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Brotli Compressed Data Format
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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.

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Brotli

October 2015

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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, and hence 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, and hence 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, and 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 well as the best currently available specialized algorithms.

[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 [[RFC 1951](#)]. 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 2.0 web font file format [\[WOFF2\]](#), therefore this specification is also intended for implementers of WOFF 2.0 compressors and decompressors.

[1.3](#). Scope

The specification 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 which 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, and since we write numbers with the most- significant digit on the left, we also write bytes with the most- significant bit 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:

```
+-----+
|76543210|
+-----+
```

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:

```

0          1
+-----+-----+
|00001000|00000010|
+-----+-----+
^         ^
|         |
|         + more significant byte = 2 x 256
+ less significant byte = 8

```

[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. We must therefore 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).

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 1 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 16 to 24. The possible sliding window sizes range from 64 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, 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: 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), a separate set of prefix codes are for literals, and a third 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 defines the number of literals that immediately follow and the copy length, and the distance defines how far back to go for the copy, used in combination with the copy length. 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 element. 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 *BlockSwitch(t, n) switches to block type t for a count of n elements. Note that in this example 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 is 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 and the matrix of the prefix code indices 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 and 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.

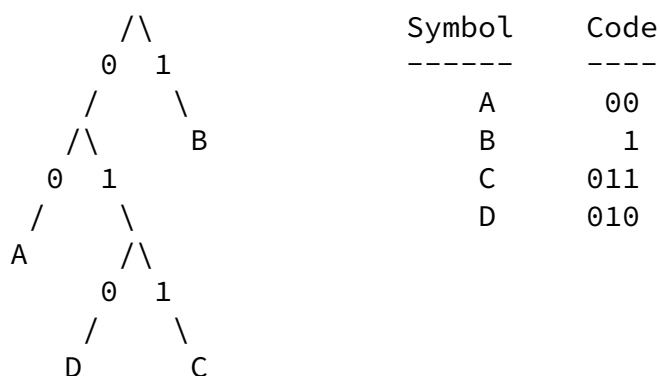
A meta-block may also be empty, which generates no uncompressed data at all. An empty meta-block may contain metadata information as bytes starting on byte boundaries, which are not part of either the sliding window or the uncompressed data. Thus, these metadata bytes can not be used to create matching 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; then 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:



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

which 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 [\[HUFFMAN\]](#) in Chapter 5, references for additional information on Huffman codes.)

Note that in the brotli format, 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 Chapter 5, references 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

I.e., 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 other parameters.

[3.4.](#) Simple prefix codes

The first two bits of the compressed representation of each prefix code distinguishes between simple and complex prefix codes. If this

value is 1, then a simple prefix code follows. Otherwise the value indicates the number of leading zeros.

A simple prefix code can have only 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 = # 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. E.g. for the alphabet of literal bytes, ALPHABET_BITS is 8. The value of each of the NSYM symbols above is the value of the ALPHABETS_BITS width integer value. (If the integer value is greater than or equal to the alphabet size, 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 Paragraph 3.2, above. 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:

$$\text{repeat count} = (4 * (\text{repeat count} - 2)) + (3 - 6 \text{ on the next 2 bits})$$
- 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.
(3 bits of length)
A repeated code length code of 17 modifies the repeat count of the previous one as follows:

$$\text{repeat count} = (8 * (\text{repeat count} - 2)) + (3 - 10 \text{ on the next 3 bits})$$

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 or 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 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 static prefix code (where the bits shown are reversed in the actual compressed stream):

Symbol	Code
-----	----
0	00
1	1110
2	110
3	01
4	10
5	1111

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

2 bits: HSKIP, values of 0, 2 or 3 represent the respective number of skipped code lengths. 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 static prefix 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 lengths 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 $(32 \gg \text{code length})$ 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. E.g. 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 lengths symbols, 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 $(32768 \gg \text{code length})$ over all the non-zero code lengths in the alphabet, including those encoded using repeat code(s) of 16, must 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 $\langle \text{distance code, extra bits} \rangle$. 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:

$$\text{POSTFIX_MASK} = ((1 \ll \text{NPOSTFIX}) - 1)$$

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 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, third, fourth)-to-last distance" means the (second, third, fourth)-to-last distance that was not represented by a 0 distance symbol. Similarly, distances that represent static dictionary words (see [Section 8](#).) are not pushed to the ring buffer of last distances.

