Common Log File System (CLFS)

Analysis of the Windows ARIES-based log system

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Summary

As of Windows Vista support for Transactional NTFS (TxF) and Transactional Registry (TxR) were added. Both systems use the Common Log File System (CLFS) which was introduced in Windows server 2003 R2.

This document is intended as a working document for the CLFS format. Which should allow existing Open Source forensic tooling to be able to process this type of file system.

Document information

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Abstract: This document contains information about the Common Log File System (CLFS)

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Version

Version	Author	Date	Comments
0.0.1	J.B. Metz	November 2010 December 2010	Initial version.
0.0.2	J.B. Metz	March 2011	Additional information.
0.0.3	J.B. Metz	September 2012	Email update.
0.0.4	J.B. Metz	February 2013	Additional information.

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1. Overview

As of Windows Vista support for Transactional NTFS (TxF) and Transactional Registry (TxR) were added. Both systems use the Common Log File System (CLFS) which was introduced in Windows server 2003 R2.

CLFS was designed on the principles of is short for Algorithm for Recovery and Isolation Exploiting Semantics (ARIES). For more information see [MOHAN92].

CLFS supports two types of logs:
- dedicated logs; contains a single stream of log records.
- multiplexed (or common) logs; contains several streams of log records.
  The first stream (stream 0) is the physical stream.

Characteristics	Description
Byte order	little-endian
Date and time values	
Character string	Unicode strings are stored in UTF-16 little-endian without the byte order mark (BOM).

1.1. Test version

The following version of programs were used to test the information within this document:
- Windows Vista
- Windows 7

TODO: Windows server 2003 R2, 2008

2. The log store

A CLFS log store consists of:
- a base log file
- one or more container files

In comparison with a disk file systems the log store is similar to a volume.

2.1. Base log file

The base log file (.blf) contains the log store metadata, like:
- the beginning of the log,
- the container size,
- the container path,
- the location from which restart operations should be per formed,
- the log state,
- the log name,
- the log clients.

For recovery purposes the base log file also contains a copy of the previous version of the metadata. A dump count value indicates which copy is newest.

The base log file is commonly 64 KiB (65536 bytes) of size, but will grow if necessary.

2.2. Container file

The size of the container file is stored in the base log file.

CLFS allows for a maximum of 1023 containers. All the containers file in the same log have an equal size. The size is a multitude of 512 KiB with a 4 GiB maximum size, due to 23-bit block offset values (which represent 32-bit file offsets). Also see: 3 Log Sequence Number.

3. Log Sequence Number

The log sequence number (LSN) consists of:

- a logical container identifier, which identifies the container that holds the record;
- a block offset within the container, which contains the file offset of the log block that holds the record;
- a record number, which contains the sequence number of the record within the log block.

The LSN (CLFS_LSN) is 8 bytes of size and consist of:

offset	**size**	**value**	**description**
0.0	9 bits		Record number Where 0 is the first record number
1.1	23 bits		Block offset
4.0	4 bytes		Logical container identifier

Note that the logical container identifier is a value maintained by the log store metadata. It is possible that the logical and physical container identifiers are the same. Over time a logical container identifier will grow, e.g. a log store of 2 containers will start out with 0 as the logical container identifier for the first container, but when the first container is reused (recycled) the logical container identifier will change into 2.

Special LSN values:

Value	**Identifier**	**Description**
0x0000000000000000	CLFS_LSN_NULL	Lower boundary for an LSN A valid LSN (0.0.0)
0x00000000ffffffff	CLFS_LSN_INVALID	Upper boundary for an LSN Not a valid LSN (0.-1.-1)

4. Log block

The log block or log IO block is variable of size, but always a multitude of the sector size. A log block consists of:

- a log block header
- one or more log records
- unused or slack block-space

- fix-up values

A log block can have at most 512 log records.

Note that [RUSSNOVICH09] refers to the fix-up values as sector signature array.

4.1. Log block header

The log block header is 112 bytes of size and consists of:

offset	size	value	description
0	2	0x0015	Signature
2	1		Fix-up placeholder value Contains the upper byte of the fix-up placeholder value
3	1		Stream number
4	2		Number of sectors Size = number x 512
6	2		Copy of number of sectors Size = number x 512
8	4		Unknown (empty value)
12	4		Checksum Contains an unknown checksum of the data in the log block with the checksum value itself set to 0 checksum is xor based with lookup table This value is not set in container block
16	4	0x01	Format version (or sentinel value)
20	4	0x00	Unknown (empty value)
24	8		The physical LSN of the block
32	8		Next block LSN Contains a (physical) block LSN Is set to CLFS_LSN_INVALID if not used.
40	4		Record data offset The offset value is relative from the start of the block (or size of log block header)
44	4		Sector mapping array offset The offset value is relative from the start of the block
48	4		Virtual log range array offset The offset value is relative from the start of the block

offset	size	value	description
52	8		Unknown (offsets array?)
60	44		Unknown (empty?)
104	4		Offset to fix-up values The offset is relative to the start of the block
108	4		Unknown (empty?)

