCP/IP networking, **including** all PC platforms. The functions are trivial and will be included in the reference implementation.

12.6 Interlacing

PNG's two-dimensional interlacing scheme is more complex to implement than GIF's line-wise interlacing. It also costs a little more in file size. However, it yields an initial image *eight times* faster than GIF (the first pass transmits only 1/64th of the pixels, compared to 1/8th for GIF). Although this initial image is coarse, it is useful in many situations. For example, if the image is a World Wide Web imagemap that the user has seen before, PNG's first pass is often enough to determine where to click. The PNG scheme also looks better than GIF's, because horizontal and vertical resolution never differ by more than a factor of two; this avoids the odd "stretched" look seen when interlaced GIFs are filled in by replicating scanlines. Preliminary results show that small text in an interlaced PNG image is typically readable about twice as fast as in an equivalent GIF, i.e., after PNG's fifth pass or 25% of the image data, instead of after GIF's third pass or 50%. This is again due to PNG's more balanced increase in resolution.

12.7 Why gamma?

It might seem natural to standardize on storing sample values proportional to display output intensity (that is, have gamma of 1.0). But in fact, it is common for images to have a gamma of less than 1. There are three good reasons for this:

- CRTs have a transfer function with an exponent of 2.2, and video signals are designed to be sent directly to CRTs. Therefore, images obtained by frame-grabbing video already have a gamma of 1/2.2.
- The human eye has a nonlinear response to intensity, so linear encoding of samples either wastes sample codes in bright areas of the image, or provides too few sample codes to avoid banding artifacts in dark areas of the image, or both. At least 12 bits per sample are needed to avoid visible artifacts in linear encoding with a 100:1 image intensity range. An image gamma in the range 0.3 to 0.5 allocates sample values in a way that roughly corresponds to the eye's response, so that 8 bits/sample are enough to avoid artifacts caused by insufficient sample precision in almost all images. This makes "gamma encoding" a much better way of storing digital images than the simpler linear encoding.
- Many images are created on PCs or workstations with no gamma correction hardware and no software willing to provide gamma correction either. In these cases, the images have had their lighting and color chosen to look best on this platform—they can be thought of as having "manual" gamma correction built in. To see what the image author intended, it is necessary to treat such images as having a gamma value of 1/2.2 (assuming the author was using a CRT).

In practice, image gamma values around 1.0, 1/2.2, and 1/1.45 are all widely found. Older image standards such as GIF and JFIF often do not account for this fact. The exchange of images among a variety of systems has led to widespread problems with images appearing "too dark" or "too light".

PNG expects viewers to compensate for image gamma at the time that the image is displayed. Another possible approach is to expect encoders to convert all images to a uniform gamma at encoding time. While that method would speed viewers slightly, it has fundamental flaws:

- Gamma correction is inherently lossy due to quantization and roundoff error. Requiring conversion at encoding time thus causes irreversible loss. Since PNG is intended to be a lossless storage format, this is undesirable; we should store unmodified source data.
- The encoder might not know the source gamma value. If the decoder does gamma correction at viewing time, it can adjust the gamma (change the displayed brightness) in response to feedback from a human user. The encoder has no such recourse.
- Whatever "standard" gamma we settled on would be wrong for some displays. Hence viewers would still need gamma correction capability.

Since there will always be images with no gamma or an incorrect recorded gamma, good viewers will need to incorporate gamma adjustment code anyway. Gamma correction at viewing time is thus the right way to go.

Historical note: Version 1.0 of this specification used the gAMA chunk to express the relationship between the file samples and the "original scene intensity" (camera input) rather than the desired display output intensity. This was changed in version 1.1 for the following reasons:

- The decoder needs to know the desired display output in order to do its job, but there was not enough information in the file to convert from the original scene to the display output. The version 1.0 specification claimed that the conversion depended only on viewing conditions at the display, but that was an error; it also depends on conditions at the camera.
- Faithful reproduction of the original scene is not always the goal. Sometimes deliberate distortion is desired.
- For hand-drawn images there is no "original scene".

Because the gamma-related recommendations in version 1.0 were imprecise, it was not clear what value to put in a gAMA chunk in common situations. For an image drawn on a CRT display with no LUT under unknown viewing conditions, an argument could be made for any value between 40000 and 50000. Real applications were observed to write 45000 or 45455, and the latter is recommended by the current specification.

See Gamma Tutorial (Chapter 13) for more information.

12.8 Non-premultiplied alpha

PNG uses "unassociated" or "non-premultiplied" alpha so that images with separate transparency masks can be stored losslessly. Another common technique, "premultiplied alpha", stores pixel values premultiplied by the alpha fraction; in effect, the image is already composited against a black background. Any image data hidden by the transparency mask is irretrievably lost by that method, since multiplying by a zero alpha value always produces zero.

Some image rendering techniques generate images with premultiplied alpha (the alpha value actually represents how much of the pixel is covered by the image). This representation can be converted to PNG by dividing the sample values by alpha, except where alpha is zero. The result will look good if displayed by a viewer that handles alpha properly, but will not look very good if the viewer ignores the alpha channel.

