

SQL Server Forensics

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ring 3



ring 2



ring 1

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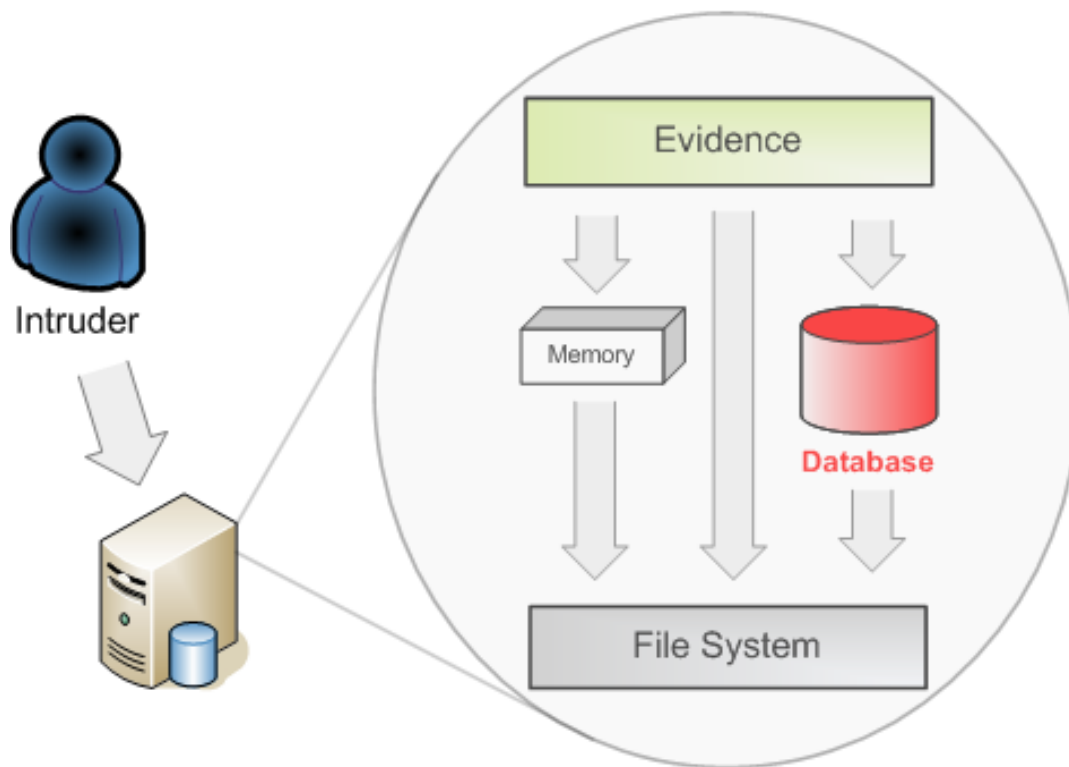
Why are databases critical assets?

❖ Why are databases critical assets?

- Databases hold critical information
- Industry trends are scaling in versus out
- Database servers today hold more sensitive information than ever before
- Data security legislations & regulations dictate that security breaches must be reported
- The Canadian Internet Policy and Public Interest Clinic (CIPPIC) is calling for a data security breach notification law in Canada
- Database security breaches are “Front Page” news
 - TJ Maxx | 45.7 million credit/debit cards disclosed
 - CardSystems Solutions | 200,000 credit/debit cards disclosed

The problem with traditional forensics

- ❖ Traditional investigations often exclude databases



SQL Server Forensics | the solution

❖ Database Forensics

The application of computer investigation and analysis techniques to gather database evidence suitable for presentation in a court of law

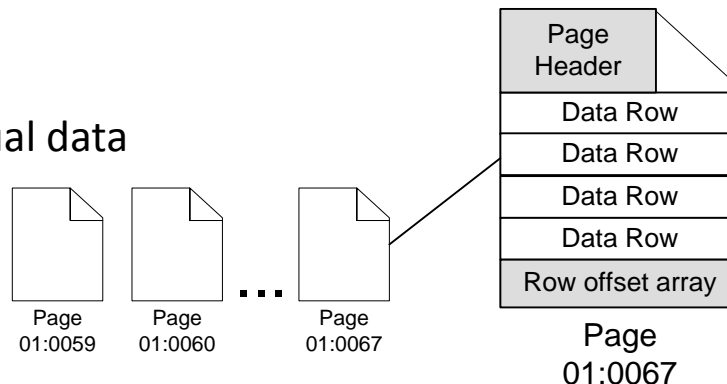
Benefits

- Retrace user DML & DDL operations
- Identify data pre and post transaction
- Recover previously deleted data rows
- Can help prove/disprove a data security breach
- Can help determine the scope of a database intrusion
- For the “real world”: No dependency on 3rd party auditing tools or pre-configured DML or DDL triggers