The next NDIRECT distance symbols, from 16 to 15 + NDIRECT, represent

distances from 1 to NDIRECT. Neither the distance special 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:

$$\text{ndistbits} = 1 + ((\text{dcode} - \text{NDIRECT} - 16) \gg (\text{NPOSTFIX} + 1))$$

The maximum number of extra bits is 24, therefore the size of the distance symbol alphabet is $(16 + \text{NDIRECT} + (48 \ll \text{NPOSTFIX}))$.

Given a distance symbol "dcode" ($\geq 16 + \text{NDIRECT}$), 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:

Extra			Extra			Extra		
Code	Bits	Lengths	Code	Bits	Lengths	Code	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:

Extra			Extra			Extra		
Code	Bits	Lengths	Code	Bits	Lengths	Code	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:

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Insert length code	Copy length code		
	0-7	8-15	16-23
0-7	0-63	64-127	<--- distance symbol 0
0-7	128-191	192-255	384-447
8-15	256-319	320-383	512-575
16-23	448-511	576-639	640-703

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 the lowest 3 bits of the insert-and-copy length code, and 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. Instead the block count for each category that has more than one type 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 NBLTYPE_{SL}, NBLTYPE_{SI}, and NBLTYPE_{SD} 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 $[0..NBLTYPEESL-1]$, $[0..NBLTYPEESI-1]$, and $[0..NBLTYPEESD-1]$, respectively. From this it follows that the alphabet size of literal, insert-and-copy length and distance block type codes is $NBLTYPEES + 2$, $NBLTYPEESI + 2$ and $NBLTYPEESD + 2$, respectively.

Each block count in the compressed data is represented with a pair $\langle \text{block count code, extra bits} \rangle$. 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:

Extra			Extra			Extra		
Code	Bits	Lengths	Code	Bits	Lengths	Code	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 context ID and the block type. 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 $\langle \text{context ID, block type} \rangle$ 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 if these bytes are produced by backward 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:

- * MSB6, where the Context ID is the value of six most significant bits of p1,
- * LSB6, where the Context ID is the value of six least 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.

$$\text{Lut0} :=$$
[illegible]

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 zlib CRC-32 (ITU-T Recommendation V.42) check values 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]

```

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

The 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 $64 * \text{NBLTYPE_SL}$ for literals, and $4 * \text{NBLTYPE_SD}$ 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 map is encoded as a one-dimensional array, $\text{CMAPL}[0..(64 * \text{NBLTYPE_SL} - 1)]$ and $\text{CMAPD}[0..(4 * \text{NBLTYPE_SD} - 1)]$.

The index of the prefix code for encoding a literal or distance code with context ID "cid" and block type "bltype" is

index of literal prefix code = $\text{CMAPL}[\text{bltype} * 64 + \text{cid}]$

index of distance prefix code = $\text{CMAPD}[\text{bltype} * 4 + \text{cid}]$

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

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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.

For the encoding of NTREES see [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;
}
}

```

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. The difference between these distances and the first invalid distance value is treated as 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 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, OmitLast1, ..., OmitLast9, UppercaseFirst, UppercaseAll,
OmitFirst1, ..., OmitFirst9
```

The form of these elementary transforms are as follows:

```
Identity(word) = word
```

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

```
UppercaseFirst(word) = first UTF-8 character of word upper-cased
```

UppercaseAll(word) = all UTF-8 characters of word upper-cased

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

For the purposes of UppercaseAll, word is parsed into UTF-8 characters and converted to upper-case by taking 1 - 3 bytes at a time, using the algorithm below:

```
i = 0
while i < length(word):
    if word[i] < 192:
        if word[i] >= 97 and word[i] <= 122:
            word[i] = word[i] ^ 32
        i = i + 1
    else if word[i] < 224:
        if i + 1 < length(word):
            word[i + 1] = word[i + 1] ^ 32
        i = i + 2
    else:
        if i + 2 < length(word):
            word[i + 2] = word[i + 2] ^ 5
        i = i + 3
```

For UppercaseFirst, the same algorithm is used, but the loop is executed only once.

[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.

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:

$$\text{window size} = (1 \ll \text{WBITS}) - 16$$

[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, # of nibbles to represent the uncompressed length, encoded as follows: if set to 3, MNIBBLES is 0, otherwise MNIBBLES is the value of this field plus 4. 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, # of bytes to represent metadata length

- MSKIPBYTES x 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

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

MNIBBLES x 4 bits: MLEN - 1, where MLEN is the length
of the meta-block uncompressed data in bytes (if the
number of nibbles 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: NBLTYPESEL, # 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 NBLTYPESEL >= 2

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

Block count code + Extra bits for first literal block

count, appears only if NBLTYPEESL ≥ 2

1-11 bits: NBLTYPEESI, # 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, only if NBLTYPEESI ≥ 2

Prefix code over the block count code alphabet for insert-and-copy block counts, only if NBLTYPEESI ≥ 2

Block count code + Extra bits for first insert-and-copy block count, only if NBLTYPEESI ≥ 2

1-11 bits: NBLTYPEESD, # 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 NBLTYPEESD ≥ 2

Prefix code over the block count code alphabet for distance block counts, only if NBLTYPEESD ≥ 2

Block count code + Extra bits for first distance block count, only if NBLTYPEESD ≥ 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

NBLTYPEESL \times 2 bits: context mode for each literal block type

1-11 bits: NTREESL, # of literal prefix trees, encoded with the same variable length code as NBLTYPEESL

Literal context map, encoded as described in Paragraph 7.3, appears only if NTREESL ≥ 2 , otherwise the context map has only zero values

1-11 bits: NTREESD, # of distance prefix trees, encoded with the same variable length code as NBLTYPEESD

Distance context map, encoded as described in Paragraph 7.3, appears only if NTREESD ≥ 2 , otherwise the context map has only zero values

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NTREESL prefix codes for literals

NBLTYPEESI 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 NBLTYPEESI ≥ 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 NBLTYPEESI ≥ 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 NBLTYPEESL ≥ 2 and the previous literal block count is zero

Block count code + Extra bits for next literal block count, appears only if NBLTYPEESL ≥ 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 Paragraph 7.3.

Block type code for next distance block type, appears only if NBLTYPEESD ≥ 2 and the previous distance block count is zero

Block count code + Extra bits for next distance block
length, 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 current distance block type index,
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 MSKIPLLEN
        skip any bits up to the next byte boundary
        skip MSKIPLLEN 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 NBLTYPESEi
    if NBLTYPESEi >= 2
        read prefix code for block types, HTREE_BTTYPE_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 268435456
    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 prefix codes for literals, HTREEL[]
    read array of prefix codes for insert-and-copy, HTREEI[]
    read array of prefix codes for distances, HTREED[]
    do
        if BLEN_I is zero
            read block type using HTREE_BTTYPE_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, ILEN, CLEN with HTREEI[BTTYPE_I]
    loop for ILEN
        if BLEN_L is zero
            read block type using HTREE_BTTYPE_L and set BTTYPE_L
            save previous block type
            read block count using HTREE_BLEN_L and set BLEN_L
            decrement BLEN_L
            look up context mode CMODE[BTTYPE_L]
            compute context ID, CIDL from last two uncompressed bytes
            read literal using HTREEL[CMAPL[64 * BTTYPE_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_BTTYPE_D and set BTTYPE_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 with HTREED[CMAPD[4 * BTTYPE_D + CIDD]]
            compute distance by distance short code substitution
            move backwards distance bytes in the uncompressed data and
            copy CLEN bytes from this position to the uncompressed
            stream, or 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. 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 discarded. A possible attack against a system containing a decompressor implementation (e.g. a web browser) is to exploit a buffer overflow caused by an invalid compressed data. Therefore decompressor implementations should perform bound-checking for each memory access that result from values decoded from the compressed stream.

[12. IANA Considerations](#)

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

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+-----+-----+-----+		+-----+-----+-----+	
Name Description		Reference	
+-----+-----+-----+		+-----+-----+-----+	
bro Brotli Compressed Data Format		RFCXXXX	
+-----+-----+-----+		+-----+-----+-----+	

[13. Informative References](#)

- [HUFFMAN] Huffman, D. A., "A Method for the Construction of Minimum Redundancy Codes", Proceedings of the Institute of Radio Engineers, September 1952, Volume 40, Number 9, pp. 1098-1101.
- [LZ77] Ziv J., Lempel A., "A Universal Algorithm for Sequential Data Compression", IEEE Transactions on Information

- [RFC1951] Deutsch, P., "DEFLATE Compressed Data Format Specification version 1.3", [RFC 1951](http://www.ietf.org/rfc/rfc1951.txt), Aladdin Enterprises, May 1996.
<http://www.ietf.org/rfc/rfc1951.txt>
- [WOFF2] Levantovsky, V. (ed.), Levien, R. (ed.), "WOFF File Format 2.0", W3C WebFonts Working Group,
<http://www.w3.org/TR/WOFF2/>

14. Source code

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

15. Acknowledgements

The authors would like to thank Mark Adler for providing helpful review comments, validating the specification by writing an independent decompressor and suggesting improvements to the format and the text of the specification.

Appendix A. Static dictionary data

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