Although each form of alpha storage has its advantages, we did not want to require all PNG viewers to handle both forms. We standardized on non-premultiplied alpha as being the lossless and more general case.

12.9 Filtering

PNG includes filtering capability because filtering can significantly reduce the compressed size of truecolor and grayscale images. Filtering is also sometimes of value on indexed-color images, although this is less common.

The filter algorithms are defined to operate on bytes, rather than pixels; this gains simplicity and speed with very little cost in compression performance. Tests have shown that filtering is usually ineffective for images

with fewer than 8 bits per sample, so providing pixelwise filtering for such images would be pointless. For 16 bit/sample data, bytewise filtering is nearly as effective as pixelwise filtering, because MSBs are predicted from adjacent MSBs, and LSBs are predicted from adjacent LSBs.

The encoder is allowed to change filters for each new scanline. This creates no additional complexity for decoders, since a decoder is required to contain defiltering logic for every filter type anyway. The only cost is an extra byte per scanline in the pre-compression datastream. Our tests showed that when the same filter is selected for all scanlines, this extra byte compresses away to almost nothing, so there is little storage cost compared to a fixed filter specified for the whole image. And the potential benefits of adaptive filtering are too great to ignore. Even with the simplistic filter-choice heuristics so far discovered, adaptive filtering usually outperforms fixed filters. In particular, an adaptive filter can change behavior for successive passes of an interlaced image; a fixed filter cannot.

12.10 Text strings

Most graphics file formats include the ability to store some textual information along with the image. But many applications need more than that: they want to be able to store several identifiable pieces of text. For example, a database using PNG files to store medical X-rays would likely want to include patient's name, doctor's name, etc. A simple way to do this in PNG would be to invent new private chunks holding text. The disadvantage of such an approach is that other applications would have no idea what was in those chunks, and would simply ignore them. Instead, we recommend that textual information be stored in standard text chunks with suitable keywords. Use of text tells any PNG viewer that the chunk contains text that might be of interest to a human user. Thus, a person looking at the file with another viewer will still be able to see the text, and even understand what it is if the keywords are reasonably self-explanatory. (To this end, we recommend spelled-out keywords, not abbreviations that will be hard for a person to understand. Saving a few bytes on a keyword is false economy.)

The ISO 8859-1 (Latin-1) character set was chosen as a compromise between functionality and portability. Some platforms cannot display anything more than 7-bit ASCII characters, while others can handle characters beyond the Latin-1 set. We felt that Latin-1 represents a widely useful and reasonably portable character set. Latin-1 is a direct subset of character sets commonly used on popular platforms such as Microsoft Windows and X Windows. It can also be handled on Macintosh systems with a simple remapping of characters.

12.11 iTXt

This section gives the reasoning behind some of the design decisions in the iTXt chunk.

Keyword: Why not Unicode?

Unicode is too fancy for the keyword, which is intended for both machine and human consumption. Even applications without Unicode support should at least be able to understand the keyword (to selectively delete chunks, for example).

Keyword: Latin-1 vs. ASCII

UTF-8 is used elsewhere in this chunk, and ASCII, unlike Latin-1, is compatible with UTF-8. There is a translated keyword, so restricting the keyword to ASCII would not be a hardship. So why use Latin-1? Because all other existing chunks containing keywords use Latin-1, so applications can reuse code they already contain.

Compression flag and compression method: Why not combine them?

We have deliberately avoided defining a null compression method in the past (for tEXt/zTXt), so that there would be no temptation to use it in IHDR.

Language tag:

It is not always clear how to render Unicode text unless it is known what language is represented by the text. Also, multiple iTXt chunks containing the same message in different languages could be present, and a decoder could automatically select the one most appropriate for its user.

Translated keyword:

Registered keywords, like "Description", are registered only once, in a single language (probably English), so that they can be recognized automatically. To be intelligible to speakers of another language, a translation must be provided.

Text: Unicode vs. MIME charset name

Including a MIME charset name would be more general, and allow the use of legacy character sets. But support for Unicode is growing, and allowing only Unicode is conceptually simpler and likely to eventually lead to greater interoperability.

UTF-8 vs. UCS-2 vs. UCS-4

UCS-2 is short-sighted. Neither UCS-2 nor UCS-4 is compatible with ASCII. UTF-8 is both backward compatible with ASCII and forward compatible with UCS-4, and is generally the preferred encoding for interchange (as opposed to internal representation).

12.12 PNG file signature

The first eight bytes of a PNG file always contain the following values:

```
(decimal)              137  80  78  71  13  10  26  10
(hexadecimal)           89  50  4e  47  0d  0a  1a  0a
(ASCII C notation)    \211   P   N   G  \r  \n \032 \n
```

This signature both identifies the file as a PNG file and provides for immediate detection of common file-transfer problems. The first two bytes distinguish PNG files on systems that expect the first two bytes to identify the file type uniquely. The first byte is chosen as a non-ASCII value to reduce the probability that a text file may be misrecognized as a PNG file; also, it catches bad file transfers that clear bit 7. Bytes two through four name the format. The CR-LF sequence catches bad file transfers that alter newline sequences. The control-Z character stops file display under MS-DOS. The final line feed checks for the inverse of the CR-LF translation problem.