Database Forensics Primer⁽¹⁾

❖ Database files

- Data files (.mdf) contain the actual data
- Consists of multiple data pages



- Data rows can be fixed or variable length
- Log files (.ldf) hold all data required to reverse transactions and recover the database
- Physical log files consist of multiple Virtual Log Files (VLF)



- A VLF is the unit of truncation for the transaction log
- According to Microsoft:
“Although you might assume that reading the transaction log directly would be interesting or even useful, it’s just too much information.”

Inside SQL Server 2005: The Storage Engine, Microsoft Press, 2006

Database Forensics Primer⁽²⁾

Inside the transaction log:

1. CurrentLSN

2. Operation

3. Context

4. Transaction ID

5. Tag Bits

6. Log Record Fixed Length

7. Log Record Length

8. PreviousLSN

9. Flag Bits

10. AllocUnitID

11. AllocUnitName

12. Page ID

13. Slot ID

14. Previous Page LSN

15. PartionID

16. RowFlags

17. Num Elements

18. Offset in Row

19. Checkpoint Begin

20. CHKPT Begin DB Version

21. MaxXDESID

22. Num Transactions

23. Checkpoint End

24. CHKPT End DB Version

25. Minimum LSN

26. Dirty Pages

27. Oldest Replicated Begin LSN

28. Next Replicated End LSN

29. Last Distributed End LSN

30. Server UID

31. UID

32. SPID

33. BeginLogStatus

34. Begin Time

35. Transaction Name

36. Transaction SID

37. End Time

38. Transaction Begin

39. Replicated Records

40. Oldest Active LSN

41. Server Name

42. Database Name

43. Mark Name

44. Master XDESID

45. Master DBID

46. PrepLogBegin LSN

47. PrepareTime

48. Virtual Clock

49. Previous Savepoint

50. Savepoint Name

51. Rowbits First Bit

52. Rowbits Bit Count

53. Rowbits Bit Value

54. Number of Locks

55. Lock Information

56. LSN Before Wrties

57. Pages Written

58. Data Pages Delta

59. Reserved Pages Delta

60. Used Pages Delta

61. Data Rows Delta

62. Command Type

63. Publication ID

64. Article ID

65. Partial Status

66. Command

67. Byte Offset

68. New Value

69. Old Value

70. New Split Page

71. Rows Deleted

72. Bytes Freed

73. CI Table ID

74. CI Index ID

75. NewAllocationUnitID

76. FilegroupID

77. Meta Status

78. File Status

79. File ID

80. Physical Name

81. Logical Name

82. Format LSN

83. RowsetID

84. TextPtr

85. Column Offset

86. Flags

87. Text Size

88. Offset

89. Old Size

90. New Size

91. Description

92. Bulk allocated extent count

93. Bulk rowinsertID

94. Bulk allocationunitID

95. Bulk allocation first IAM Page ID

96. Bulk allocated extent ids

97. RowLog Contents 0

98. RowLog Contents 1

99. RowLog Contents 2

100. RowLog Contents 3

101. RowLog Contents 4



Database Forensics Primer⁽³⁾

❖ Server Process ID (SPID)

- A unique value used by SQL Server to track a given session within the database server
- Transaction log activity is logged against the executing SPID

❖ Data type storage and retrieval

- 31 different data types
- Data types are stored and retrieved differently within SQL Server
- Little-endian ordering (LEO) is applicable to selected data types
- Storing and retrieving value: **21976** in various data types results in the following:

Data type	On disk value	Retrieved value
CHAR	3231393736	21976
INT	D855	21976
DATETIME	D855	3/3/1960

Procedure Cache

- Contains ad-hoc and parameterized statements

Database Evidence Repositories

❖ SQL Server data resides natively within SQL Server and stored externally within the native Windows operating system

❖ Evidence repositories

- **SQL Server**

- Volatile database data
- Database data files
- Database log files
- Plan cache
- Data cache
- Indexes
- Tempdb
- Version store

