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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.

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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 (1sb), 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:

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

Within a computer, a number may occupy multiple bytes. All multibyte 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:

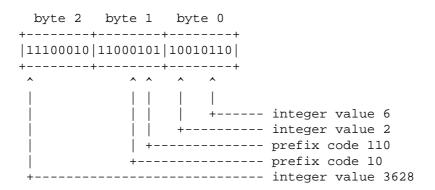
1.5.1. Packing into Bytes

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 metablocks. 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 metablock.

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:

- 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</pre>
```

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 metablock 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.

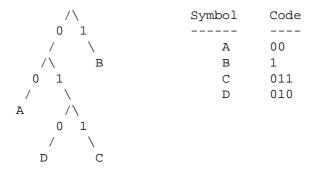
A meta-block may also be empty, which generates no uncompressed data at all. An empty meta-block may contain metadata information as bytes starting on byte boundaries, which are not part of either the sliding window or the uncompressed data. Thus, these metadata bytes cannot be used to create matching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



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
В	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]++;
    }
}</pre>
```

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
В	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, \ldots, 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, \ldots, 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 \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 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:

- o 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.)
- o 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.

o 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</pre>
```

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	a.		Extra	Э		Extra	a.
Code	Bits	Lengths	Code	Bits	Lengths	Code	Bits	Lengths
0	0	0	8	2	1013	16	6	130193
1	0	1	9	2	1417	17	7	194321
2	0	2	10	3	1825	18	8	322577
3	0	3	11	3	2633	19	9	5781089
4	0	4	12	4	3449	20	10	10902113
5	0	5	13	4	5065	21	12	21146209
6	1	6,7	14	5	6697	22	14	621022593
7	1	8,9	15	5	98129	23	24	2259416799809

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	э		Extra	a		Extra	a.
Code	Bits	Lengths	Code	Bits	Lengths	Code	Bits	Lengths
0	0	2	8	1	10,11	16	5	70101
1	0	3	9	1	12,13	17	5	102133
2	0	4	10	2	1417	18	6	134197
3	0	5	11	2	1821	19	7	198325
4	0	6	12	3	2229	20	8	326581
5	0	7	13	3	3037	21	9	5821093
6	0	8	14	4	3853	22	10	10942117
7	0	9	15	4	5469	23	24	211816779333

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

Insert	Copy	longth gods	
code		815	
-		 	
07	063 +	64127 	< distance symbol 0
07	 128191 	192255	384447
815	 256319 	320383	512575
1623	 448511 	576639	640703
-	+		+

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

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	a		Exti	ra		Extra	3.
Code	Bits	Lengths	Code	Bits	s Lengths	Code	Bits	Lengths
0	2	14	9	4	6580	18	7	369496
1	2	58	10	4	8196	19	8	497752
2	2	912	11	4	97112	20	9	7531264
3	2	1316	12	5	113144	21	10	12652288
4	3	1724	13	5	145176	22	11	22894336
5	3	2532	14	5	177208	23	12	43378432
6	3	3340	15	5	209240	24	13	843316624
7	3	4148	16	6	241304	25	24	1662516793840
8	4	4964	17	6	305368			

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 metablocks, 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 pl,
- * 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, 4, 4, 0, 0, 4, 0,
 8, 12, 16, 12, 12, 20, 12, 16, 24, 28, 12, 12, 32, 12, 36, 12,
 12, 48, 52, 52, 52, 48, 52, 52, 52, 48, 52, 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, 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
Lut1 :=
 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 1, 1, 1, 1,
 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 1, 1, 1,
 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 1, 1, 1, 1, 0,
```

```
Lut2 :=
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]</pre>
```

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:

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.

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;
    }
}</pre>
```

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:

