**[MS-PATCH]:**

**LZX DELTA Compression and Decompression**

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**Revision Summary**

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| 6/27/2008 | 1.0 | Major | Initial Release. |
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# Introduction

LZX DELTA Compression and Decompression enables one set of data to be compressed within the context of a reference set of data that is supplied to both the compressor and the decompressor.

Sections 1.7 and 2 of this specification are normative. All other sections and examples in this specification are informative.

## Glossary

This document uses the following terms:

**encoding**: A process that specifies a Content-Transfer-Encoding for transforming character data from one form to another.

**Lempel-Ziv Extended (LZX)**: An LZ77-based compression engine, as described in [[UASDC]](https://go.microsoft.com/fwlink/?LinkId=90549), that is a universal lossless data compression algorithm. It performs no analysis on the data.

**Lempel-Ziv Extended Delta (LZXD)**: A derivative of the Lempel-Ziv Extended (LZX) format with some modifications to facilitate efficient delta compression. Delta compression is a technique in which one set of data can be compressed within the context of a reference set of data that is supplied both to the compressor and decompressor. Delta compression is commonly used to encode updates to similar existing data sets so that the size of compressed data can be significantly reduced relative to ordinary non-delta compression techniques. Expanding a delta-compressed set of data requires that the exact same reference data be provided during decompression.

**little-endian**: Multiple-byte values that are byte-ordered with the least significant byte stored in the memory location with the lowest address.

**offline address book (OAB)**: A collection of address lists that are stored in a format that a client can save and use locally.

**padding**: Bytes that are inserted in a data stream to maintain alignment of the protocol requests on natural boundaries.

**path length**: The number of edges in the canonical Huffman tree between the top of the tree and the element.

**stream**: A flow of data from one host to another host, or the data that flows between two hosts.

**MAY, SHOULD, MUST, SHOULD NOT, MUST NOT:** These terms (in all caps) are used as defined in [[RFC2119]](https://go.microsoft.com/fwlink/?LinkId=90317). All statements of optional behavior use either MAY, SHOULD, or SHOULD NOT.

## References

Links to a document in the Microsoft Open Specifications library point to the correct section in the most recently published version of the referenced document. However, because individual documents in the library are not updated at the same time, the section numbers in the documents may not match. You can confirm the correct section numbering by checking the [Errata](https://go.microsoft.com/fwlink/?linkid=850906).

### Normative References

We conduct frequent surveys of the normative references to assure their continued availability. If you have any issue with finding a normative reference, please contact dochelp@microsoft.com. We will assist you in finding the relevant information.

[Cormen] Cormen, T., Leiserson, C., Rivest, R., and Stein, C., "Introduction to Algorithms", 3rd edition, Massachusetts Institute of Technology, 2009, ISBN: 978-0-262-03384-8.

[IEEE1003.1] The Open Group, "IEEE Std 1003.1, 2004 Edition", 2004, [http://www.unix.org/version3/ieee\_std.html](https://go.microsoft.com/fwlink/?LinkId=89897)

[MS-DTYP] Microsoft Corporation, "[Windows Data Types](%5BMS-DTYP%5D.pdf#Section_cca2742956894a16b2b49325d93e4ba2)".

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997, [http://www.rfc-editor.org/rfc/rfc2119.txt](https://go.microsoft.com/fwlink/?LinkId=90317)

[UASDC] Ziv, J. and Lempel, A., "A Universal Algorithm for Sequential Data Compression", May 1977, [http://www.cs.duke.edu/courses/spring03/cps296.5/papers/ziv\_lempel\_1977\_universal\_algorithm.pdf](https://go.microsoft.com/fwlink/?LinkId=90549)

### Informative References

[MS-OXOAB] Microsoft Corporation, "[Offline Address Book (OAB) File Format and Schema](%5BMS-OXOAB%5D.pdf#Section_b475038666ec4e69abb6208dd131c7de)".

[MS-OXPROTO] Microsoft Corporation, "[Exchange Server Protocols System Overview](%5BMS-OXPROTO%5D.pdf#Section_734ab967e43e425babe1974af56c0283)".

## Overview

[**Lempel-Ziv Extended Delta (LZXD)**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compression provides a mechanism for both the compressor and the decompressor to refer to a common reference set of data. It relaxes the constraint that the match offset be constrained to less than the current position in the output [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6), allowing the match offset to refer to the logically prepended reference data. This relaxed constraint effectively enables the compressed data stream to encode "matches" both from the reference data and from the uncompressed data stream.

## Relationship to Protocols and Other Structures

[**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) (D for Delta) is an [**LZX**](#gt_32d18f6a-e4e7-4c48-b919-5dea39ebf301) variant that is modified to facilitate efficient delta compression.

LZX is a compressor that is based on the Lempel-Ziv 1977 (LZ77) sliding window data compression algorithm, as described in [[UASDC]](https://go.microsoft.com/fwlink/?LinkId=90549), that uses static Huffman [**encoding**](#gt_84791550-b1fe-4392-97fe-7533e3e8eda4) and a sliding window of selectable size. Data symbols are encoded either as an uncompressed symbol or as a logical (offset, length) pair indicating that length symbols shall be copied from a displacement of offset symbols from the current position in the output [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6). The value of the offset is constrained to be less than the current position in the output stream, up to the size of the sliding window.

The LZXD compression format is used by [[MS-OXOAB]](%5BMS-OXOAB%5D.pdf#Section_b475038666ec4e69abb6208dd131c7de) to compress data in the [**offline address book (OAB)**](#gt_6b51bb3d-00aa-43d0-9b01-7634e5341183).

