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Brotli Compressed Data Format

Abstract

This specification defines a lossless compressed data format that compresses data using a combination of the LZ77 algorithm and Huffman coding, with efficiency comparable to the best currently available general-purpose compression methods.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for informational purposes.

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1. Introduction

1.1. Purpose

The purpose of this specification is to define a lossless compressed data format that:

* is independent of CPU type, operating system, file system, and character set; hence, it can be used for interchange.

* can be produced or consumed, even for an arbitrarily long, sequentially presented input data stream, using only an a priori bounded amount of intermediate storage; hence, it can be used in data communications or similar structures, such as Unix filters.

* compresses data with a compression ratio comparable to the best currently available general-purpose compression methods, in particular, considerably better than the gzip program.

* decompresses much faster than current LZMA implementations.

The data format defined by this specification does not attempt to:

* allow random access to compressed data.

* compress specialized data (e.g., raster graphics) as densely as the best currently available specialized algorithms.

This document is the authoritative specification of the brotli compressed data format. It defines the set of valid brotli compressed data streams and a decoder algorithm that produces the uncompressed data stream from a valid brotli compressed data stream.

1.2. Intended Audience

This specification is intended for use by software implementers to compress data into and/or decompress data from the brotli format.

The text of the specification assumes a basic background in programming at the level of bits and other primitive data representations. Familiarity with the technique of Huffman coding is helpful but not required.

This specification uses (heavily) the notations and terminology introduced in the DEFLATE format specification [RFC1951]. For the sake of completeness, we always include the whole text of the relevant parts of RFC 1951; therefore, familiarity with the DEFLATE format is helpful but not required.

The compressed data format defined in this specification is an integral part of the WOFF File Format 2.0 [WOFF2]; therefore, this specification is also intended for implementers of WOFF 2.0 compressors and decompressors.

1.3. Scope

This document specifies a method for representing a sequence of bytes as a (usually shorter) sequence of bits and a method for packing the latter bit sequence into bytes.

1.4. Compliance

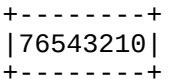
Unless otherwise indicated below, a compliant decompressor must be able to accept and decompress any data set that conforms to all the specifications presented here. A compliant compressor must produce data sets that conform to all the specifications presented here.

1.5. Definitions of Terms and Conventions Used

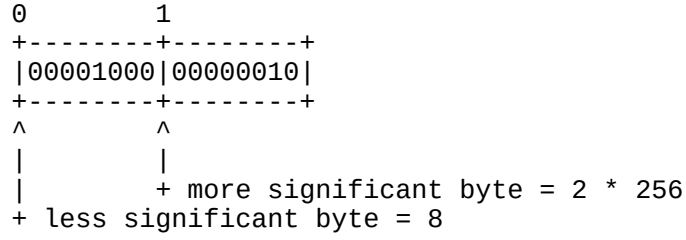
Byte: 8 bits stored or transmitted as a unit (same as an octet). For this specification, a byte is exactly 8 bits, even on machines that store a character on a number of bits different from eight. See below for the numbering of bits within a byte.

String: a sequence of arbitrary bytes.

Bytes stored within a computer do not have a "bit order", since they are always treated as a unit. However, a byte considered as an integer between 0 and 255 does have a most and least significant bit (lsb), and since we write numbers with the most significant digit on the left, we also write bytes with the most significant bit (msb) on the left. In the diagrams below, we number the bits of a byte so that bit 0 is the least significant bit, i.e., the bits are numbered:



Within a computer, a number may occupy multiple bytes. All multi-byte numbers in the format described here are stored with the least significant byte first (at the lower memory address). For example, the decimal number 520 is stored as:



1.5.1. Packing into Bytes

This document does not address the issue of the order in which bits of a byte are transmitted on a bit-sequential medium, since the final data format described here is byte rather than bit oriented. However, we describe the compressed block format below as a sequence of data elements of various bit lengths, not a sequence of bytes. Therefore, we must specify how to pack these data elements into bytes to form the final compressed byte sequence:

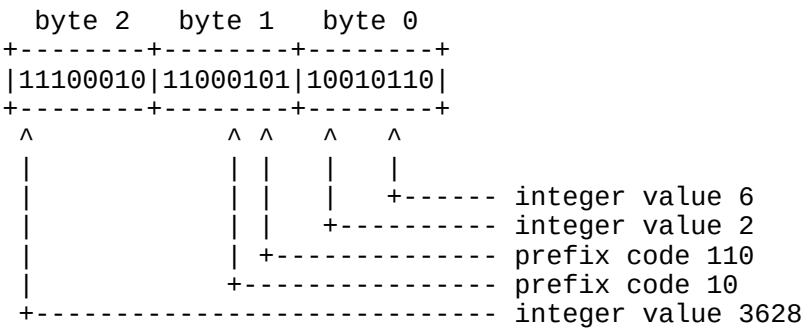
* Data elements are packed into bytes in order of increasing bit number within the byte, i.e., starting with the least significant bit of the byte.

* Data elements other than prefix codes are packed starting with the least significant bit of the data element. These are referred to here as "integer values" and are considered unsigned.

* Prefix codes are packed starting with the most significant bit of the code.

In other words, if one were to print out the compressed data as a sequence of bytes, starting with the first byte at the *right* margin and proceeding to the *left*, with the most significant bit of each byte on the left as usual, one would be able to parse the result from right to left, with fixed-width elements in the correct msb-to-lsb order and prefix codes in bit-reversed order (i.e., with the first bit of the code in the relative lsb position).

As an example, consider packing the following data elements into a sequence of 3 bytes: 3-bit integer value 6, 4-bit integer value 2, prefix code 110, prefix code 10, 12-bit integer value 3628.



2. Compressed Representation Overview

A compressed data set consists of a header and a series of meta-blocks. Each meta-block decompresses to a sequence of 0 to 16,777,216 (16 MiB) uncompressed bytes. The final uncompressed data is the concatenation of the uncompressed sequences from each meta-block.

The header contains the size of the sliding window that was used during compression. The decompressor must retain at least that amount of uncompressed data prior to the current position in the stream, in order to be able to decompress what follows. The sliding window size is a power of two, minus 16, where the power is in the range of 10 to 24. The possible sliding window sizes range from 1 KiB - 16 B to 16 MiB - 16 B.

Each meta-block is compressed using a combination of the LZ77 algorithm (Lempel-Ziv 1977, [LZ77]) and Huffman coding. The result of Huffman coding is referred to here as a "prefix code". The prefix codes for each meta-block are independent of those for previous or subsequent meta-blocks; the LZ77 algorithm may use a reference to a duplicated string occurring in a previous meta-block, up to the sliding window size of uncompressed bytes before. In addition, in the brotli format, a string reference may instead refer to a static dictionary entry.

Each meta-block consists of two parts: a meta-block header that describes the representation of the compressed data part and a compressed data part. The compressed data consists of a series of commands. Each command consists of two parts: a sequence of literal bytes (of strings that have not been detected as duplicated within the sliding window) and a pointer to a duplicated string, which is represented as a pair <length, backward distance>. There can be zero literal bytes in the command. The minimum length of the string to be

duplicated is two, but the last command in the meta-block is permitted to have only literals and no pointer to a string to duplicate.

Each command in the compressed data is represented using three categories of prefix codes:

1) One set of prefix codes are for the literal sequence lengths (also referred to as literal insertion lengths) and backward copy lengths. That is, a single code word represents two lengths: one of the literal sequence and one of the backward copy.

2) One set of prefix codes are for literals.

3) One set of prefix codes are for distances.

The prefix code descriptions for each meta-block appear in a compact form just before the compressed data in the meta-block header. The insert-and-copy length and distance prefix codes may be followed by extra bits that are added to the base values determined by the codes. The number of extra bits is determined by the code.

One meta-block command then appears as a sequence of prefix codes:

Insert-and-copy length, literal, literal, ..., literal, distance

where the insert-and-copy length defines an insertion length and a copy length. The insertion length determines the number of literals that immediately follow. The distance defines how far back to go for the copy and the copy length determines the number of bytes to copy. The resulting uncompressed data is the sequence of bytes:

literal, literal, ..., literal, copy, copy, ..., copy

where the number of literal bytes and copy bytes are determined by the insert-and-copy length code. (The number of bytes copied for a static dictionary entry can vary from the copy length.)

The last command in the meta-block may end with the last literal if the total uncompressed length of the meta-block has been satisfied. In that case, there is no distance in the last command, and the copy length is ignored.

There can be more than one prefix code for each category, where the prefix code to use for the next element of that category is determined by the context of the compressed stream that precedes that element. Part of that context is three current block types, one for

each category. A block type is in the range of 0..255. For each category there is a count of how many elements of that category remain to be decoded using the current block type. Once that count is expended, a new block type and block count is read from the stream immediately preceding the next element of that category, which will use the new block type.

The insert-and-copy block type directly determines which prefix code to use for the next insert-and-copy length. For the literal and distance elements, the respective block type is used in combination with other context information to determine which prefix code to use for the next element.

Consider the following example:

```
(IaC0, L0, L1, L2, D0)(IaC1, D1)(IaC2, L3, L4, D2)(IaC3, L5, D3)
```

The meta-block here has four commands, contained in parentheses for clarity, where each of the three categories of symbols within these commands can be interpreted using different block types. Here we separate out each category as its own sequence to show an example of block types assigned to those elements. Each square-bracketed group is a block that uses the same block type:

```
[IaC0, IaC1][IaC2, IaC3]  <-- insert-and-copy: block types 0 and 1

[L0, L1][L2, L3, L4][L5]  <-- literals: block types 0, 1, and 0

[D0][D1, D2, D3]          <-- distances: block types 0 and 1
```

The subsequent blocks within each block category must have different block types, but we see that block types can be reused later in the meta-block. The block types are numbered from 0 to the maximum block type number of 255, and the first block of each block category is type 0. The block structure of a meta-block is represented by the sequence of block-switch commands for each block category, where a block-switch command is a pair <block type, block count>. The block-switch commands are represented in the compressed data before the start of each new block using a prefix code for block types and a separate prefix code for block counts for each block category. For the above example, the physical layout of the meta-block is then:

```
IaC0 L0 L1 LBlockSwitch(1, 3) L2 D0 IaC1 DBlockSwitch(1, 3) D1
IaCBlockSwitch(1, 2) IaC2 L3 L4 D2 IaC3 LBlockSwitch(0, 1) L5 D3
```

where xBlockSwitch(t, n) switches to block type t for a count of n elements. In this example, note that DBlockSwitch(1, 3) immediately precedes the next required distance, D1. It does not follow the last

distance of the previous block, D0. Whenever an element of a category is needed, and the block count for that category has reached zero, then a new block type and count are read from the stream just before reading that next element.

The block-switch commands for the first blocks of each category are not part of the meta-block compressed data. Instead, the first block type is defined to be 0, and the first block count for each category is encoded in the meta-block header. The prefix codes for the block types and counts, a total of six prefix codes over the three categories, are defined in a compact form in the meta-block header.

