

# The Power of Traceability

The ability to record and verify exactly what has happened (or is happening) inside the computer at a particular moment has widespread usefulness in matters of consequence in Autonomic Computing.

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*An increasingly critical problem confronting corporate computing and programmer capability is the inability of computer programs to record and analyze the entire execution of the program and data in real time. This lack of traceability prevents true autonomic (self-healing) computing and prevents real-time and permanent analysis of exactly what executing program statements and data are actually processed. Therefore, as computers become millions of times more powerful and program environments become ever more complex and critical, the programmer is still using tools developed at the dawn of computing—tools like step debugging, reconstruction of events, and guessing--to attempt to understand what happened, rather than simply observing exactly what happened and automatically implementing true autonomic computing to self-heal the program.*

*In this paper I present a technique—**Electronic Program Auditing**—and a software tool—**The Real-Time Program Audit**—designed to capture and record all of the executing source program statements in virtually any programming language, along with all of the data being processed and the moment-in-time of the statement execution without programmer intervention. This technique and unique tool provide a video-camera-like recording of the exact environment of the entire program execution (or selected conditions of the execution) as the program executes—thus delivering the potential of true autonomic computing and capturing previously unrecorded critical information. This paper presents my technique and tool, some actual and possible applications, and evidence of the value of my approach.*

## 1 Introduction

Today's computer hardware is incredibly powerful: Indeed, IBM recently announced a supercomputer reaching 1.026 petaflops (1 petaflop is equal to a quadrillion, or one thousand trillion, calculations per second) [1]. However, much of that processing power is wasted, since even the latest software cannot come close to fully harnessing it and fully utilizing the information generated.

Current corporate computer software programming languages were introduced more than a decade ago (Java, in 1995); COBOL, introduced in 1959, has been in use for half a century [2,3]. When all these corporate languages were introduced, computers were millions of times less powerful than they are today, and software applications and environments were significantly more simple than the sophisticated applications and hardware now driving corporate computing—including, for example, the “stream computing” for real-time data analysis that IBM introduced in May 2009 [4].

Full Electronic Program Auditing [5]—which I define as “the complete real-time recording, auditing, and analysis of all executing computer source statements, all data processed, and the moment-in-time of each statement execution to electronic storage (normally disk)” —is the most obvious, comprehensive, and powerful technique for enabling today's software to take full advantage of today's hardware and application requirements and implementation true autonomic computing [6]. Electronic program auditing provides a video-camera-like, real-time permanent record of everything happening in the computer.

This ability to record and verify exactly what has happened (or is happening) inside the computer at a particular moment has widespread usefulness in matters of consequence, as in true Autonomic Computing. Since full recording, auditing, and analysis of all program execution allows for a permanent and unalterable record of the actual program execution, this technique could be used, for example, to expose financial fraud; provide verification—without the possibility of alteration—of actual ballots cast in an election; and provide proof of transactions for Sarbanes-Oxley legislation [7] purposes. The importance of moment-to-moment verification of activity has already been recognized in other contexts: For

instance, the city of London [8], hotel casinos [9], and even cruise ships [10] have installed thousands of video cameras to record and analyze virtually all public activity in order to provide a true, unaltered, real-time, and contemporaneous permanent record of significant activity.

Electronic program auditing was initially implemented by using a patented software invention—the **Real-Time Program Audit (RTPA)** [11]—to make existing programming languages capable of recording to disk the execution of all source statements, data processed, and the moment of time as a pre-processor to make the existing source statements smart enough to record their execution in real time, together with all data processed.