- **Operating System**

- Trace files
- System event logs
- SQL Server error logs
- Page file
- Memory

Investigation Tools

- ❖ SQL Server Management Studio Express
- ❖ SQLCMD
- ❖ Windows Forensic Toolchest
- ❖ DD\DCFLDD
- ❖ MD5SUM
- ❖ Netcat\CryptCat
- ❖ WinHex
- ❖ Native SQL Server views, functions and statements
 - Dynamic Management Views (DMV)
 - Database Consistency Checker (DBCC) commands
 - FN_*
- ❖ Lots of sanitized acquisition media

Evidence Collection

Evidence Collection⁽²⁾

- ❖ Determine the scope of evidence collection

- ❖ Prioritize evidence collection
 1. Volatile database data (sessions/connections, active requests, active users, memory, etc.)
 2. Transaction logs
 3. Database files
 4. SQL Server error logs
 5. System event logs
 6. Trace files

Evidence Collection⁽³⁾

❖ Collecting volatile database data

- Can be automated using WFT & command line SQL tools
- GUI front end, binary validation and thorough logging
- Gathers volatile data internal and external to SQL Server

Menu	SQL_LOGINS
MAIN	Command md5=28731C04B854CC1570DBDACC89A6C3F2
ABOUT	SQLCMD.exe -E -Q "select name, type_desc, create_date, modify_date from sys.sql_logins order by create_date, modify_date" > e:\sql_logins.txt
LOG	Description
CONFIG	SQL_LOGINS
START	File sql_logins.txt md5=42AB71BA778BBDD2F89C7587902705C0
START TIME	name
SQL SERVER	-----
DB LISTING	sa
DM EXEC CONNECTIONS	EASYACCESS
DM EXEC SESSIONS	
SQL LOGINS	(2 rows affected)
DM EXEC REQUESTS	
MEMORY	
PCCLIP	Computer Name: PRODSQL05 Date/Time: 03/02/2007 10:17:4
MEM	Windows Forensic Toolchest (WFT) v1.0.03 (2003.09.20) Copyright (C) 2003 Monty McDougal . All rights :

Evidence Collection⁽⁴⁾

❖ SQLCMD

- Load command line tool and establish logging

```
D:\FResponse>Sqlcmd -S RZ-SQL-2005 -e -s"," -E  
1> :out z:\initialconnection.txt
```

❖ Collecting the active transaction log

- Determine on disk locations of the transaction log files

```
D:\FResponse>Sqlcmd -S RZ-SQL-2005 -e -s"," -E  
1> sp_helpdb OnlineSales  
2> go
```

Results:

name	fileid	filename	...
OnlineSales	1	C:\Program Files\Microsoft SQL Server\MSSQL.1\MSSQL\DATA\OnlineSales.mdf	...
OnlineSales_log	2	C:\Program Files\Microsoft SQL Server\MSSQL.1\MSSQL\DATA\OnlineSales_log.ldf	...
OnlineSales_log2	3	C:\OtherLogs\OnlineSales_log2.ldf	...

Evidence Collection⁽⁵⁾

❖ Collecting the active transaction log (cont'd)

- Gather the VLF allocations

```
Changed database context to 'OnlineSales'.  
1> dbcc loginfo
```

Results:

FileId	FileSize	StartOffset	FSeqNo	Status	Parity	CreateLSN
2	14352384	8192	16	2	64	0
2	14352384	14360576	0	0	0	0
2	14352384	28712960	0	0	0	0
2	14606336	43065344	0	0	0	0
3	14352384	8192	0	0	0	0
3	14352384	14360576	0	0	0	0
3	14352384	28712960	0	0	0	0
3	14606336	43065344	0	0	0	0

2 = Active

0 = Recoverable or unused

Evidence Collection⁽⁶⁾

❖ Collecting the active transaction log (cont'd)

- Fn_dblog filters transactions by:
 - Target database object
 - Specific columns
 - SPID and/or date/time range

*Select * from ::fn_dblog(NULL, NULL)*

- DBCC Log
 - More resource intensive
 - Dumps transaction log in its entirety

dbcc log(<dbname>, 3)

0 = minimal info

1 = slightly more info

2 = detailed info including (page id, slot id, etc.)