For conceptual background information and overviews of the relationships and interactions between this and other protocols, see [[MS-OXPROTO]](%5BMS-OXPROTO%5D.pdf#Section_734ab967e43e425babe1974af56c0283).

## Applicability Statement

[**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compression is commonly used to encode updates to similar existing data sets so that the size of compressed data can be significantly reduced relative to ordinary compression techniques that do not use the delta between a common reference set of data. One use for this compression format is the compression data in [**OAB**](#gt_6b51bb3d-00aa-43d0-9b01-7634e5341183) version 4 Differential Patch or Compressed OAB Template files.

## Versioning and Localization

None.

## Vendor-Extensible Fields

None.

# Structures

[**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compressed data consists of a header that indicates the file translation size, followed by a sequence of compressed blocks. A [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6) of uncompressed input can be output as multiple compressed LZXD blocks to improve compression, because each compressed block contains its own statistical tree structures.



Figure 1: The structure of LZXD compressed data

A block can be one of the following types:

* Uncompressed block, as specified in section [2.3.2.1](#Section_755e7336aa484a41bcb565530323e879).
* Verbatim block, as specified in section [2.3.2.2](#Section_37d8d8586d5643e8a9240dc44c4db535).
* Aligned offset, as specified in section [2.3.2.3](#Section_d40b8fb3ccb743dd87714732b6696389).

In this document, ranges are specified using interval notation. A range in parenthesis "()" does not include the upper and lower endpoints. A range in brackets "[]" does include the upper and lower endpoints.

## Concepts

### Bitstream

An [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) bitstream is encoded as a sequence of aligned 16-bit (or 2-byte) integers stored in the least-significant-byte to most-significant-byte order, also known as byte-swapped, or [**little-endian**](#gt_079478cb-f4c5-4ce5-b72b-2144da5d2ce7), words. Given an input byte [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6) in hex 1A, 2B, 3C, 4D, 5E, 6F, …, the output byte stream MUST be as follows:

|  |  |
| --- | --- |
| Lower address |  Higher address |
| 2B | 1A | 4D | 3C | 6F | 5E |

Figure 2: An example output byte stream

### Window Size

The sliding window size MUST be a power of 2, from 2^17 (128 kilobytes (KB)) up to 2^25 (32 megabytes (MB)). The window size is not stored in the compressed data [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6) and MUST be specified to the decoder before decoding begins. The window size SHOULD be the smallest power of two between 2^17 and 2^25 that is greater than or equal to the sum of the size of the reference data rounded up to a multiple of 32,768 and the size of the subject data.

### Reference Data

For delta compression, the reference data is a sequence of bytes given to the compressor before compressing the subject data. The exact same reference data sequence MUST be given to the decompressor before decompression. The reference data sequence is treated as logically prepended to the subject data sequence being compressed or decompressed. During decompression, match offsets are negative displacements from the "current position" in the output [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6), up to the specified window size. When match offset values exceed the number of bytes already emitted in the uncompressed output stream, they are pointing into the reference data that is logically prepended to the subject data.



Figure 3: Example reference data and subject data

In this example, the reference data is 10 bytes long and consists of the sequence "ABCDEFGHIJ". The data to be compressed, or the subject data, is also 10 bytes long (although the data does not have to be the same length as the reference data) and consists of "abcDEFabce". A valid encoded sequence would consist of the following tokens:

'a', 'b', 'c', (match offset -10, length 3), (match offset -6, length 3), 'e'

The first match offset exceeds the amount of subject data already in the window, pointing instead into the reference data portion. The second match offset does not exceed the amount of subject data in the window and instead refers to a portion of the subject data previously compressed or decompressed.

### Repeated Offsets

[**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compression extends the conventional Lempel-Ziv 1977 sliding window data compression algorithm format, as specified in [[UASDC]](https://go.microsoft.com/fwlink/?LinkId=90549), in several ways, one of which is in the use of repeated offset codes. Three match offset codes, named the repeated offset codes, are reserved to indicate that the current match offset is the same as that of one of the three previous matches, which is not itself a repeated offset.

The three special offset codes are encoded as offset values 0, 1, and 2 (for example, encoding an offset of 0 means "use the most recent nonrepeated match offset"; an offset of 1 means "use the second most recent nonrepeated match offset"; and so on). All remaining encoded offset values are displaced by real offset +2, as is shown in the following table, which prevents matches at offsets WINDOW\_SIZE, WINDOW\_SIZE-1, and WINDOW\_SIZE-2.

| Encoded offset | Real offset |
| --- | --- |
| 0 | Most recent real match offset |
| 1 | Second most recent match offset |
| 2 | Third most recent match offset |
| 3 | 1 (closest allowable) |
| 4 | 2 |
| 5 | 3 |
| 6 | 4 |
| 7 | 5 |
| 8 | 6 |
| 500 | 498 |
| X+2 | X |
| WINDOW\_SIZE-1(maximum possible) | WINDOW\_SIZE-3 |

The three most recent real match offsets are kept in a list, the behavior of which is explained as follows:

* Let R0 be defined as the most recent real offset.
* Let R1 be defined as the second most recent offset.
* Let R2 be defined as the third most recent offset.

The list is managed similarly to a least recently used queue, with the exception of the cases when R1 or R2 is output. In these cases, R1 or R2 is simply swapped with R0, which requires fewer operations than a least recently used queue would.