Figure 1 shows a partial source program in a free-format programming language that is an example for real-time program auditing. The executable source statements end with a semi-colon, similar to Java and C++ programming languages, and contain programming language commands that are audited based on the command, and program variables that are audited with the data processed by the executing statement. This source program reads a data file named DATAFILE and converts the program variable DATA to hexadecimal (two hexadecimal characters in a program variable **szhex** per input data character) using a function **cvthc**, then the program converts the hexadecimal variable back into the input variable character data with function **cvtch**. This sample source program is a modified source from [www.rpgworld.com](http://www.rpgworld.com).

```

0001.00 H BNDDIR('QC2LE')
0002.00 H Dftactgrp(*NO)
0003.00 * Source program from www.rpgworld.com
0004.00 fdatafile if e          disk
0005.00
0006.00 D cvthc                PR          extproc('cvthc')
0007.00 D  szRtnHexVar          65532A    OPTIONS(*VARSIZE)
0008.00 D  szSourceVal         32766A    CONST OPTIONS(*VARSIZE)
0009.00 D  nHexLen              10I 0    VALUE
0010.00
0011.00 D cvtch                PR          extproc('cvtch')
0012.00 D  szRtnCharVar        32766A    OPTIONS(*VARSIZE)
0013.00 D  szInputHex          65532A    CONST OPTIONS(*VARSIZE)
0014.00 D  nHexLen              10I 0    VALUE
0015.00
0016.00 D szHex                 S          40A
0017.00 D szChars               S          20A
0018.00 D Result                S          40A
0019.00
0020.00 /free
0021.00 // Source program example from www.rpgworld.com
0022.00     read datafile;
0023.00     dow not %eof(datafile);
0024.00 // convert character to hex
0025.00     cvthc(szHex : data : %len(data)*2);
0026.00     eval result = szHex;
0027.00     if (szHex <> *blanks);
0028.00 // convert hex to character
0029.00     cvtch(szChars : szHex : %len(%TrimR(szHex)));
0030.00     eval result = szChars;
0031.00     endif;
0032.00     read datafile;
0033.00     enddo;
0034.00     eval *inlr = *on;
0035.00     return;
0036.00 /end-free

```

**Figure 1. Source program for electronic program auditing.**

Future programming languages could easily incorporate this real-time RTPA audit recording, auditing, and analysis capability directly into the language itself. And the powerful business intelligence (BI) [12] tools of today could be linked directly into these programming languages in order to provide real-time analysis and autonomic computing.

The processing transactions—relatively small in number in comparison with the exponentially increasing power of the computer—can easily be fully program-audited, stored, and analyzed with electronic program auditing and RTPA without noticeable processing overhead.

The reality of corporate business computing is that the vast majority of computing processes a quite small number of transactions—typically, several thousands of customer orders, invoices, inventory transactions, employee payroll processing, etc., in a typical program execution, rather than millions or billions of transactions. And the number of transactions

processed each year in a typical application, such as data on the students in a university, gets only incrementally larger even if the business grows rapidly. Another characteristic of corporate business computing is that the corporate databases such as customer, inventory item, employee and transaction activity are typically changed or updated by normal transaction processing, making rerunning or reconstruction of the exact same processing conditions in exactly the same processing environment (including time) impossible.

**State of the Art.** There are many program step-through debuggers, interactive program debuggers, and capture-replay techniques and tools [13,14,15] that attempt to display the details of program statement execution. All of these techniques have critical limitations in that they stop the program execution (as in debuggers), allow program and data alteration, or capture only selected parts of the program execution, and require programmer intervention and knowledge of the program. These debuggers can provide, at best, a tiny part of the information needed for program analysis. All of these techniques fail to provide the exact processing conditions as the original processing program, as at least the time has changed and other programs may be altering or have altered the data files. However, there is no known software other than the Real-Time Program Audit (RTPA) that provides full electronic program recording, auditing, and analysis of all executing program statements and all data processed in real time as the program executes, without intervention and without program or data alteration, while providing a permanent record of the original exact environment of the program execution for real-time or future analysis.

**Advantages of This Approach.** The objective of recording, auditing, and analyzing the entire program statement execution, all data processed, and the moment-in-time in real time (as in video-camera recording) is simple, paradigm-shifting, powerful, and takes advantage of advancing computer capability and greatly reduced cost. This objective has been proven to be easily achievable in multiple programming languages, and it does not require any programmer or operational intervention at the time of program execution.

Real-time recording, auditing, and analysis of the original program execution, with the exact data and conditions at original program execution, provides a permanent record of exactly what happened, thereby eliminating the need for program rerunning, debugging, and guessing what happened. And the wealth of information recorded from the executed source statements, data, and moment-in-time provides information for real-time autonomic computing, business analysis and optimization, and business intelligence that is not possible without full electronic program auditing.

The programmer and operations need not even be aware that electronic program auditing is being performed by the smarter enabled source program, which, like a concealed video camera, provides a permanent and unobtrusive record of events. Electronic program auditing, like that provided by RTPA, audits and records in real time, but does not change or alter the program statements or data, as does most debugging software.