```
 \begin{split} & \texttt{NWORDS[length]} = 0 & (if length < 4) \\ & \texttt{NWORDS[length]} = (1 << \texttt{NDBITS[length]}) & (if length >= 4) \\ \end{aligned}
```

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

 $\label{eq:condition} \begin{array}{lll} \text{OmitLastk(word) = the first (length(word) - k) bytes of word, or} \\ & & \text{empty string if length(word) < k} \end{array}$

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 \text{ and } word[pos] <= 122) {
         word[pos] = word[pos] ^ 32;
      return 1;
   } else if (word[pos] < 224) {</pre>
      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) {</pre>
      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:

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</pre>

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, $$\operatorname{\mathtt{must}}$$ 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 metablock 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	C
2	0001
34	x0011
58	xx0101
916	xxx0111
1732	xxxx1001
3364	xxxxx1011
65128	xxxxxx1101
129256	xxxxxxxx1111

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
   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 $\texttt{HTREE_BLEN_D}$ and set $\texttt{BLEN_D}$ decrement BLEN D

compute context ID, CIDD from CLEN

read distance code using $\mbox{HTREED[CMAPD[4*BTYPE_D + CIDD]]}$ 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. 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 74657874796561726f766572626f64796c6f7665666f726d626f6f6b706c6179 6c6976656c696e6568656c70686f6d65736964656d6f7265776f72646c6f6e67 7468656d7669657766696e64706167656461797366756c6c686561647465726d 656163686172656166726f6d747275656d61726b61626c6575706f6e68696768 646174656c616e646e6577736576656e6e65787463617365626f7468706f7374 757365646d61646568616e6468657265776861746e616d654c696e6b626c6f67 73697a656261736568656c646d616b656d61696e757365722729202b686f6c64 656e6473776974684e65777372656164776572657369676e74616b6568617665 67616d657365656e63616c6c7061746877656c6c706c75736d656e7566696c6d 706172746a6f696e746869736c697374676f6f646e6565647761797377657374 6a6f62736d696e64616c736f6c6f676f72696368757365736c6173747465616d 61726d79666f6f646b696e6777696c6c65617374776172646265737466697265 506167656b6e6f77617761792e706e676d6f76657468616e6c6f616467697665 73656c666e6f74656d756368666565646d616e79726f636b69636f6e6f6e6365 6c6f6f6b6869646564696564486f6d6572756c65686f7374616a6178696e666f 636c75626c6177736c65737368616c66736f6d65737563687a6f6e6531303025 686f706567617665686172646c6f73747768656e7061726b6b65707470617373 73686970726f6f6d48544d4c706c616e54797065646f6e65736176656b656570 666c61676c696e6b736f6c6466697665746f6f6b72617465746f776e6a756d70 746875736461726b6361726466696c6566656172737461796b696c6c74686174 66616c6c6175746f657665722e636f6d74616c6b73686f70766f746564656570 736b696e726f6c65636f6d6561637473616765736d656574676f6c642e6a7067 6974656d7661727966656c747468656e73656e6464726f7056696577636f7079 312e30223c2f613e73746f70656c73656c696573746f75727061636b2e676966 706173746373733f677261796d65616e2667743b7269646573686f746c617465 73616964726f6164766172206665656c6a6f686e7269636b706f727466617374 2755412d646561643c2f623e706f6f7262696c6c74797065552e532e776f6f64 6d7573743270783b496e666f72616e6b7769646577616e7477616c6c6c656164 5b305d3b7061756c776176657375726524282723776169746d61737361726d73 676f65736761696e6c616e6770616964212d2d206c6f636b756e6974726f6f74 77616c6b6669726d77696665786d6c22736f6e6774657374323070786b696e64 726f7773746f6f6c666f6e746d61696c73616665737461726d617073636f7265 7261696e666c6f77626162797370616e736179733470783b3670783b61727473 666f6f747265616c77696b696865617473746570747269706f72672f6c616b65 7765616b746f6c64466f726d6361737466616e7362616e6b7665727972756e73 6a756c797461736b3170783b676f616c67726577736c6f776564676569643d22 736574733570783b2e6a733f3430707869662028736f6f6e736561746e6f6e65 747562657a65726f73656e747265656466616374696e746f676966746861726d

3138707863616d6568696c6c626f6c647a6f6f6d766f69646561737972696e67 66696c6c7065616b696e6974636f73743370783b6a61636b7461677362697473 726f6c6c656469746b6e65776e6561723c212d2d67726f774a534f4e64757479 4e616d6573616c65796f75206c6f74737061696e6a617a7a636f6c6465796573 $666973687777772 \\ e7269736 \\ b7461627370726576313070787269736532357078$ 426c756564696e673330302c62616c6c666f72646561726e77696c64626f782e 666169726c61636b76657273706169726a756e6574656368696628217069636b 6576696c242822237761726d6c6f7264646f657370756c6c2c30303069646561 647261776875676573706f7466756e646275726e6872656663656c6c6b657973 7469636b686f75726c6f73736675656c31327078737569746465616c52535322 6167656467726579474554226561736561696d736769726c616964733870783b 6e617679677269647469707323393939776172736c61647963617273293b207d 7068703f68656c6c74616c6c77686f6d7a683ae52a2f0d0a2031303068616c6c 2e0a0a413770783b70757368636861743070783b637265772a2f3c2f68617368 37357078666c6174726172652026262074656c6c63616d706f6e746f6c616964 6d697373736b697074656e7466696e656d616c6567657473706c6f743430302c 0d0a0d0a636f6f6c666565742e7068703c62723e657269636d6f737467756964 62656c6c64657363686169726d61746861746f6d2f696d67262338326c75636b 63656e743030303b74696e79676f6e6568746d6c73656c6c6472756746524545 6e6f64656e69636b3f69643d6c6f73656e756c6c7661737477696e6452535320 7765617272656c796265656e73616d6564756b656e6173616361706577697368 67756c665432333a68697473736c6f74676174656b69636b626c757274686579 313570782727293b293b223e6d73696577696e7362697264736f727462657461 7365656b5431383a6f726473747265656d616c6c3630707866661726de2809973 626f79735b305d2e27293b22504f5354626561726b696473293b7d7d6d617279 74656e6428554b29717561647a683ae62d73697a2d2d2d2d70726f7027293b0d 6c6966745431393a76696365616e6479646562743e525353706f6f6c6e65636b 626c6f775431363a646f6f726576616c5431373a6c6574736661696c6f72616c 706f6c6c6e6f7661636f6c7367656e6520e28094736f6674726f6d6574696c6c 726f73733c68333e706f75726661646570696e6b3c74723e6d696e69297c2128 667265646469736b77656e74736f696c707574732f6a732f686f6c795432323a 4953424e5432303a6164616d736565733c68323e6a736f6e272c2027636f6e74 