A decoder may further verify that the next eight bytes contain an IHDR chunk header with the correct chunk length; this will catch bad transfers that drop or alter null (zero) bytes.

Note that there is no version number in the signature, nor indeed anywhere in the file. This is intentional: the chunk mechanism provides a better, more flexible way to handle format extensions, as explained in Chunk naming conventions (Section 12.14).

12.13 Chunk layout

The chunk design allows decoders to skip unrecognized or uninteresting chunks: it is simply necessary to skip the appropriate number of bytes, as determined from the length field.

Limiting chunk length to $2^{31} - 1$ bytes avoids possible problems for implementations that cannot conveniently handle 4-byte unsigned values. In practice, chunks will usually be much shorter than that anyway.

A separate CRC is provided for each chunk in order to detect badly-transferred images as quickly as possible. In particular, critical data such as the image dimensions can be validated before being used.

The chunk length is excluded from the CRC so that the CRC can be calculated as the data is generated; this avoids a second pass over the data in cases where the chunk length is not known in advance. Excluding the length from the CRC does not create any extra risk of failing to discover file corruption, since if the length is wrong, the CRC check will fail: the CRC will be computed on the wrong set of bytes and then be tested against the wrong value from the file.

12.14 Chunk naming conventions

The chunk naming conventions allow safe, flexible extension of the PNG format. This mechanism is much better than a format version number, because it works on a feature-by-feature basis rather than being an overall indicator. Decoders can process newer files if and only if the files use no unknown critical features (as

indicated by finding unknown critical chunks). Unknown ancillary chunks can be safely ignored. We decided against having an overall format version number because experience has shown that format version numbers hurt portability as much as they help. Version numbers tend to be set unnecessarily high, leading to older decoders rejecting files that they could have processed (this was a serious problem for several years after the GIF89 spec came out, for example). Furthermore, private extensions can be made either critical or ancillary, and standard decoders should react appropriately; overall version numbers are no help for private extensions.

A hypothetical chunk for vector graphics would be a critical chunk, since if ignored, important parts of the intended image would be missing. A chunk carrying the Mandelbrot set coordinates for a fractal image would be ancillary, since other applications could display the image without understanding what the image represents. In general, a chunk type should be made critical only if it is impossible to display a reasonable representation of the intended image without interpreting that chunk.

The public/private property bit ensures that any newly defined public chunk type name cannot conflict with proprietary chunks that could be in use somewhere. However, this does not protect users of private chunk names from the possibility that someone else may use the same chunk name for a different purpose. It is a good idea to put additional identifying information at the start of the data for any private chunk type.

When a PNG file is modified, certain ancillary chunks may need to be changed to reflect changes in other chunks. For example, a histogram chunk needs to be changed if the image data changes. If the file editor does not recognize histogram chunks, copying them blindly to a new output file is incorrect; such chunks should be dropped. The safe/unsafe property bit allows ancillary chunks to be marked appropriately.

Not all possible modification scenarios are covered by the safe/unsafe semantics. In particular, chunks that are dependent on the total file contents are not supported. (An example of such a chunk is an index of IDAT chunk locations within the file: adding a comment chunk would inadvertently break the index.) Definition of such chunks is discouraged. If absolutely necessary for a particular application, such chunks can be made critical chunks, with consequent loss of portability to other applications. In general, ancillary chunks can depend on critical chunks but not on other ancillary chunks. It is expected that mutually dependent information should be put into a single chunk.

In some situations it may be unavoidable to make one ancillary chunk dependent on another. Although the chunk property bits are insufficient to represent this case, a simple solution is available: in the dependent chunk, record the CRC of the chunk depended on. It can then be determined whether that chunk has been changed by some other program.

The same technique can be useful for other purposes. For example, if a program relies on the palette being in a particular order, it can store a private chunk containing the CRC of the PLTE chunk. If this value matches when the file is again read in, then it provides high confidence that the palette has not been tampered with. Note that it is not necessary to mark the private chunk unsafe-to-copy when this technique is used; thus, such a private chunk can survive other editing of the file.

12.15 Palette histograms

A viewer may not be able to provide as many colors as are listed in the image's palette. (For example, some colors could be reserved by a window system.) To produce the best results in this situation, it is helpful to have information about the frequency with which each palette index actually appears, in order to choose the best palette for dithering or to drop the least-used colors. Since images are often created once and viewed many times, it makes sense to calculate this information in the encoder, although it is not mandatory for the encoder to provide it.

Other image formats have usually addressed this problem by specifying that the palette entries should appear in order of frequency of use. That is an inferior solution, because it doesn't give the viewer nearly as much information: the viewer can't determine how much damage will be done by dropping the last few colors. Nor does a sorted palette give enough information to choose a target palette for dithering, in the case that the viewer needs to reduce the number of colors substantially. A palette histogram provides the information needed to choose such a target palette without making a pass over the image data.

13 Appendix: Gamma Tutorial

(This appendix is not part of the formal PNG specification.)