3 = full information about each operation

4 = full information on each operation in addition to hex dump of current data row

Evidence Collection⁽⁷⁾

❖ Collecting the database plan cache

▪ Collecting the plan cache

```
select * from sys.dm_exec_cached_plans cross apply  
sys.dm_exec_sql_text(plan_handle)
```

▪ Collect additional plan cache specifics

```
- select * from sys.dm_exec_query_stats
```

```
- select * from sys.dm_exec_cached_plans cross apply  
sys.dm_exec_plan_attributes(plan_handle)
```

❖ Collecting database data files & logs (\\Microsoft SQL Server\MSSQL.1\MSSQL\DATA*.MDF | *.LDF)

❖ Collecting default trace files (\\Microsoft SQL Server\MSSQL.1\MSSQL\LOG\LOG_#.TRC)

❖ Collecting SQL Server error logs (\\Microsoft SQL Server\MSSQL.1\MSSQL\LOG\ERRORLOG)

❖ Collecting system event log (WFT)

Evidence Analysis

Evidence Analysis⁽²⁾

❖ Windows event log

- SQL Server authentication data (failures, successful log-on/off)
- SQL Server startup and shutdown
- IP addresses of SQL Server client connections

❖ Error log

- SQL Server authentication data (failures, successful log-on/off)
- SQL Server startup and shutdown
- IP addresses of SQL Server client connections

```
17-03-02 07:39:10.80 Logon Login failed for user 'sa'. [CLIENT: 192.168.1.20]
17-03-02 07:39:11.00 Logon Error: 18456, Severity: 14, State: 8.
17-03-02 07:39:11.00 Logon Login failed for user 'sa'. [CLIENT: 192.168.1.20]
17-03-02 07:39:11.20 Logon Error: 18456, Severity: 14, State: 8.
17-03-02 07:39:11.20 Logon Login failed for user 'sa'. [CLIENT: 192.168.1.20]
17-03-02 07:53:07.39 Logon Login succeeded for user 'sa'. Connection: non-trusted. [CLIENT: 192.168.1.20]
17-03-02 08:09:37.60 Logon Login succeeded for user 'EASYACCESS'. Connection: non-trusted. [CLIENT: 192.168.1.20]
```

Evidence Analysis⁽³⁾

❖ Default database trace

- Complete authentication history
- DDL operations (schema changes)
- IP addresses of SQL Server client connections

ssID	ApplicationName	LoginName	SPID	StartTime	EventSubClass	Success	LoginSid	RequestID	EventSe
160	squeld 1.0	sa	51	2007-03-02 07:39:11.003		0		0	
160	squeld 1.0	sa	51	2007-03-02 07:39:11.203		0		0	
1300	OSQL-32	sa	51	2007-03-02 07:54:07.180	1 - Add	1	0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:54:34.030	1 - Commit		0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:54:35.740			0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:54:35.903	0 - Begin		0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:54:35.913	1 - Commit		0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:55:52.783	3 - Grant ...	1	0X01	0	
1300	OSQL-32	sa	51	2007-03-02 07:56:18.440	1 - Add	1	0X01	0	
1660	OSQL-32	EASYACCESS	51	2007-03-02 08:09:33.773	1 - Commit		0XB89...	0	
			2	2007-03-02 08:13:29.350	1 - Increase			0	
1660	OSQL-32	EASYACCESS	51	2007-03-02 08:13:31.433	1 - Commit		0XB89...	0	
1660	OSQL-32	EASYACCESS	51	2007-03-02 08:13:32.667	1 - Commit		0XB89...	0	