5432313a205253536c6f6f70617369616d6f6f6e3c2f703e736f756c4c494e45 6d696b653a34365a6e696365696e6368596f726b726963657a683ae42729293b 707572656d61676570617261746f6e65626f6e643a33375a5f6f665f275d293b 3030302c7a683ae774616e6b79617264626f776c627573683a35365a4a617661 333070780a7c7d0a254333253a33345a6a656666455850496361736876697361 676f6c66736e6f777a683ae9717565722e6373737369636b6d6561746d696e2e 62696e6464656c6c686972657069637372656e743a33365a485454502d323031 666f746f776f6c66454e442078626f783a35345a424f44596469636b3b0a7d0a 657869743a33355a7661727362656174277d293b646965743939393b616e6e65 7d7d3c2f5b695d2e4c616e676b6dc2b277697265746f7973616464737365616c 616c65783b0a097d6563686f6e696e652e6f726730303529746f6e796a657773 73616e646c656773726f6f66303030292032303077696e6567656172646f6773 626f6f74676172796375747374796c6574656d7074696f6e2e786d6c636f636b 67616e672428272e3530707850682e446d697363616c616e6c6f616e6465736b

6d696c657279616e756e697864697363293b7d0a64757374636c6970292e0a0a 373070782d32303044564473375d3e3c7461706564656d6f692b2b2977616765 6575726f7068696c6f707473686f6c65464151736173696e2d3236546c616273 7065747355524c2062756c6b636f6f6b3b7d0d0a484541445b305d2961626272 6a75616e283139386c6573687477696e3c2f693e736f6e79677579736675636b 706970657c2d0a21303032296e646f775b315d3b5b5d3b0a4c6f672073616c74 0d0a090962616e677472696d62617468297b0d0a303070780a7d293b6b6f3aec 6665657361643e0d733a2f2f205b5d3b746f6c6c706c756728297b0a7b0d0a20 2e6a7327323030706475616c626f61742e4a5047293b0a7d71756f74293b0a0a 27293b0a0d0a7d0d323031343230313532303136323031373230313832303139 323032303230323132303232323233332303234323032353230323632303237 32303238323032393230333303230333132303333232303333230333432303335 3230333632303337323031333230313232303131323031303230303932303038 32303037323030363230303532303034323030333230303232303031323030303139393931393938313939373139393631393935313939343139393331393932 3139393131393930313938393139383831393837313938363139383531393834 3139383331393832313938313139383031393739313937383139373731393736 3139373531393734313937333139373231393731313937303139363931393638 3139363731393636313936353139363431393633313936323139363131393630 3139353931393538313935373139353631393535313935343139353331393532 31393531313935303130303031303234313339343030303939393939636f6d6f 6dc3a17365737465657374617065726f746f646f686163656361646161c3b16f 6269656e64c3ad616173c3ad766964616361736f6f74726f666f726f736f6c6f 6f7472616375616c64696a6f7369646f6772616e7469706f74656d6164656265 616c676f7175c3a96573746f6e61646174726573706f636f6361736162616a6f 746f646173696e6f6167756170756573756e6f73616e7465646963656c756973 656c6c616d61796f7a6f6e61616d6f727069736f6f627261636c6963656c6c6f 64696f73686f726163617369d0b7d0b0d0bdd0b0d0bed0bcd180d0b0d180d183 d182d0b0d0bdd0b5d0bfd0bed0bed182d0b8d0b7d0bdd0bed0b4d0bed182d0be d0b6d0b5d0bed0bdd0b8d185d09dd0b0d0b5d0b5d0b1d18bd0bcd18bd092d18b d181d0bed0b2d18bd0b2d0bed09dd0bed0bdd0bfd0bed0bbd0bbd0b8d0bdd0b8 d0a0d0a4d09dd0b5d09cd18bd182d18bd09ed0bdd0b8d0bcd0b4d0b0d097d0b0 d094d0b0d09dd183d09ed0b1d182d0b5d098d0b7d0b5d0b9d0bdd183d0bcd0bc d0a2d18bd183d0b6d981d98ad8a3d986d985d8a7d985d8b9d983d984d8a3d988 d8b1d8afd98ad8a7d981d989d987d988d984d985d984d983d8a7d988d984d987 d8a8d8b3d8a7d984d8a5d986d987d98ad8a3d98ad982d8afd987d984d8abd985 d8a8d987d984d988d984d98ad8a8d984d8a7d98ad8a8d983d8b4d98ad8a7d985 d8a3d985d986d8aad8a8d98ad984d986d8add8a8d987d985d985d8b4d988d8b4 6669727374766964656f6c69676874776f726c646d656469617768697465636c6f7365626c61636b7269676874736d616c6c626f6f6b73706c6163656d757369 636669656c646f72646572706f696e7476616c75656c6576656c7461626c6562 6f617264686f75736567726f7570776f726b7379656172737374617465746f64 6179776174657273746172747374796c656465617468706f77657270686f6e65 $6 \hspace{-0.05cm} = \hspace{-0.05cm} 696768746572726 \hspace{-0.05cm} f72696 \hspace{-0.05cm} e70757461626 \hspace{-0.05cm} f75747465726 \hspace{-0.05cm} d737469746 \hspace{-0.05cm} c65746 \hspace{-0.05cm} f75747465726 \hspace{-0.05cm} d737469746 \hspace{-0.05cm} e70746 \hspace{-0.05cm} e70$ 6f6c736576656e746c6f63616c74696d65736c61726765776f72647367616d65 7373686f72747370616365666f637573636c6561726d6f64656c626c6f636b67 75696465726164696f7368617265776f6d656e616761696e6d6f6e6579696d61 67656e616d6573796f756e676c696e65736c61746572636f6c6f72677265656e

66726f6e7426616d703b7761746368666f726365707269636572756c65736265 67696e616674657276697369746973737565617265617362656c6f77696e6465 78746f74616c686f7572736c6162656c7072696e7470726573736275696c746c 696e6b73737065656473747564797472616465666f756e6473656e7365756e64 657273686f776e666f726d7372616e676561646465647374696c6c6d6f766564 74616b656e61626f7665666c61736866697865646f6674656e6f746865727669 657773636865636b6c6567616c72697665726974656d73717569636b73686170 6568756d616e6578697374676f696e676d6f7669657468697264626173696370 65616365737461676577696474686c6f67696e696465617377726f7465706167 65737573657273647269766573746f7265627265616b736f757468766f696365 73697465736d6f6e746877686572656275696c6477686963686561727468666f 72756d746872656573706f72747061727479436c69636b6c6f7765726c697665 73636c6173736c61796572656e74727973746f72797573616765736f756e6463 6f757274796f7572206269727468706f70757074797065736170706c79496d61 67656265696e6775707065726e6f746573657665727973686f77736d65616e73 65787472616d61746368747261636b6b6e6f776e6561726c79626567616e7375 70657270617065726e6f7274686c6561726e676976656e6e616d6564656e6465 645465726d73706172747347726f75706272616e647573696e67776f6d616e66 616c73657265616479617564696f74616b65737768696c652e636f6d2f6c6976 656463617365736461696c796368696c6467726561746a7564676574686f7365 756e6974736e6576657262726f6164636f617374636f7665726170706c656669 6c65736379636c657363656e65706c616e73636c69636b777269746571756565 6e7069656365656d61696c6672616d656f6c64657270686f746f6c696d697463 61636865636976696c7363616c65656e7465727468656d657468657265746f75 6368626f756e64726f79616c61736b656477686f6c6573696e636573746f636b 206e616d6566616974686865617274656d7074796f6666657273636f70656f77 6e65646d69676874616c62756d7468696e6b626c6f6f6461727261796d616a6f 