The initial state of R0, R1, R2 is (1, 1, 1).

| Match offset X where... | Operation |
| --- | --- |
| X≠R0 and X≠R1 and X≠R2 | R2←R1R1←R0R0←X |
| X = R0 | None |
| X = R1 | swap R0↔R1 |
| X = R2 | swap R0↔R2 |

### Match Lengths

The minimum match length (number of bytes) encoded by [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) is 2 bytes, and the maximum match length is 32,768 bytes. However, no match of any length can span a modulo 32-KB boundary in the uncompressed [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6). Match-length encoding is combined with match-position encoding as described in section [2.6](#Section_687e0350b2364b808b432c85c5bf078d). Match length can be larger than the repeated offset, which means the matched substrings can overlap.

### Position Slot

The window size determines the number of window subdivisions, or position slots, as shown in the following table.

| Window size | Position slots required |
| --- | --- |
| 128 KB | 34 |
| 256 KB | 36 |
| 512 KB | 38 |
| 1 MB | 42 |
| 2 MB | 50 |
| 4 MB | 66 |
| 8 MB | 98 |
| 16 MB | 162 |
| 32 MB | 290 |

## Header

### Chunk Size

The [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compressor emits chunks of compressed data. A chunk represents exactly 32 KB of uncompressed data until the last chunk in the [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6), which can represent less than 32 KB. To ensure that an exact number of input bytes represent an exact number of output bytes for each chunk, after each 32 KB of uncompressed data is represented in the output compressed bitstream, the output bitstream is padded with up to 15 bits of zeros to realign the bitstream on a 16-bit boundary (even byte boundary) for the next 32 KB of data. This results in a compressed chunk of a byte-aligned size. The compressed chunk could be smaller than 32 KB or larger than 32 KB if the data is incompressible when the chunk is not the last one.

The LZXD engine encodes a compressed, chunk-size prefix field preceding each compressed chunk in the compressed byte stream. The compressed, chunk-size prefix field is a byte aligned, [**little-endian**](#gt_079478cb-f4c5-4ce5-b72b-2144da5d2ce7), 16-bit field. The chunk prefix chain could be followed in the compressed stream without decompressing any data. The next chunk prefix is at a location computed by the absolute byte offset location of this chunk prefix plus 2 (for the size of the chunk-size prefix field) plus the current chunk size.

### E8 Call Translation

E8 call translation is an optional feature that can be used when the data to compress contains x86 instruction sequences. E8 translation operates as a preprocessing stage before compressing each chunk, and the compressed [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6) header contains a bit that indicates whether the decoder shall reverse the translation as a postprocessing step after decompressing each chunk.

The x86 instruction beginning with a byte value of 0xE8 is followed by a 32-bit, [**little-endian**](#gt_079478cb-f4c5-4ce5-b72b-2144da5d2ce7) relative displacement to the call target. When E8 call translation is enabled, the following preprocessing steps are performed on the uncompressed input before compression (assuming little-endian byte ordering):

Let chunk\_offset refer to the total number of uncompressed bytes preceding this chunk.

Let E8\_file\_size refer to the caller-specified value given to the compressor or decoded from the header of the compressed stream during decompression.

The following example shows how E8 translation is performed for each 32-KB chunk of uncompressed data (or less than 32 KB if last chunk to compress).

1. if (( chunk\_offset < 0x40000000 ) && ( chunk\_size > 10 ))
2. for ( i = 0; i < (chunk\_size – 10); i++ )
3. if ( chunk\_byte[ i ] == 0xE8 )
4. long current\_pointer = chunk\_offset + i;
5. long displacement = chunk\_byte[ i+1 ] |
6. chunk\_byte[ i+2 ] << 8 |
7. chunk\_byte[ i+3 ] << 16 |
8. chunk\_byte[ i+4 ] << 24;
9. long target = current\_pointer + displacement;
10. if (( target >= 0 ) && ( target < E8\_file\_size+current\_pointer))
11. if ( target >= E8\_file\_size )
12. target = displacement – E8\_file\_size;
13. endif
14. chunk\_byte[ i+1 ] = (byte)( target );
15. chunk\_byte[ i+2 ] = (byte)( target >> 8 );
16. chunk\_byte[ i+3 ] = (byte)( target >> 16 );
17. chunk\_byte[ i+4 ] = (byte)( target >> 24 );
18. endif
19. i += 4;
20. endif
21. endfor
22. endif

After decompression, the E8 scanning algorithm is the same. The following example shows how E8 translation reversal is performed.

1. long value = chunk\_byte[ i+1 ] |
2. chunk\_byte[ i+2 ] << 8 |
3. chunk\_byte[ i+3 ] << 16 |
4. chunk\_byte[ i+4 ] << 24;
5. if (( value >= -current\_pointer ) && ( value < E8\_file\_size ))
6. if ( value >= 0 )
7. displacement = value – current\_pointer;
8. else
9. displacement = value + E8\_file\_size;
10. endif
11. chunk\_byte[ i+1 ] = (byte)( displacement );
12. chunk\_byte[ i+2 ] = (byte)( displacement >> 8 );
13. chunk\_byte[ i+3 ] = (byte)( displacement >> 16 );
14. chunk\_byte[ i+4 ] = (byte)( displacement >> 24 );
15. endif

The first bit in the first chunk in the [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) bitstream (following the 2-byte, chunk-size prefix described in section [2.2.1](#Section_ce9bcad132054d2aab6b8c8dd4b56588)) indicates the presence or absence of two 16-bit fields immediately following the single bit. If the bit is set, E8 translation is enabled for all the following chunks in the stream using the 32-bit value derived from the two 16-bit fields as the E8\_file\_size provided to the compressor when E8 translation was enabled. Note that E8\_file\_size is completely independent of the length of the uncompressed data. E8 call translation is disabled after the 32,768th chunk (after 1 gigabyte (GB) of uncompressed data).

