[MS-PATCH]:
LZX DELTA Compression and Decompression

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Revision Summary

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07/15/2009	3.0	Major	Revised and edited for technical content.
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			the technical content.
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Table of Contents

1 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 and can contain the terms MAY, SHOULD, MUST, MUST NOT, and SHOULD NOT as defined in [RFC2119]. All other sections and examples in this specification are informative.

1.1 Glossary

The following terms are defined in [MS-OXGLOS]:

encoding
Lempel-Ziv Extended (LZX)
Lempel-Ziv Extended Delta (LZXD)
little-endian
offline address book (OAB)
padding
stream

The following terms are specific to this document:

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

MAY, SHOULD, MUST, SHOULD NOT, MUST NOT: These terms (in all caps) are used as defined in [RFC2119]. All statements of optional behavior use either MAY, SHOULD, or SHOULD NOT.

1.2 References

References to Microsoft Open Specification documents do not include a publishing year because links are to the latest version of the documents, which are updated frequently. References to other documents include a publishing year when one is available.

1.2.1 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

[MS-DTYP] Microsoft Corporation, "Windows Data Types".

[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

[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

1.2.2 Informative References

[MS-OXGLOS] Microsoft Corporation, "Exchange Server Protocols Master Glossary".

[MS-OXOAB] Microsoft Corporation, "Offline Address Book (OAB) File Format and Schema".

[MS-OXPROTO] Microsoft Corporation, "Exchange Server Protocols System Overview".

1.3 Overview

Lempel-Ziv Extended Delta (LZXD) 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** (2), allowing the match offset to refer to the logically prepended reference data. This relaxed constraint effectively enables the compressed data stream (2) to encode "matches" both from the reference data and from the uncompressed data stream (2).

1.4 Relationship to Protocols and Other Structures

LZXD (D for Delta) is an **LZX** 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], that uses static Huffman **encoding** 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 (2). The value of the offset is constrained to be less than the current position in the output stream (2), up to the size of the sliding window.

The LZXD compression format is used by [MS-OXOAB] to compress data in the **offline address book (OAB)**.

For conceptual background information and overviews of the relationships and interactions between this and other protocols, see [MS-OXPROTO].

1.5 Applicability Statement

LZXD 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 version 4 Differential Patch or Compressed OAB Template files.

1.6 Versioning and Localization

None.

1.7 Vendor-Extensible Fields

None.

2 Structures

LZXD compressed data consists of a header that indicates the file translation size, followed by a sequence of compressed blocks. A stream (2) 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:

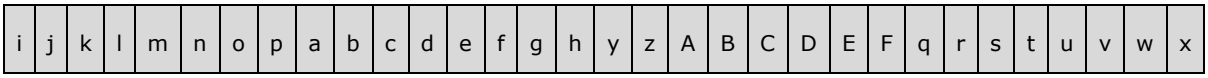
- Uncompressed block, as specified in section 2.3.2.1.
- Verbatim block, as specified in section 2.3.2.2.
- Aligned offset, as specified in section 2.3.2.3.

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.

2.1 Concepts

2.1.1 Bitstream

An LZXD bitstream is encoded as a sequence of aligned 16-bit integers stored in the least-significant-byte to most-significant-byte order, also known as byte-swapped, or **little-endian**, words. Given an input stream (2) of bits named a, b, c,..., x, y, z, A, B, C, D, E, F, the output byte stream (2) MUST be as follows:



2.1.2 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 (2) 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.

2.1.3 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 (2), up to the specified window size. When match offset values exceed the number of bytes already emitted in the uncompressed output stream (2), they are pointing into the reference data that is logically prepended to the subject data.

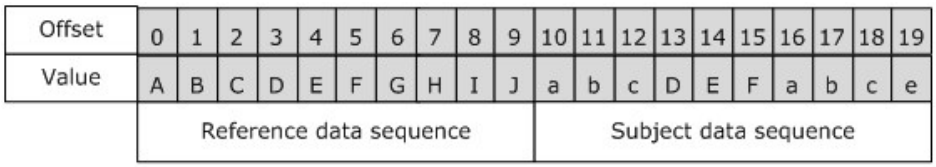


Figure 2: Example reference data and subject data

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.