72747275737463616e6f6e756e696f6e636f756e7476616c696473746f6e6553 74796c654c6f67696e68617070796f636375726c6566743a6672657368717569 746566696c6d7367726164656e65656473757262616e66696768746261736973 686f7665726175746f3b726f7574652e68746d6c6d6978656466696e616c596f 757220736c696465746f70696362726f776e616c6f6e65647261776e73706c69 747265616368526967687464617465736d6172636871756f7465676f6f64734c 696e6b73646f7562746173796e637468756d62616c6c6f776368696566796f75 74686e6f76656c313070783b7365727665756e74696c68616e6473436865636b 537061636571756572796a616d6573657175616c7477696365302c3030305374 61727470616e656c736f6e6773726f756e6465696768747368696674776f7274 68706f7374736c656164737765656b7361766f696474686573656d696c657370 6c616e65736d617274616c706861706c616e746d61726b737261746573706c61 7973636c61696d73616c65737465787473737461727377726f6e673c2f68333e 7468696e672e6f72672f6d756c74696865617264506f7765727374616e64746f 6b656e736f6c696428746869736272696e677368697073737461666674726965 6463616c6c7366756c6c7966616374736167656e7454686973202f2f2d2d3e61 646d696e65677970744576656e74313570783b456d61696c747275652263726f 73737370656e74626c6f6773626f78223e6e6f7465646c656176656368696e61 73697a657367756573743c2f68343e726f626f746865617679747275652c7365 76656e6772616e646372696d657369676e73617761726564616e636570686173 653e3c212d2d656e5f5553262333393b32303070785f6e616d656c6174696e65

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6475616c696d706f737369626c656d756c74696d65646961616c6d6f73742061 6c6c707820736f6c6964202361706172742066726f6d7375626a65637420746f 696e20456e676c697368637269746963697a656465786365707420666f726775 6964656c696e65736f726967696e616c6c7972656d61726b61626c6574686520 7365636f6e64683220636c6173733d223c61207469746c653d2228696e636c75 64696e67706172616d657465727370726f686962697465643d2022687474703a 2f2f64696374696f6e61727970657263657074696f6e7265766f6c7574696f6e 666f756e646174696f6e70783b6865696768743a7375636365737366756c7375 70706f72746572736d696c6c656e6e69756d6869732066617468657274686520 2671756f743b6e6f2d7265706561743b636f6d6d65726369616c696e64757374 7269616c656e636f757261676564616d6f756e74206f6620756e6f6666696369 616c656666696369656e63795265666572656e636573636f6f7264696e617465 646973636c61696d657265787065646974696f6e646576656c6f70696e676361 $6\mathtt{c} 63756\mathtt{c} 6174656473696d706\mathtt{c} 69666965646\mathtt{c} 65676974696d61746573756273$ 7472696e6728302220636c6173733d22636f6d706c6574656c79696c6c757374 7261746566697665207965617273696e737472756d656e745075626c69736869 6e67312220636c6173733d2270737963686f6c6f6779636f6e666964656e6365 6e756d626572206f6620616273656e6365206f66666f6375736564206f6e6a6f 696e6564207468657374727563747572657370726576696f75736c793e3c2f69 6672616d653e6f6e636520616761696e62757420726174686572696d6d696772 616e74736f6620636f757273652c612067726f7570206f664c69746572617475 7265556e6c696b65207468653c2f613e266e6273703b0a66756e6374696f6e20 69742077617320746865436f6e76656e74696f6e6175746f6d6f62696c655072 6f74657374616e74616767726573736976656166746572207468652053696d69 6c61726c792c22202f3e3c2f6469763e636f6c6c656374696f6e0d0a66756e63 74696f6e7669736962696c69747974686520757365206f66766f6c756e746565 727361747472616374696f6e756e6465722074686520746872656174656e6564 2a3c215b43444154415b696d706f7274616e6365696e2067656e6572616c7468 65206c61747465723c2f666f726d3e0a3c2f2e696e6465784f66282769203d20 303b2069203c646966666572656e63656465766f74656420746f747261646974 696f6e7373656172636820666f72756c74696d6174656c79746f75726e616d65 6e7461747472696275746573736f2d63616c6c6564207d0a3c2f7374796c653e 6576616c756174696f6e656d70686173697a656461636365737369626c653c2f 73656374696f6e3e73756363657373696f6e616c6f6e6720776974684d65616e 7768696c652c696e64757374726965733c2f613e3c6272202f3e686173206265 636f6d6561737065637473206f6654656c65766973696f6e7375666669636965 6e746261736b657462616c6c626f7468207369646573636f6e74696e75696e67 616e2061727469636c653c696d6720616c743d22616476656e74757265736869 73206d6f746865726d616e636865737465727072696e6369706c657370617274 6963756c6172636f6d6d656e7461727965666665637473206f66646563696465 6420746f223e3c7374726f6e673e7075626c6973686572734a6f75726e616c20 6f66646966666963756c7479666163696c697461746561636365707461626c65 7374796c652e637373220966756e6374696f6e20696e6e6f766174696f6e3e43 6f70797269676874736974756174696f6e73776f756c64206861766562757369 6e657373657344696374696f6e61727973746174656d656e74736f6674656e20 7573656470657273697374656e74696e204a616e75617279636f6d7072697369 6e673c2f7469746c653e0a096469706c6f6d61746963636f6e7461696e696e67 706572666f726d696e67657874656e73696f6e736d6179206e6f74206265636f

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74656769657362757420696e2074686561732070617274206f66636f6e737469 74757465636c61696d20746861746c61626f7261746f7279636f6d7061746962 6c656661696c757265206f662c207375636820617320626567616e2077697468 7573696e672074686520746f2070726f7669646566656174757265206f666672 6f6d2077686963682f2220636c6173733d2267656f6c6f676963616c73657665 72616c206f6664656c69626572617465696d706f7274616e7420686f6c647320 74686174696e672671756f743b2076616c69676e3d746f70746865204765726d 616e6f757473696465206f666e65676f74696174656468697320636172656572 73657061726174696f6e69643d227365617263687761732063616c6c65647468 6520666f7572746872656372656174696f6e6f74686572207468616e70726576 656e74696f6e7768696c652074686520656475636174696f6e2c636f6e6e6563 74696e6761636375726174656c7977657265206275696c74776173206b696c6c 656461677265656d656e74736d756368206d6f72652044756520746f20746865 77696474683a20313030736f6d65206f746865724b696e67646f6d206f667468 6520656e7469726566616d6f757320666f72746f20636f6e6e6563746f626a65 637469766573746865204672656e636870656f706c6520616e64666561747572 6564223e6973207361696420746f7374727563747572616c7265666572656e64 756d6d6f7374206f6674656e612073657061726174652d3e0a3c646976206964 204f6666696369616c20776f726c64776964652e617269612d6c6162656c7468 6520706c616e6574616e642069742077617364222076616c75653d226c6f6f6b 696e6720617462656e6566696369616c61726520696e207468656d6f6e69746f 