Sometimes CLFS chains multiple blocks. The reason for this is probably related to writing records.

If a record is in a block-chain, every block in the chain should be read until either the specific or last record is found. Note that the next block LSN value of the last block in the chain not necessarily has to point to a block.

4.2. Log block fix-up values

The fix-up values are 2 bytes of size and are stored front-to-back. They are stored in 8 byte-aligned chunks.

There is also placeholder fix-up value of the upper byte at offset 2 in the block header.

E.g. consider a block of 3 sectors of 512 byte in size and the following fix-up values:

```
00 00 00 00 00 00 30 44
```

Where 0x4430 is the fixed-up byte value of the last sector.

The first fix-up value is 0x0000 and applies to bytes 511 and 512:

```
50 44
```

The the byte value is checked using the following rules:

- The upper byte should be similar to the placeholder (0x44)
- The lower byte should be smaller than 0x80
- The lower byte of the first sector should have 0x40 set
- The lower byte of the last sector should have 0x20 set
- The lower byte of the first sector should have a value of either 0, 4, 8 or 16

Note that the first and last sector rule both apply for a single sector block.

In this case the byte value matches the rules and can be replaces by the fix-up value.

Notes:
Fix-up lower byte value base log 0x10
for container block

- if stream number = 0x00 => 0x08
- if stream number = 0x01 => 0x04

5. Base log file

The base log file consists of:

- Block containing base log block descriptors record
- 2 x empty sectors
- Block containing current base log metadata information record
- Block containing previous base log metadata information record
- 1 x sector-sized empty block
- 1 x empty sectors

The highest dump count of the base log metadata information record indicates the most recent version.

5.1. Base log block descriptors block

The base log block descriptors block is the first block in the base log it is 2 sectors (1024 bytes) of size. The base log block descriptors block contains a single record namely the base log block descriptors record.

5.1.1. Base log block descriptors record

The base log block descriptors record is variable of size and consists of:

offset	size	value	description
0	4	0x00000001	Dump count?
4	4	0x00000000	Unknown (empty value)
8	4	0x00005f1c	Unknown (fixed value)
12	4	0xc1f5c1f5	Unknown (fixed value)
16	8	0x00000001	Unknown (version?)
24	48		Unknown (empty values)
72	4		Number of block descriptors Value should be within the range [6, 31]
76	...		Block descriptor array

5.1.2. Base log block descriptor

A base log block descriptor is 24 bytes of size and consists of

offset	size	value	description
0	12		Unknown (empty values)
12	4		Block size Value in bytes
16	4		Block offset
20	4		Block number (or index)

5.2. Base log store metadata block

The base log store metadata block is the second and third block in the base log it is 61 sectors (31232 bytes) of size. The base log store metadata block contains a single record namely the base log store metadata record.

5.2.1. Base log store metadata record

The base log metadata record is variable of size and consists of:

offset	size	value	description
0	4		Dump count
4	4		Unknown
8	16		Log store (or volume) identifier Unique GUID for log store
24	44		Record offsets array Contains offset to file information record (type 0xc1fdf006) The offsets are relative to the start of the log block
68	44		Unknown
112	44		Unknown (array)
156	44		Unknown
200	44		Unknown (array)
244	44		Unknown
288	4		Unknown
292	4		Number of values 1
296	4		Unknown
300	4		Number of values 2
304	4		Unknown
308	4		Unknown
312	124 x 4 = 496		Values 1 array Array of 4-byte values Unused values are set to 0 Maximum of 124 values Contains offset to stream attributes record data record (type 0xc1fdf007) The offsets are relative to the start of the log block
808	1024 x 4 = 4096		Values 2 array Array of 4-byte values Unused values are set to 0 Maximum of 1024 values

offset	size	value	description
			Contains offset to container attributes record (type 0xc1fdf008) The offsets are relative to the start of the log block
4904	4		Information records data size
4908	4		Unknown
4912	2		Unknown
4914	1		Unknown (flags) 0x01 0x02 has number of values2 ? 0x40 has number of values1 ?
4915	1		Unknown backup of number of values1?
4916	1		Unknown backup of number of values2?
4917	3		Unknown
4920	...		Information records data

5.3. Base log information record

The base log information record is variable of size and consists of:

offset	size	value	description
0	4		Information record type (or 3 byte signature with 1 byte type)
4	4		Information record size Including the type and size values
8	(record size – 8)		Information record data

5.3.1. The file information record

The file information record (type 0xc1fdf006) is 48 bytes of size.