```
74696d65646f776e6c6966656c6566746261636b636f64656461746173686f77
6f6e6c7973697465636974796f70656e6a7573746c696b6566726565776f726b
74657874796561726f766572626f64796c6f7665666f726d626f6b706c6179
```

```
6c6976656c696e6568656c70686f6d65736964656d6f7265776f72646c6f6e67
7468656d7669657766696e64706167656461797366756c6c686561647465726d
656163686172656166726f6d747275656d61726b61626c6575706f6e68696768
646174656c616e646e6577736576656e6e65787463617365626f7468706f7374
757365646d61646568616e6468657265776861746e616d654c696e6b626c6f67
73697a656261736568656c646d616b656d61696e757365722729202b686f6c64
656e6473776974684e65777372656164776572657369676e74616b6568617665
67616d657365656e63616c6c7061746877656c6c706c75736d656e7566696c6d
```


706172746a6f696e746869736c697374676f6f646e6565647761797377657374
6a6f62736d696e64616c736f6c6f676f72696368757365736c6173747465616d
61726d79666f6f646b696e6777696c6c65617374776172646265737466697265
506167656b6e6f77617761792e706e676d6f76657468616e6c6f616467697665
73656c666e6f74656d756368666565646d616e79726f636b69636f6e6f6e6365
6c6f6f6b6869646564696564486f6d6572756c65686f7374616a6178696e666f
636c75626c6177736c65737368616c66736f6d65737563687a6f6e6531303025
6f6e65736361726554696d6572616365626c7565666f75727765656b66616365
686f706567617665686172646c6f73747768656e7061726b6b65707470617373
73686970726f6f6d48544d4c706c616e54797065646f6e65736176656b656570
666c61676c696e6b736f6c6466697665746f6f6b72617465746f776e6a756d70
746875736461726b6361726466696c6566656172737461796b696c6c74686174
66616c6c6175746f657665722e636f6d74616c6b73686f70766f746564656570
6d6f6465726573747475726e626f726e62616e6466656c6c726f736575726c28
736b696e726f6c65636f6d6561637473616765736d656574676f6c642e6a7067
6974656d7661727966656c747468656e73656e6464726f7056696577636f7079
312e30223c2f613e73746f70656c73656c696573746f75727061636b2e676966
706173746373733f677261796d65616e2667743b7269646573686f746c617465
73616964726f6164766172206665656c6a6f686e7269636b706f727466617374
2755412d646561643c2f623e706f6f7262696c6c74797065552e532e776f6f64
6d7573743270783b496e666f72616e6b7769646577616e7477616c6c6c656164
5b305d3b7061756c776176657375726524282723776169746d61737361726d73
676f65736761696e6c616e6770616964212d2d206c6f636b756e6974726f6f74
77616c6b6669726d77696665786d6c22736f6e6774657374323070786b696e64
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7261696e666c6f77626162797370616e736179733470783b3670783b61727473
666f6f747265616c77696b696865617473746570747269706f72672f6c616b65
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6a756c797461736b3170783b676f616c67726577736c6f776564676569643d22
736574733570783b2e6a733f3430707869662028736f6f6e736561746e6f6e65
747562657a65726f73656e747265656466616374696e746f676966746861726d
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426c756564696e673330302c62616c6c666f72646561726e77696c64626f782e
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6167656467726579474554226561736561696d736769726c616964733870783b
6e617679677269647469707323393939776172736c61647963617273293b207d
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2e6a7327323030706475616c626f61742e4a5047293b0a7d71756f74293b0a0a

[illegible]

6568756d616e6578697374676f696e676d6f7669657468697264626173696370
65616365737461676577696474686c6f67696e696465617377726f7465706167

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65737573657273647269766573746f7265627265616b736f757468766f696365
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64686f727365466f6375737261697365626f786573547261636b656d656e743c
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77616e7473746869732e7265736574776865656c6769726c732f6373732f3130
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d0b5d0b3d0b8d181d182d180d0b0d186d0b8d0b8d0b2d0bed0b7d0bcd0bed0b6