Newly emerging software, such as the IBM System S real-time business analysis [16] would benefit greatly by using Real-time Program Audit output, including data processed, to view not only externally available data now written to disk by other programs, but also the information of the executing source statements and all data processed as the majority of program computation and data is never written to external files. Only electronic program auditing records and audits the actual program statement computations and data content of every statement executed and thus eliminates the opportunity for fraud by manipulating summarized data. For example, the classic fraud of altering summarized voting machine tabulations by adding 25 votes to one candidate's totals and subtracting 25 votes from a competing candidates total vote count is exposed (and thus prevented) only by electronic program auditing which audits the computation and summarization of each and every voter. Additionally, electronic program auditing as in RTPA provides the capability for all logically related sub-programs in an application to be sequenced by the moment-in-time each statement was actually executed, regardless of the architecture or structure of the programs.

## 2 Real-Time Program Audit Technique

The Real-Time Program Audit (RTPA)[11] software overall technique is to enhance the capability of source programs in virtually all corporate (mainstream) programming languages to record the execution of source program statements (including auditing all source statements executing in real time, all data processed, and the moment-in-time) to an independent audit log or receiver. This independent audit log file is normally a disk file.

Thus, the RTPA auditing provides full electronic program auditing by enabling or enhancing the input source program to audit itself, even if the programming language does not provide recording and auditing capability.

### 2.1 Overview of the Approach

This technique consists of two phases: audit-enabling or enhancing the original input source program and the resulting executable object program to make it smart enough to completely audit its execution, and then executing the audit-enabled object program in the normal program execution environment to produce the real-time audit file and audit spool file and real-time business analysis. Future programming languages could easily provide this auditing capability as part of the standard programming language capability by providing for the automatic auditing and recording of all of the source statements and data executed similar to current disk file journaling.

## 2.2 Audit-Enabling the Original Input Source Program

Figure 2 shows the initial implementation of full electric program auditing in the Real-Time Program Audit (RTPA), U.S. Patent 6,775,827 [17], as a pre-processor that inputs source programs of audited programming languages, copies the source program to an enabled source program, and allows the enabled program source statements to be fully audited and recorded in real time during program execution together with all data processed, and outputs an expanded or enabled source program. Executable program object programs are compiled from the enabled source programs and have the capability of auditing themselves during program execution. The audit default is to record and audit all executing program statements and all data processed. However, extensive conditional auditing is also provided to allow focus and auditing on issues of interest.

RTPA provides real-time full recording and auditing capability of executing programs by examining every executable statement or command in the original source program, and adding the capability to log the source statement, the content of statement variables (the data processed by the executing statement), and the moment-in-time to an independent audit file when the statement is actually executed.

The basic process for RTPA auditing is quite similar for most programming languages, and is defined in detail in U.S. Patent 6,775,827.

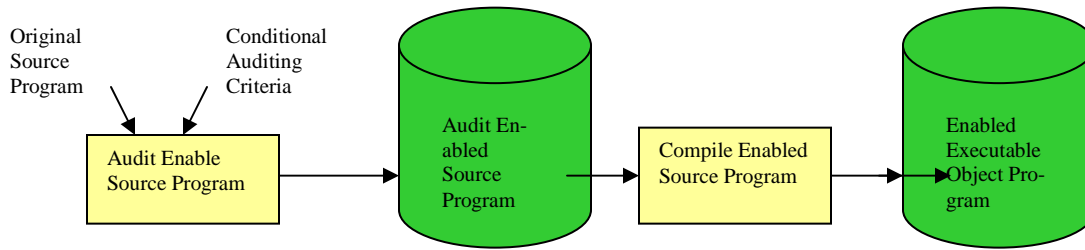
For the programming language being audited, define all valid language commands, or operation codes, and the auditing to be performed when processing a source statement using that command. For example, in COBOL the IF reserved word (command) would be defined, together with all other commands such as MULTIPLY, together with their RTPA auditing attributes.

1. For instance, the COBOL statement with a MULTIPLY command would be audited in real time in the enabled source program *after* the MULTIPLY command was executed, together with the data of program variables in the MULTIPLY source statement. The COBOL statement with an IF conditional command would be audited in real time in the enabled source program *before* the IF command was executed, together with the data of program variables in the IF source statement, in case the IF condition was not true, so the RTPA audit would show the contents of the IF statement variables that caused the IF condition statements not to be executed.
2. Define an audit recording file for logging all audit output. This file will be included in the audit-enabled source program.
3. Optionally define a printer spool file audit log.