2.1.4 Repeated Offsets

LZXD compression extends the conventional Lempel-Ziv 1977 sliding window data compression algorithm format, as specified in [UASDC], 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

Encoded offset	Real offset
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←R1 R1←R0 R0←X
X = R0	None
X = R1	swap R0↔R1
X = R2	swap R0↔R2

2.1.5 Match Lengths

The minimum match length (number of bytes) encoded by LZXD 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 (2). Match-length encoding is combined with match-position encoding as described in section 2.6.

2.1.6 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

Window size	Position slots required
4 MB	66
8 MB	98
16 MB	162
32 MB	290

2.2 Header

2.2.1 Chunk Size

The LZXD compressor emits chunks of compressed data. A chunk represents exactly 32 KB of uncompressed data until the last chunk in the stream (2), 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 (2). The compressed, chunk-size prefix field is a byte aligned, little-endian, 16-bit field. The chunk prefix chain could be followed in the compressed stream (2) 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.

2.2.2 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 (2) 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 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 (2) 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).

```
if (( chunk_offset < 0x40000000 ) && ( chunk_size > 10 ))
   for ( i = 0; i < (chunk_size - 10); i++ )
if ( chunk_byte[ i ] == 0xE8 )
   long current_pointer = chunk_offset + i;
long displacement =    chunk_byte[ i+1 ] |
chunk_byte[ i+2 ] << 8  |
```

```
chunk_byte[ i+3 ] << 16 |
chunk_byte[ i+4 ] << 24;
long target = current_pointer + displacement;
if (( target >= 0 ) && ( target < E8_file_size+current_pointer))
if ( target >= E8_file_size )
target = displacement – E8_file_size;
endif
chunk_byte[ i+1 ] = (byte)( target );
chunk_byte[ i+2 ] = (byte)( target >> 8 );
chunk_byte[ i+3 ] = (byte)( target >> 16 );
chunk_byte[ i+4 ] = (byte)( target >> 24 );
endif
   i += 4;
endif
endfor
endif
```

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

```
long value =    chunk_byte[ i+1 ]       |
chunk_byte[ i+2 ] << 8  |
chunk_byte[ i+3 ] << 16 |
chunk_byte[ i+4 ] << 24;

if (( value >= -current_pointer ) && ( value < E8_file_size ))
if ( value >= 0 )
displacement = value – current_pointer;
else
displacement = value + E8_file_size;
endif
chunk_byte[ i+1 ] = (byte)( displacement );
chunk_byte[ i+2 ] = (byte)( displacement >> 8 );
chunk_byte[ i+3 ] = (byte)( displacement >> 16 );
chunk_byte[ i+4 ] = (byte)( displacement >> 24 );
endif
```

The first bit in the first chunk in the LZXD bitstream (following the 2-byte, chunk-size prefix described in section 2.2.1) 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 (2) 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

2.3 Block

2.3.1 Block Header

An LZXD 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 (2), 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, indicates which type of block follows, and the **Block Size** field, as specified in section 2.3.1.2, 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	Block size 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

2.3.1.1 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, and then type-specific block data, as specified in section 2.3.2. 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

2.3.1.2 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 224-1 (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.

2.3.2 Block Data

2.3.2.1 Uncompressed Block

Following the generic block header, an uncompressed block begins with 1 to 16 bits of zero **padding** to align the bit buffer on a 16-bit boundary. At this point, the bitstream ends and a byte stream (2) begins. Following the zero padding, new 32-bit values for R0, R1, and R2 are output in little-endian

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 (2), 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]))	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]	[1..224-1] 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.

2.3.2.2 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 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	Variable

2.3.2.3 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 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	Variable

2.4 Huffman Trees

LZXD 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 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. 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.