| Field | Comments | Size |
| --- | --- | --- |
| E8 translation | 0-disabled, 1-enabled | 1 bit |
| Translation size high word | Only present if enabled | 0 or 16 bits |
| Translation size low word | Only present if enabled | 0 or 16 bits |

## Block

### Block Header

An [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) block represents a sequence of compressed data that is encoded with the same set of Huffman trees, or a sequence of uncompressed data. There can be one or more LZXD blocks in a compressed [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6), each with its own set of Huffman trees. Blocks do not have to start or end on a chunk boundary; blocks can span multiple chunks, or a single chunk can contain multiple blocks. The number of chunks is related to the size of the data being compressed, while the number of blocks is related to how well the data is compressed. The **Block Type** field, as specified in section [2.3.1.1](#Section_579b1b808df143e7b32a2a5979062bf4), indicates which type of block follows, and the **Block Size** field, as specified in section [2.3.1.2](#Section_5179cf1105fa47f3af1e00dfbb768199), indicates the number of uncompressed bytes represented by the block. Following the generic block header is a type-specific header that describes the remainder of the block.

| Field | Comments | Size |
| --- | --- | --- |
| **Block Type** | See valid values in section 2.3.1.1 | 3 bits |
| **Block Size** most significant bit  | Blocksize is the high 8 bits of 24 | 8 bits |
| **Block Size** byte 2 | Block size is the middle 8 bits of 24 | 8 bits |
| **Block Size** least significant bit | Block size is the low 8 bits of 24 | 8 bits |

#### Block Type Field

Each block of compressed data begins with a 3-bit **Block Type** field, followed by the **Block Size** field, as specified in section [2.3.1.2](#Section_5179cf1105fa47f3af1e00dfbb768199), and then type-specific block data, as specified in section [2.3.2](#Section_1fd29d87c372450c88131a68b3734b54). Of the eight possible values, only three are valid values for the **Block Type** field.

| Bits | Value | Meaning |
| --- | --- | --- |
| 001 | 1 | Verbatim block |
| 010 | 2 | Aligned offset block |
| 011 | 3 | Uncompressed block |
| other | 0, 4-7 | Not valid |

#### Block Size Field

The **Block Size** field indicates the number of uncompressed bytes that are represented by the block. The maximum value for the **Block Size** field is 2^24-1 (16 MB-1, or 0x00FFFFFF). The **Block Size** field is encoded in the bitstream as three 8-bit fields comprising a 24-bit value, most significant to least significant, immediately following the value of the **Block Type** field.

### Block Data

#### Uncompressed Block

Following the generic block header, an uncompressed block begins with 1 to 16 bits of zero [**padding**](#gt_40c6d4a3-eadf-49d1-8241-c1cab3a0fdf4) to align the bit buffer on a 16-bit boundary. At this point, the bitstream ends and a byte [**stream**](#gt_f3529cd8-50da-4f36-aa0b-66af455edbb6) begins. Following the zero padding, new 32-bit values for R0, R1, and R2 are output in [**little-endian**](#gt_079478cb-f4c5-4ce5-b72b-2144da5d2ce7) form, followed by the uncompressed data bytes themselves. Finally, if the uncompressed data length is odd, one extra byte of zero padding is encoded to realign the following bitstream.

| Field | Comments | Size |
| --- | --- | --- |
| Padding to align following field on 16-bit boundary | Bits have a value of zero | Variable,[1..16] bits |

Then, the following fields are encoded directly in the byte stream, not in the bitstream of byte-swapped 16-bit words:

| Field | Comments | Size |
| --- | --- | --- |
| R0  | Least significant to most significant byte (little-endian **DWORD** ([[MS-DTYP]](%5BMS-DTYP%5D.pdf#Section_cca2742956894a16b2b49325d93e4ba2))) | 4 bytes |
| R1 | Least significant to most significant byte (little-endian **DWORD**) | 4 bytes |
| R2 | Least significant to most significant byte (little-endian **DWORD**) | 4 bytes |
| Uncompressed raw data bytes | Can use the direct **memcpy** function, as specified in [[IEEE1003.1]](https://go.microsoft.com/fwlink/?LinkId=89897) | [2^24 - 1] bytes |
| Padding to realign bitstream | Only if uncompressed size is odd | 0 or 1 byte |

Then the bitstream of byte-swapped 16-bit integers resumes for the next **Block Type** field (if there are subsequent blocks).

The decoded R0, R1, and R2 values are used as initial repeated offset values to decode the subsequent compressed block if present.

#### Verbatim Block

The fields of a verbatim block that follow the generic block header are listed in the following table.

| Entry | Comments | Size |
| --- | --- | --- |
| Pretree for first 256 elements of main tree | 20 elements, 4 bits each | 80 bits |
| [**Path lengths**](#gt_dfa0f2c4-524f-47e9-9b55-cceea09a8204) of first 256 elements of main tree | Encoded using pretree | Variable |
| Pretree for remainder of main tree | 20 elements, 4 bits each | 80 bits |
| Path lengths of remaining elements of main tree | Encoded using pretree | Variable |
| Pretree for length tree | 20 elements, 4 bits each | 80 bits |
| Path lengths of elements in length tree | Encoded using pretree | Variable |
| Token sequence (matches and literals) | Specified in section [2.6](#Section_687e0350b2364b808b432c85c5bf078d) | Variable |

#### Aligned Offset Block

An aligned offset block is identical to the verbatim block except for the presence of the aligned offset tree preceding the other trees.