For each original source program to be audit-enabled:

1. Copy the original input source program to an audit-enabled source program. The original input source program is not altered.
2. Compile the original source program and retrieve all detailed program information needed to fully audit the program and program variables.
3. Read the copied source program and audit every executable source statement so that it is recorded in the audit file when the statement is executed, together with the content of statement variables and the moment-in-time of execution.
4. Scan each executable source statement to identify the language command and program variables and special conditions such as complex statement groups such as IF, AND conditional statements.
5. Audit enable each executable source statement including the statement itself, program variables data processed, and the moment-in-time when the statement is executed, together with control information such as the program name.
6. Audit complex statements (commands) such Execute Format (EXFMT) which is a WRITE then READ as a group with the elapsed time between them (user wait time), and audit complex conditional statements like IF, AND as a group.
7. Audit comment statements to provide better program comprehension.
8. Time stamp the moment-in-time of the executing statement to the audit file.
9. Output control and analysis information including the program ID and statements group level to the audit file, so that real-time auditing and analysis may be easily accomplished.
10. Output the file definition for the independent audit file, which will contain the full electronic program audit of the executing program statements, and optionally output the printer spool audit file definition.
11. Optionally selectively audit based on audit criteria or conditions or audit output limits.

12. Compile the audit-enabled source program and create an audit-enabled executable object program.



**Figure 2. Real-Time Program Audit (RTPA) pre-processor overview.**

Figure 3 shows a partial listing of the audit-enabled source program statements with RTPA inserted statement to record and audit every executing source program statement, all data processed, and the moment-in-time the statement was executed. The subroutines or subprocedures actually accomplishing the output to the RTPA audit file and RTPA audit analysis (spool) file, such as EXSR Z\$INIT to initialize the audit file and analysis spool file, vary by the programming language being audited. However, these routines always audit and output the source statements being executed, the data content of program variables in the executing statement, date, and the moment-in-time the statement is executed, together with control information such as the program name.

The complete input example source program, the RTPA audit-enabled source program, and the RTPA audit file and audit analysis output for this CVTTOHEX example program are available on [www.harkinsaudit.com](http://www.harkinsaudit.com) in the Users Manual and in RTPA videos.

The audit inserted source statement EXSR Z\$INIT; opens the audit file and initializes the inserted audit routines in the audit-enabled source program (and in the executable audit-enabled object program) and outputs audit control information including the program name, job number, and moment-in-time of the program activation. The inserted Z\$INIT source statement also outputs optional spool file audit report headings which include the moment of program initiation. The inserted audit source statement EXSR Z\$GENS; outputs the source statement to the audit file.

Note: The RTPA source statements inserted into the audit-enabled source program to accomplish full electronic program auditing could easily be inserted by the language compiler (processor) as part of a smarter audit-enabled programming language by the language vendor. A similar technique for accomplishing disk record journaling before-and-after images has long been available as part of the vendor-provided operating system software.

The elapsed time of complex source statements like EXFMT (Execute Format) is computed including the elapsed time it takes for a terminal user to respond to a WRITE then READ statement and the elapsed time it takes for external program calls to other programs or sub-procedures. The exact time a statement is executed and the elapsed time of the statement is invaluable in program traceability, analysis and optimization.

For example, the expanded audit capable source program contains the following source statements to read the DATA file input disk record and to audit the read statement and the data being read. The inserted audit statement are in blue.

```

66      read datafile;
67          Z$SRC# = 2      ;
68          EXSR      Z$GENS;
69          EXCEPT  Z$00002;
70          IF        NOT %EOF;
71          EXCEPT  Z$00002D;
72          ENDIF;

```

The input source statement **read datafile;** reads the next record from the disk file.

The inserted audit statements below output the audit of the read datafile; statement when it is executed with the moment-in-time of the statement execution

```

67          Z$SRC# = 2      ;
68          EXSR      Z$GENS;
69          EXCEPT  Z$00002;

```

The inserted audit statements below output the audit of the actual data if a disk record was read.

```

70         IF      NOT %EOF;
71         EXCEPT Z$00002D;
72         ENDIF;