Each category of value (insert-and-copy lengths, literals, and distances) can be encoded with any prefix code from a collection of prefix codes belonging to the same category appearing in the meta-block header. The particular prefix code used can depend on two factors: the block type of the block the value appears in and the context of the value. In the case of the literals, the context is the previous two bytes in the uncompressed data; and in the case of distances, the context is the copy length from the same command. For insert-and-copy lengths, no context is used and the prefix code depends only on the block type. In the case of literals and distances, the context is mapped to a context ID in the range 0..63 for literals and 0..3 for distances. The matrix of the prefix code indexes for each block type and context ID, called the context map, is encoded in a compact form in the meta-block header.

For example, the prefix code to use to decode L2 depends on the block type (1), and the literal context ID determined by the two uncompressed bytes that were decoded from L0 and L1. Similarly, the prefix code to use to decode D0 depends on the block type (0) and the distance context ID determined by the copy length decoded from IaC0. The prefix code to use to decode IaC3 depends only on the block type (1).

In addition to the parts listed above (prefix code for insert-and-copy lengths, literals, distances, block types, block counts, and the context map), the meta-block header contains the number of uncompressed bytes coded in the meta-block and two additional parameters used in the representation of match distances: the number of postfix bits and the number of direct distance codes.

A compressed meta-block may be marked in the header as the last meta-block, which terminates the compressed stream.

A meta-block may, instead, simply store the uncompressed data directly as bytes on byte boundaries with no coding or matching strings. In this case, the meta-block header information only

contains the number of uncompressed bytes and the indication that the meta-block is uncompressed. An uncompressed meta-block cannot be the last meta-block.

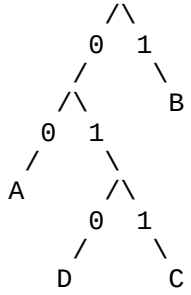
A meta-block may also be empty, which generates no uncompressed data at all. An empty meta-block may contain metadata information as bytes starting on byte boundaries, which are not part of either the sliding window or the uncompressed data. Thus, these metadata bytes cannot be used to create matching strings in subsequent meta-blocks and are not used as context bytes for literals.

3. Compressed Representation of Prefix Codes

3.1. Introduction to Prefix Coding

Prefix coding represents symbols from an a priori known alphabet by bit sequences (codes), one code for each symbol, in a manner such that different symbols may be represented by bit sequences of different lengths, but a parser can always parse an encoded string unambiguously symbol-by-symbol.

We define a prefix code in terms of a binary tree in which the two edges descending from each non-leaf node are labeled 0 and 1, and in which the leaf nodes correspond one-for-one with (are labeled with) the symbols of the alphabet. The code for a symbol is the sequence of 0's and 1's on the edges leading from the root to the leaf labeled with that symbol. For example:



Symbol	Code
A	00
B	1
C	011
D	010

A parser can decode the next symbol from the compressed stream by walking down the tree from the root, at each step choosing the edge corresponding to the next compressed data bit.

Given an alphabet with known symbol frequencies, the Huffman algorithm allows the construction of an optimal prefix code (one that represents strings with those symbol frequencies using the fewest

bits of any possible prefix codes for that alphabet). Such a prefix code is called a Huffman code. (See [HUFFMAN] for additional information on Huffman codes.)

In the brotli format, note that the prefix codes for the various alphabets must not exceed certain maximum code lengths. This constraint complicates the algorithm for computing code lengths from symbol frequencies. Again, see [HUFFMAN] for details.

3.2. Use of Prefix Coding in the Brotli Format

The prefix codes used for each alphabet in the brotli format are canonical prefix codes, which have two additional rules:

* All codes of a given bit length have lexicographically consecutive values, in the same order as the symbols they represent;

* Shorter codes lexicographically precede longer codes.

We could recode the example above to follow this rule as follows, assuming that the order of the alphabet is ABCD:

Symbol	Code
A	10
B	0
C	110
D	111

That is, 0 precedes 10, which precedes 11x, and 110 and 111 are lexicographically consecutive.

Given this rule, we can define the canonical prefix code for an alphabet just by giving the bit lengths of the codes for each symbol of the alphabet in order; this is sufficient to determine the actual codes. In our example, the code is completely defined by the sequence of bit lengths (2, 1, 3, 3). The following algorithm generates the codes as integers, intended to be read from most to least significant bit. The code lengths are initially in tree[I].Len; the codes are produced in tree[I].Code.

1) Count the number of codes for each code length. Let bl_count[N] be the number of codes of length N, N >= 1.

2) Find the numerical value of the smallest code for each code length:

```
code = 0;
bl_count[0] = 0;
for (bits = 1; bits <= MAX_BITS; bits++) {
   code = (code + bl_count[bits-1]) << 1;
   next_code[bits] = code;
}
```

3) Assign numerical values to all codes, using consecutive values for all codes of the same length with the base values determined at step 2. Codes that are never used (which have a bit length of zero) must not be assigned a value.

```
for (n = 0; n <= max_code; n++) {
   len = tree[n].Len;
   if (len != 0) {
      tree[n].Code = next_code[len];
      next_code[len]++;
   }
}
```

Example:

Consider the alphabet ABCDEFGH, with bit lengths (3, 3, 3, 3, 3, 2, 4, 4). After step 1, we have:

N	bl_count[N]
2	1
3	5
4	2

Step 2 computes the following next_code values:

N	next_code[N]
1	0
2	0
3	2
4	14

Step 3 produces the following code values:

Symbol	Length	Code
A	3	010
B	3	011
C	3	100
D	3	101
E	3	110
F	2	00
G	4	1110
H	4	1111

3.3. Alphabet Sizes

Prefix codes are used for different purposes in the brotli format, and each purpose has a different alphabet size. For literal codes, the alphabet size is 256. For insert-and-copy length codes, the alphabet size is 704. For block count codes, the alphabet size is 26. For distance codes, block type codes, and the prefix codes used in compressing the context map, the alphabet size is dynamic and is based on parameters defined in later sections. The following table summarizes the alphabet sizes for the various prefix codes and the sections of this document in which they are defined.

Prefix Code	Alphabet Size	Definition
literal	256	
distance	16 + NDIRECT + (48 << NPOSTFIX)	Section 4
insert-and-copy length	704	Section 5
block count	26	Section 6
block type	NBLTYPESx + 2, (where x is I, L, or D)	Section 6
context map	NTREESx + RLEMAXx (where x is L or D)	Section 7

3.4. Simple Prefix Codes

The first two bits of the compressed representation of each prefix code distinguish between simple and complex prefix codes. If this value is 1, then a simple prefix code follows as described in this section. Otherwise, a complex prefix code follows as described in Section 3.5.

A simple prefix code can have up to four symbols with non-zero code length. The format of the simple prefix code is as follows:

```
2 bits: value of 1 indicates a simple prefix code
2 bits: NSYM - 1, where NSYM = number of symbols coded

NSYM symbols, each encoded using ALPHABET_BITS bits

1 bit:  tree-select, present only for NSYM = 4
```

The value of ALPHABET_BITS depends on the alphabet of the prefix code: it is the smallest number of bits that can represent all symbols in the alphabet. For example, for the alphabet of literal bytes, ALPHABET_BITS is 8. The value of each of the NSYM symbols above is the value of the ALPHABET_BITS width integer value. If the integer value is greater than or equal to the alphabet size, or the value is identical to a previous value, then the stream should be rejected as invalid.

Note that the NSYM symbols may not be presented in sorted order. Prefix codes of the same bit length must be assigned to the symbols in sorted order.

The (non-zero) code lengths of the symbols can be reconstructed as follows:

* if NSYM = 1, the code length for the one symbol is zero -- when encoding this symbol in the compressed data stream using this prefix code, no actual bits are emitted. Similarly, when decoding a symbol using this prefix code, no bits are read and the one symbol is returned.

* if NSYM = 2, both symbols have code length 1.

* if NSYM = 3, the code lengths for the symbols are 1, 2, 2 in the order they appear in the representation of the simple prefix code.

* if NSYM = 4, the code lengths (in order of symbols decoded) depend on the tree-select bit: 2, 2, 2, 2 (tree-select bit 0), or 1, 2, 3, 3 (tree-select bit 1).

3.5. Complex Prefix Codes

A complex prefix code is a canonical prefix code, defined by the sequence of code lengths, as discussed in Section 3.2. For even greater compactness, the code length sequences themselves are compressed using a prefix code. The alphabet for code lengths is as follows:

```
 0..15: Represent code lengths of 0..15
    16: Copy the previous non-zero code length 3..6 times.
        The next 2 bits indicate repeat length
              (0 = 3, ... , 3 = 6)
        If this is the first code length, or all previous
        code lengths are zero, a code length of 8 is
        repeated 3..6 times.
        A repeated code length code of 16 modifies the
        repeat count of the previous one as follows:
           repeat count = (4 * (repeat count - 2)) +
                          (3..6 on the next 2 bits)
        Example:  Codes 7, 16 (+2 bits 11), 16 (+2 bits 10)
                  will expand to 22 code lengths of 7
                  (1 + 4 * (6 - 2) + 5)
    17: Repeat a code length of 0 for 3..10 times.
        The next 3 bits indicate repeat length
              (0 = 3, ... , 7 = 10)
        A repeated code length code of 17 modifies the
        repeat count of the previous one as follows:
           repeat count = (8 * (repeat count - 2)) +
                          (3..10 on the next 3 bits)
```

Note that a code of 16 that follows an immediately preceding 16 modifies the previous repeat count, which becomes the new repeat count. The same is true for a 17 following a 17. A sequence of three or more 16 codes in a row or three of more 17 codes in a row is possible, modifying the count each time. Only the final repeat count is used. The modification only applies if the same code follows. A 16 repeat does not modify an immediately preceding 17 count nor vice versa.

A code length of 0 indicates that the corresponding symbol in the alphabet will not occur in the compressed data, and it should not participate in the prefix code construction algorithm given earlier. A complex prefix code must have at least two non-zero code lengths.

The bit lengths of the prefix code over the code length alphabet are compressed with the following variable-length code (as it appears in the compressed data, where the bits are parsed from right to left):

Symbol	Code
0	00
1	0111
2	011
3	10
4	01
5	1111

We can now define the format of the complex prefix code as follows:

- 2 bits: HSKIP, the number of skipped code lengths, can have values of 0, 2, or 3. The skipped lengths are taken to be zero. (An HSKIP of 1 indicates a Simple prefix code.)

- Code lengths for symbols in the code length alphabet given just above, in the order: 1, 2, 3, 4, 0, 5, 17, 6, 16, 7, 8, 9, 10, 11, 12, 13, 14, 15. If HSKIP is 2, then the code lengths for symbols 1 and 2 are zero, and the first code length is for symbol 3. If HSKIP is 3, then the code length for symbol 3 is also zero, and the first code length is for symbol 4.

  The code lengths of code length symbols are between 0 and 5, and they are represented with 2..4 bits according to the variable-length code above. A code length of 0 means the corresponding code length symbol is not used.

  If HSKIP is 2 or 3, a respective number of leading code lengths are implicit zeros and are not present in the code length sequence above.