The information record data is 40 bytes of size and consists of:

offset	size	value	description
0	4		Checksum Contains an unknown checksum of the data in the log block with the checksum value itself set to 0
4	4		Name offset The offset is relative to the start of the file information record (or the combined size of the file and

offset	size	value	description
			attributes information records)
8	16		Unknown (empty values)
24	4		Block name offset The offset is relative to the start of the log block
28	4		Block file attributes offset The offset is relative to the start of the log block and points to a stream or container attributes information record
32	8		Unknown (empty values)

The name is an UTF-16 little-endian string with an end-of-string character.

The information records are 8 byte aligned therefore there can be alignment padding after the name. The size of the name and alignment padding is not part of the information record size.

5.3.2. The stream attributes information record

The stream attributes information record (type 0xc1fdf007) is 136 bytes of size.

The information record data is 128 bytes of size and consists of:

offset	size	value	description
0	2		Stream number 0x00 = physical log other values are logical logs
2	2	0x0100 0x0102	Unknown 0x0100 => dedicated log type?
4	4		Flush queue (threshold) size Only set for stream number 0
8	40		Unknown (empty values?)
48	8		Unknown LSN? Last written owner page ? Multiplexed log only?
56	8		Base (or log start) LSN
64	8		Last flushed LSN
72	8		Last LSN
80	8		Unknown LSN?
88	8		Unknown LSN?
96	32		Unknown (empty values?)

The name following this record contains the stream name.

5.3.3. The container attribute information record

The container attributes information record (type 0xc1fdf008) is 48 bytes of size.

The information record data is 40 bytes of size and consists of:

offset	size	value	description
0	4		Container file size
4	4		Unknown (empty values)
8	4		Physical container number
12	4		Logical container number
16	4		Unknown (LSN?) Seen: 0x00000000 if container file does not exists?
20	4	0x00000000	Unknown (empty values)
24	4		Number of streams in container
28	4	0x00000002 0x00200004	Unknown
32	8		Unknown (empty values)

The name following this record contains the container filename.

The logical container number is increased if the container is reused (recycled). Also see: 3 Log Sequence Number.

Multiple container files with the same logical container number ?

5.3.4. Unknown information record

The unknown information record (type 0xc1fdf003) is 184 bytes of size.

The unknown information record (type 0xc1fdf009) is 84 bytes of size.

The unknown information record (type 0xc1fdf00a) is 168 bytes of size.

The unknown information record (type 0xc1fdf00d) is 28 bytes of size.

The unknown information record (type 0xc1fdf00e) is 56 bytes of size.

The unknown information record (type 0xc1fdf00f) is 128 bytes of size.

6. Container file

The containers of multiplexed logs are made up of 512 KiB regions, which contain 4 KiB pages. The last page of a region contains the owner page. What about dedicated logs?

6.1. Owner page

The last 4 KiB of a 512 KiB region in a multiplexed log contains the owner page. The owner page is used to provide information about virtual logs and sectors in a specific region.

The owner page consists of:

- the virtual log range, consisting of the lower and upper LSNs
- the mapping between sectors and virtual logs

The owner page is only written if the region has become full. The last block of the previous region can be split by the insertion of the owner page block. The remainder of the split-block data is stored in the next region.

The owner page data is stored in a log block without a block data offset (at block header offset 112) but uses the values at block header offset:

- 44 for the sector mapping array
- 48 for the virtual log range array

Note that not all owner pages contain valid log range data, e.g. the last owner page of the log is not written until the region has become full.

6.1.1. Sector mappings

The sector mappings array contains a maximum of 1024 sector mapping entries (512 KiB / 512 bytes per sector). Each mapping entry defines a mapping between a virtual LSN to a physical LSN.

The sector mapping entry is 2 bytes of size and consists of:

offset	**size**	**value**	**description**
0	1		Stream (or client) number Should be larger than 0 and smaller than the number of streams in the log store
1	1		Block sector number

A sector mapping entry of 0xff 0xff is used to represent the owner page itself.

The first virtual log stream has either a block sector number of 0. Sector mappings before the first virtual log stream mapping correspond to the last segment of a split block started in the previous region.

6.1.2. Virtual log range

The virtual log range array contains an entry for every stream. The first entry is the virtual log range for stream 0.