```

```

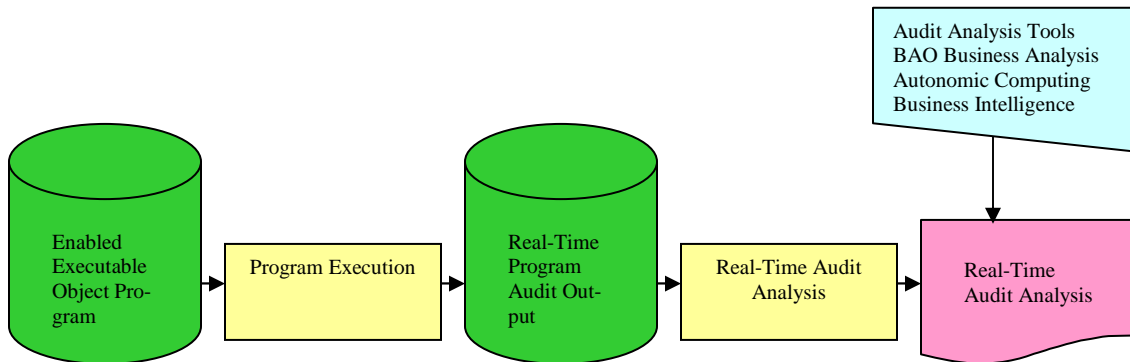
61 C          EXSR      Z$INIT
62 /free
63 // Source program example from www.rpgworld.com
64          Z$SRC# = 1 ;
65          EXSR      Z$GENS;
66          read datafile;
67          Z$SRC# = 2 ;
68          EXSR      Z$GENS;
69          EXCEPT  Z$00002;
70          IF      NOT %EOF;
71          EXCEPT Z$00002D;
72          ENDIF;
73          Z$SRC# = 3 ;
74          EXSR      Z$GENS;
75          dow not %eof(datafile);
76 // convert character to hex
77          Z$SRC# = 4 ;
78          EXSR      Z$GENS;
79          cvthc(szHex : data : %len(data)*2);
80          Z$SRC# = 5 ;
81          EXSR      Z$GENS;
82          EXCEPT  Z$00005;
83          eval  result = szHex;
84          Z$SRC# = 6 ;
85          EXSR      Z$GENS;
86          EXCEPT  Z$00006;
87          Z$SRC# = 7 ;
88          EXSR      Z$GENS;
89          EXCEPT  Z$00007;
90          if (szHex <> *blanks);
91 // convert hex to character
92          Z$SRC# = 8 ;
93          EXSR      Z$GENS;
94          cvtch(szChars : szHex : %len(%TrimR(szHex)));
95          Z$SRC# = 9 ;
96          EXSR      Z$GENS;
97          EXCEPT  Z$00009;
98          eval  result = szChars;
99          Z$SRC# = 10 ;
100         EXSR      Z$GENS;
101         EXCEPT  Z$00010;
102         endif;
103         Z$SRC# = 11 ;
104         EXSR      Z$GENS;
105         read datafile;
106         Z$SRC# = 12 ;
107         EXSR      Z$GENS;
108         EXCEPT  Z$00012;
109         IF      NOT %EOF;
110         EXCEPT Z$00012D;
111         ENDIF;
112         enddo;
113         Z$SRC# = 13 ;
114         EXSR      Z$GENS;
115         eval  *inlr = *on;
116         Z$SRC# = 14 ;
117         EXSR      Z$GENS;
118         EXCEPT  Z$00014;
119         Z$SRC# = 15 ;
120         EXSR      Z$GENS;
121         return;

```

Figure 3. Source program with RTPA auditing.

### 2.3 Execution of the Audit-Enabled Program

Figure 4 shows the processing of the audit-enabled executable Object Program with the output of Real-Time Program Audit output, including data processed and real-time audit analysis, business intelligence tools, and business analytics and optimization (BAO) tools [18]. The Real-Time Program Audit Query analysis tool provides extensive real-time analysis of the audit output file, including the capability to view executing subprograms, source program statements, and program variable contents of different programming languages in a logical application in moment-of-time sequence as the computer actually executes them.



**Figure 4. Real-Time Program Audit (RTPA) audit output and analysis.**

Figure 5 shows the RTPA real-time audit output file from execution of the audit-enabled program. The audit output file is a *permanent contemporaneous record of the original program execution*.

The electronic program audit of the executed program contains the source program statements as they were actually executed, and shows the compile listing statement numbers as in the original compile listing of the original source program, together with the data executed by the program and the moment-in-time of the statement execution.

The audit output of the read statement below shows the **read** statement and the data read by the read statement with the moment-in-time of the read statement execution. The DATA- line is the variable DATA followed by the contents of the variable DATA.

|    |  |                  |
|----|--|------------------|
| 22 | <code>read datafile;</code>            | 19.46.37.452     |
|    |  | File- 00002 Key- |
|    | <code>DATA-1234567890ABCDEFGHIJ</code> |                  |

The **dow not (eof)** statement (do while not end-of-file) and the source statements 23 and 24 are executed if the read statement read an input record into the variable DATA.