72696e677265706f727465646c79746865206d6f6465726e776f726b696e6720 6f6e616c6c6f77656420746f77686572652074686520696e6e6f766174697665 3c2f613e3c2f6469763e736f756e64747261636b736561726368466f726d7465 72696374656461646f7074656420627961646472657373696e677468656f6c6f 6769616e6d6574686f6473206f6676617269616e74206f664368726973746961 72616e67652066726f6d70757273756974206f66666f6c6c6f77207468656272 6f7567687420746f696e20456e676c616e646167726565207468617461636375 736564206f66636f6d65732066726f6d70726576656e74696e67646976207374 796c653d686973206f72206865727472656d656e646f757366726565646f6d20 6f66636f6e6365726e696e67302031656d2031656d3b4261736b657462616c6c 2f7374796c652e637373616e206561726c6965726576656e2061667465722f22 207469746c653d222e636f6d2f696e64657874616b696e672074686570697474 736275726768636f6e74656e74223e0d3c7363726970743e28667475726e6564 206f7574686176696e67207468653c2f7370616e3e0d0a206f63636173696f6e 616c626563617573652069747374617274656420746f706879736963616c6c79 3e3c2f6469763e0a20206372656174656420627943757272656e746c792c2062 67636f6c6f723d22746162696e6465783d22646973617374726f7573416e616c 797469637320616c736f2068617320613e3c6469762069643d223c2f7374796c 653e0a3c63616c6c656420666f7273696e67657220616e642e737263203d2022 2f2f76696f6c6174696f6e737468697320706f696e74636f6e7374616e746c79 6973206c6f63617465647265636f7264696e6773642066726f6d207468656e65 6465726c616e6473706f7274756775c3aa73d7a2d791d7a8d799d7aad981d8a7 d8b1d8b3db8c6465736172726f6c6c6f636f6d656e746172696f656475636163 69c3b36e7365707469656d6272657265676973747261646f64697265636369c3 b36e75626963616369c3b36e7075626c69636964616472657370756573746173

726573756c7461646f73696d706f7274616e746572657365727661646f736172 74c3ad63756c6f736469666572656e7465737369677569656e746573726570c3 ba626c69636173697475616369c3b36e6d696e6973746572696f707269766163 696461646469726563746f72696f666f726d616369c3b36e706f626c616369c3 b36e707265736964656e7465636f6e74656e69646f7361636365736f72696f73 746563686e6f72617469706572736f6e616c657363617465676f72c3ad616573 70656369616c6573646973706f6e69626c6561637475616c6964616472656665 72656e63696176616c6c61646f6c69646269626c696f7465636172656c616369 6f6e657363616c656e646172696f706f6cc3ad7469636173616e746572696f72 6573646f63756d656e746f736e61747572616c657a616d6174657269616c6573 6469666572656e63696165636f6ec3b36d6963617472616e73706f727465726f 6472c3ad6775657a70617274696369706172656e6375656e7472616e64697363 757369c3b36e6573747275637475726166756e64616369c3b36e667265637565 6e7465737065726d616e656e7465746f74616c6d656e7465d0bcd0bed0b6d0bd d0bed0b1d183d0b4d0b5d182d0bcd0bed0b6d0b5d182d0b2d180d0b5d0bcd18f 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65206e6f776869636820626563616d656865207075626c697368656465787072 657373656420696e746f20776869636820746865636f6d6d697373696f6e6572 666f6e742d7765696768743a7465727269746f7279206f66657874656e73696f 6e73223e526f6d616e20456d70697265657175616c20746f20746865496e2063 6f6e74726173742c686f77657665722c20616e646973207479706963616c6c79 616e6420686973207769666528616c736f2063616c6c65643e3c756c20636c61 73733d226566666563746976656c792065766f6c76656420696e746f7365656d 20746f2068617665776869636820697320746865746865726520776173206e6f 616e20657863656c6c656e74616c6c206f662074686573656465736372696265 64206279496e2070726163746963652c62726f616463617374696e6763686172 67656420776974687265666c656374656420696e7375626a656374656420746f 6d696c697461727920616e64746f2074686520706f696e7465636f6e6f6d6963 616c6c79736574546172676574696e676172652061637475616c6c7976696374 6f7279206f76657228293b3c2f7363726970743e636f6e74696e756f75736c79 726571756972656420666f7265766f6c7574696f6e617279616e206566666563 746976656e6f727468206f66207468652c207768696368207761732066726f6e 74206f66207468656f72206f7468657277697365736f6d6520666f726d206f66 686164206e6f74206265656e67656e657261746564206279696e666f726d6174 696f6e2e7065726d697474656420746f696e636c756465732074686564657665 6c6f706d656e742c656e746572656420696e746f7468652070726576696f7573 636f6e73697374656e746c79617265206b6e6f776e206173746865206669656c 64206f66746869732074797065206f66676976656e20746f2074686574686520 7469746c65206f66636f6e7461696e7320746865696e7374616e636573206f66 696e20746865206e6f72746864756520746f2074686569726172652064657369 676e6564636f72706f726174696f6e737761732074686174207468656f6e6520 6f662074686573656d6f726520706f70756c617273756363656564656420696e 737570706f72742066726f6d696e20646966666572656e74646f6d696e617465 6420627964657369676e656420666f726f776e657273686970206f66616e6420 706f737369626c797374616e64617264697a6564726573706f6e736554657874 77617320696e74656e646564726563656976656420746865617373756d656420 746861746172656173206f66207468657072696d6172696c7920696e74686520 6261736973206f66696e207468652073656e73656163636f756e747320666f72 64657374726f7965642062796174206c656173742074776f776173206465636c 61726564636f756c64206e6f74206265536563726574617279206f6661707065 617220746f2062656d617267696e2d746f703a312f5e5c732b7c5c732b242f67 65297b7468726f7720657d3b746865207374617274206f6674776f2073657061 726174656c616e677561676520616e6477686f20686164206265656e6f706572 6174696f6e206f666465617468206f66207468657265616c206e756d62657273 093c6c696e6b2072656c3d2270726f7669646564207468657468652073746f72 79206f66636f6d7065746974696f6e73656e676c6973682028554b29656e676c 6973682028555329d09cd0bed0bdd0b3d0bed0bbd0a1d180d0bfd181d0bad0b8 d181d180d0bfd181d0bad0b8d181d180d0bfd181d0bad0bed984d8b9d8b1d8a8 d98ad8a9e6ada3e9ab94e4b8ade69687e7ae80e4bd93e4b8ade69687e7b981e4 bd93e4b8ade69687e69c89e99990e585ace58fb8e4babae6b091e694bfe5ba9c e998bfe9878ce5b7b4e5b7b4e7a4bee4bc9ae4b8bbe4b989e6938de4bd9ce7b3 bbe7bb9fe694bfe7ad96e6b395e8a784696e666f726d616369c3b36e68657272 616d69656e746173656c65637472c3b36e69636f646573637269706369c3b36e 636c61736966696361646f73636f6e6f63696d69656e746f7075626c69636163