13.1 Nonlinear transfer functions

It would be convenient for graphics programmers if all of the components of an imaging system were linear. The voltage coming from an electronic camera would be directly proportional to the intensity (power) of light in the scene, the light emitted by a CRT would be directly proportional to its input voltage, and so on. However, real-world devices do not behave in this way. All CRT displays, almost all photographic film, and many electronic cameras have nonlinear signal-to-light-intensity or intensity-to-signal characteristics.

Fortunately, all of these nonlinear devices have a transfer function that is approximated fairly well by a single type of mathematical function: a power function. This power function has the general equation

$$\mathrm{output} = \mathrm{input}^{\mathrm{exponent}}$$

The exponent is often called "gamma" and denoted by the Greek letter gamma.

By convention, `input` and `output` are both scaled to the range 0 to 1, with 0 representing black and 1 representing maximum white (or red, etc). Normalized in this way, the power function is completely described by the exponent.

So, given a particular device, we can measure its output as a function of its input, fit a power function to this measured transfer function, and extract the exponent. People often say "this device has a gamma of 2.2" as a shorthand for "this device has a power-law response with an exponent of 2.2". People also talk about the gamma of a mathematical transform, or of a lookup table in a frame buffer, if its input and output are related by the power-law expression above.

But using the term "gamma" to refer to the exponents of transfer functions of many different stages in imaging pipelines has led to confusion. Therefore, this specification uses "gamma" to refer specifically to the function from display output to image samples, and simply uses "exponent" when referring to other functions.

13.2 Combining exponents

Real imaging systems will have several components, and more than one of these can be nonlinear. If all of the components have transfer characteristics that are power functions, then the transfer function of the entire system is also a power function. The exponent of the whole system's transfer function is just the product of all of the individual exponents of the separate stages in the system.

Also, stages that are linear pose no problem, since a power function with an exponent of 1.0 is really a linear function. So a linear transfer function is just a special case of a power function, with an exponent of 1.0.

Thus, as long as our imaging system contains only stages with linear and power-law transfer functions, we can meaningfully talk about the exponent of the entire system. This is indeed the case with most real imaging systems.

13.3 End-to-end exponent

If the end-to-end exponent of an imaging system is 1.0, its output is proportional to its input. This means that the ratio between the intensities of any two areas in the reproduced image will be the same as it was in the original scene. It might seem that this should always be the goal of an imaging system: to accurately reproduce the tones of the original scene. Alas, that is not the case.

One complication is that the response of the human visual system to low light levels is not a scaled-down version of its response to high light levels. Therefore, if the display device emits less intense light than entered the capture device (as is usually the case for television cameras and television sets, for example), an end-to-end linear response will not produce an image that appears correct. There are also other perceptual factors, like the affect of the ambient light level and the field of view surrounding the display, and physical factors, like reflectance of ambient light off the display.

Good end-to-end exponents are determined from experience. For example, for photographic prints it's about 1.0; for slides intended to be projected in a dark room it's about 1.5; for television it's about 1.14.

13.4 CRT exponent

All CRT displays have a power-law transfer characteristic with an exponent of about 2.2. This is mainly due to the physical processes involved in controlling the electron beam in the electron gun.

An exception to this rule is fancy "calibrated" CRTs that have internal electronics to alter their transfer function. If you have one of these, you probably should believe what the manufacturer tells you its exponent is. But in all other cases, assuming 2.2 is likely to be pretty accurate.

There are various images around that purport to measure a display system's exponent, usually by comparing the intensity of an area containing alternating white and black with a series of areas of continuous gray of different intensity. These are usually not reliable. Test images that use a "checkerboard" pattern of black and white are the worst, because a single white pixel will be reproduced considerably darker than a large area of white. An image that uses alternating black and white horizontal lines (such as the `gamma.png` test image at ftp://ftp.uu.net/graphics/png/images/suite/gamma.png) is much better, but even it may be inaccurate at high "picture" settings on some CRTs.

If you have a good photometer, you can measure the actual light output of a CRT as a function of input voltage and fit a power function to the measurements. However, note that this procedure is very sensitive to the CRT's black level adjustment, somewhat sensitive to its picture adjustment, and also affected by ambient light. Furthermore, CRTs spread some light from bright areas of an image into nearby darker areas; a single bright spot against a black background may be seen to have a "halo". Your measuring technique will need to minimize the effects of this.

Because of the difficulty of measuring the exponent, using either test images or measuring equipment, you're usually better off just assuming 2.2 rather than trying to measure it.

13.5 Gamma correction

A CRT has an exponent of 2.2, and we can't change that. To get an end-to-end exponent closer to 1, we need to have at least one other component of the "image pipeline" that is nonlinear. If, in fact, there is only one nonlinear stage in addition to the CRT, then it's traditional to say that the other nonlinear stage provides "gamma correction" to compensate for the CRT. However, exactly where the "correction" is done depends on circumstance.