  If there are at least two non-zero code lengths, any trailing zero code lengths are omitted, i.e., the last code length in the sequence must be non-zero. In this case, the sum of (32 >> code length) over all the non-zero code lengths must equal to 32.

  If the lengths have been read for the entire code length alphabet and there was only one non-zero code length, then the prefix code has one symbol whose code has zero length. In this case, that symbol results in no bits being emitted by the compressor and no bits consumed by the decompressor. That single symbol is immediately returned when this code is decoded. An example of where this occurs is if the entire code to be represented has symbols of length 8. For example, a literal code that represents

all literal values with equal probability. In this case the single symbol is 16, which repeats the previous length. The previous length is taken to be 8 before any code length code lengths are read.

- Sequence of code length symbols, which is at most the size of the alphabet, encoded using the code length prefix code. Any trailing 0 or 17 must be omitted, i.e., the last encoded code length symbol must be between 1 and 16. The sum of (32768 >> code length) over all the non-zero code lengths in the alphabet, including those encoded using repeat code(s) of 16, must be equal to 32768. If the number of times to repeat the previous length or repeat a zero length would result in more lengths in total than the number of symbols in the alphabet, then the stream should be rejected as invalid.

4. Encoding of Distances

As described in Section 2, one component of a compressed meta-block is a sequence of backward distances. In this section, we provide the details to the encoding of distances.

Each distance in the compressed data part of a meta-block is represented with a pair <distance code, extra bits>. The distance code and the extra bits are encoded back-to-back, the distance code is encoded using a prefix code over the distance alphabet, while the extra bits value is encoded as a fixed-width integer value. The number of extra bits can be 0..24, and it is dependent on the distance code.

To convert a distance code and associated extra bits to a backward distance, we need the sequence of past distances and two additional parameters: the number of "postfix bits", denoted by NPOSTFIX (0..3), and the number of direct distance codes, denoted by NDIRECT (0..120). Both of these parameters are encoded in the meta-block header. We will also use the following derived parameter:

```
POSTFIX_MASK = (1 << NPOSTFIX) - 1
```

The first 16 distance symbols are special symbols that reference past distances as follows:

```
   0: last distance
   1: second-to-last distance
   2: third-to-last distance
   3: fourth-to-last distance
   4: last distance - 1
   5: last distance + 1
   6: last distance - 2
   7: last distance + 2
   8: last distance - 3
   9: last distance + 3
  10: second-to-last distance - 1
  11: second-to-last distance + 1
  12: second-to-last distance - 2
  13: second-to-last distance + 2
  14: second-to-last distance - 3
  15: second-to-last distance + 3
```

The ring buffer of the four last distances is initialized by the values 16, 15, 11, and 4 (i.e., the fourth-to-last is set to 16, the third-to-last to 15, the second-to-last to 11, and the last distance to 4) at the beginning of the *stream* (as opposed to the beginning of the meta-block), and it is not reset at meta-block boundaries. When a distance symbol 0 appears, the distance it represents (i.e., the last distance in the sequence of distances) is not pushed to the ring buffer of last distances; in other words, the expression "second-to-last distance" means the second-to-last distance that was not represented by a 0 distance symbol (and similar for "third-to-last distance" and "fourth-to-last distance"). Similarly, distances that represent static dictionary words (see Section 8) are not pushed to the ring buffer of last distances.

If a special distance symbol resolves to a zero or negative value, the stream should be rejected as invalid.

If NDIRECT is greater than zero, then the next NDIRECT distance symbols, from 16 to 15 + NDIRECT, represent distances from 1 to NDIRECT. Neither the special distance symbols nor the NDIRECT direct distance symbols are followed by any extra bits.

Distance symbols 16 + NDIRECT and greater all have extra bits, where the number of extra bits for a distance symbol "dcode" is given by the following formula:

```
ndistbits = 1 + ((dcode - NDIRECT - 16) >> (NPOSTFIX + 1))
```

The maximum number of extra bits is 24; therefore, the size of the distance symbol alphabet is (16 + NDIRECT + (48 << NPOSTFIX)).

Given a distance symbol "dcode" (>= 16 + NDIRECT), and extra bits "dextra", the backward distance is given by the following formula:

```
hcode = (dcode - NDIRECT - 16) >> NPOSTFIX
lcode = (dcode - NDIRECT - 16) & POSTFIX_MASK
offset = ((2 + (hcode & 1)) << ndistbits) - 4
distance = ((offset + dextra) << NPOSTFIX) + lcode + NDIRECT + 1
```

5. Encoding of Literal Insertion Lengths and Copy Lengths

As described in Section 2, the literal insertion lengths and backward copy lengths are encoded using a single prefix code. This section provides the details to this encoding.

Each <insertion length, copy length> pair in the compressed data part of a meta-block is represented with the following triplet:

```
<insert-and-copy length code, insert extra bits, copy extra bits>
```

The insert-and-copy length code, the insert extra bits, and the copy extra bits are encoded back-to-back, the insert-and-copy length code is encoded using a prefix code over the insert-and-copy length code alphabet, while the extra bits values are encoded as fixed-width integer values. The number of insert and copy extra bits can be 0..24, and they are dependent on the insert-and-copy length code.

Some of the insert-and-copy length codes also express the fact that the distance symbol of the distance in the same command is 0, i.e., the distance component of the command is the same as that of the previous command. In this case, the distance code and extra bits for the distance are omitted from the compressed data stream.

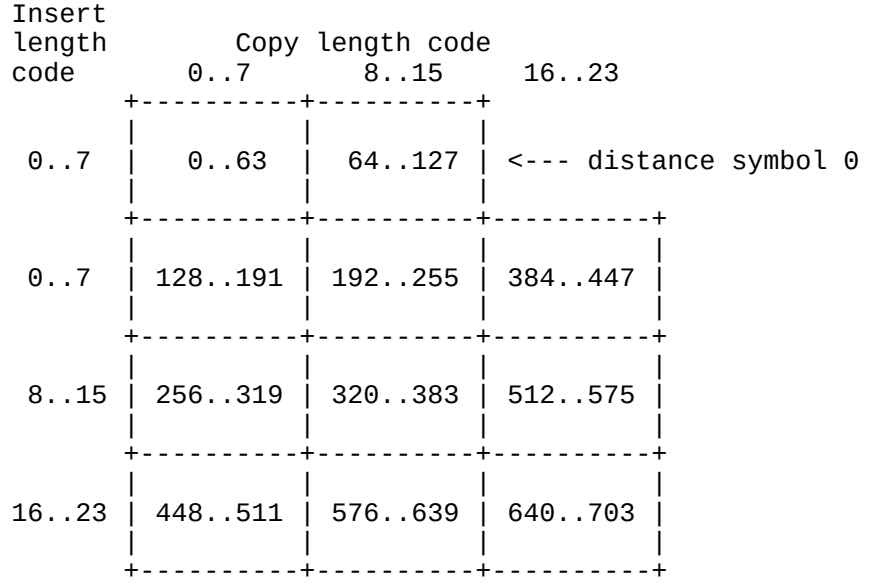
We describe the insert-and-copy length code alphabet in terms of the (not directly used) insert length code and copy length code alphabets. The symbols of the insert length code alphabet, along with the number of insert extra bits, and the range of the insert lengths are as follows:

Code	Extra Bits	Lengths	Code	Extra Bits	Lengths	Code	Extra Bits	Lengths
0	0	0	8	2	10..13	16	6	130..193
1	0	1	9	2	14..17	17	7	194..321
2	0	2	10	3	18..25	18	8	322..577
3	0	3	11	3	26..33	19	9	578..1089
4	0	4	12	4	34..49	20	10	1090..2113
5	0	5	13	4	50..65	21	12	2114..6209
6	1	6,7	14	5	66..97	22	14	6210..22593
7	1	8,9	15	5	98..129	23	24	22594..16799809

The symbols of the copy length code alphabet, along with the number of copy extra bits, and the range of copy lengths are as follows:

Code	Extra Bits	Lengths	Code	Extra Bits	Lengths	Code	Extra Bits	Lengths
0	0	2	8	1	10,11	16	5	70..101
1	0	3	9	1	12,13	17	5	102..133
2	0	4	10	2	14..17	18	6	134..197
3	0	5	11	2	18..21	19	7	198..325
4	0	6	12	3	22..29	20	8	326..581
5	0	7	13	3	30..37	21	9	582..1093
6	0	8	14	4	38..53	22	10	1094..2117
7	0	9	15	4	54..69	23	24	2118..16779333

To convert an insert-and-copy length code to an insert length code and a copy length code, the following table can be used:



First, look up the cell with the 64 value range containing the insert-and-copy length code; this gives the insert length code and the copy length code ranges, both 8 values long. The copy length code within its range is determined by bits 0..2 (counted from the lsb) of the insert-and-copy length code. The insert length code within its range is determined by bits 3..5 (counted from the lsb) of the insert-and-copy length code. Given the insert length and copy length codes, the actual insert and copy lengths can be obtained by reading the number of extra bits given by the tables above.

If the insert-and-copy length code is between 0 and 127, the distance code of the command is set to zero (the last distance reused).

6. Encoding of Block-Switch Commands

As described in Section 2, a block-switch command is a pair <block type, block count>. These are encoded in the compressed data part of the meta-block, right before the start of each new block of a particular block category.

Each block type in the compressed data is represented with a block type code, encoded using a prefix code over the block type code alphabet. A block type symbol 0 means that the new block type is the same as the type of the previous block from the same block category, i.e., the block type that preceded the current type, while a block type symbol 1 means that the new block type equals the current block type plus one. If the current block type is the maximal possible, then a block type symbol of 1 results in wrapping to a new block type of 0. Block type symbols 2..257 represent block types 0..255, respectively. The previous and current block types are initialized to 1 and 0, respectively, at the end of the meta-block header.

Since the first block type of each block category is 0, the block type of the first block-switch command is not encoded in the compressed data. If a block category has only one block type, the block count of the first block-switch command is also omitted from the compressed data; otherwise, it is encoded in the meta-block header.

Since the end of the meta-block is detected by the number of uncompressed bytes produced, the block counts for any of the three categories need not count down to exactly zero at the end of the meta-block.

The number of different block types in each block category, denoted by NBLTYPESL, NBLTYPESI, and NBLTYPESD for literals, insert-and-copy lengths, and distances, respectively, is encoded in the meta-block header, and it must equal to the largest block type plus one in that block category. In other words, the set of literal, insert-and-copy length, and distance block types must be [0..NBLTYPESL-1], [0..NBLTYPESI-1], and [0..NBLTYPESD-1], respectively. From this it follows that the alphabet size of literal, insert-and-copy length, and distance block type codes is NBLTYPESL + 2, NBLTYPESI + 2, and NBLTYPESD + 2, respectively.

Each block count in the compressed data is represented with a pair <block count code, extra bits>. The block count code and the extra bits are encoded back-to-back, the block count code is encoded using a prefix code over the block count code alphabet, while the extra bits value is encoded as a fixed-width integer value. The number of extra bits can be 0..24, and it is dependent on the block count code.