The comment statement at line 24 `// convert character to hex` is audited each time the comment statement is executed. Auditing executing comment statements is very important in programmer comprehension of what actually happened in the executing program.

The **cvthc** statement converts the variable DATA into hexadecimal format (two characters per input character) and places the output in the variable szHex.

|    |   |     |
|----|---|-----|
| 23 | <code>dow not %eof(datafile);</code>                  |     |
| 24 | <code>// convert character to hex</code>              |     |
| 25 | <code>cvthc(szHex : data : %len(data)*2);</code>      | B01 |
|    | <code>F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1</code> |     |
|    | <code>1234567890ABCDEFGHIJ</code>                     |     |
|    | <code>1234567890ABCDEFGHIJ</code>                     |     |

```

Program-CVTTTOHEX   Convert Character to Hex Data in PF DATAFILE   Obj Lib: Z$AUDITE   Initiated: 6/10/09
CVTTTOHEX         CVTTTOHEX
Job: 334040         User Profile: PHH           Source Type: RPGLE   Y   Source File/Library: QRPGLSRC
Line#              Do# SrcId
21 // Source program example from www.rpgworld.com
22 read datafile;
                                     File-      00002 Key-
DATA-1234567890ABCDEFGHIJ
23 dow not %eof(datafile);
24 // convert character to hex
25 cvthc(szHex : data : %len(data)*2);                                     B01
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
    1234567890ABCDEFGHIJ
    1234567890ABCDEFGHIJ
26 eval result = szHex;
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
27 if (szHex <> *blanks);                                               01
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
28 // convert hex to character                                           01
29 cvtch(szChars : szHex : %len(%TrimR(szHex)));                         B02
    1234567890ABCDEFGHIJ
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
    F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1
30 eval result = szChars;
    1234567890ABCDEFGHIJ
    1234567890ABCDEFGHIJ
31 endif;                                                                 02
32 read datafile;                                                         02
                                     File-DATAFILE Key-
DATA-KLMNOPQRSTUVWXYZ!@#
24 // convert character to hex
25 cvthc(szHex : data : %len(data)*2);                                     B01
    D2D3D4D5D6D7D8D9E2E3E4E5E6E7E8E95A7C7B40
    KLMNOPQRSTUVWXYZ!@#
    KLMNOPQRSTUVWXYZ!@#
26 eval result = szHex;
    D2D3D4D5D6D7D8D9E2E3E4E5E6E7E8E95A7C7B40
    D2D3D4D5D6D7D8D9E2E3E4E5E6E7E8E95A7C7B40
27 if (szHex <> *blanks);                                               01
    D2D3D4D5D6D7D8D9E2E3E4E5E6E7E8E95A7C7B40
28 // convert hex to character                                           01
(truncated output)
34 eval *inlr = *on;                                                     01
    1
35 return;                                                                 E01

```

**Figure 5. RTPA audit file output from Audit-Enabled Executable Object Program.**

Real-time program audit analysis with the RTPA Query tool, conventional business intelligence (BI) tools, business analysis and optimization (BAO) tools such as the IBM System S, and autonomic computing can access this real-time RTPA audit file and spool file and achieve real-time analysis and true autonomic computing while the program is executing. Audited source statements and source statement data including the contents of program variables provide unprecedented capability to analyze detailed program information never before available for analysis and action.

Figure 6 shows the right side of the audit output containing control information including the conditional do level, source statement number, change date, and time stamp of the moment-in-time of the execution of each statement.

Figure 5 and Figure 6 are actually the left-hand and right-hand sections of the same 198 position audit output, and together illustrate the executing source statement, all data processed by the executing statement, the moment in time of the executing statement, the date and time, and control information including the program do level and the program id. The audit output can be queried and analyzed immediately in real-time or analyzed later with a variety of existing analytic and business intelligence tools.