In all broadcast video systems, gamma correction is done in the camera. This choice was made because it was more cost effective to place the expensive processing in the small number of capture devices (studio television cameras) than in the large number of broadcast receivers. The original NTSC video standard required cameras to have a transfer function with an exponent of 1/2.2, or about 0.45. Recently, a more complex two-part transfer function has been adopted [SMPTE-170M], but its behavior can be well approximated by a power function with an exponent of 0.52. When the resulting image is displayed on a CRT with an exponent of 2.2, the end-to-end exponent is about 1.14, which has been found to be appropriate for typical television studio conditions and television viewing conditions.

These days, video signals are often digitized and stored in computer frame buffers. The digital image is intended to be sent through a CRT, which has exponent 2.2, so the image has a gamma of 1/2.2.

Computer rendering programs often produce samples proportional to scene intensity. Suppose the desired end-to-end exponent is near 1, and the program would like to write its samples directly into the frame buffer. For correct display, the CRT output intensity must be nearly proportional to the sample values in the frame buffer. This can be done with a special hardware lookup table between the frame buffer and the CRT hardware. The lookup table (often called LUT) is loaded with a mapping that implements a power function with an exponent near 1/2.2, providing "gamma correction" for the CRT gamma.

Thus, gamma correction sometimes happens before the frame buffer, sometimes after. As long as images created on a particular platform are always displayed on that platform, everything is fine. But when people try to exchange images, differences in gamma correction conventions often result in images that seem far too bright and washed out, or far too dark and contrasty.

13.6 Benefits of gamma encoding

So, is it better to do gamma correction before or after the frame buffer?

In an ideal world, sample values would be stored as floating-point numbers, there would be lots of precision, and it wouldn't really matter much. But in reality, we're always trying to store images in as few bits as we can.

If we decide to use samples proportional to intensity, and do the gamma correction in the frame buffer LUT, it turns out that we need to use at least 12 bits for each of red, green, and blue to have enough precision in intensity. With any less than that, we will sometimes see "contour bands" or "Mach bands" in the darker areas of the image, where two adjacent sample values are still far enough apart in intensity for the difference to be visible.

However, through an interesting coincidence, the human eye's subjective perception of brightness is related to the physical stimulation of light intensity in a manner that is very much like the power function used for gamma correction. If we apply gamma correction to measured (or calculated) light intensity before quantizing to an integer for storage in a frame buffer, we can get away with using many fewer bits to store the image. In fact, 8 bits per color is almost always sufficient to avoid contouring artifacts. This is because, since gamma correction is so closely related to human perception, we are assigning our 256 available sample codes to intensity values in a manner that approximates how visible those intensity changes are to the eye. Compared to a linearly encoded image, we allocate fewer sample values to brighter parts of the tonal range and more sample values to the darker portions of the tonal range.

Thus, for the same apparent image quality, images using gamma-encoded sample values need only about two-thirds as many bits of storage as images using linearly encoded samples.

13.7 General gamma handling

When more than two nonlinear transfer functions are involved in the image pipeline, the term "gamma correction" becomes too vague. If we consider a pipeline that involves capturing (or calculating) an image, storing it in an image file, reading the file, and displaying the image on some sort of display screen, there are at least 5 places in the pipeline that could have nonlinear transfer functions. Let's give a specific name to each exponent:

camera exponent
: the exponent of the image sensor

encoding exponent
: the exponent of any transformation performed by the software writing the image file

decoding exponent
the exponent of any transformation performed by the software reading the image file

LUT exponent
the exponent of the frame buffer LUT, if present

CRT exponent
the exponent of the CRT, generally 2.2

In addition, let's add a few other names:

display exponent
the exponent of the "display system" downstream of the frame buffer

```
display_exponent = LUT_exponent * CRT_exponent
```

gamma
the exponent of the function mapping display output intensity to file samples

```
gamma = 1.0 / (decoding_exponent * display_exponent)
```

end-to-end exponent
the exponent of the function mapping image sensor input intensity to display output intensity, generally 1.0 to 1.5

When displaying an image file, the image decoding program is responsible for making gamma equal to the value specified in the gAMA chunk, by selecting the decoding exponent appropriately:

```
decoding_exponent = 1.0 / (gamma * display_exponent)
```

The display exponent might be known for this machine, or it might be obtained from the system software, or the user might have to be asked what it is.

13.8 Some specific examples

In digital video systems, the camera exponent is about 0.52 by declaration of the various video standards documents. The CRT exponent is 2.2 as usual, while the encoding exponent, decoding exponent, and LUT exponent are all 1.0. As a result, the end-to-end exponent is about 1.14.

On frame buffers that have hardware gamma correction tables, and that are calibrated to display samples that are proportional to display output intensity, the display exponent is 1.0.

Many workstations and X terminals and PC clones lack gamma correction lookup tables. Here, the LUT exponent is always 1.0, so the display exponent is 2.2.