The symbols of the block count code alphabet along with the number of extra bits and the range of block counts are as follows:

Code	Extra Bits	Lengths	Code	Extra Bits	Lengths	Code	Extra Bits	Lengths
0	2	1..4	9	4	65..80	18	7	369..496
1	2	5..8	10	4	81..96	19	8	497..752
2	2	9..12	11	4	97..112	20	9	753..1264
3	2	13..16	12	5	113..144	21	10	1265..2288
4	3	17..24	13	5	145..176	22	11	2289..4336
5	3	25..32	14	5	177..208	23	12	4337..8432
6	3	33..40	15	5	209..240	24	13	8433..16624
7	3	41..48	16	6	241..304	25	24	16625..16793840
8	4	49..64	17	6	305..368			

The first block-switch command of each block category is special in the sense that it is encoded in the meta-block header, and as described earlier, the block type code is omitted since it is an implicit zero.

7. Context Modeling

As described in Section 2, the prefix tree used to encode a literal byte or a distance code depends on the block type and the context ID. This section specifies how to compute the context ID for a particular literal and distance code and how to encode the context map that maps a <block type, context ID> pair to the index of a prefix code in the array of literal and distance prefix codes.

7.1. Context Modes and Context ID Lookup for Literals

The context for encoding the next literal is defined by the last two bytes in the stream (p1, p2, where p1 is the most recent byte), regardless of whether these bytes are produced by uncompressed meta-blocks, backward references, static dictionary references, or by literal insertions. At the start of the stream, p1 and p2 are initialized to zero.

There are four methods, called context modes, to compute the Context ID:

* LSB6, where the Context ID is the value of six least significant bits of p1,

* MSB6, where the Context ID is the value of six most significant bits of p1,

* UTF8, where the Context ID is a complex function of p1, p2, optimized for text compression, and

* Signed, where Context ID is a complex function of p1, p2, optimized for compressing sequences of signed integers.

The Context ID for the UTF8 and Signed context modes is computed using the following lookup tables Lut0, Lut1, and Lut2.

```
Lut0 :=
   0,  0,  0,  0,  0,  0,  0,  0,  0,  4,  4,  0,  0,  4,  0,  0,
   0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,
   8, 12, 16, 12, 12, 20, 12, 16, 24, 28, 12, 12, 32, 12, 36, 12,
  44, 44, 44, 44, 44, 44, 44, 44, 44, 44, 32, 32, 24, 40, 28, 12,
  12, 48, 52, 52, 52, 48, 52, 52, 52, 48, 52, 52, 52, 52, 52, 48,
  52, 52, 52, 52, 52, 48, 52, 52, 52, 52, 52, 24, 12, 28, 12, 12,
  12, 56, 60, 60, 60, 56, 60, 60, 60, 56, 60, 60, 60, 60, 60, 56,
  60, 60, 60, 60, 60, 56, 60, 60, 60, 60, 60, 24, 12, 28, 12,  0,
   0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1,
   0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1,
   0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1,
   0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1,
   2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3,
   2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3,
   2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3,
   2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3

Lut1 :=
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 1, 1, 1, 1,
   1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 1, 1, 1,
   1, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 1, 1, 1, 1, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
```

```
Lut2 :=
   0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
   2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,
   4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4,
   4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4,
   4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4,
   4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4,
   5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5,
   5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5,
   5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5,
   6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 7
```

The lengths and the CRC-32 check values (see Appendix C) of each of these tables as a sequence of bytes are as follows:

Table	Length	CRC-32
Lut0	256	0x8e91efb7
Lut1	256	0xd01a32f4
Lut2	256	0x0dd7a0d6

Given p1 is the last uncompressed byte and p2 is the second-to-last uncompressed byte, the context IDs can be computed as follows:

```
For LSB6:    Context ID = p1 & 0x3f
For MSB6:    Context ID = p1 >> 2
For UTF8:    Context ID = Lut0[p1] | Lut1[p2]
For Signed:  Context ID = (Lut2[p1] << 3) | Lut2[p2]
```

From the lookup tables defined above and the operations to compute the context IDs, we can see that context IDs for literals are in the range of 0..63.

The context modes LSB6, MSB6, UTF8, and Signed are denoted by integers 0, 1, 2, 3.

A context mode is defined for each literal block type and they are stored in a consecutive array of bits in the meta-block header, always two bits per block type.

7.2. Context ID for Distances

The context for encoding a distance code is defined by the copy length corresponding to the distance. The context IDs are 0, 1, 2, and 3 for copy lengths 2, 3, 4, and more than 4, respectively.

7.3. Encoding of the Context Map

There are two context maps, one for literals and one for distances. The size of the context map is 64 * NBLTYPESL for literals, and 4 * NBLTYPESD for distances. Each value in the context map is an integer between 0 and 255, indicating the index of the prefix code to be used when encoding the next literal or distance.

The context maps are two-dimensional matrices, encoded as one-dimensional arrays:

```
CMAPL[0..(64 * NBLTYPESL - 1)]
CMAPD[0..(4 * NBLTYPESD - 1)]
```

The index of the prefix code for encoding a literal or distance code with block type, BTYPE_x, and context ID, CIDx, is:

```
index of literal prefix code = CMAPL[64 * BTYPE_L + CIDL]
index of distance prefix code = CMAPD[4 * BTYPE_D + CIDD]
```

The values of the context map are encoded with the combination of run length encoding for zero values and prefix coding. Let RLEMAX denote the number of run length codes and NTREES denote the maximum value in the context map plus one. NTREES must equal the number of different values in the context map; in other words, the different values in the context map must be the [0..NTREES-1] interval. The alphabet of the prefix code has the following RLEMAX + NTREES symbols:

```
0: value zero
1: repeat a zero 2 to 3 times, read 1 bit for repeat length
2: repeat a zero 4 to 7 times, read 2 bits for repeat length
...
RLEMAX: repeat a zero (1 << RLEMAX) to (1 << (RLEMAX+1))-1
        times, read RLEMAX bits for repeat length
RLEMAX + 1: value 1
...
RLEMAX + NTREES - 1: value NTREES - 1
```

If RLEMAX = 0, the run length coding is not used and the symbols of the alphabet are directly the values in the context map. We can now define the format of the context map (the same format is used for literal and distance context maps):

1..5 bits: RLEMAX, 0 is encoded with one 0 bit, and values 1..16 are encoded with bit pattern xxxx1 (so 01001 is 5)

Prefix code with alphabet size NTREES + RLEMAX

Context map size values encoded with the above prefix code and run length coding for zero values. If a run length would result in more lengths in total than the size of the context map, then the stream should be rejected as invalid.

1 bit: IMTF bit, if set, we do an inverse move-to-front transform on the values in the context map to get the prefix code indexes.

Note that RLEMAX may be larger than the value necessary to represent the longest sequence of zero values. Also, the NTREES value is encoded right before the context map as described in Section 9.2.

We define the inverse move-to-front transform used in this specification by the following C language function:

```
void InverseMoveToFrontTransform(uint8_t* v, int v_len) {
   uint8_t mtf[256];
   int i;
   for (i = 0; i < 256; ++i) {
      mtf[i] = (uint8_t)i;
   }
   for (i = 0; i < v_len; ++i) {
      uint8_t index = v[i];
      uint8_t value = mtf[index];
      v[i] = value;
      for (; index; --index) {
         mtf[index] = mtf[index - 1];
      }
      mtf[0] = value;
   }
}
```

Note that the inverse move-to-front transform will not produce values outside the [0..NTREES-1] interval.

8. Static Dictionary

At any given point during decoding the compressed data, a reference to a duplicated string in the uncompressed data produced so far has a maximum backward distance value, which is the minimum of the window size and the number of uncompressed bytes produced. However, decoding a distance from the compressed stream, as described in Section 4, can produce distances that are greater than this maximum allowed value. In this case, the distance is treated as a reference to a word in the static dictionary given in Appendix A. The copy length for a static dictionary reference must be between 4 and 24. The static dictionary has three parts:

* DICT[0..DICTSIZE], an array of bytes
* DOFFSET[0..24], an array of byte-offset values for each length
* NDBITS[0..24], an array of bit-depth values for each length

The number of static dictionary words for a given length is:

```
NWORDS[length] = 0                        (if length < 4)
NWORDS[length] = (1 << NDBITS[length])    (if length >= 4)
```

DOFFSET and DICTSIZE are defined by the following recursion:

```
DOFFSET[0] = 0
DOFFSET[length + 1] = DOFFSET[length] + length * NWORDS[length]
DICTSIZE = DOFFSET[24] + 24 * NWORDS[24]
```

The offset of a word within the DICT array for a given length and index is:

```
offset(length, index) = DOFFSET[length] + index * length
```

Each static dictionary word has 121 different forms, given by applying a word transformation to a base word in the DICT array. The list of word transformations is given in Appendix B. The static dictionary word for a <length, distance> pair can be reconstructed as follows:

```
word_id = distance - (max allowed distance + 1)
index = word_id % NWORDS[length]
base_word = DICT[offset(length, index)..offset(length, index+1)-1]
transform_id = word_id >> NDBITS[length]
```

The string copied to the uncompressed stream is computed by applying the transformation to the base dictionary word. If transform_id is greater than 120, or the length is smaller than 4 or greater than 24, then the compressed stream should be rejected as invalid.

Each word transformation has the following form:

```
transform_i(word) = prefix_i + T_i(word) + suffix_i
```

where the _i subscript denotes the transform_id above. Each T_i is one of the following 21 elementary transforms:

```
Identity, FermentFirst, FermentAll,
OmitFirst1, ..., OmitFirst9, OmitLast1, ..., OmitLast9
```

The form of these elementary transforms is as follows:

```
Identity(word) = word

FermentFirst(word) = see below

FermentAll(word) = see below

OmitFirstk(word) = the last (length(word) - k) bytes of word, or
                   empty string if length(word) < k

OmitLastk(word) = the first (length(word) - k) bytes of word, or
                  empty string if length(word) < k
```

We define the FermentFirst and FermentAll transforms used in this specification by the following C language functions:

```
int Ferment(uint8_t* word, int word_len, int pos) {
   if (word[pos] < 192) {
      if (word[pos] >= 97 and word[pos] <= 122) {
         word[pos] = word[pos] ^ 32;
      }
      return 1;
   } else if (word[pos] < 224) {
      if (pos + 1 < word_len) {
         word[pos + 1] = word[pos + 1] ^ 32;
      }
      return 2;
   } else {
      if (pos + 2 < word_len) {
         word[pos + 2] = word[pos + 2] ^ 5;
      }
      return 3;
   }
}

void FermentFirst(uint8_t* word, int word_len) {
   if (word_len > 0) {
      Ferment(word, word_len, 0);
   }
}

void FermentAll(uint8_t* word, int word_len) {
   int i = 0;
   while (i < word_len) {
      i += Ferment(word, word_len, i);
   }
}
```

Appendix B contains the list of transformations by specifying the prefix, elementary transform and suffix components of each of them. Note that the OmitFirst8 elementary transform is not used in the list of transformations. The strings in Appendix B are in C-string format with respect to escape (backslash) characters.