2.5 Encoding the Trees and Pretrees

Because all trees used in LZXD compression are created in the form of a canonical Huffman tree, the path length 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 17 Len[*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.

2.6 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.

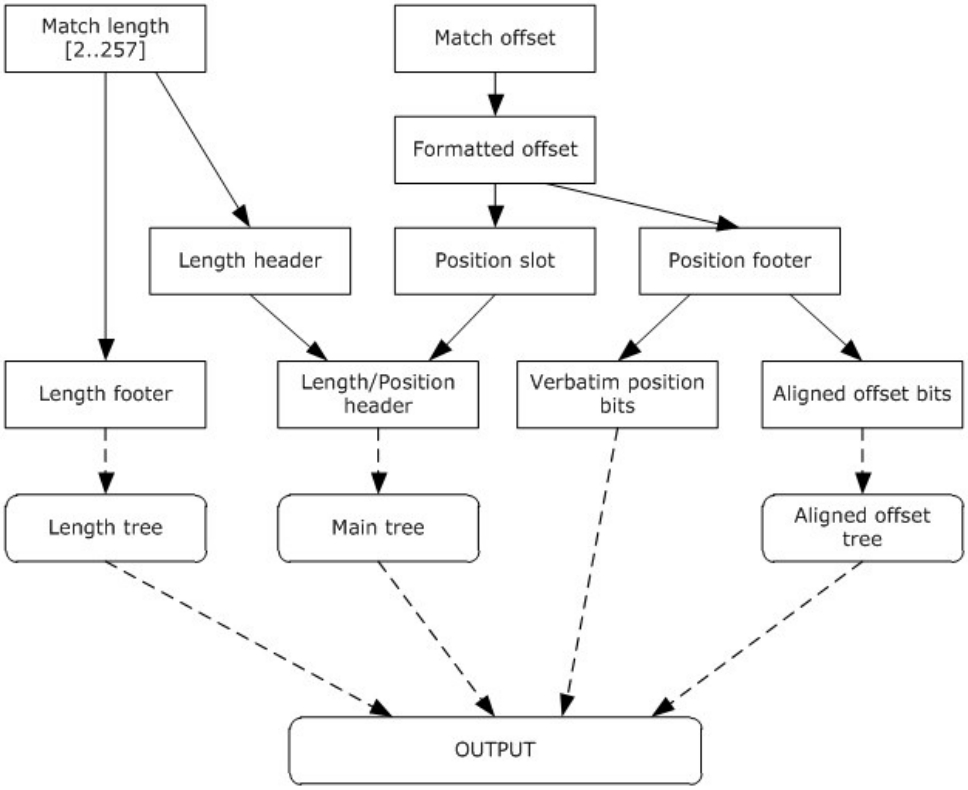


Figure 3: Match encoding subcomponents

2.6.1 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.

```
if offset == R0 then
   formatted offset ←  0
else if offset == R1 then
   formatted offset ←  1
else if offset == R2 then
   formatted offset ←  2
else
   formatted offset ←  offset + 2
endif
```

2.6.2 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

Position slot number	Base position	Footer bits	Range of base position and position footer (formatted offset)
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

Position slot number	Base position	Footer bits	Range of base position and position footer (formatted offset)
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.

```
position_slot ← calculate_the position_slot from the formatted_offset
position_footer_bits ← determine the number of footer bits from the position slot value
if position_footer_bits > 0
    position_footer ← formatted_offset & ((2^position_footer_bits)-1)
else
    position_footer ← null
```

2.6.3 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. 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.

```
if block_type is aligned_offset_block then
   if formatted_offset <= 15 then
      verbatim_bits ← position_footer
      aligned_offset ← null
   else
      aligned_offset ← position_footer
      verbatim_bits ← position_footer >> 3
   endif
else
   verbatim_bits ← position_footer
   aligned_offset ← null
endif
```

2.6.4 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.

```
if match_length <= 8
   length_header ← match_length-2
   length_footer ← null
else
   length_header ← 7
   length_footer ← match_length-9
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

2.6.5 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:

```
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.