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787072657373696f6e206f667068696c6f736f706879206f66666f72206d6f72 65207468616e636976696c697a6174696f6e736f6e207468652069736c616e64 73656c6563746564496e64657863616e20726573756c7420696e222076616c75 653d2222202f3e74686520737472756374757265202f3e3c2f613e3c2f646976 3e4d616e79206f66207468657365636175736564206279207468656f66207468 6520556e697465647370616e20636c6173733d226d63616e2062652074726163 656469732072656c6174656420746f626563616d65206f6e65206f6669732066 72657175656e746c796c6976696e6720696e207468657468656f726574696361 6c6c79466f6c6c6f77696e67207468655265766f6c7574696f6e617279676f76 65726e6d656e7420696e69732064657465726d696e656474686520706f6c6974 6963616c696e74726f647563656420696e73756666696369656e7420746f6465 736372697074696f6e223e73686f72742073746f726965737365706172617469 6f6e206f66617320746f20776865746865726b6e6f776e20666f722069747377 617320696e697469616c6c79646973706c61793a626c6f636b697320616e2065 78616d706c65746865207072696e636970616c636f6e7369737473206f662061 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696f6e206f662074686570617274696369706174656420696e20746865746865 20696e74726f64756374696f6e206f666964656e746966696564207769746820 74686566696374696f6e616c20636861726163746572204f78666f726420556e 6976657273697479206d6973756e6465727374616e64696e67206f6654686572 $65206172652 \\ \texttt{c} 20686 \\ \texttt{f} 77657665722 \\ \texttt{c} 7374796 \\ \texttt{c} 6573686565742220687265663 \\ \texttt{d}$ 222f436f6c756d62696120556e6976657273697479657870616e64656420746f 20696e636c756465757375616c6c7920726566657272656420746f696e646963 6174696e6720746861742074686568617665207375676765737465642074686174616666696c6961746564207769746820746865636f7272656c6174696f6e20 6265747765656e6e756d626572206f6620646966666572656e743e3c2f74643e 3c2f74723e3c2f7461626c653e52657075626c6963206f66204972656c616e64 0a3c2f7363726970743e0a3c73637269707420756e6465722074686520696e66 6c75656e6365636f6e747269627574696f6e20746f207468654f666669636961656e74657265642061726f756e6420746865696d706c69636174696f6e73206f 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0a3c2f7363726970743e0d0a3c736372697074203c2f613e3c2f6c693e3c2f75 6c3e3c2f6469763e6173736f6369617465642077697468207468652070726f67 72616d6d696e67206c616e67756167653c2f613e3c6120687265663d22687474 703a2f2f3c2f613e3c2f6c693e3c6c6920636c6173733d22666f726d20616374 696f6e3d22687474703a2f2f3c646976207374796c653d22646973706c61793a 747970653d227465787422206e616d653d2271223c7461626c65207769647468 3d223130302522206261636b67726f756e642d706f736974696f6e3a2220626f 726465723d2230222077696474683d2272656c3d2273686f7274637574206963 6f6e222068363e3c756c3e3c6c693e3c6120687265663d2220203c6d65746120 687474702d65717569763d2263737322206d656469613d2273637265656e2220 726573706f6e7369626c6520666f7220746865202220747970653d226170706c 69636174696f6e2f22207374796c653d226261636b67726f756e642d68746d6c 3b20636861727365743d7574662d382220616c6c6f777472616e73706172656e 63793d227374796c6573686565742220747970653d2274650d0a3c6d65746120 687474702d65717569763d223e3c2f7370616e3e3c7370616e20636c6173733d 2230222063656c6c73706163696e673d2230223e3b0a3c2f7363726970743e0a 3c73637269707420736f6d6574696d65732063616c6c656420746865646f6573 206e6f74206e65636573736172696c79466f72206d6f726520696e666f726d61 74696f6e61742074686520626567696e6e696e67206f66203c21444f43545950 452068746d6c3e3c68746d6c706172746963756c61726c7920696e2074686520 747970653d2268696464656e22206e616d653d226a6176617363726970743a76 6f69642830293b226566666563746976656e657373206f662074686520617574 6f636f6d706c6574653d226f6666222067656e6572616c6c7920636f6e736964 657265643e3c696e70757420747970653d22746578742220223e3c2f73637269 70743e0d0a3c7363726970747468726f7567686f75742074686520776f726c64 636f6d6d6f6e206d6973636f6e63657074696f6e6173736f63696174696f6e20 77697468207468653c2f6469763e0a3c2f6469763e0a3c646976206364757269 20746865747970653d22696d6167652f782d69636f6e2220616e20696e637265 6173696e67206e756d6265726469706c6f6d617469632072656c6174696f6e73 617265206f6674656e20636f6e736964657265646d6574612063686172736574 3d227574662d3822203c696e70757420747970653d227465787422206578616d 706c657320696e636c75646520746865223e3c696d67207372633d2268747470 3a2f2f6970617274696369706174696f6e20696e207468657468652065737461 626c6973686d656e74206f660a3c2f6469763e0a3c64697620636c6173733d22 26616d703b6e6273703b26616d703b6e6273703b746f2064657465726d696e65 2077686574686572717569746520646966666572656e742066726f6d6d61726b 65642074686520626567696e6e696e6764697374616e6365206265747765656e20746865636f6e747269627574696f6e7320746f20746865636f6e666c696374 206265747765656e20746865776964656c7920636f6e7369646572656420746f 776173206f6e65206f6620746865206669727374776974682076617279696e67 $2064656772656573686176652073706563756 \\ {c}61746564207468617428646 \\ {f}63$ 756d656e742e676574456c656d656e7470617274696369706174696e6720696e 207468656f726967696e616c6c7920646576656c6f7065646574612063686172 7365743d227574662d38223e20747970653d22746578742f63737322202f3e0a 696e7465726368616e676561626c7920776974686d6f726520636c6f73656c79 2072656c61746564736f6369616c20616e6420706f6c69746963616c74686174 20776f756c64206f746865727769736570657270656e646963756c617220746f 207468657374796c6520747970653d22746578742f637373747970653d227375 626d697422206e616d653d2266616d696c696573207265736964696e6720696e 646576656c6f70696e6720636f756e7472696573636f6d70757465722070726f