Evidence Analysis⁽⁴⁾

❖ Data files & log files

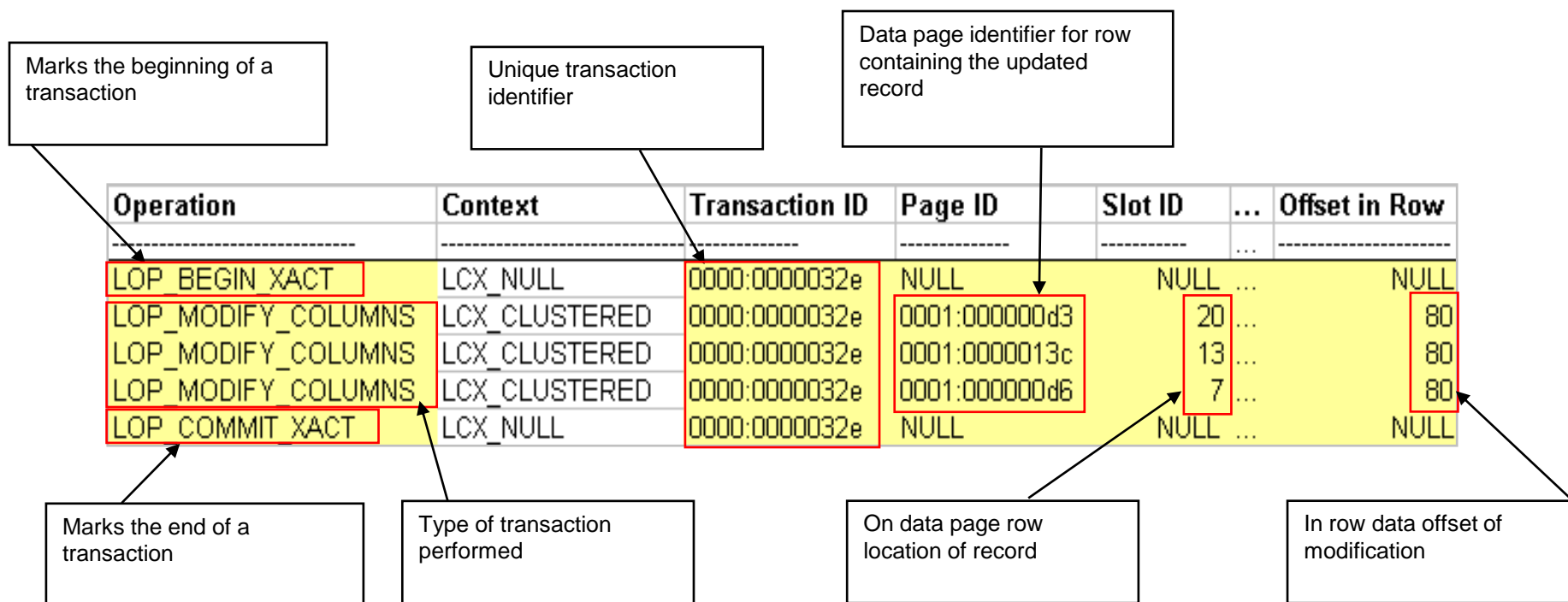
- Attach files
- Use to obtain on-demand schema info, data page contents, etc.

❖ Active transaction log

- Import into Excel / Access for viewing
- Identify DML & DDL statements
- Map transactions to a SPID

Evidence Analysis⁽⁵⁾

❖ Transaction log – Update operations



Identifier	Hex	Decimal
Transaction ID	0000:0000032e	0:814
Data Page	0001:000000d3	1:211

Evidence Analysis⁽⁶⁾

- ❖ DBCC Page will pull up the modified data page
dbcc page (OnlineSales, 1, 211, 1)

```
Page @0x04304000

m_pageId = (1:211)                m_headerVersion = 1                m_type = 1
m_typeFlagBits = 0x0              m_level = 0                          m_flagBits = 0x0
m_objId (AllocUnitId.idObj) = 87  m_indexId (AllocUnitId.idInd) = 256
Metadata: AllocUnitId = 72057594043629568
Metadata: PartitionId = 72057594039500800
Metadata: ObjectId = 629577281    m_prevPage = (1:314)                Metadata: IndexId = 1
pminlen = 108                     m_slotCnt = 22                       m_nextPage = (1:315)
m_freeData = 5918                 m_reservedCnt = 0                     m_freeCnt = 3263
m_xactReserved = 0               m_xdesId = (0:0)                     m_lsn = (16:3686:2)
m_tornBits = -1731484635          m_ghostRecCnt = 0
```

- ❖ Lookup the owning object: *Select * from sysobjects where id = 629577281*

Resu

	name	id	xtype	uid	info	status	base_schema_ver	replinfo	parent_obj	crdate
1	Order	629577281	U	1	0	0	0	0	0	2007-02-26 16:08:21.320

Evidence Analysis⁽⁷⁾

❖ Gather the object schema

*“SELECT sc.colorder, sc.name, st.name as 'datatype', sc.length FROM syscolumns sc, systypes st
WHERE sc.xusertype = st.xusertype and sc.id = 629577281
ORDER BY colorder”*

❖ Results:

colorder	name	datatype	length
1	OrderID	int	4
2	FirstName	varchar	20
3	LastName	varchar	20
4	Address	varchar	50
5	City	nchar	40
6	State	nchar	4
7	ZIP	nchar	10
8	CCType	varchar	15
9	CCNumber	varchar	20
11	ShipStatusID	int	4
12	OrderDate	datetime	8
13	Product	nvarchar	100
14	Price	nchar	30