d0bdd0bed181d182d0b8d0bed0b1d18fd0b7d0b0d182d0b5d0bbd18cd0bdd0b0
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6c2f2f7777772e77332e6f72672f54522f7868746d6c312f7065203d20277465
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78742f6a6176617363726928646f63756d656e74292e72656164792866756e63
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6e6b2072656c3d2273686f72746375742069636f6e3c6c696e6b2072656c3d22
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6765743d225f626c616e6b2220687265663d20646f63756d656e742e67657445
6c656d656e747342696e70757420747970653d227465787422206e616d653d61
2e74797065203d2027746578742f6a617661736372696e70757420747970653d

2268696464656e22206e616d6568746d6c3b20636861727365743d7574662d38
22202f3e647464223e0a3c68746d6c20786d6c6e733d22687474702d2f2f5733
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2720747970653d27746578742f6a61766173637269707427696e707574207479
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61674e616d6528736e6963616c2220687265663d22687474703a2f2f7777772e
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78742f637373223e696f6e616c2e647464223e0a3c68746d6c20786d6c6e733d
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662d3822202f3e0a207374796c653d22646973706c61793a6e6f6e653b223e3c
3c6c693e3c6120687265663d22687474703a2f2f7777772e20747970653d2774
6578742f6a617661736372697074273ed0b4d0b5d18fd182d0b5d0bbd18cd0bd
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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 UppercaseFirst, 2 for UppercaseAll, 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 zlib CRC is 0x3d965f81.

ID	Prefix	Transform	Suffix
--	-----	-----	-----
0	""	Identity	""
1	""	Identity	" "
2	" "	Identity	" "
3	""	OmitFirst1	""
4	""	UppercaseFirst	" "
5	""	Identity	" the "
6	" "	Identity	""
7	"s "	Identity	" "
8	""	Identity	" of "
9	""	UppercaseFirst	""
10	""	Identity	" and "
11	""	OmitFirst2	""
12	""	OmitLast1	""
13	", "	Identity	" "
14	""	Identity	", "
15	" "	UppercaseFirst	" "
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	" "	UppercaseFirst	""
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	""	UppercaseAll	""
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	""	UppercaseFirst	", "
59	""	OmitLast8	""
60	""	Identity	" at "
61	""	Identity	"ly "
62	" the "	Identity	" of "
63	""	OmitLast5	""
64	""	OmitLast9	""
65	" "	UppercaseFirst	", "
66	""	UppercaseFirst	"\""
67	". "	Identity	"("
68	""	UppercaseAll	" "
69	""	UppercaseFirst	"\">"
70	""	Identity	"=\\""
71	" "	Identity	". "
72	".com/"	Identity	""
73	" the "	Identity	" of the "
74	""	UppercaseFirst	""
75	""	Identity	". This "

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76	""	Identity	","
77	","	Identity	" "
78	""	UppercaseFirst	"("
79	""	UppercaseFirst	","
80	""	Identity	" not "
81	" "	Identity	"=\\"
82	""	Identity	"er "
83	" "	UppercaseAll	" "
84	""	Identity	"al "
85	" "	UppercaseAll	""
86	""	Identity	"='"
87	""	UppercaseAll	"\\"
88	""	UppercaseFirst	","
89	" "	Identity	"("
90	""	Identity	"ful "
91	" "	UppercaseFirst	","
92	""	Identity	"ive "
93	""	Identity	"less "
94	""	UppercaseAll	""
95	""	Identity	"est "
96	" "	UppercaseFirst	","
97	""	UppercaseAll	"\>"
98	" "	Identity	"='"
99	""	UppercaseFirst	","
100	""	Identity	"ize "
101	""	UppercaseAll	","
102	"\xc2\xa0"	Identity	""
103	" "	Identity	","
104	""	UppercaseFirst	"=\\"
105	""	UppercaseAll	"=\\"
106	""	Identity	"ous "
107	""	UppercaseAll	","
108	""	UppercaseFirst	"='"
109	" "	UppercaseFirst	","
110	" "	UppercaseAll	"=\\"
111	" "	UppercaseAll	","
112	""	UppercaseAll	","
113	""	UppercaseAll	"("
114	""	UppercaseAll	","
115	" "	UppercaseAll	","
116	""	UppercaseAll	"='"
117	" "	UppercaseAll	","
118	" "	UppercaseFirst	"=\\"

119	" "	UppercaseAll	"='"
120	" "	UppercaseFirst	"='"

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