On the Macintosh, there is a LUT. By default, it is loaded with a table whose exponent is 1/1.45, giving a display exponent (LUT and CRT combined) of about 1.52. Some Macs have a "Gamma" control panel with

selections labeled 1.0, 1.2, 1.4, 1.8, or 2.2. These settings load alternate LUTs, but beware: the selection labeled with the value g loads a LUT with exponent g/2.61, yielding

```
display_exponent = (g/2.61) * 2.2
```

On recent SGI systems, there is a hardware gamma-correction table whose contents are controlled by the (privileged) gamma program. The exponent of the table is actually the reciprocal of the number g that gamma prints. You can obtain g from the file /etc/config/system.glGammaVal and calculate

```
display_exponent = 2.2 / g
```

You will find SGI systems with g set to 1.0 and 2.2 (or higher), but the default when machines are shipped is 1.7.

On NeXT systems the LUT has exponent 1/2.2 by default, but it can be modified by third-party applications.

In summary, for images designed to need no correction on these platforms:

Platform	LUT exponent	Default LUT exponent	Default gAMA
PC clone	1.0	1.0	45455
Macintosh	g/2.61	1.8/2.61 = 1/1.45	65909
SGI	1/g	1/1.7	77273
NeXT	1/g	1/2.2	100000

The default gAMA values assume a CRT display.

13.9 Video camera transfer functions

The original NTSC video standards specified a simple power-law camera transfer function with an exponent of 1/2.2 (about 0.45). This is not possible to implement exactly in analog hardware because the function has infinite slope at x=0, so all cameras deviated to some degree from this ideal. More recently, a new camera transfer function that is physically realizable has been accepted as a standard [SMPTE-170M]. It is

```
if (Vin < 0.018)  Vout = 4.5 * Vin
if (Vin >= 0.018) Vout = 1.099 * (Vin^0.45) - 0.099
```

where Vin and Vout are measured on a scale of 0 to 1. Although the exponent remains 0.45, the multiplication and subtraction change the shape of the transfer function, so it is no longer a pure power function. It can be well approximated, however, by a power function with exponent 0.52.

The PAL and SECAM video standards specify a power-law camera transfer function with an exponent of 1/2.8 (about 0.36). However, this is too low in practice, so real cameras are likely to have exponents close to NTSC practice.

13.10 Further reading

Charles Poynton's "Gamma FAQ" [GAMMA-FAQ] is a excellent source of information about gamma, although it claims that CRTs have an exponent of 2.5. See also his book [DIGITAL-VIDEO].

14 Appendix: Color Tutorial

(This appendix is not part of the formal PNG specification.)

14.1 About chromaticity

The cHRM chunk is used, together with the gAMA chunk, to convey precise color information so that a PNG image can be displayed or printed with better color fidelity than is possible without this information. The preceding chapters state how this information is encoded in a PNG image. This tutorial briefly outlines the underlying color theory for those who might not be familiar with it.

Note that displaying an image with incorrect gamma will produce *much* larger color errors than failing to use the chromaticity data. First be sure the monitor set-up and gamma correction are right, then worry about chromaticity.

14.2 The problem of color

The color of an object depends not only on the precise spectrum of light emitted or reflected from it, but also on the observer—their species, what else they can see at the same time, even what they have recently looked at! Furthermore, two very different spectra can produce exactly the same color sensation. Color is not an objective property of real-world objects; it is a subjective, biological sensation. However, by making some simplifying assumptions (such as: we are talking about *human* vision) it is possible to produce a mathematical model of color and thereby obtain good color accuracy.

14.3 Device-dependent color

Display the same RGB data on three different monitors, side by side, and you will get a noticeably different color balance on each display. This is because each monitor emits a slightly different shade and intensity of red, green, and blue light. RGB is an example of a *device-dependent color model*—the color you get depends on the device. This also means that a particular color—represented as say RGB 87, 146, 116 on one monitor—might have to be specified as RGB 98, 123, 104 on another to produce the *same* color.

14.4 Device-independent color

A full physical description of a color would require specifying the exact spectral power distribution of the light source. Fortunately, the human eye and brain are not so sensitive as to require exact reproduction of a spectrum. Mathematical, device-independent color models exist that describe fairly well how a particular color will be seen by humans. The most important device-independent color model, to which all others can be related, was developed by the International Commission on Illumination (CIE, in French) and is called "CIE XYZ" or simply "XYZ".

In XYZ, X is the sum of a weighted power distribution over the whole visible spectrum. So are Y and Z, each with different weights. Thus any arbitrary spectral power distribution is condensed down to just three floating-point numbers. The weights were derived from color matching experiments done on human subjects in the 1920s. CIE XYZ has been an International Standard since 1931, and it has a number of useful properties:

- two colors with the same XYZ values will look the same to humans
- two colors with different XYZ values will not look the same
- the Y value represents all the brightness information (luminance)
- the XYZ color of any object can be objectively measured

Color models based on XYZ have been used for many years by people who need accurate control of color—lighting engineers for film and TV, paint and dyestuffs manufacturers, and so on. They are thus proven in industrial use. Accurate, device-independent color started to spread from high-end, specialized areas into the mainstream during the late 1980s and early 1990s, and PNG takes notice of that trend.