Evidence Analysis⁽⁸⁾

❖ Viewing data page 1:211 modified using Slot 20 & Row offset 80

```
Slot 20 Offset 0x147f Length 237

Record Type = PRIMARY_RECORD           Record Attributes = NULL_BITMAP VARIABLE_COLUMNS

Memory Dump @0x2F3AD47F

00000000: 30006c00 6f000000 53007000 72006900 +0.1.o...S.p.r.i.
00000010: 6e006700 4c006100 6b006500 20002000 tn.g.L.a.k.e. . .
00000020: 20002000 20002000 20002000 20002000 + . . . . .
00000030: 41005a00 31003400 34003100 30000a00 +A.Z.1.4.4.1.O...
00000040: 00000100 00000000 0000e498 00003300 +.....3.
00000050: 2e003500 30002000 20002000 20002000 +..5.O. . . . .
00000060: 20002000 20002000 20002000 0e0000c0 + . . . . .
00000070: 06008400 88009900 9d00ad00 ed00416e +.....An
00000080: 6f736f6e 456d696c 37322053 74617266 tosonEmil72 Starf
00000090: 656c6c20 44726976 65566973 61343931 tell DriveVisa491
000000A0: 36383833 38343033 38323330 3056006f +6883840382300V.o
000000B0: 006c0063 0061006e 006f0020 00360032 +.l.c.a.n.o. .6.2
000000C0: 00200069 006e0063 00680020 0050006c +. .i.n.c.h. .P.1
000000D0: 00610073 006d0061 00200054 00560020 +.a.s.m.a. .T.V.
000000E0: 00560043 00320033 00330032 00+++++++t.V.C.2.3.3.2.
```

Start of transaction.

Start of column



Evidence Analysis⁽⁹⁾

❖ Price column pre and post transaction modification

...	RowLog Contents 0	RowLog Contents 1
...	0x3500300030002E00300030	0x2E00350030002000200020

❖ Price column pre and post transaction modification

RowLog0

Hex	35	00	30	00	30	00	2E	00	30	00	30
ASCII	5		0		0		.		0		0

RowLog1

Hex	2E	00	35	00	30	00	20	00	20	00	20
ASCII	.		5		0		SP		SP		SP

❖ 1st record affected by transaction 814 had the price column updated from “3500.00” to “3.50” (including leading byte “33”)

Evidence Analysis⁽¹⁰⁾

❖ Transaction log - Insert operations

Operation	Context	Transaction ID	Page ID	Slot ID	...	Offset in Row
LOP_BEGIN_XACT	LCX_NULL	0000:00000330	NULL	NULL		NULL
LOP_INSERT_ROWS	LCX_CLUSTERED	0000:00000330	0001:00000138	8		NULL
LOP_COMMIT_XACT	LCX_NULL	0000:00000330	NULL	NULL		NULL

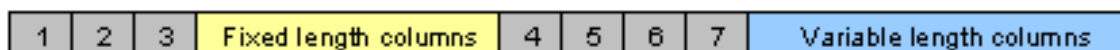
❖ Reconstruct the data row

❖ RowLog Contents 0:

“0x30006C00A101000053007000720069006E0067004C0061006B0065002000200
02000200020002000200020002000200041005A003100340034003100300001000
00000000000E498000034002E00300030002000200020002000200020002000200
02000200020000E0000C206008200870098009C00AC00BC004E696E6F426C61636
B3732205374617266656C6C2044726976655669736135353138353330303030303
030303030580042004F0058002000330036003000”

Evidence Analysis⁽¹¹⁾

- ❖ Lookup the schema and reconstruct the data row
- ❖ Structure of a variable length data row:



Source: Inside SQL Server 2005 The Storage Engine³



Legend		
Item	Storage Allocation	Description
1	1 byte	StatusBits A contains data row properties ³
2	1 byte	Unused in SQL Server 2005 ³
3	2 bytes	Row offset to in row location containing the number of columns in the data row ³
Fixed length columns	Fixed column length for all fixed columns	Location of in row fixed length data columns ³
4	2 bytes	Total number of columns in data row ³
5	1 bit for each row column	Null Bitmap ³
6	2 bytes	Number of variable length columns within data row ³
7	2 bytes for each variable length column	Row offset marking the end of each variable length column ³
Variable length columns	Used length of all variable length columns	Location of in row variable length data columns ³