| Entry | Comments | Size |
| --- | --- | --- |
| Aligned offset tree | 8 elements, 3 bits each | 24 bits |
| Pretree for first 256 elements of main tree | 20 elements, 4 bits each | 80 bits |
| [**Path lengths**](#gt_dfa0f2c4-524f-47e9-9b55-cceea09a8204) of first 256 elements of main tree | Encoded using pretree | Variable |
| Pretree for remainder of main tree | 20 elements, 4 bits each | 80 bits |
| Path lengths of remaining elements of main tree | Encoded using pretree | Variable |
| Pretree for length tree | 20 elements, 4 bits each | 80 bits |
| Path lengths of elements in length tree | Encoded using pretree | Variable |
| Token sequence (matches and literals) | Specified in section [2.6](#Section_687e0350b2364b808b432c85c5bf078d) | Variable |

## Huffman Trees

[**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compression uses canonical Huffman tree structures to represent elements. Huffman trees, as specified in [Cormen], are well known in data compression and are not described here. Because an LZXD decoder uses only the [**path lengths**](#gt_dfa0f2c4-524f-47e9-9b55-cceea09a8204) of the Huffman tree to reconstruct the identical tree, the following constraints are made on the tree structure.

For any two elements with the same path length, the lower-numbered element MUST be farther left on the tree than the higher-numbered element. An alternative way of stating this constraint is that lower-numbered elements MUST have lower path traversal values; for example, 0010 (left-left-right-left) is lower than 0011 (left-left-right-right).

For each level, starting at the deepest level of the tree and then moving upward, leaf nodes MUST start as far left as possible. An alternative way of stating this constraint is that if any tree node has children, all tree nodes to the right of it with the same path length MUST also have children.

A non-empty Huffman tree MUST contain at least two elements. In the case where all but one tree element has zero frequency, the resulting tree MUST minimally consist of two Huffman codes, "0" and "1".

LZXD compression uses several Huffman tree structures. The main tree comprises 256 elements that correspond to all possible 8-bit characters, plus 8 \* **NUM\_POSITION\_SLOTS** elements that correspond to matches. The **NUM\_POSITION\_SLOTS** elements refer to the position slots required, as specified in section [2.1.6](#Section_cc2c0753a5ff454e9b350bf92c79b5ca). The value of the **NUM\_POSITION\_SLOTS** elements depends on the specified window size as described in section 2.1.6. The length tree comprises 249 elements. Other trees, such as the aligned offset tree (comprising 8 elements), and the pretrees (comprising 20 elements each), have a smaller role.

## Encoding the Trees and Pretrees

Because all trees used in [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) compression are created in the form of a canonical Huffman tree, the [**path length**](#gt_dfa0f2c4-524f-47e9-9b55-cceea09a8204) of each element in the tree is sufficient to reconstruct the original tree. The main tree and the length tree are each encoded using the method described here. However, the main tree is encoded in two components as if it were two separate trees, the first tree corresponding to the first 256 tree elements (uncompressed symbols), and the second tree corresponding to the remaining elements (matches).

Because trees are output several times during compression of large amounts of data (multiple blocks), LZXD optimizes compression by encoding only the delta path lengths between the current and previous trees. In the case of the very first such tree, the delta is calculated against a tree in which all elements have a zero path length.

Each tree element can have a path length of [0, 16], where a zero path length indicates that the element has a zero frequency and is not present in the tree. Tree elements are output in sequential order starting with the first element. Elements can be encoded in one of two ways: if several consecutive elements have the same path length, run-length encoding is employed; otherwise, the element is output by encoding the difference between the current path length and the previous path length of the tree, mod 17. To represent a canonical Huffman tree, specify the path lengths of each of the elements in the tree. The following table specifies how to interpret a code.

| Code | Operation |
| --- | --- |
| 0 to 16 | Len[*x*] = (prev\_len[*x*] - code + 17) mod 17 |
| 17 | *Zeros* = getbits(4)Len[*x*] = 0 for next (4 + *Zeros*) elements |
| 18 | *Zeros* = getbits(5)Len[*x*] = 0 for next (20 + *Zeros*) elements |
| 19 | *Same* = getbits(1)Decode new code*Value* = (prev\_len[*x*] - code + 17) mod 17Len[*x*] = Value for next (4 + Same) elements |

Codes 17, 18, and 19 are used to represent consecutive elements that have the same path length. *Zeros*, *Same*, and *Value* are variables created for the purpose of this sample code, and **getbits(*n*)** is a function that fetches the next *n* bits from the bitstream. "Decode new code" is used to parse the next code from the bitstream, which has a value range of [0, 16].

Each of the 17 possible values of (len[*x*] - prev\_len[*x*]) mod 17, plus three additional codes used for run-length encoding, are not output directly as 5-bit numbers but are instead encoded via a Huffman tree called the pretree. The pretree is generated dynamically according to the frequencies of the 20 allowable tree codes. The structure of the pretree is encoded in a total of 80 bits by using 4 bits to output the path length of each of the 20 pretree elements. Once again, a zero path length indicates a zero-frequency element.

| Code | Operation |
| --- | --- |
| Length of tree code 0 | 4 bits |
| Length of tree code 1 | 4 bits |
| Length of tree code 2 | 4 bits |
| ... | ... |
| Length of tree code 18 | 4 bits |
| Length of tree code 19 | 4 bits |

The "real" tree is then encoded using the pretree Huffman codes.

## Compressed Token Sequence

The compressed token sequence (bitstream) contains the Huffman-encoded matches and literals using the Huffman trees specified in the block header. Decompression continues until the number of decompressed bytes corresponds exactly to the number of uncompressed bytes indicated in the block header.

The representation of an unmatched literal character in the output is simply the appropriate element index [0..255] from the main Huffman tree.