The virtual log range entry is 16 bytes of size and consists of:

offset	**size**	**value**	**description**
0	8		Start LSN
8	8		End LSN

6.1.3. Example mapping virtual to physical LSNs

The following example was taken from [RUSSNOVICH09] but adjusted to match the actual on-disk data.

Let's start with the stream 1 virtual LSN 0.1000.0 (container 0, block 0x1000, record 0). The owner page for the corresponding region contains the following information:

Virtual log ranges:

```
Stream 1 virtual LSN range (0.0.0 - 0.1400.0)
Stream 2 virtual LSN range (0.0.0 - 0.1600.0)
```

Sector mappings:

```
Physical sector              Stream      Block sector number
00 (0x0000 - 0x01ff)         1           0
01 (0x0200 - 0x03ff)         1           1
02 (0x0400 - 0x05ff)         2           0
03 (0x0600 - 0x07ff)         2           1
04 (0x0800 - 0x09ff)         2           2
05 (0x0a00 - 0x0bff)         2           3
06 (0x0c00 - 0x0dff)         1           0
07 (0x0e00 - 0x0fff)         1           1
08 (0x1000 - 0x11ff)         1           0
09 (0x1200 - 0x13ff)         1           1
10 (0x1400 - 0x15ff)         2           0
...

Physical sector range        Stream      Virtual sector range
00 – 01 (0x0000 - 0x03ff)    1           00 – 01 (0x0000 - 0x03ff)
02 – 05 (0x0400 - 0x0bff)    2           00 – 03 (0x0000 – 0x07ff)
06 – 07 (0x0c00 - 0x0fff)    1           03 – 04 (0x0400 – 0x06ff)
08 – 09 (0x1000 - 0x13ff)    1           08 – 09 (0x1000 – 0x11ff)
10      (0x1400 - 0x15ff)    2           06      (0x0c00 – 0x0dff)
...
```

The text has been made bold to emphasize the non-continuous behavior of the virtual sector range.

The first sector that belongs to stream 1 is physical LSN 0.0.0.
This block's size is 2 sectors, therefore the next virtual LSN is 0.0.0 + 0.400.0 = 0.400.0

The next block that belongs to stream 1 is physical LSN 0.c00.0.
This block's size is 2 sectors, therefore the next virtual LSN is 0.c00.0 + 0.400.0 = 0.1000.0

The next block that belongs to stream 1 is physical LSN 0.1000.0.
This is virtual LSN 0.1000.0.

6.2. Record

The container record consist of:

- record header
- record data
- alignment padding

Note that the records are 8 byte aligned.

6.2.1. Record header

The record header is 40 bytes of size and consists of:

offset	size	value	description
0	8		The virtual LSN of the record
8	8		Undo-next LSN Contains the first LSN of a chain of records Contains a (virtual) record LSN
16	8		Previous LSN Contains a (virtual) record LSN
24	4		Record size
28	4		Next (undo) record size
32	2		Record flags See section: 6.2.2 Record flags
34	2		Data offset
36	4		Record type See section: 6.2.3 Record type

6.2.2. Record flags

Value	Identifier	Description
0x0020		Unknown

6.2.3. Record type

The record type consist of multiple record type flags.

Value	Identifier	Description
0x00000000	ClfsNullRecord	Null record
0x00000001	ClfsDataRecord	The log record contains client data
0x00000002	ClfsRestartRecord	The log record is a restart record
0x00000004	ClfsStartRecord	Start of continuation record
0x00000008	ClfsEndRecord	End of continuation record
0x00000010	ClfsContinuationRecord	Continuation record
0x00000020	ClfsLastRecord	The last record in the log block

Appendix A. References

[MOHAN92]
Title: ARIES: A Transaction Recovery Method Supporting Fine-Granularity Locking and Partial Rollbacks Using Write-Ahead Logging
Author(s): C. Mohan, Don Haderle, Bruce Lindsay, Hamid Pirahesh and Peter Schwarz
Date: March 1992
URL: http://www.sai.msu.su/~megera/postgres/gist/papers/concurrency/p94-mohan.pdf

[RUSSNOVICH09]
Title: Windows Internals 5 - Covering Windows Server 2008 and Windows Vista
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Date: June 17, 2009
ISBN-13: 978-0735625303

[MSDN]
Title: Microsoft Developer Network
Subject: CLFS Stable Storage
URL: http://msdn.microsoft.com/en-us/library/ff541862.aspx

[WIKI]
Title: Common Log File System
URL: http://en.wikipedia.org/wiki/Common_Log_File_System

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