2.6.6 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) value is 257, and an encoded **Extra Length** field follows the other match encoding components, as specified in section 2.6.7, 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.

2.6.7 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).

2.6.8 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.

2.7 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.

```
main_element = main_tree.decode_element()
/* Check if it is a literal character. */
if (main_element < 256 )
/* It is a literal, so copy the literal to output. */
window[ curpos ] ← (byte) main_element
```

```
curpos ← curpos + 1

/* Decode the match. For a match, there are two components, offset and length. */
else
length_header ← (main_element - 256) & 7

if (length_header == 7)

/* Length of the footer. */
match_length ← length_tree.decode_element() + 7 + 2
else
match_length ← length_header + 2 /* no length footer */

/* Decoding a match length (if a match length < 257). */
endif

position_slot ← (main_element - 256) >> 3

/* Check for repeated offsets (positions 0,1,2). */
if (position_slot == 0)
match_offset ← R0
else if (position_slot == 1)
match_offset ← R1
swap(R0 ↔ R1)
else if (position_slot == 2)
match_offset ← R2
swap(R0 ↔ R2)

/* Not a repeated offset. */
else
offset_bits ← footer_bits[ position_slot ]

if (block_type == aligned_offset_block)

/* This means there are some aligned bits. */
if (offset_bits >= 3)
verbatim_bits ← (readbits(offset_bits-3)) << 3
aligned_bits  ← aligned_offset_tree.decode_element();
else /* 0, 1, or 2 verbatim bits */
verbatim_bits ← readbits(offset_bits)
aligned_bits  ← 0
endif

formatted_offset ← base_position[ position_slot ]
+ verbatim_bits + aligned_bits

/* Block_type is a verbatim_block. */
else
verbatim_bits ← readbits(offset_bits)
formatted_offset ← base_position[ position_slot ] + verbatim_bits
endif

/* Decoding a match offset. */
match_offset ← formatted_offset - 2

/* Update repeated offset least recently used queue. */
R2 ← R1
R1 ← R0
R0 ← match_offset
```

```
  endif

  /* Check for extra length. */

  if (match_length == 257)
  if (readbits( 1 ) != 0)
  if (readbits( 1 ) != 0)
  if (readbits( 1 ) != 0)
  extra_len = readbits( 15 )
  else
  extra_len = readbits( 12 ) + 1024 + 256
  endif
  else
  extra_len = readbits( 10 ) + 256
  endif
  else
  extra_len = readbits( 8 )

  /* Decode the extra length. */
  endif

  /* Get the match length (if match length >= 257). */
  match_length ← 257 + extra_len

  endif

  /* Get match length and offset. Perform copy and paste work. */
  for (i = 0; i < match_length; i++)
  window[curpos + i] ← window[curpos + i – match_offset]

  curpos ← curpos + match_length

  endif
```

3 Structure Examples

The LZXD 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 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]))	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:

```
14 00 00 30 30 00 01 00 00 00 01 00 00 00 01 00 00 00 61 62 63 00
```

4 Security

4.1 Security Considerations for Implementers

None.

4.2 Index of Security Parameters

None.

5 Appendix A: Product Behavior

The information in this specification is applicable to the following Microsoft products or supplemental software. References to product versions include released service packs:

- Microsoft Exchange Server 2003
- Microsoft Exchange Server 2007
- Microsoft Exchange Server 2010
- Microsoft Exchange Server 2013
- Microsoft Office Outlook 2003
- Microsoft Office Outlook 2007
- Microsoft Outlook 2010
- Microsoft Outlook 2013

Exceptions, if any, are noted below. If a service pack or Quick Fix Engineering (QFE) number appears with the product version, behavior changed in that service pack or QFE. The new behavior also applies to subsequent service packs of the product 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.

6 Change Tracking

No table of changes is available. The document is either new or has had no changes since its last release.

7 Index