Evidence Analysis⁽¹³⁾

- ❖ Swap the bytes (endian ordering)
- ❖ Translate data types
- ❖ The inserted record was:
 - OrderID: 4122
 - FirstName: Nino
 - LastName: Black
 - Address: 72 Starfell Drive
 - City: SpringLake
 - State: AZ
 - ZIP: 14410
 - CCType: Visa
 - CCNumber: 5518530000000000
 - ShipStatusID: 1
 - OrderDate: March 1st, 2007
 - Product: XBOX 360
 - Price: 4.00

Evidence Analysis⁽¹⁴⁾

- ❖ Transaction Log – Delete operations
- ❖ Ghost records

Operation	Context	Transaction ID	Page ID	Slot ID	...	Offset in Row
LOP_BEGIN_XACT	LCX_NULL	0000:00000332	NULL	NULL		
LOP_DELETE_ROWS	LCX_MARK_AS_GHOST	0000:00000332	0001:00000158	24		
LOP_SET_BITS	LCX_PFS	0000:00000000	0001:00000001	0		
LOP_COMMIT_XACT	LCX_NULL	0000:00000332	NULL	NULL		

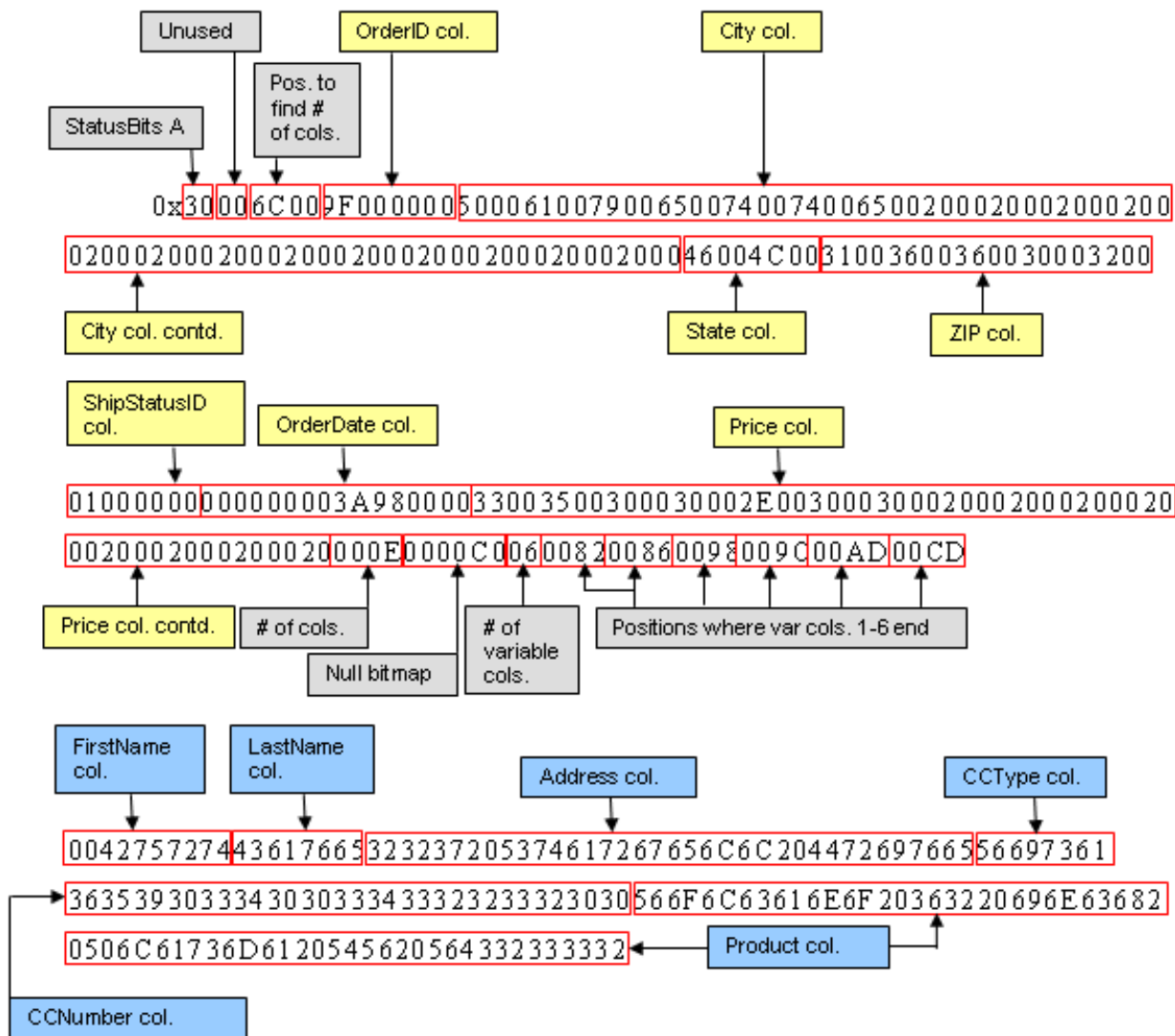
RowLog Contents 0:

```

“0x30006C009F0000005000610079006500740074006500200020002000200
  020002000200020002000200020002000200046004C0031003600360030
  003200020000000000000003A98000033003500300030002E00300030002
  00020002000200020002000200020000E0000C006008200860098009C00
  AD00CD004275727443617665323237205374617267656C6C20447269766
  5566973613635393033343030333433323233323030566F6C63616E6F203
  63220696E636820506C61736D6120545620564332333332”
  