| o Hex Data in PF DATAFILE                |                    | Obj Lib: Z\$AUDITE | Initiated: 6/10/09 19.46.37.452        | PAGE 1   | RPGLE        | Y |
|--|--------------------|--------------------|--|----------|--------------|---|
| PHH                                      | Source Type: RPGLE | Y                  | Source File/Library: QRPGLSRC Z\$AUDIT | CVTTOHEX | JOB 297949   |   |
| www.rpgworld.com                         |                    |                    | Do# SrcId ChgDat                       | Seq#     | Time         |   |
|  |                    |                    | 080612                                 | 2100     | 19.46.37.452 |   |
|  |                    |                    |  |          | 19.46.37.452 |   |
|  | File-              | 00002              | Key-                                   |          |              |   |
|  |                    |                    |  |          | 19.46.37.452 |   |
| %len(data)*2);                           |                    | B01                | 080611                                 | 2200     | 19.46.37.452 |   |
| 8F9F0C1C2C3C4C5C6C7C8C9D1                |                    |                    | 080612                                 | 2300     | 19.46.37.452 |   |
| 890ABCDEFGHIJ                            |                    |                    |  |          |              |   |
| 1234567890ABCDEFGHIJ                     |                    |                    |  |          |              |   |
|  |                    |                    | 080611                                 | 2400     | 19.46.37.452 |   |
| F0C1C2C3C4C5C6C7C8C9D1                   |                    |                    |  |          |              |   |
| 5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1          |                    |                    |  |          |              |   |
|  |                    | 01                 | 080611                                 | 2500     | 19.46.37.452 |   |
| C1C2C3C4C5C6C7C8C9D1                     |                    |                    |  |          |              |   |
|  |                    | 01                 | 080612                                 | 2600     | 19.46.37.452 |   |
| : %len(%TrimR(szHex));                   |                    | B02                | 080611                                 | 2700     | 19.46.37.452 |   |
| FGHIJ                                    |                    |                    |  |          |              |   |
| 3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1      |                    |                    |  |          |              |   |
| F1F2F3F4F5F6F7F8F9F0C1C2C3C4C5C6C7C8C9D1 |                    |                    |  |          |              |   |
|  |                    |                    | 080611                                 | 2800     | 19.46.37.452 |   |
| IJ                                       |                    |                    |  |          |              |   |
| 0ABCDEFGHIJ                              |                    |                    |  |          |              |   |
|  |                    | 02                 | 080611                                 | 2900     | 19.46.37.452 |   |
|  |                    | 02                 | 080612                                 | 3000     | 19.46.37.452 |   |
|  | File-DATAFILE      | Key-               |  |          |              |   |
|  |                    |                    | 080611                                 | 2200     | 19.46.37.456 |   |
| %len(data)*2);                           |                    | B01                | 080612                                 | 2300     | 19.46.37.456 |   |
| 9E2E3E4E5E6E7E8E95A7C7B40                |                    |                    |  |          |              |   |
| RSTUVWXYZ!@#                             |                    |                    |  |          |              |   |
| KLMNOPQRSTUVWXYZ!@#                      |                    |                    |  |          |              |   |
|  |                    |                    | 080611                                 | 2400     | 19.46.37.456 |   |
| E3E4E5E6E7E8E95A7C7B40                   |                    |                    |  |          |              |   |
| (output truncated)                       |                    |                    |  |          |              |   |
|  |                    | E02                | 080611                                 | 3100     | 19.46.37.456 |   |
|  |                    | 01                 | 080611                                 | 3200     | 19.46.37.456 |   |
|  |                    | E01                | 080611                                 | 3300     | 19.46.37.456 |   |

Figure 6. RTPA audit output right side of report with the moment-in-time of the executing statement.

## 2.4 Additional Technical Details

This section discusses several of the most relevant technical details of this approach that relate to its implementation into programming languages with varying capabilities to produce audit files (normally disk) and audit spool (printer) files and to allow business analysis and optimization tools (BAO) to be utilized for autonomic computing.

### 2.4.1 Assumptions

First, this Real-Time Program Audit (RTPA) electronic program audit technique should work for virtually all current corporate programming languages that have the capability to produce an audit file as a disk file output, and optionally a printer spool file output in the programming language. Programming languages without the capability of producing an audit file as a disk file output or a printer spool file, such as the IBM Control Language Program (CLP), can currently be audited with this technique using calls to sub-procedures or subprograms to a language such as COBOL that does provide auditing capability. Future implementation of real-time program auditing in the vendor distributed language would provide this auditing capability in a manner transparent to the programmer for both the executing source statements and for all the data processed with an audit file similar to the current vendor supplied disk journal file for before and after images of disk record updates, additions, and deletes.

Second, the audit enabling statements and techniques currently inserted into the copied, expanded, and enabled source program should not alter the normal execution of the source (enabled object) program. Again, this could be easily incorpo-

rated by the vendor of the programming language directly into the language without requiring a separate preprocessor step to audit-enable the source program. Then, audit processing would produce a hugely beneficial and transparent result (similar to video-camera recording) of virtually all corporate computer processing.