The representation of a match in the output involves several transformations, as shown in the following diagram. At the top of the diagram are the match length [2..257] and the match offset [0..WINDOW\_SIZE-3]. The match offset and match length are split into subcomponents and encoded separately. For matches of length [258..32768], the token indicates match length 257, and then the additional value of the **Extra Length** field is encoded in the bitstream following the other match subcomponent fields.

The match subcomponents are shown in the following figure.



Figure 4: Match encoding subcomponents

### Converting Match Offset into Formatted Offset Values

The match offset, range [1..WINDOW\_SIZE-3], is converted into a formatted offset by determining whether the offset can be encoded as a repeated offset, as shown in the following pseudocode. It is acceptable not to encode a match as a repeated offset even if it is possible to do so.

1. if offset == R0 then
2. formatted offset ← 0
3. else if offset == R1 then
4. formatted offset ← 1
5. else if offset == R2 then
6. formatted offset ← 2
7. else
8. formatted offset ← offset + 2
9. endif

### Converting Formatted Offset into Position Slot and Position Footer Values

The formatted offset is subdivided into a position slot and a position footer. The position slot defines the most significant bits of the formatted offset in the form of a base position as shown in the following table. The position footer defines the remaining least significant bits of the formatted offset. As the following table shows, the number of bits dedicated to the position footer grows as the formatted offset becomes larger, meaning that each position slot addresses a larger and larger range.

The number of position slots available depends on the window size. The number of bits of position footer for each position slot is fixed and is shown in the following table.

| Position slot number | Base position | Footer bits | Range of base position and position footer (formatted offset) |
| --- | --- | --- | --- |
| 0 (R0) | 0 | 0 | 0 |
| 1 (R1) | 1 | 0 | 1 |
| 2 (R2) | 2 | 0 | 2 |
| 3 (offset 1) | 3 | 0 | 3 |
| 4 (offset 2..3) | 4 | 1 | 4-5 |
| 5 (offset 4..5) | 6 | 1 | 6-7 |
| 6 (offset 6..9) | 8 | 2 | 8-11 |
| 7 (..etc..) | 12 | 2 | 12-15 |
| 8 | 16 | 3 | 16-23 |
| 9 | 24 | 3 | 24-31 |
| 10 | 32 | 4 | 32-47 |
| 11 | 48 | 4 | 48-63 |
| 12 | 64 | 5 | 64-95 |
| 13 | 96 | 5 | 96-127 |
| 14 | 128 | 6 | 128-191 |
| 15 | 192 | 6 | 192-255 |
| 16 | 256 | 7 | 256-383 |
| 17 | 384 | 7 | 384-511 |
| 18 | 512 | 8 | 512-767 |
| 19 | 768 | 8 | 768-1023 |
| 20 | 1024 | 9 | 1024-1535 |
| 21 | 1536 | 9 | 1536-2047 |
| 22 | 2048 | 10 | 2048-3071 |
| 23 | 3072 | 10 | 3072-4095 |
| 24 | 4096 | 11 | 4096-6143 |
| 25 | 6144 | 11 | 6144-8191 |
| 26 | 8192 | 12 | 8192-12287 |
| 27 | 12288 | 12 | 12288-16383 |
| 28 | 16384 | 13 | 16384-24575 |
| 29 | 24576 | 13 | 24576-32767 |
| 30 | 32768 | 14 | 32768-49151 |
| 31 | 49152 | 14 | 49152-65535 |
| 32 | 65536 | 15 | 65536-98303 |
| 33 | 98304 | 15 | 98304-131071 |
| 34 | 131072 | 16 | 131072-196607 |
| 35 | 196608 | 16 | 196608-262143 |
| 36 | 262144 | 17 | 262144-393215 |
| 37 | 393216 | 17 | 393216-524287 |
| 38 | 524288 | 17 | 524288-655359 |
| 39 | 655360 | 17 | 655360-786431 |
| 40 | 786432 | 17 | 786432-917503 |
| 41 | 917504 | 17 | 917504-1048575 |
| 42 | 1048576 | 17 | 1048576-1179647 |
| ..etc.. | ..etc.. | 17 (all) | ..etc.. |
| 288 | 33292288 | 17 | 33292288-33423359 |
| 289 | 33423360 | 17 | 33423360-33554431 |

The following pseudocode demonstrates how to determine the position slot and the position footer.

1. position\_slot ← calculate\_the position\_slot from the formatted\_offset
2. position\_footer\_bits ← determine the number of footer bits from the position slot value
3. if position\_footer\_bits > 0
4. position\_footer ← formatted\_offset & ((2^position\_footer\_bits)-1)
5. else
6. position\_footer ← null

### Converting Position Footer into Verbatim Bits or Aligned Offset Bits

The position footer can be further subdivided into verbatim bits and aligned offset bits if the current value of the **Block Type** field is 010 (aligned offset), as specified in section [2.3.1.1](#Section_579b1b808df143e7b32a2a5979062bf4). If the current block is not an aligned offset block, there are no aligned offset bits, and the verbatim bits are the position footer.

If aligned offsets are used, the lower 3 bits of the position footer are the aligned offset bits, while the remaining portion of the position footer is the verbatim bits. In the case where fewer than 3 bits are in the position footer (for example, formatted offset is <= 15), it is not possible to take the "lower 3 bits of the position footer", and therefore, there are no aligned offset bits and the verbatim bits and the position footer are the same.

In situations where it is determined that there is a relatively larger number of position footers with identical lower 3 bits, the aligned offset block could be used to reduce the number of bits required to represent the position footer component in the match encoding.

The verbatim block could be used when the lower 3 bits of the position footer are relatively evenly distributed.

The following is a pseudocode example of splitting the position footer into verbatim bits and aligned offset.