6772616d6d696e6765636f6e6f6d696320646576656c6f706d656e7464657465 726d696e6174696f6e206f6620746865666f72206d6f726520696e666f726d61 74696f6e6f6e207365766572616c206f63636173696f6e73706f7274756775c3 aa7320284575726f70657529d0a3d0bad180d0b0d197d0bdd181d18cd0bad0b0 d183d0bad180d0b0d197d0bdd181d18cd0bad0b0d0a0d0bed181d181d0b8d0b9 d181d0bad0bed0b9d0bcd0b0d182d0b5d180d0b8d0b0d0bbd0bed0b2d0b8d0bd d184d0bed180d0bcd0b0d186d0b8d0b8d183d0bfd180d0b0d0b2d0bbd0b5d0bd d0b8d18fd0bdd0b5d0bed0b1d185d0bed0b4d0b8d0bcd0bed0b8d0bdd184d0bed180d0bcd0b0d186d0b8d18fd098d0bdd184d0bed180d0bcd0b0d186d0b8d18f d0a0d0b5d181d0bfd183d0b1d0bbd0b8d0bad0b8d0bad0bed0bbd0b8d187d0b5 d181d182d0b2d0bed0b8d0bdd184d0bed180d0bcd0b0d186d0b8d18ed182d0b5 d180d180d0b8d182d0bed180d0b8d0b8d0b4d0bed181d182d0b0d182d0bed187 d0bdd0bed8a7d984d985d8aad988d8a7d8acd8afd988d986d8a7d984d8a7d8b4 d8aad8b1d8a7d983d8a7d8aad8a7d984d8a7d982d8aad8b1d8a7d8add8a7d8aa 68746d6c3b20636861727365743d5554462d38222073657454696d656f757428 66756e6374696f6e2829646973706c61793a696e6c696e652d626c6f636b3b3c 696e70757420747970653d227375626d6974222074797065203d202774657874 2f6a617661736372693c696d67207372633d22687474703a2f2f7777772e2220 22687474703a2f2f7777772e77332e6f72672f73686f72746375742069636f6e 2220687265663d2222206175746f636f6d706c6574653d226f666622203c2f61 3e3c2f6469763e3c64697620636c6173733d3c2f613e3c2f6c693e0a3c6c6920 636c6173733d226373732220747970653d22746578742f63737322203c666f72 6d20616374696f6e3d22687474703a2f2f78742f6373732220687265663d2268 7474703a2f2f6c696e6b2072656c3d22616c7465726e61746522200d0a3c7363 7269707420747970653d22746578742f206f6e636c69636b3d226a6176617363 726970743a286e65772044617465292e67657454696d6528297d686569676874 3d2231222077696474683d2231222050656f706c6527732052657075626c6963 206f6620203c6120687265663d22687474703a2f2f7777772e746578742d6465 636f726174696f6e3a756e64657274686520626567696e6e696e67206f662074 6865203c2f6469763e0a3c2f6469763e0a3c2f6469763e0a65737461626c6973 686d656e74206f6620746865203c2f6469763e3c2f6469763e3c2f6469763e3c 2f642376696577706f72747b6d696e2d6865696768743a0a3c73637269707420 7372633d22687474703a2f2f6f7074696f6e3e3c6f7074696f6e2076616c7565 3d6f6674656e20726566657272656420746f206173202f6f7074696f6e3e0a3c 6f7074696f6e2076616c753c21444f43545950452068746d6c3e0a3c212d2d5b 496e7465726e6174696f6e616c20416972706f72743e0a3c6120687265663d22 687474703a2f2f7777773c2f613e3c6120687265663d22687474703a2f2f77e0 b8a0e0b8b2e0b8a9e0b8b2e0b984e0b897e0b8a2e183a5e18390e183a0e18397 e183a3e1839ae18398e6ada3e9ab94e4b8ade696872028e7b981e9ab9429e0a4 a8e0a4bfe0a4b0e0a58de0a4a6e0a587e0a4b6e0a4a1e0a4bee0a489e0a4a8e0 a4b2e0a58be0a4a1e0a495e0a58de0a4b7e0a587e0a4a4e0a58de0a4b0e0a49c e0a4bee0a4a8e0a495e0a4bee0a4b0e0a580e0a4b8e0a482e0a4ace0a482e0a4a7e0a4bfe0a4a4e0a4b8e0a58de0a4a5e0a4bee0a4aae0a4a8e0a4bee0a4b8e0 a58de0a4b5e0a580e0a495e0a4bee0a4b0e0a4b8e0a482e0a4b8e0a58de0a495 e0a4b0e0a4a3e0a4b8e0a4bee0a4aee0a497e0a58de0a4b0e0a580e0a49ae0a4 bfe0a49fe0a58de0a4a0e0a58be0a482e0a4b5e0a4bfe0a49ce0a58de0a49ee0 a4bee0a4a8e0a485e0a4aee0a587e0a4b0e0a4bfe0a495e0a4bee0a4b5e0a4bf e0a4ade0a4bfe0a4a8e0a58de0a4a8e0a497e0a4bee0a4a1e0a4bfe0a4afe0a4 bee0a481e0a495e0a58de0a4afe0a58be0a482e0a495e0a4bfe0a4b8e0a581e0 a4b0e0a495e0a58de0a4b7e0a4bee0a4aae0a4b9e0a581e0a481e0a49ae0a4a4 e0a580e0a4aae0a58de0a4b0e0a4ace0a482e0a4a7e0a4a8e0a49fe0a4bfe0a4 aae0a58de0a4aae0a4a3e0a580e0a495e0a58de0a4b0e0a4bfe0a495e0a587e0a49fe0a4aae0a58de0a4b0e0a4bee0a4b0e0a482e0a4ade0a4aae0a58de0a4b0 e0a4bee0a4aae0a58de0a4a4e0a4aee0a4bee0a4b2e0a4bfe0a495e0a58be0a4 82e0a4b0e0a4abe0a4bce0a58de0a4a4e0a4bee0a4b0e0a4a8e0a4bfe0a4b0e0 a58de0a4aee0a4bee0a4a3e0a4b2e0a4bfe0a4aee0a4bfe0a49fe0a587e0a4a1 6465736372697074696f6e2220636f6e74656e743d22646f63756d656e742e6c 6f636174696f6e2e70726f742e676574456c656d656e747342795461674e616d 65283c21444f43545950452068746d6c3e0a3c68746d6c203c6d657461206368 61727365743d227574662d38223e3a75726c2220636f6e74656e743d22687474 703a2f2f2e637373222072656c3d227374796c657368656574227374796c6520 747970653d22746578742f637373223e747970653d22746578742f6373732220 687265663d2277332e6f72672f313939392f7868746d6c2220786d6c74797065 3d22746578742f6a61766173637269707422206d6574686f643d226765742220 616374696f6e3d226c696e6b2072656c3d227374796c6573686565742220203d 20646f63756d656e742e676574456c656d656e74747970653d22696d6167652f 782d69636f6e22202f3e63656c6c70616464696e673d2230222063656c6c7370 2e6373732220747970653d22746578742f63737322203c2f613e3c2f6c693e3c 6c693e3c6120687265663d222222077696474683d223122206865696768743d22 3122223 e 3 c 6120687265663 d 22687474703 a 2 f 2 f 7777772 e 7374796 c 653 d 22647676 a 26676 a 2666973706c61793a6e6f6e653b223e616c7465726e6174652220747970653d2261 70706c692d2f2f5733432f2f445444205848544d4c20312e3020656c6c737061 616c75653d222f613e266e6273703b3c7370616e20726f6c653d22730a3c696e 70757420747970653d2268696464656e22206c616e67756167653d224a617661 536372697074222020646f63756d656e742e676574456c656d656e747342673d 2230222063656c6c73706163696e673d223022207970653d22746578742f6373 7322206d656469613d22747970653d27746578742f6a61766173637269707427 776974682074686520657863657074696f6e206f66207970653d22746578742f 637373222072656c3d227374206865696768743d2231222077696474683d2231 22203d272b656e636f6465555249436f6d706f6e656e74283c6c696e6b207265 6c3d22616c7465726e61746522200a626f64792c2074722c20696e7075742c20 746578746d657461206e616d653d22726f626f74732220636f6e6d6574686f64 3d22706f73742220616374696f6e3d223e0a3c6120687265663d22687474703a 2f2f7777772e637373222072656c3d227374796c65736865657422203c2f6469 763e3c2f6469763e3c64697620636c6173736c616e67756167653d226a617661 736372697074223e617269612d68696464656e3d2274727565223ec2b73c7269 70742220747970653d22746578742f6a617661736c3d303b7d2928293b0a2866 756e6374696f6e28297b6261636b67726f756e642d696d6167653a2075726c28 2f613e3c2f6c693e3c6c693e3c6120687265663d226809093c6c693e3c612068 7265663d22687474703a2f2f61746f722220617269612d68696464656e3d2274 72753e203c6120687265663d22687474703a2f2f7777772e6c616e6775616765 3d226a61766173637269707422202f6f7074696f6e3e0a3c6f7074696f6e2076 616c75652f6469763e3c2f6469763e3c64697620636c6173733d7261746f7222 20617269612d68696464656e3d227472653d286e65772044617465292e676574 54696d652829706f7274756775c3aa732028646f2042726173696c29d0bed180