The maximum number of additional bytes that a transform may add to a base word is 13. Since the largest base word is 24 bytes long, a buffer of 38 bytes is sufficient to store any transformed words (counting a terminating zero byte).

9. Compressed Data Format

In this section, we describe the format of the compressed data set in terms of the format of the individual data items described in the previous sections.

9.1. Format of the Stream Header

The stream header has only the following one field:

1..7 bits: WBITS, a value in the range 10..24, encoded with the following variable-length code (as it appears in the compressed data, where the bits are parsed from right to left):

Value	Bit Pattern
10	0100001
11	0110001
12	1000001
13	1010001
14	1100001
15	1110001
16	0
17	0000001
18	0011
19	0101
20	0111
21	1001
22	1011
23	1101
24	1111

Note that bit pattern 0010001 is invalid and must not be used.

The size of the sliding window, which is the maximum value of any non-dictionary reference backward distance, is given by the following formula:

```
window size = (1 << WBITS) - 16
```

9.2. Format of the Meta-Block Header

A compliant compressed data set has at least one meta-block. Each meta-block contains a header with information about the uncompressed length of the meta-block, and a bit signaling if the meta-block is the last one. The format of the meta-block header is the following:

1 bit: ISLAST, set to 1 if this is the last meta-block

1 bit: ISLASTEMPTY, if set to 1, the meta-block is empty; this field is only present if ISLAST bit is set -- if it is 1, then the meta-block and the brotli stream ends at that bit, with any remaining bits in the last byte of the compressed stream filled with zeros (if the fill bits are not zero, then the stream should be rejected as invalid)

2 bits: MNIBBLES, number of nibbles to represent the uncompressed length, encoded with the following fixed-length code:

Value	Bit Pattern
0	11
4	00
5	01
6	10

If MNIBBLES is 0, the meta-block is empty, i.e., it does not generate any uncompressed data. In this case, the rest of the meta-block has the following format:

1 bit: reserved, must be zero

2 bits: MSKIPBYTES, number of bytes to represent metadata length

MSKIPBYTES * 8 bits: MSKIPLEN - 1, where MSKIPLEN is the number of metadata bytes; this field is only present if MSKIPBYTES is positive; otherwise, MSKIPLEN is 0 (if MSKIPBYTES is greater than 1, and the last byte is all zeros, then the stream should be rejected as invalid)

0..7 bits: fill bits until the next byte boundary, must be all zeros

MSKIPLEN bytes of metadata, not part of the uncompressed data or the sliding window

MNIBBLES * 4 bits: MLEN - 1, where MLEN is the length of the meta-block uncompressed data in bytes (if MNIBBLES is greater than 4, and the last nibble is all zeros, then the stream should be rejected as invalid)

1 bit: ISUNCOMPRESSED, if set to 1, any bits of compressed data up to the next byte boundary are ignored, and the rest of the meta-block contains MLEN bytes of literal data; this field is only present if the ISLAST bit is not set (if the ignored bits are not all zeros, the stream should be rejected as invalid)

1..11 bits: NBLTYPESL, number of literal block types, encoded with the following variable-length code (as it appears in the compressed data, where the bits are parsed from right to left, so 0110111 has the value 12):

Value	Bit Pattern
1	0
2	0001
3..4	x0011
5..8	xx0101
9..16	xxx0111
17..32	xxxx1001
33..64	xxxxx1011
65..128	xxxxxx1101
129..256	xxxxxxx1111

Prefix code over the block type code alphabet for literal block types, appears only if NBLTYPESL >= 2

Prefix code over the block count code alphabet for literal block counts, appears only if NBLTYPESL >= 2

Block count code + extra bits for first literal block count, appears only if NBLTYPESL >= 2

1..11 bits: NBLTYPESI, number of insert-and-copy block types, encoded with the same variable-length code as above

Prefix code over the block type code alphabet for insert-and-copy block types, appears only if NBLTYPESI >= 2

Prefix code over the block count code alphabet for insert-and-copy block counts, appears only if NBLTYPESI >= 2

Block count code + extra bits for first insert-and-copy block count, appears only if NBLTYPESI >= 2

1..11 bits: NBLTYPESD, number of distance block types, encoded with the same variable-length code as above

Prefix code over the block type code alphabet for distance block types, appears only if NBLTYPESD >= 2

Prefix code over the block count code alphabet for distance block counts, appears only if NBLTYPESD >= 2

Block count code + extra bits for first distance block count, appears only if NBLTYPESD >= 2

2 bits: NPOSTFIX, parameter used in the distance coding

4 bits: four most significant bits of NDIRECT, to get the actual value of the parameter NDIRECT, left-shift this four-bit number by NPOSTFIX bits

NBLTYPESL * 2 bits: context mode for each literal block type

1..11 bits: NTREESL, number of literal prefix trees, encoded with the same variable-length code as NBLTYPESL

Literal context map, encoded as described in Section 7.3, appears only if NTREESL >= 2; otherwise, the context map has only zero values

1..11 bits: NTREESD, number of distance prefix trees, encoded with the same variable-length code as NBLTYPESD

Distance context map, encoded as described in Section 7.3, appears only if NTREESD >= 2; otherwise, the context map has only zero values

NTREESL prefix codes for literals

NBLTYPESI prefix codes for insert-and-copy lengths

NTREESD prefix codes for distances

9.3. Format of the Meta-Block Data

The compressed data part of a meta-block consists of a series of commands. Each command has the following format:

- Block type code for next insert-and-copy block type, appears only if NBLTYPESI >= 2 and the previous insert-and-copy block count is zero
- Block count code + extra bits for next insert-and-copy block count, appears only if NBLTYPESI >= 2 and the previous insert-and-copy block count is zero
- Insert-and-copy length, encoded as in Section 5, using the insert-and-copy length prefix code with the current insert-and-copy block type index
- Insert length number of literals, with the following format:
  - Block type code for next literal block type, appears only if NBLTYPESL >= 2 and the previous literal block count is zero
  - Block count code + extra bits for next literal block count, appears only if NBLTYPESL >= 2 and the previous literal block count is zero
  - Next byte of the uncompressed data, encoded with the literal prefix code with the index determined by the previous two bytes of the uncompressed data, the current literal block type, and the context map, as described in Section 7.3
- Block type code for next distance block type, appears only if NBLTYPESD >= 2 and the previous distance block count is zero
- Block count code + extra bits for next distance block count, appears only if NBLTYPESD >= 2 and the previous distance block count is zero
- Distance code, encoded as in Section 4, using the distance prefix code with the index determined by the copy length, the current distance block type, and the distance context map, as described in Section 7.3, appears only if the distance code is not an implicit 0, as indicated by the insert-and-copy length code

The number of commands in the meta-block is such that the sum of the uncompressed bytes produced (i.e., the number of literals inserted plus the number of bytes copied from past data or generated from the static dictionary) over all the commands gives the uncompressed length, MLEN encoded in the meta-block header.

If the total number of uncompressed bytes produced after the insert part of the last command equals MLEN, then the copy length of the last command is ignored and will not produce any uncompressed output. In this case, the copy length of the last command can have any value. In any other case, if the number of literals to insert, the copy length, or the resulting dictionary word length would cause MLEN to be exceeded, then the stream should be rejected as invalid.

If the last command of the last non-empty meta-block does not end on a byte boundary, the unused bits in the last byte must be zeros.

10. Decoding Algorithm

The decoding algorithm that produces the uncompressed data is as follows:

```
read window size
do
   read ISLAST bit
   if ISLAST
      read ISLASTEMPTY bit
      if ISLASTEMPTY
         break from loop
   read MNIBBLES
   if MNIBBLES is zero
      verify reserved bit is zero
      read MSKIPLEN
      skip any bits up to the next byte boundary
      skip MSKIPLEN bytes
      continue to the next meta-block
   else
      read MLEN
   if not ISLAST
      read ISUNCOMPRESSED bit
      if ISUNCOMPRESSED
         skip any bits up to the next byte boundary
         copy MLEN bytes of compressed data as literals
         continue to the next meta-block
```

```
loop for each three block categories (i = L, I, D)
   read NBLTYPESi
   if NBLTYPESi >= 2
      read prefix code for block types, HTREE_BTYPE_i
      read prefix code for block counts, HTREE_BLEN_i
      read block count, BLEN_i
      set block type, BTYPE_i to 0
      initialize second-to-last and last block types to 0 and 1
   else
      set block type, BTYPE_i to 0
      set block count, BLEN_i to 16777216
read NPOSTFIX and NDIRECT
read array of literal context modes, CMODE[]
read NTREESL
if NTREESL >= 2
   read literal context map, CMAPL[]
else
   fill CMAPL[] with zeros
read NTREESD
if NTREESD >= 2
   read distance context map, CMAPD[]
else
   fill CMAPD[] with zeros
read array of literal prefix codes, HTREEL[]
read array of insert-and-copy length prefix codes, HTREEI[]
read array of distance prefix codes, HTREED[]
do
   if BLEN_I is zero
      read block type using HTREE_BTYPE_I and set BTYPE_I
         save previous block type
      read block count using HTREE_BLEN_I and set BLEN_I
   decrement BLEN_I
   read insert-and-copy length symbol using HTREEI[BTYPE_I]
   compute insert length, ILEN, and copy length, CLEN
   loop for ILEN
      if BLEN_L is zero
         read block type using HTREE_BTYPE_L and set BTYPE_L
            save previous block type
         read block count using HTREE_BLEN_L and set BLEN_L
      decrement BLEN_L
      look up context mode CMODE[BTYPE_L]
      compute context ID, CIDL from last two uncompressed bytes
      read literal using HTREEL[CMAPL[64*BTYPE_L + CIDL]]
      write literal to uncompressed stream
   if number of uncompressed bytes produced in the loop for
      this meta-block is MLEN, then break from loop (in this
      case the copy length is ignored and can have any value)
```

```
            if distance code is implicit zero from insert-and-copy code
               set backward distance to the last distance
            else
               if BLEN_D is zero
                  read block type using HTREE_BTYPE_D and set BTYPE_D
                     save previous block type
                  read block count using HTREE_BLEN_D and set BLEN_D
               decrement BLEN_D
               compute context ID, CIDD from CLEN
               read distance code using HTREED[CMAPD[4*BTYPE_D + CIDD]]
               compute distance by distance short code substitution
               if distance code is not zero,
                  and distance is not a static dictionary reference,
                  push distance to the ring buffer of last distances
            if distance is less than the max allowed distance plus one
               move backwards distance bytes in the uncompressed data,
               and copy CLEN bytes from this position to
               the uncompressed stream
            else
               look up the static dictionary word, transform the word as
               directed, and copy the result to the uncompressed stream
         while number of uncompressed bytes for this meta-block < MLEN
      while not ISLAST
```

If the stream ends before the completion of the last meta-block, then the stream should be rejected as invalid.