1. if block\_type is aligned\_offset\_block then
2. if formatted\_offset <= 15 then
3. verbatim\_bits ← position\_footer
4. aligned\_offset ← null
5. else
6. aligned\_offset ← position\_footer
7. verbatim\_bits ← position\_footer >> 3
8. endif
9. else
10. verbatim\_bits ← position\_footer
11. aligned\_offset ← null
12. endif

### Converting Match Length into Length Header and Length Footer Values

The match length is converted into a length header and a length footer. The length header can have one of eight possible values, with a range of [0, 7], indicating a match of length 2, 3, 4, 5, 6, 7, 8, or a length greater than 8. If the match length is 8 or less, there is no length footer. Otherwise, the value of the length footer is equal to the match length minus 9. The following is a pseudocode example of obtaining the length header and footer.

1. if match\_length <= 8
2. length\_header ← match\_length-2
3. length\_footer ← null
4. else
5. length\_header ← 7
6. length\_footer ← match\_length-9
7. endif

| Match length | Length header | Length footer value |
| --- | --- | --- |
| 2 | 0 | None |
| 3 | 1 | None |
| 4 | 2 | None |
| 5 | 3 | None |
| 6 | 4 | None |
| 7 | 5 | None |
| 8 | 6 | None |
| 9 | 7 | 0 |
| 10 | 7 | 1 |
| … | … | … |
| 256 | 7 | 247 |
| 257 or larger | 7 | 248 |

### Converting Length Header and Position Slot into Length/Position Header Values

The length/position header is the stage that correlates the match position with the match length (using only the most significant bits) and is created by combining the length header and the position slot, as follows:

1. len\_pos\_header ←(position\_slot << 3) + length\_header

This operation creates a unique value for every combination of match length 2, 3, 4, 5, 6, 7, 8 with every possible position slot. The remaining match lengths greater than 8 are all lumped together and, as a group, are correlated with every possible position slot.

### Extra Length Field

If the match length is 257 or larger, the encoded match length token (or match length, as specified in section [2.6](#Section_687e0350b2364b808b432c85c5bf078d)) value is 257, and an encoded **Extra Length** field follows the other match encoding components, as specified in section [2.6.7](#Section_9387a3c177ea4f9490241ca36de95e52), in the bitstream.

| Prefix (in binary) | Number of bits to decode | Base value to add to decoded value |
| --- | --- | --- |
| 0 | 8 | 257 |
| 10 | 10 | 257 + 256 |
| 110 | 12 | 257 + 256 + 1024 |
| 111 | 15 | 257 |

If the encoded match length token is equal to 257, it indicates the length of the match is >= 257. If this is the case, the **Extra Length** field is after the other match encoding components in the bitstream. If the prefix of the **Extra Length** field is 0, the match length is the decoded value of the next 8 bits plus 257. If the prefix is 10, the match length is the decoded value of the next 10 bits plus 257 plus 256. If the prefix is 110, the match length is the decoded value of the next 12 bits plus 257 plus 256 plus 1024. If the prefix is 111, the match length is the decoded value of the next 15 bits plus 257.

### Encoding a Match

The match is finally output as part of the compressed bitstream in up to five components, in the following order:

1. Main tree element at index (len\_pos\_header + 256).
2. If length\_footer != null, the output length tree element is length\_footer.
3. If verbatim\_bits != null, the output is verbatim\_bits.
4. If aligned\_offset\_bits != null, the output element is aligned\_offset from the aligned offset tree.
5. If the match length is 257 or larger, the output consists of the prefix and value of the **Extra Length** field (section [2.6.6](#Section_a81659d1ae584dba943362eb31bf310e)).

### Encoding a Literal

A literal byte that is not part of a match is encoded simply as a main tree element index with a range of [0, 255] corresponding to the value of the literal byte.

## Decoding Matches and Literals (Aligned and Verbatim Blocks)

Decoding is performed by first decoding an element from the main tree and then, if the item is a match, determining which additional components are required to decode to reconstruct the match. The following is a pseudocode example of decoding a match or an uncompressed character.

1. main\_element = main\_tree.decode\_element()
2.
3. /\* Check if it is a literal character. \*/
4. if (main\_element < 256 )
5.
6. /\* It is a literal, so copy the literal to output. \*/
7. window[ curpos ] ← (byte) main\_element
8. curpos ← curpos + 1
9.
10. /\* Decode the match. For a match, there are two components, offset and length. \*/
11. else
12.
13. length\_header ← (main\_element – 256) & 7
14.
15. /\* Length of the footer. \*/
16. if (length\_header == 7)
17. match\_length ← length\_tree.decode\_element() + 7 + 2
18. else
19. /\* no length footer \*/
20. match\_length ← length\_header + 2
21. endif
22.
23. /\* Decoding a match length (if a match length < 257). \*/
24. position\_slot ← (main\_element – 256) >> 3
25.
26. /\* Check for repeated offsets (positions 0,1,2). \*/
27. if (position\_slot == 0)
28. match\_offset ← R0
29. else if (position\_slot == 1)
30. match\_offset ← R1
31. swap(R0 ↔ R1)
32. else if (position\_slot == 2)
33. match\_offset ← R2
34. swap(R0 ↔ R2)
35. /\* Not a repeated offset. \*/
36. else
37. offset\_bits ← footer\_bits[ position\_slot ]
38.
39. if (block\_type == aligned\_offset\_block)
40. /\* This means there are some aligned bits. \*/
41. if (offset\_bits > 3)
42. verbatim\_bits ← (readbits(offset\_bits-3)) << 3
43. aligned\_bits ← aligned\_offset\_tree.decode\_element();
44. else
45. /\* 0, 1, or 2 verbatim bits \*/
46. verbatim\_bits ← readbits(offset\_bits)
47. aligned\_bits ← 0
48. endif
49.
50. formatted\_offset ← base\_position[ position\_slot ]
51. + verbatim\_bits + aligned\_bits