14.5 Calibrated device-dependent color

Traditionally, image file formats have used uncalibrated, device-dependent color. If the precise details of the original display device are known, it becomes possible to convert the device-dependent colors of a particular image to device-independent ones. Making simplifying assumptions, such as working with CRTs (which are much easier than printers), all we need to know are the XYZ values of each primary color and the CRT exponent.

So why does PNG not store images in XYZ instead of RGB? Well, two reasons. First, storing images in XYZ would require more bits of precision, which would make the files bigger. Second, all programs would have to convert the image data before viewing it. Whether calibrated or not, all variants of RGB are close enough that undemanding viewers can get by with simply displaying the data without color correction. By storing calibrated RGB, PNG retains compatibility with existing programs that expect RGB data, yet provides enough information for conversion to XYZ in applications that need precise colors. Thus, we get the best of both worlds.

14.6 Chromaticity and luminance

Chromaticity is an objective measurement of the color of an object, leaving aside the brightness information. Chromaticity uses two parameters x and y, which are readily calculated from XYZ:

```
x = X / (X + Y + Z)
y = Y / (X + Y + Z)
```

XYZ colors having the same chromaticity values will appear to have the same hue but can vary in absolute brightness. Notice that x,y are dimensionless ratios, so they have the same values no matter what units we've used for X,Y,Z.

The Y value of an XYZ color is directly proportional to its absolute brightness and is called the luminance of the color. We can describe a color either by XYZ coordinates or by chromaticity x,y plus luminance Y. The XYZ form has the advantage that it is linearly related to RGB intensities.

14.7 Characterizing computer monitors

The "white point" of a monitor is the chromaticity x,y of the monitor's nominal white, that is, the color produced when R=G=B=maximum.

It's customary to specify monitor colors by giving the chromaticities of the individual phosphors R, G, and B, plus the white point. The white point allows one to infer the relative brightnesses of the three phosphors, which isn't determined by their chromaticities alone.

Note that the absolute brightness of the monitor is not specified. For computer graphics work, we generally don't care very much about absolute brightness levels. Instead of dealing with absolute XYZ values (in which X,Y,Z are expressed in physical units of radiated power, such as candelas per square meter), it is convenient to work in "relative XYZ" units, where the monitor's nominal white is taken to have a luminance (Y) of 1.0. Given this assumption, it's simple to compute XYZ coordinates for the monitor's white, red, green, and blue from their chromaticity values.

Why does cHRM use x,y rather than XYZ? Simply because that is how manufacturers print the information in their spec sheets! Usually, the first thing a program will do is convert the cHRM chromaticities into relative XYZ space.

14.8 Uses for XYZ

If a PNG file has the gAMA and cHRM chunks, the source RGB values can be converted to XYZ. This lets you:

- do accurate grayscale conversion (just use the Y component)
- convert to RGB for your own monitor (to see the original colors)

- print the image in Level 2 PostScript with better color fidelity than a simple RGB to CMYK conversion could provide
- calculate an optimal color palette
- pass the image data to a color management system
- etc.

14.9 Converting between RGB and XYZ

Make a few simplifying assumptions first, like the monitor really is jet black with no input and the guns don't interfere with one another. Then, given that you know the CIE XYZ values for each of red, green, and blue for a particular monitor, you put them into a matrix `M`:

```
      Xr Xg Xb
M =   Yr Yg Yb
      Zr Zg Zb
```

RGB intensity samples normalized to the range 0 to 1 can be converted to XYZ by matrix multiplication. (If you have gamma-encoded RGB samples, first undo the gamma encoding.)

```
X      R
Y = M  G
Z      B
```

In other words, `X = Xr*R + Xg*G + Xb*B`, and similarly for `Y` and `Z`. You can go the other way too:

```
R         X
G = invM  Y
B         Z
```

where `invM` is the inverse of the matrix `M`.

14.10 Device gamut

The gamut of a device is the subset of visible colors that the device can display. (It has nothing to do with *gamma*.) The gamut of an RGB device can be visualized as a polyhedron in XYZ space; the vertices correspond to the device's black, blue, red, green, magenta, cyan, yellow, and white.

Different devices have different gamuts, in other words one device will be able to display certain colors (usually highly saturated ones) that another device cannot. The gamut of a particular RGB device can be determined from its R, G, and B chromaticities and white point (the same values given in the cHRM chunk). The gamut of a color printer is more complex and can be determined only by measurement. However, printer

gamuts are typically smaller than monitor gamuts, meaning that there can be many colors in a displayable image that cannot physically be printed.

Converting image data from one device to another generally results in gamut mismatches—colors that cannot be represented exactly on the destination device. The process of making the colors fit, which can range from a simple clip to elaborate nonlinear scaling transformations, is termed gamut mapping. The aim is to produce a reasonable visual representation of the original image.

Further reading

14.11 Further reading

References [COLOR-1] through [COLOR-5] provide more detail about color theory.

15 Appendix: Sample CRC Code

The following sample code represents a practical implementation of the CRC (Cyclic Redundancy Check) employed in PNG chunks. (See also ISO 3309 [ISO-3309] or ITU-T V.42 [ITU-T-V42] for a formal specification.)

The sample code is in the ANSI C programming language. Non C users may find it easier to read with these hints:

&
: Bitwise AND operator.