d0b3d0b0d0bdd0b8d0b7d0b0d186d0b8d0b8d0b2d0bed0b7d0bcd0bed0b6d0bd d0bed181d182d18cd0bed0b1d180d0b0d0b7d0bed0b2d0b0d0bdd0b8d18fd180 d0b5d0b3d0b8d181d182d180d0b0d186d0b8d0b8d0b2d0bed0b7d0bcd0bed0b6 d0bdd0bed181d182d0b8d0bed0b1d18fd0b7d0b0d182d0b5d0bbd18cd0bdd0b0 3c21444f43545950452068746d6c205055424c494320226e742d547970652220 636f6e74656e743d22746578742f3c6d65746120687474702d65717569763d22 436f6e746572616e736974696f6e616c2f2f454e222022687474703a3c68746d 6c20786d6c6e733d22687474703a2f2f7777772d2f2f5733432f2f4454442058 48544d4c20312e3020544454442f7868746d6c312d7472616e736974696f6e61 6c2f2f7777772e77332e6f72672f54522f7868746d6c312f7065203d20277465 78742f6a617661736372697074273b3c6d657461206e616d653d226465736372 697074696f6e706172656e744e6f64652e696e736572744265666f72653c696e 70757420747970653d2268696464656e22206e616a732220747970653d227465 78742f6a6176617363726928646f63756d656e74292e72656164792866756e63 746973637269707420747970653d22746578742f6a61766173696d6167652220 636f6e74656e743d22687474703a2f2f55412d436f6d70617469626c65222063 6f6e74656e743d746d6c3b20636861727365743d7574662d3822202f3e0a6c69 6e6b2072656c3d2273686f72746375742069636f6e3c6c696e6b2072656c3d22 7374796c65736865657422203c2f7363726970743e0a3c736372697074207479 70653d3d20646f63756d656e742e637265617465456c656d656e3c6120746172 6765743d225f626c616e6b2220687265663d20646f63756d656e742e67657445 6c656d656e747342696e70757420747970653d227465787422206e616d653d61 2e74797065203d2027746578742f6a617661736372696e70757420747970653d 2268696464656e22206e616d6568746d6c3b20636861727365743d7574662d38 22202f3e647464223e0a3c68746d6c20786d6c6e733d22687474702d2f2f5733 432f2f4454442048544d4c20342e30312054656e747342795461674e616d6528 277363726970742729696e70757420747970653d2268696464656e22206e616d 3c73637269707420747970653d22746578742f6a6176617322207374796c653d 22646973706c61793a6e6f6e653b223e646f63756d656e742e676574456c656d 656e7442794964283d646f63756d656e742e637265617465456c656d656e7428 2720747970653d27746578742f6a61766173637269707427696e707574207479 70653d227465787422206e616d653d22642e676574456c656d656e7473427954 61674e616d6528736e6963616c2220687265663d22687474703a2f2f7777772e 432f2f4454442048544d4c20342e3031205472616e7369743c7374796c652074 7970653d22746578742f637373223e0a0a3c7374796c6520747970653d227465 78742f637373223e696f6e616c2e647464223e0a3c68746d6c20786d6c6e733d 687474702d65717569763d22436f6e74656e742d5479706564696e673d223022 2063656c6c73706163696e673d22302268746d6c3b20636861727365743d7574 662d3822202f3e0a207374796c653d22646973706c61793a6e6f6e653b223e3c 6578742f6a617661736372697074273ed0b4d0b5d18fd182d0b5d0bbd18cd0bd d0bed181d182d0b8d181d0bed0bed182d0b2d0b5d182d181d182d0b2d0b8d0b8 d0bfd180d0bed0b8d0b7d0b2d0bed0b4d181d182d0b2d0b0d0b1d0b5d0b7d0be d0bfd0b0d181d0bdd0bed181d182d0b8e0a4aae0a581e0a4b8e0a58de0a4a4e0 a4bfe0a495e0a4bee0a495e0a4bee0a482e0a497e0a58de0a4b0e0a587e0a4b8 a7e0a4bee0a4a8e0a4b8e0a4ade0a4bee0a4abe0a4bfe0a495e0a58de0a4b8e0 a4bfe0a482e0a497e0a4b8e0a581e0a4b0e0a495e0a58de0a4b7e0a4bfe0a4a4 $e0a495e0a589e0a4aae0a580e0a4b0e0a4bee0a487e0a49fe0a4b5e0a4bfe0a4\\9ce0a58de0a49ee0a4bee0a4aae0a4a8e0a495e0a4bee0a4b0e0a58de0a4b0e0\\a4b5e0a4bee0a488e0a4b8e0a495e0a58de0a4b0e0a4bfe0a4afe0a4a4e0a4be$

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

Appendix B. List of Word Transformations

The string literals are in ${\tt C}$ 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	н н	Identity	11 11
1	11 11	Identity	11 11
2	11 11	Identity	11 11
3	11 11	OmitFirst1	пп
4	11 11	FermentFirst	п п
5	11 11	Identity	" the "
6	11 11	Identity	11 11
7	"s "	Identity	п п
8	11 11	Identity	" of "
9	11 11	FermentFirst	пп
10	11 11	Identity	" and "
11	11 11	OmitFirst2	пп
12	11 11	OmitLast1	пп
13	","	Identity	п п
14	11 11	Identity	","
15	11 11	FermentFirst	11 11
16	11 11	Identity	" in "
17	11 11	Identity	" to "
18	"e "	Identity	11 11

19	11 11	Identity	"\""
20	п п	Identity	" "
21	п п	Identity	"\">"
22	11 11	Identity	"\n"
23	п п	OmitLast3	" " "
24	11 11	Identity	"]"
25	п п	Identity	" for "
26	11 11	OmitFirst3	11 11
27	п п	OmitLast2	пп
28	пп	Identity	" a "
29	п п	Identity	" that "
30	п п	FermentFirst	11 11
31	11 11	Identity	11 11
32	" . "	Identity	
33	" "	Identity	11 11
34	п п	OmitFirst4	" " "
35	п п	Identity	" with "
36	п п	Identity	W I CII
37	11 11	Identity	" from "
38	11 11	Identity	" by "
39	11 11	OmitFirst5	Dy
40	11 11	OmitFirst6	11 11
41	" the "	Identity	п п
42	CITE	OmitLast4	п п
43	" "	Identity	" The "
44			". The "
44		FermentAll	
46		Identity	011
46 47	" "	Identity	as
48		Identity	" is "
-	" "	OmitLast7	
49	" "	OmitLast1	1119
50	" "	Identity	"\n\t"
51	" "	Identity	":"
52	" "	Identity	•
53		Identity	"ed "
54		OmitFirst9	" "
55	" "	OmitFirst7	п п
56	" "	OmitLast6	" "
57	" "	Identity .	" ("
58	" "	FermentFirst	","
59	" "	OmitLast8	II II
60	" "	Identity	" at "
61	!! !!	Identity	"ly "
62	" the "	Identity	" of "
63	11 11	OmitLast5	11 11
64	11 11	OmitLast9	11 11
65	11 11	FermentFirst	","
66	11 11	FermentFirst	" / " "

-			
67	"•"	Identity	" ("
68	" "	FermentAll	" "
69	" "	FermentFirst	"\">"
70	" "	Identity	" = \ " "
71	11 11	Identity	"."
72	".com/"	Identity	11 11
73	" the "	Identity	" of the "
74	11 11	FermentFirst	п / п
75	" "	Identity	". This "
76	п п	Identity	","
77	"."	Identity	11 11
78	пп	FermentFirst	" ("
79	11 11	FermentFirst	"."
80	11 11	Identity	" not "
81	11 11	Identity	"=\""
82	11 11	Identity	"er "
83	11 11	FermentAll	11 11
84	пп	Identity	"al "
85	11 11	FermentAll	11 11
86	п п	Identity	"='"
87	11 11	FermentAll	11 \ 11 11
88	п п	FermentFirst	" "
89	11 11	Identity	" ("
90	11 11	Identity	"ful "
91	11 11	FermentFirst	" "
92	п п	Identity	"ive "
93	11 11	Identity	"less "
94	11 11	FermentAll	"/"
95	п п	Identity	"est "
96	п п	FermentFirst	" "
97	11 11	FermentAll	"\">"
98	11 11	Identity	"=/"
99	11 11	FermentFirst	
100	11 11	Identity	"ize "
101	11 11	FermentAll	120
102	"\xc2\xa0"	Identity	
103	\XC2 \XaU	Identity	11 11
103	" "	FermentFirst	"=\""
	11 11		- \ " = \ " "
105	" "	FermentAll	·
106	и и	Identity	"ous "
107		FermentAll	", "
108	" "	FermentFirst	"='"
109	" "	FermentFirst	","
110		FermentAll	"=\""
111	" "	FermentAll	", "
112	" "	FermentAll	","
113	" "	FermentAll	" ("
114	" "	FermentAll	". "

```
115
           11 11
                  FermentAll
           11 11
                                       " = ' "
116
                 FermentAll
           11 11
                                        ". "
117
                 FermentAll
           11 11
                  FermentFirst
                                      "=\""
118
           11 11
                                       "='"
119
                  FermentAll
           11 11
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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