Note that a duplicated string reference may refer to a string in a previous meta-block, i.e., the backward distance may cross one or more meta-block boundaries. However, a backward copy distance will not refer past the beginning of the uncompressed stream or the window size; any such distance is interpreted as a reference to a static dictionary word. Also, note that the referenced string may overlap the current position, for example, if the last 2 bytes decoded have values X and Y, a string reference with <length = 5, distance = 2> adds X,Y,X,Y,X to the uncompressed stream.

11. Considerations for Compressor Implementations

Since the intent of this document is to define the brotli compressed data format without reference to any particular compression algorithm, the material in this section is not part of the definition of the format, and a compressor need not follow it in order to be compliant.

11.1. Trivial Compressor

In this section, we present a very simple algorithm that produces a valid brotli stream representing an arbitrary sequence of uncompressed bytes in the form of the following C++ language function.

```
string BrotliCompressTrivial(const string& u) {
   if (u.empty()) {
      return string(1, 6);
   }
   int i;
   string c;
   c.append(1, 12);
   for (i = 0; i + 65535 < u.size(); i += 65536) {
      c.append(1, 248);
      c.append(1, 255);
      c.append(1, 15);
      c.append(&u[i], 65536);
   }
   if (i < u.size()) {
      int r = u.size() - i - 1;
      c.append(1, (r & 31) << 3);
      c.append(1, r >> 5);
      c.append(1, 8 + (r >> 13));
      c.append(&u[i], r + 1);
   }
   c.append(1, 3);
   return c;
}
```

Note that this simple algorithm does not actually compress data, that is, the brotli representation will always be bigger than the original, but it shows that every sequence of N uncompressed bytes can be represented with a valid brotli stream that is not longer than N + (3 * (N >> 16) + 5) bytes.

11.2. Aligning Compressed Meta-Blocks to Byte Boundaries

As described in Section 9, only those meta-blocks that immediately follow an uncompressed meta-block or a metadata meta-block are guaranteed to start on a byte boundary. In some applications, it might be required that every non-metadata meta-block starts on a byte boundary. This can be achieved by appending an empty metadata meta-block after every non-metadata meta-block that does not end on a byte boundary.

11.3. Creating Self-Contained Parts within the Compressed Data

In some encoder implementations, it might be required to make a sequence of bytes within a brotli stream self-contained, that is, such that they can be decompressed independently from previous parts of the compressed data. This is a useful feature for three reasons. First, if a large compressed file is damaged, it is possible to recover some of the file after the damage. Second, it is useful when doing differential transfer of compressed data. If a sequence of uncompressed bytes is unchanged and compressed independently from previous data, then the compressed representation may also be unchanged and can therefore be transferred very cheaply. Third, if sequences of uncompressed bytes are compressed independently, it allows for parallel compression of these byte sequences within the same file, in addition to parallel compression of multiple files.

Given two sequences of uncompressed bytes, U0 and U1, we will now describe how to create two sequences of compressed bytes, C0 and C1, such that the concatenation of C0 and C1 is a valid brotli stream, and that C0 and C1 (together with the first byte of C0 that contains the window size) can be decompressed independently from each other to U0 and U1.

When compressing the byte sequence U0 to produce C0, we can use any compressor that works on the complete set of uncompressed bytes U0, with the following two changes. First, the ISLAST bit of the last meta-block of C0 must not be set. Second, C0 must end at a byte-boundary, which can be ensured by appending an empty metadata meta-block to it, as in Section 11.2.

When compressing the byte sequence U1 to produce C1, we can use any compressor that starts a new meta-block at the beginning of U1 within the U0+U1 input stream, with the following two changes. First, backward distances in C1 must not refer to static dictionary words or uncompressed bytes in U0. Even if a sequence of bytes in U1 would match a static dictionary word, or a sequence of bytes that overlaps U0, the compressor must represent this sequence of bytes with a combination of literal insertions and backward references to bytes in U1 instead. Second, the ring buffer of last four distances must be replenished first with distances in C1 before using it to encode other distances in C1. Note that both compressors producing C0 and C1 have to use the same window size, but the stream header is emitted only by the compressor that produces C0.

Note that this method can be easily generalized to more than two sequences of uncompressed bytes.

12. Security Considerations

As with any compressed file formats, decompressor implementations should handle all compressed data byte sequences, not only those that conform to this specification, where non-conformant compressed data sequences should be rejected as invalid.

A possible attack against a system containing a decompressor implementation (e.g., a web browser) is to exploit a buffer overflow triggered by invalid compressed data. Therefore, decompressor implementations should perform bounds-checking for each memory access that result from values decoded from the compressed stream and derivatives thereof.

Another possible attack against a system containing a decompressor implementation is to provide it (either valid or invalid) compressed data that can make the decompressor system's resource consumption (CPU, memory, or storage) to be disproportionately large compared to the size of the compressed data. In addition to the size of the compressed data, the amount of CPU, memory, and storage required to decompress a single compressed meta-block within a brotli stream is controlled by the following two parameters: the size of the uncompressed meta-block, which is encoded at the start of the compressed meta-block, and the size of the sliding window, which is encoded at the start of the brotli stream. Decompressor implementations in systems where memory or storage is constrained should perform a sanity-check on these two parameters. The uncompressed meta-block size that was decoded from the compressed stream should be compared against either a hard limit, given by the system's constraints or some expectation about the uncompressed data, or against a certain multiple of the size of the compressed data. If the uncompressed meta-block size is determined to be too high, the compressed data should be rejected. Likewise, when the complete uncompressed stream is kept in the system containing the decompressor implementation, the total uncompressed size of the stream should be checked before decompressing each additional meta-block. If the size of the sliding window that was decoded from the start of the compressed stream is greater than a certain soft limit, then the decompressor implementation should, at first, allocate a smaller sliding window that fits the first uncompressed meta-block, and afterwards, before decompressing each additional meta-block, it should increase the size of the sliding window until the sliding window size specified in the compressed data is reached.

Correspondingly, possible attacks against a system containing a compressor implementation (e.g., a web server) are to exploit a buffer overflow or cause disproportionately large resource consumption by providing, e.g., uncompressible data. As described in Section 11.1, an output buffer of

$$S(N) = N + (3 * (N >> 16) + 5)$$

bytes is sufficient to hold a valid compressed brotli stream representing an arbitrary sequence of N uncompressed bytes. Therefore, compressor implementations should allocate at least S(N) bytes of output buffer before compressing N bytes of data with unknown compressibility and should perform bounds-checking for each write into this output buffer. If their output buffer is full, compressor implementations should revert to the trivial compression algorithm described in Section 11.1. The resource consumption of a compressor implementation for a particular input data depends mostly on the algorithm used to find backward matches and on the algorithm used to construct context maps and prefix codes and only to a lesser extent on the input data itself. If the system containing a compressor implementation is overloaded, a possible way to reduce resource usage is to switch to more simple algorithms for backward reference search and prefix code construction, or to fall back to the trivial compression algorithm described in Section 11.1.

A possible attack against a system that sends compressed data over an encrypted channel is the following. An attacker who can repeatedly mix arbitrary (attacker-supplied) data with secret data (passwords, cookies) and observe the length of the ciphertext can potentially reconstruct the secret data. To protect against this kind of attack, applications should not mix sensitive data with non-sensitive, potentially attacker-supplied data in the same compressed stream.

13. IANA Considerations

The "HTTP Content Coding Registry" has been updated with the registration below:

Name	Description	Reference
br	Brotli Compressed Data Format	RFC 7932

14. Informative References

[HUFFMAN] Huffman, D. A., "A Method for the Construction of Minimum Redundancy Codes", Proceedings of the Institute of Radio Engineers, September 1952, Vol. 40, No. 9, pp. 1098-1101.

[LZ77] Ziv, J. and A. Lempel, "A Universal Algorithm for Sequential Data Compression", IEEE Transactions on Information Theory, Vol. 23, No. 3, pp. 337-343, DOI 10.1109/TIT.1977.1055714, May 1977, <https://www.cs.duke.edu/courses/spring03/cps296.5/papers/ziv_lempel_1977_universal_algorithm.pdf>.

[RFC1951] Deutsch, P., "DEFLATE Compressed Data Format Specification version 1.3", RFC 1951, DOI 10.17487/RFC1951, May 1996, <http://www.rfc-editor.org/info/rfc1951>.

[WOFF2] Levantovsky, V., Ed., and R. Levien, Ed., "WOFF File Format 2.0", W3C Candidate Recommendation, March 2016, <http://www.w3.org/TR/WOFF2/>.