^
: Bitwise exclusive-OR operator.

>>
: Bitwise right shift operator. When applied to an unsigned quantity, as here, right shift inserts zeroes at the left.

!
: Logical NOT operator.

++
: `N++` increments the variable `N`.

0xNNN
: `0x` introduces a hexadecimal (base 16) constant. Suffix `L` indicates a long value (at least 32 bits).

```
/* Table of CRCs of all 8-bit messages. */
unsigned long crc_table[256];

/* Flag: has the table been computed? Initially false. */
int crc_table_computed = 0;

/* Make the table for a fast CRC. */
void make_crc_table(void)
{
  unsigned long c;
  int n, k;

  for (n = 0; n < 256; n++) {
    c = (unsigned long) n;
    for (k = 0; k < 8; k++) {
      if (c & 1)
        c = 0xedb88320L ^ (c >> 1);
      else
        c = c >> 1;
    }
    crc_table[n] = c;
  }
  crc_table_computed = 1;
}

/* Update a running CRC with the bytes buf[0..len-1]--the CRC
   should be initialized to all 1's, and the transmitted value
   is the 1's complement of the final running CRC (see the
   crc() routine below)). */

unsigned long update_crc(unsigned long crc, unsigned char *buf,
                         int len)
{
  unsigned long c = crc;
  int n;

  if (!crc_table_computed)
    make_crc_table();
  for (n = 0; n < len; n++) {
    c = crc_table[(c ^ buf[n]) & 0xff] ^ (c >> 8);
  }
  return c;
}

/* Return the CRC of the bytes buf[0..len-1]. */
unsigned long crc(unsigned char *buf, int len)
{
  return update_crc(0xffffffffL, buf, len) ^ 0xffffffffL;
}
```

16 Appendix: Online Resources

(This appendix is not part of the formal PNG specification.)

This appendix gives the locations of some Internet resources for PNG software developers. By the nature of the Internet, the list is incomplete and subject to change.

Archive sites

The latest released versions of this document and related information can always be found at the PNG FTP archive site, ftp://ftp.uu.net/graphics/png/. The PNG specification is available in several formats, including HTML, plain text, and PostScript.

Reference implementation and test images

A reference implementation in portable C is available from the PNG FTP archive site, ftp://ftp.uu.net/graphics/png/src/. The reference implementation (libpng) is freely usable in all applications, including commercial applications.

Test images are available from ftp://ftp.uu.net/graphics/png/images/.

Electronic mail

The maintainers of the PNG specification can be contacted by e-mail at png-info@uunet.uu.net or at png-group@w3.org.

PNG web site

There is a World Wide Web site for PNG at http://www.cdrom.com/pub/png/. This is a central location for current information about PNG and PNG-related tools.

17 Appendix: Revision History

(This appendix is not part of the formal PNG specification.)

The PNG format has been frozen since the Ninth Draft of 7 March 1995, and all future changes are intended to be backward compatible. The revisions since the Ninth Draft are simply clarifications, improvements in presentation, additions of supporting material, and specifications for additional chunks.

On 1 October 1996, the PNG 1.0 specification was approved as a W3C (World Wide Web Consortium) Recommendation.

In January 1997 it was published as RFC-2083 (informational) with technical content identical to that of the W3C Recommendation.

In October 1998, the PNG 1.1 specification was approved by the PNG Development Group, and it was released in December 1998.

In February 1999, changes were approved by the PNG Development Group, and the PNG 1.2 specification containing the changes was released in July 1999.

Changes since version 1.1

Note: These changes have been approved by the PNG Development Group, but not by any standards body.

- Added the iTXt chunk
- Rearranged the order of presentation of ancillary chunks.
- Updated the authors' email addresses

Changes since version 1.0

(W3C Recommendation 01-October-1996, RFC 2083 January 1997)

Note: These changes have been approved by the PNG Development Group, but not by any standards body.

- Redefined gAMA to be in terms of the desired display output rather than the original scene, and revised all discussions of gamma and references to gamma accordingly
- Added the iCCP, sPLT, and sRGB chunks
- Extended the scope of the 31-bit limit on chunk lengths and image dimensions to apply to all four-byte unsigned integers, and disallowed the value -2^{31} in four-byte signed integers
- Mentioned the possibility of dithering the alpha channel when converting it to binary transparency
- Clarified that zlib window sizes smaller than 32K are valid
- Updated the PNG web site URL and authors' email addresses
- Editing and reformatting

Changes since the Tenth Draft of 5 May 1995

- Clarified meaning of a suggested-palette PLTE chunk in a truecolor image that uses transparency
- Clarified exact semantics of sBIT and allowed sample depth scaling procedures
- Clarified status of spaces in text chunk keywords

- Distinguished private and public extension values in type and method fields
- Added a "Creation Time" text keyword
- Macintosh representation of PNG specified
- Added discussion of security issues
- Added more extensive discussion of gamma and chromaticity handling, including tutorial appendixes
- Clarified terminology, notably sample depth vs. bit depth
- Added a glossary
- Editing and reformatting

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