 else

 /\* Block\_type is a verbatim\_block. \*/

1. verbatim\_bits ← readbits(offset\_bits)
2. formatted\_offset ← base\_position[ position\_slot ] + verbatim\_bits
3. endif
4.
5. /\* Decoding a match offset. \*/
6. match\_offset ← formatted\_offset – 2
7.
8. /\* Update repeated offset least recently used queue. \*/
9. R2 ← R1
10. R1 ← R0
11. R0 ← match\_offset
12.
13. endif
14.
15. /\* Check for extra length. \*/
16.
17. if (match\_length == 257)
18. if (readbits( 1 ) != 0)
19. if (readbits( 1 ) != 0)
20. if (readbits( 1 ) != 0)
21. extra\_len = readbits( 15 )
22. else
23. extra\_len = readbits( 12 ) + 1024 + 256
24. endif
25. else
26. extra\_len = readbits( 10 ) + 256
27. endif
28. else
29. extra\_len = readbits( 8 )
30. endif
31.
32. /\* Get the match length (if match length >= 257). \*/
33. match\_length ← 257 + extra\_len
34.
35. endif
36.
37. /\* Get match length and offset. Perform copy and paste work. \*/
38. for (i = 0; i < match\_length; i++)
39. window[curpos + i] ← window[curpos + i – match\_offset]
40. endfor
41.
42. curpos ← curpos + match\_length
43. endif

# Structure Examples

The [**LZXD**](#gt_713bf82d-7765-4db1-bb8e-5bffff50e478) bitstream is to be interpreted as a sequence of aligned 16-bit integers stored in the order least significant byte to most significant byte ([**little-endian**](#gt_079478cb-f4c5-4ce5-b72b-2144da5d2ce7) words).

The only exception is the uncompressed data bytes stored in the uncompressed block interpreted as a sequence of bytes. The following example is a sample encoding sequence of a simple 3-byte text input "abc" encoded with a **Block Type** field value of 3 (uncompressed block).

| Bits to decode | Value of decoded bits | Interpretation |
| --- | --- | --- |
| 16 | 0x0014 | Chunk size: 20 bytes |
| 1 | 0 | E8 translation:disabled |
| 3 | 3 (binary 011) | **Block Type**: uncompressed |
| 24 | 0x000003 | **Block Size**: 3 bytes |
| 4 | binary 0000 | Padding to word-align following |
| 4 bytes | 0x00000001 (little-endian **DWORD** ([[MS-DTYP]](%5BMS-DTYP%5D.pdf#Section_cca2742956894a16b2b49325d93e4ba2))) | R0: 1 |
| 4 bytes | 0x00000001 (little-endian **DWORD**) | R1: 1 |
| 4 bytes | 0x00000001 (little-endian **DWORD**) | R2: 1 |
| 3 bytes | 0x61, 0x62, 0x63 | Uncompressed bytes: "abc" |
| 1 byte | 0x00 | Padding to restore word alignment |

This is the raw hexadecimal compressed byte sequence of the encoded fields:

1. 14 00 00 30 30 00 01 00 00 00 01 00 00 00 01 00 00 00 61 62 63 00

# Security

## Security Considerations for Implementers

None.

## Index of Security Parameters

None.

# Appendix A: Product Behavior

The information in this specification is applicable to the following Microsoft products or supplemental software. References to product versions include updates to those products.

* Microsoft Exchange Server 2003
* Microsoft Exchange Server 2007
* Microsoft Exchange Server 2010
* Microsoft Exchange Server 2013
* Microsoft Exchange Server 2016
* Microsoft Office Outlook 2003
* Microsoft Office Outlook 2007
* Microsoft Outlook 2010
* Microsoft Outlook 2013
* Microsoft Outlook 2016
* Microsoft Exchange Server 2019
* Microsoft Outlook 2019

Exceptions, if any, are noted in this section. If an update version, service pack or Knowledge Base (KB) number appears with a product name, the behavior changed in that update. The new behavior also applies to subsequent updates unless otherwise specified. If a product edition appears with the product version, behavior is different in that product edition.

Unless otherwise specified, any statement of optional behavior in this specification that is prescribed using the terms "SHOULD" or "SHOULD NOT" implies product behavior in accordance with the SHOULD or SHOULD NOT prescription. Unless otherwise specified, the term "MAY" implies that the product does not follow the prescription.

# Change Tracking

This section identifies changes that were made to this document since the last release. Changes are classified as Major, Minor, or None.

The revision class **Major** means that the technical content in the document was significantly revised. Major changes affect protocol interoperability or implementation. Examples of major changes are:

* A document revision that incorporates changes to interoperability requirements.
* A document revision that captures changes to protocol functionality.

The revision class **Minor** means that the meaning of the technical content was clarified. Minor changes do not affect protocol interoperability or implementation. Examples of minor changes are updates to clarify ambiguity at the sentence, paragraph, or table level.

The revision class **None** means that no new technical changes were introduced. Minor editorial and formatting changes may have been made, but the relevant technical content is identical to the last released version.

The changes made to this document are listed in the following table. For more information, please contact dochelp@microsoft.com.

| Section | Description | Revision class |
| --- | --- | --- |
| [2.7](#Section_06ee7ce0730a4907be3cf1f5673b0300) Decoding Matches and Literals (Aligned and Verbatim Blocks) | Improved formatting of pseudocode. | Minor |

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