Appendix A. Static Dictionary Data

The hexadecimal form of the DICT array is the following, where the length is 122,784 bytes and the CRC-32 of the byte sequence is 0x5136cb04.

```
74696d65646f776e6c6966656c6566746261636b636f64656461746173686f77
6f6e6c7973697465636974796f70656e6a7573746c696b6566726565776f726b
7465787479656172 6f766572626f64796c6f7665666f726d626f6f6b706c6179
6c6976656c696e6568656c70686f6d6573696465 6d6f7265776f72646c6f6e67
7468656d7669657766696e6470616765646179736675 6c6c686561647465726d
6561636861726561667 26f6d747275656d61726b61626c6575706f6e68696768
646174656c616e646e6577736576656e6e6578746361736562 6f7468706f7374
757365646d6164656861 6e64686572657686174 6e616d654c696e6b626c6f67
73697a656261736568656c646d616b656d61696e757365722729202b686f6c64
656e6473776974684e65777372656164776572657369676e74616b6568617665
67616d657365656e63616c6c706174687656c6c706c75736d656e7566696c6d
706172746a6f696e746869736c697374676f6f646e656564776179737765737 4
6a6f62736d696e64616c736f6c6f676f72696368757365736c6173747465616d
61726d79666f6f646b696e6777696c6c656173747761726462657374666972 65
506167656b6e6f77617761792e706e676d6f76657468616e6c6f616467697665
73656c666e6f74656d756368666565646d616e79726f636b69636f6e6f6e6365
6c6f6f6b6869646564696564486f6d6572756c65686f7374616a6178696e666f
636c75626c6177736c65737368616c66736f6d65737563687a6f6e6531303025
6f6e6573636172655469 6d6572616365626c7565666f75727765656b66616365
686f706567617665686172646c6f73747768656e7061726b6b65707470617373
73686970726f6f6d48544d4c706c616e54797065646f6e65736176656b656570
666c61676c696e6b736f6c6466697665746f6f6b72617465746f776e6a756d70
746875736461726b6361726466696c656665617273746 1796b696c6c74686174
66616c6c6175746f657665722e636f6d74616c6b73686f70766f746564656570
6d6f646572657374747 5726e626f726e62616e6466656c6c726f736575726c28
736b696e726f6c65636f6d656163747361676573 6d656574676f6c642e6a7067
6974656d7661727966656c747468656e73656e6464726f7056696577636f7079
312e30223c2f613e73746f70656c73656c696573746f75727061636b2e676966
706173746373733f677261796d65616e2667743b7269646573686f746c617465
73616964726f6164766172206665656c6a6f686e7269636b706f727466617374
2755412d646561643c2f623e706f6f7262696c6c74797065552e532e776f6f64
6d7573743270783b496e666f72616e6b7769646577616e7477616c6c6c656164
5b305d3b7061756c7761766573757265242827237616976974 6d1737361726d73
676f65736761696e6c616e6770616964212d2d206c6f636b756e6974726f6f74
77616c6b6669726d77696665786d6c22736f6e6774657374323070786b696e64
726f7773746f6f6c666f6e746d61696c7361666573746172 6d617073636f7265
7261696e666c6f7762616279737 0616e736179733470783b3670783b61727473
666f6f747265616c77696b6968656174737465707472697 06f72672f6c616b65
7765616b746f6c64466f726d6361737466616e7362616e6b7665727972756e73
6a756c797461736b3170783b676f616c67726577736c6f776564676569643d22
736574733570783b2e6a733f343070786966202873 6f6f6e736561746e6f6e65
747562657a65726f73656e747265656466616374696e746f676966746861726d
```

```
3138707863616d6568696c6c626f6c647a6f6f6d766f69646561737972696e67
66696c6c7065616b696e6974636f73743370783b6a61636b7461677362697473
726f6c6c656469746b6e65776e6561723c212d2d67726f774a534f4e64757479
4e616d6573616c65796f75206c6f74737061696e6a617a7a636f6c6465796573
666973687777772e7269736b7461627370726576313070787269736532357078
426c756564696e673330302c62616c6c666f72646561726e77696c64626f782e
666169726c61636b76657273706169726a756e6574656368696628217069636b
6576696c242822377617 26d6c6f7264646f657370756c6c2c30303069646561
6472617768756765737 06f7466756e646275726e6872656663656c6c6b657973
7469636b686f75726c6f73736675656c3132707873756974646561 6c52535322
6167656467726579474554226561736561696d736769726c616964733870783b
6e6176796772696474697073233939397761727 36c6164796361727 3293b207d
7068703f68656c6c74616c6c77686f6d7a683ae52a2f0d0a203130306861 6c6c
2e0a0a413770783b707573686368617430707 83b637265772a2f3c2f68617368
37357078666c617472617265202626207 4656c6c63616d706f6e746f6c616964
6d697373736b697074656e7466696e656d616c6567657473706c6f743430302c
0d0a0d0a636f6f6c666565742e7068703c62723e657269636d6f737467756964
62656c6c6465736368616972 6d61746861746f6d2f696d67262338326c75636b
63656e743030303b74696e79676f6e6568746d6c73656c6c6472756746524545
6e6f64656e69636b3f69643d6c6f73656e756c6c7661737477696e6452535320
7765617272656c796265656e73616d6564756b656e617361636170657769736 8
67756c665432333a68697473736c6f74676174656b69636b626c757274686579
313570782727293b293b223e6d73696577696e7362697264736f727462657461
7365656b5431383a6f726473747265656d616c6c363070786617 26de2809973
626f79735b305d2e27293b22504f5354626561726b696473293b7d7d6d617279
74656e6428554b29717561647a683ae62d73697a2d2d2d2d70726f7027293b0d
6c6966745431393a76696365616e6479646562743e525353706f6f6c6e65636b
626c6f775431363a646f6f726576616c5431373a6c6574736661696c6f72616c
706f6c6c6e6f7661636f6c7367656e6520e28094736f6674726f6d6574696c6c
726f73733c68333e706f7572666164657 0696e6b3c74723e6d696e69297c2128
6d696e657a683ae8626172736865617230302 93b6d696c6b202d2d3e69726f6e
667265646469736b77656e74736f696c707574732f6a732f686f6c795432323a
4953424e5432303a6164616d736565733c68323e6a736f6e272c2027636f6e74
5432313a205253536c6f6f7061369616d6f6f6e3c2f703e736f756c4c494e45
666f72746361727 45431343a3c68313e38307078212d2d3c3970783b5430343a
6d696b653a34365a6e696365696e6368596f726b726963657a683ae42729293b
707572656d61676570617261746f6e65626f6e643a33375a5f6f665f275d293b
3030302c7a683ae774616e6b79617264626f776c627573683a35365a4a617661
333070780a7c7d0a254333253a33345a6a6566664558504963617368766973 61
676f6c66736e6f777a683ae9717565722e6373737369636b6d6561746d696e2e
62696e6464656c6c6869726570696373726 56e743a33365a485454502d323031
666f746f776f6c66454e442078626f783a35345a424f44596469636b3b0a7d0a
657869743a33355a766172736265617427 7d293b646965743939393b616e6e65
7d7d3c2f5b695d2e4c616e676b6dc2b277697265746f7973616464737365616c
616c65783b0a097d6563686f6e696e652e6f726730303529746f6e796a657773
73616e646c656773726f6f6630303029203230307769 6e6567656172646f6773
626f6f7467617279637574737479 6c6574656d7074696f6e2e786d6c636f636b
67616e672428272e3530707850682e446d697363616c616e6c6f616e6465736b
```

```
6d696c657279616e756e697864697363293b7d0a64757374636c6970292e0a0a
373070782d32303044564473375d3e3c7461706564656d6f692b2b2977616765
6575726f7068696c6f707473686f6c6546415173617369 6e2d3236546c616273
7065747355524c2062756c6b636f6f6b3b7d0d0a484541445b305d2961626272
6a75616e283139386c6573687477696e3c2f693e736f6e79677579736675636b
706970657c2d0a21303032296e646f775b315d3b5b5d3b0a4c6f672073616c74
0d0a090962616e677472696d62617468297b0d0a303070780a7d293b6b6f3aec
6665657361643e0d733a2f2f205b5d3b746f6c6c706c756728297b0a7b0d0a20
2e6a732732303070647 5616c626f61742e4a5047293b0a7d71756f74293b0a0a
27293b0a0d0a7d0d323031343230313532303136323031373230313832303139
323032303230323132303232323032333230323432303235323032363230323 7
323032383230323932303330323033313230333232303333323033343230323 5
323033363230333732303133323031323230313132303130323030393230303 8
323030373230303632303035323030343230303332303032323030313230303 0
313939393139393831393937313939363139393531393934313939393319393 2
313939313139393031393839313938383139383731393836313938353139383 4
313938333139383231393831313938303139373931393738313937373139373 6
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a4b2e0a58be0a4a1e0a495e0a58de0a4b7e0a587e0a4a4e0a58de0a4b0e0a49c
e0a4bee0a4a8e0a495e0a4bee0a4b0e0a580e0a4b8e0a482e0a4ace0a482e0a4
a7e0a4bfe0a4a4e0a4b8e0a58de0a4a5e0a4bee0a4aae0a4a8e0a4bee0a4b8e0
a58de0a4b5e0a580e0a495e0a4bee0a4b0e0a4b8e0a482e0a4b8e0a58de0a495
e0a4b0e0a4a3e0a4b8e0a4bee0a4aee0a497e0a58de0a4b0e0a580e0a49ae0a4
bfe0a49fe0a58de0a4a0e0a58be0a482e0a4b5e0a4bfe0a49ce0a58de0a49ee0
a4bee0a4a8e0a485e0a4aee0a587e0a4b0e0a4bfe0a495e0a4bee0a4b5e0a4bf
e0a4ade0a4bfe0a4a8e0a58de0a4a8e0a497e0a4bee0a4a1e0a4bfe0a4afe0a4
```

```
bee0a481e0a495e0a58de0a4afe0a58be0a482e0a495e0a4bfe0a4b8e0a581e0
a4b0e0a495e0a58de0a4b7e0a4bee0a4aae0a4b9e0a581e0a481e0a49ae0a4a4
e0a580e0a4aae0a58de0a4b0e0a4ace0a482e0a4a7e0a4a8e0a49fe0a4bfe0a4
aae0a58de0a4aae0a4a3e0a580e0a495e0a58de0a4b0e0a4bfe0a495e0a587e0
a49fe0a4aae0a58de0a4b0e0a4bee0a4b0e0a482e0a4ade0a4aae0a58de0a4b0
e0a4bee0a4aae0a58de0a4a4e0a4aee0a4bee0a4b2e0a4bfe0a495e0a58be0a4
82e0a4b0e0a4abe0a4bce0a58de0a4a4e0a4bee0a4b0e0a4a8e0a4bfe0a4b0e0
a58de0a4aee0a4bee0a4a3e0a4b2e0a4bfe0a4aee0a4bfe0a49fe0a587e0a4a1
6465736372697074696f6e2220636f6e74656e743d22646f63756d656e742e6c
6f636174696f6e2e70726f742e676574456c656d656e747342795461674e616d
65283c21444f43545950452068746d6c3e0a3c68746d6c203c6d657461206368
61727365743d227574662d38223e3a75726c2220636f6e74656e743d22687474
703a2f2f2e637373222072656c3d227374796c657368656574227374796c6520
747970653d22746578742f637373223e747970653d22746578742f6373732220
687265663d2277332e6f72672f313939392f7868746d6c2220786d6c74797065
3d22746578742f6a617661736372697074222206d6574686f643d226765742220
616374696f6e3d226c696e6b2072656c3d227374796c657368656574220203d
20646f63756d656e742e676574456c656d656e74747970653d22696d6167652f
782d69636f6e22202f3e63656c6c70616464696e673d2230222063656c6c7370
2e6373732220747970653d22746578742f63737322203c2f613e3c2f6c693e3c
6c693e3c6120687265663d22222077696474683d22312220686569676874 3d22
3122223e3c6120687265663d22687474703a2f2f7777772e7374796c653d2264
6973706c61793a6e6f6e653b223e616c7465726e617465222074797065 3d2261
70706c692d2f2f5733432f2f445444205848544d4c20312e3020656c6c737061
63696e673d2230222063656c6c706164207479065 3d2268696464656e222076
616c75653d222f613e266e6273703b3c7370616e20726f6c653d22730a3c696e
707574207479065 3d2268696464656e22206c616e67756167653d224a617661
536372697074222020646f63756d656e742e676574456c656d656e747342673d
2230222063656c6c73706163696e673d223022207970653d22746578742f6373
7322206d656469613d22747970653d22746578742f6a6176617363726970742 7
7769746820746865206578636574696f6e206f66207970653d22746578742f
637373222072656c3d22737420686569676874 3d223122207696474683d2231
22203d272b656e636f6465555249436f6d706f6e656e74283c6c696e6b207265
6c3d22616c7465726e61746522200a626f64792c2074722c20696e7075742c20
746578746d657461206e616d653d22726f626f74732220636f6e6d6574686f64
3d22706f737422206163746963696f6e3d223e0a3c6120687265663d22687474703a
2f2f7777772e637373222072656c3d227374796c657368656574227422203c2f6469
763e3c2f6469763e3c64697620636c6173736c616e67756167653d226a617661
736372697074223e617269612d68696464656e3d2274727565223ec2b73c7269
707422207479065 3d22746578742f6a617661736c3d303b7d2928293b0a2866
756e6374696f6e28297b6261636b67726f756e642d696d6167653a2075726c28
2f613e3c2f6c693e3c6c693e3c6120687265663d226809093c6c693e3c612068
7265663d22687474703a2f2f61746f722220617269612d68696464656e3d2274
72753e203c6120687265663d22687474703a2f2f7777772e6c616e6775616765
3d226a617661736372697074222202f6f7074696f6e3e0a3c6f7074696f6e2076
616c75652f6469763e3c2f6469763e3c64697620636c6173733d7261746f7222
20617269612d68696464656e3d227472653d286e6577204461746 5292e676574
54696d652829706f7274756775c3aa732028646f2042726173696c29d0bed180
```

```
d0b3d0b0d0bdd0b8d0b7d0b0d186d0b8d0b8d0b2d0bed0b7d0bcd0bed0b6d0bd
d0bed181d182d18cd0bed0b1d180d0b0d0b7d0bed0b2d0b0d0bdd0b8d18fd180
d0b5d0b3d0b8d181d182d180d0b0d186d0b8d0b8d0b2d0bed0b7d0bcd0bed0b6
d0bdd0bed181d182d0b8d0bed0b1d18fd0b7d0b0d182d0b5d0bbd18cd0bdd0b0
3c21444f43545950452068746d6c205055424c494320226e742d547970652220
636f6e74656e743d22746578742f3c6d65746120687474702d65717569763d22
436f6e746572616e736974696f6e616c2f2f454e222022687474703a3c68746d
6c20786d6c6e733d22687474703a2f2f7777772d2f2f5733432f2f4454442058
48544d4c20312e3020544454442f7868746d6c312d7472616e736974696f6e61
6c2f2f7777772e77332e6f72672f54522f7868746d6c312f7065203d20277465
78742f6a617661736372697074273b3c6d657461206e616d653d226465736372
697074696f6e706172656e744e6f64652e696e736572744265666f72653c696e
70757420747970653d2268696464656e22206e616a732220747970653d227465
78742f6a617661736372692864 6f63756d656e74292e72656164792866756e63
7469736372697074207479706 53d22746578742f6a61766173696d6167652220
636f6e74656e743d22687474703a2f2f55412d436f6d70617469626c65222063
6f6e74656e743d746d6c3b20636861727365743d7574662d3822202f3e0a6c69
6e6b2072656c3d2273686f72746375742069636f6e3c6c696e6b2072656c3d22
7374796c657368657422203c2f7363726970743e0a3c736372697074207479
70653d3d20646f63756d656e742e637265617465456c656d656e3c6120746172
6765743d225f626c616e6b2220687265663d20646f63756d656e742e67657445
6c656d656e747342696e70757420747970653d227465787422206e616d653d61
2e74797065203d2027746578742f6a617661736372696e70757420747970653d
2268696464656e22206e616d6568746d6c3b20636861727365743d7574662d38
22202f3e647464223e0a3c68746d6c20786d6c6e733d22687474702d2f2f5733
432f2f4454442048544d4c20342e30312054656e747342795461674e616d6528
27736372697074272969 6e70757420747970653d2268696464656e22206e616d
3c736372697074207479706 53d22746578742f6a617661732220737479 6c653d
22646973706c61793a6e6f6e653b223e646f63756d656e742e676574456c656d
656e7442794964283d646f63756d656e742e637265617465456c656d656e7428
2720747970653d2746578742f6a617661736372697074276 96e707574207479
70653d227465787422206e616d653d22642e676574456c656d656e7473427954
61674e616d6528736e6963616c2220687265663d22687474703a2f2f7777772e
432f2f4454442048544d4c20342e3031205472616e7369743c7374796c652074
7970653d22746578742f637373223e0a0a3c7374796c6520747970653d227465
78742f637373223e696f6e616c2e647464223e0a3c68746d6c20786d6c6e733d
687474702d65717569763d22436f6e74656e742d5479706564696e673d223022
2063656c6c73706163696e673d22302268746d6c3b20636861727365743d7574
662d3822202f3e0a207374796c653d22646973706c61793a6e6f6e653b223e3c
3c6c693e3c6120687265663d22687474703a2f2f7777772e20747970653d2774
6578742f6a617661736372697074273ed0b4d0b5d18fd182d0b5d0bbd18cd0bd
d0bed181d182d0b8d181d0bed0bed182d0b2d0b5d182d181d182d0b2d0b8d0b8
d0bfd180d0bed0b8d0b7d0b2d0bed0b4d181d182d0b2d0b0d0b1d0b5d0b7d0be
d0bfd0b0d181d0bdd0bed181d182d0b8e0a4aae0a581e0a4b8e0a58de0a4a4e0
a4bfe0a495e0a4bee0a495e0a4bee0a482e0a497e0a58de0a4b0e0a587e0a4b8
e0a489e0a4a8e0a58de0a4b9e0a58be0a482e0a4a8e0a587e0a4b5e0a4bfe0a4
a7e0a4bee0a4a8e0a4b8e0a4ade0a4bee0a4abe0a4bfe0a495e0a58de0a4b8e0
a4bfe0a482e0a497e0a4b8e0a581e0a4b0e0a495e0a58de0a4b7e0a4bfe0a4a4
```

```
e0a495e0a589e0a4aae0a580e0a4b0e0a4bee0a487e0a49fe0a4b5e0a4bfe0a4
9ce0a58de0a49ee0a4bee0a4aae0a4a8e0a495e0a4bee0a4b0e0a58de0a4b0e0
a4b5e0a4bee0a488e0a4b8e0a495e0a58de0a4b0e0a4bfe0a4afe0a4a4e0a4be
```