```

- ❖ Reconstruct the data row

Evidence Analysis⁽¹⁵⁾



Evidence Analysis⁽¹⁶⁾

- ❖ Swap the bytes (endian ordering)
- ❖ Translate data types
- ❖ The deleted record was:
 - OrderID: 159
 - FirstName: Burt
 - LastName: Cave
 - Address: 227 Stargell Drive
 - City: Payette
 - State: FL
 - ZIP: 16602
 - CCType: Visa
 - CCNumber: 65903400343223200
 - ShipStatusID: 1
 - OrderDate: September 12th, 2006
 - Product: Volcano 62 inch Plasma TV VC2332
 - Price: 3500.00

Evidence Analysis⁽¹⁷⁾

❖ Plan cache

- Review for applicable statements within scope of investigation (date, objects, etc.)
- Look for **non-standard** statements

bucketid	refcounts	usecounts	cacheobdtype	obdtype	plan_ha...				text
6514	2	1	Compiled Plan	Adhoc	0x06000...				SELECT CAST(fti.is_enabled AS bit) AS [IsEnabled], OBJECTPROPERTY(fti.object_id,'TableFullIT...
3485	2	1	Compiled Plan	Adhoc	0x06000...				SELECT col.name AS [Name] FROM sys.tables AS tbl INNER JOIN sys.fulltext_indexes AS fti ON ...
942	2	1	Compiled Plan	Adhoc	0x06000...				SELECT dtb.is_fulltext_enabled AS [IsFullTextEnabled] FROM master.sys.databases AS dtb WHE...
6312	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 1967
551	2	1	Compiled Plan	Adhoc	0x06000...				select * from OrderHistory
8567	2	4	Compiled Plan	Adhoc	0x06000...				select * from sys.dm_exec_cached_plans cross apply sys.dm_exec_sql_text(plan_handle)
944	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 1
9441	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 5
8278	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 22
6913	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 1823
3005	2	1	Compiled Plan	Adhoc	0x06000...				select CCNumber, Firstname, Lastname from OrderHistory where OrderID = 1639

Investigation Pitfalls

Investigation Pitfalls⁽²⁾

❖ What to look out for!

- Know the schema your working with
- Data type storage formats
- Reduce large data sets
- Correlate on-disk values with transaction log data
- Encryption
- This takes time so be patient!

Conclusion⁽¹⁾

Conclusion

Conclusion⁽²⁾

❖ Conclusion

- Don't ignore the database when conducting computer forensics investigations
- Database forensics techniques learned today can augment traditional forensics skills to uncover the evidence needed to support your case

❖ Additional information within the presentation white paper

- Real world database forensics scenario
- Database forensics methodology
- Additional evidence collection and analysis techniques
 - Code pages and collation settings
 - Obtaining server configuration
 - Identifying user account creation and elevation of privilege activity
 - Transaction log data carving
 - And more...

Questions ?

Questions



Presentation References

❖ Presentation References

- Kalen Delaney, Inside SQL Server 2005 The Storage Engine, Microsoft Press, 2006
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