The number of words for each length is given by the following bit-depth array:

```
NDBITS :=  0,  0,  0,  0, 10, 10, 11, 11, 10, 10,
          10, 10, 10,  9,  9,  8,  7,  7,  8,  7,
           7,  6,  6,  5,  5
```

Appendix B. List of Word Transformations

The string literals are in C format, with respect to the use of backslash escape characters.

In order to generate a length and check value, the transforms can be converted to a series of bytes, where each transform is the prefix sequence of bytes plus a terminating zero byte, a single-byte value identifying the transform, and the suffix sequence of bytes plus a terminating zero. The value for the transforms are 0 for Identity, 1 for FermentFirst, 2 for FermentAll, 3 to 11 for OmitFirst1 to OmitFirst9, and 12 to 20 for OmitLast1 to OmitLast9. The byte sequences that represent the 121 transforms are then concatenated to a single sequence of bytes. The length of that sequence is 648 bytes, and the CRC-32 is 0x3d965f81.

ID	Prefix	Transform	Suffix
0	""	Identity	""
1	""	Identity	" "
2	" "	Identity	" "
3	""	OmitFirst1	""
4	""	FermentFirst	" "
5	""	Identity	" the "
6	" "	Identity	""
7	"s "	Identity	" "
8	""	Identity	" of "
9	""	FermentFirst	""
10	""	Identity	" and "
11	""	OmitFirst2	""
12	""	OmitLast1	""
13	", "	Identity	" "
14	""	Identity	", "
15	" "	FermentFirst	" "
16	""	Identity	" in "
17	""	Identity	" to "
18	"e "	Identity	" "

19	""	Identity	"\""
20	""	Identity	"."
21	""	Identity	"\">"
22	""	Identity	"\n"
23	""	OmitLast3	""
24	""	Identity	"]"
25	""	Identity	" for "
26	""	OmitFirst3	""
27	""	OmitLast2	""
28	""	Identity	" a "
29	""	Identity	" that "
30	" "	FermentFirst	""
31	""	Identity	". "
32	"."	Identity	""
33	" "	Identity	", "
34	""	OmitFirst4	""
35	""	Identity	" with "
36	""	Identity	"'"
37	""	Identity	" from "
38	""	Identity	" by "
39	""	OmitFirst5	""
40	""	OmitFirst6	""
41	" the "	Identity	""
42	""	OmitLast4	""
43	""	Identity	". The "
44	""	FermentAll	""
45	""	Identity	" on "
46	""	Identity	" as "
47	""	Identity	" is "
48	""	OmitLast7	""
49	""	OmitLast1	"ing "
50	""	Identity	"\n\t"
51	""	Identity	":"
52	" "	Identity	". "
53	""	Identity	"ed "
54	""	OmitFirst9	""
55	""	OmitFirst7	""
56	""	OmitLast6	""
57	""	Identity	"("
58	""	FermentFirst	", "
59	""	OmitLast8	""
60	""	Identity	" at "
61	""	Identity	"ly "
62	" the "	Identity	" of "
63	""	OmitLast5	""
64	""	OmitLast9	""
65	" "	FermentFirst	", "
66	""	FermentFirst	"\""

67	"."	Identity	"("	
68	""	FermentAll	" "	
69	""	FermentFirst	"\">"	
70	""	Identity	"=\""	
71	" "	Identity	"."	
72	".com/"	Identity	""	
73	" the "	Identity	" of the "	
74	""	FermentFirst	"’"	
75	""	Identity	". This "	
76	""	Identity	","	
77	"."	Identity	" "	
78	""	FermentFirst	"("	
79	""	FermentFirst	"."	
80	""	Identity	" not "	
81	" "	Identity	"=\""	
82	""	Identity	"er "	
83	" "	FermentAll	" "	
84	""	Identity	"al "	
85	" "	FermentAll	""	
86	""	Identity	"=’"	
87	""	FermentAll	"\""	
88	""	FermentFirst	". "	
89	" "	Identity	"("	
90	""	Identity	"ful "	
91	" "	FermentFirst	". "	
92	""	Identity	"ive "	
93	""	Identity	"less "	
94	""	FermentAll	"’"	
95	""	Identity	"est "	
96	" "	FermentFirst	"."	
97	""	FermentAll	"\">"	
98	" "	Identity	"=’"	
99	""	FermentFirst	","	
100	""	Identity	"ize "	
101	""	FermentAll	"."	
102	"\xc2\xa0"	Identity	""	
103	" "	Identity	","	
104	""	FermentFirst	"=\""	
105	""	FermentAll	"=\""	
106	""	Identity	"ous "	
107	""	FermentAll	", "	
108	""	FermentFirst	"=’"	
109	" "	FermentFirst	","	
110	" "	FermentAll	"=\""	
111	" "	FermentAll	", "	
112	""	FermentAll	","	
113	""	FermentAll	"("	
114	""	FermentAll	". "	

115	" "	FermentAll	"."
116	""	FermentAll	"=’"
117	" "	FermentAll	". "
118	" "	FermentFirst	"=\""
119	" "	FermentAll	"=’"
120	" "	FermentFirst	"=’"

Appendix C. Computing CRC-32 Check Values

For the purpose of this specification, we define the CRC-32 check value of a byte sequence with the following C language function:

```
uint32_t CRC32(const uint8_t* v, const int len) {
   const uint32_t poly = 0xedb88320UL;
   uint32_t crc, c;
   int i, k;
   crc = 0xffffffffUL;
   for (i = 0; i < len; ++i) {
      c = (crc ^ v[i]) & 0xff;
      for (k = 0; k < 8; k++) c = c & 1 ? poly ^ (c >> 1) : c >> 1;
      crc = c ^ (crc >> 8);
   }
   return crc ^ 0xffffffffUL;
}
```

Appendix D. Source Code

Source code for a C language implementation of a brotli-compliant compressor and decompressor is available in the brotli open-source project <https://github.com/google/brotli>.

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