Third, the program execution processing time of the audit-enabled statements, including creation of the real-time audit file, incurs very little additional processing time, as is evidenced in the audit output in Figure 5. Real-life execution of audit-enabled program processing has shown that audit processing requires minimal additional time or overhead for typical corporate application environments for which the original processing time for an application is only a few processing seconds. Additionally, audit recording and logging may be turned on or off based on conditions or the size of the audit file. The emergence of solid-state disk drives (SSDs) [19], which have throughput of some twenty times that of conventional disk drives, ensures that RTPA auditing overhead will be insignificant in the future. That, coupled with the immense and largely unused processing capacity, presents a huge opportunity for pervasive implementation of full electronic program auditing.

### **3 Possible Applications of This Technique**

Eight possible applications of this real-time program audit technique are discussed: Full electronic program auditing of computer program execution; debugging and analysis of computer program execution; business analysis and optimization (BAO) of executing program statements and data; verification of the business initiative “Data as an Asset on the Balance Sheet” [20]; real-time autonomic computing using executing program statements and data; vote-count tabulation verification [21]; and security and authentication verification[22].

#### **3.1 Electronic Program Auditing of Program Execution**

This technique, together with the dramatic increase in power and decrease in cost of computing, increases a paradigm shift in how computing is accomplished and analyzed. Full electronic program recording and auditing should become the normal method of corporate computing, making obsolete many of the ancient and inefficient techniques in use today and greatly multiplying the understanding and capability of programmers. This full electronic program audit information would be available as a permanent and unalterable record of the details of exactly how the program executed and exactly how the data were processed.

#### **3.2 Debugging and Analysis of Program Execution**

Step-program debuggers and interactive program debuggers were developed literally at the dawn of computing in the 1950s, when programs were small and relatively simple, and only one program at a time was processed by the computer. These debuggers are also slow and labor intensive, requiring programmer intervention by manually stopping the program and they require program knowledge to be used. And, the debuggers can never exactly re-create the original environment, since at least the time and computing environment will have changed by the time the debugging begins. Debuggers also require speculation—guessing about what might have happened or where the problem might be. Real-time electronic program auditing totally eliminates the need for step debuggers and eliminates the need for guessing what happened during program execution.

#### **3.3 Business Analysis and Optimization (BAO) of Executing Program**

Much critical business-analysis information processed in executing programs, including exactly how the information is computed statement by statement, is simply not recorded, and therefore is not available for business analysis and business intelligence tools.

For example, end-user screen error messages are typically not recorded, but electronic program auditing records all of the end-user error messages and all the data displayed to the end user and entered by the end user. This error-message recording, auditing, and analysis allows needed end-user training to be customized to the end user and pinpoints how a series of end-user errors can result in error or abnormal processing.

For successful error detection and correction, knowing the content of program variables that are currently not recorded can be crucial. Consider the need for comparison of the estimated carton weight of packed products to the actual packing-line real-time scale carton weight, including the estimated weight of each product. This comparison is critical to successful detection of cartons not matching the estimated carton weight. Real-time recording of all program variable

contents at the moment of time of statement execution allows real-time analysis of products in this error carton with products in other error cartons—signaling a potential error in the estimated weight of a particular product, without the need to open the error carton. This allows for the kind of rapid and sure resolution of problems, like errors in estimated weights of a product that may be changed and corrected at any time during the day that would not be possible without this detail information—and it enables the prevention of future packing-weight errors for cartons of the product. Current applications not providing this program-auditing capability simply cannot provide this real-time analysis and correction capability, and result in massive and time consuming error detection and correction procedures and missed shipments.

### **3.4 Verification of the Initiative “Data as an Asset on the Balance Sheet”**

The emerging business initiative that data will become an asset on the balance sheet [20], together with the attention drawn by recent massive corporate financial frauds, requires that summarized data must be verifiable with drilldown not to other summarized data as is normally the output of computer processing, but to the actual program statements and program variable contents used to create the information. Program auditing is the only technique that will accomplish this ultimate drilldown to the original and unalterable audit record created during program execution.

### **3.5 Real-time true Autonomic Computing Using Executing Program Statements and Data**

In order for true autonomic (self-healing) computing [12] to be self-managed or to be self-healing, it is obvious that the executing program must have access to, and utilize, real-time detail information that is often computed in the executing program, such as error messages, and is not available externally outside the program, and never output to disk as part of the application. The RTPA audit file, and spool file do provide all of this internally created program information (all executing source statements, all data processed, and the moment-in-time the statement was executed) and make this information immediately available for a full range of business intelligence tools and business analysis and optimization (BAO) tools, and especially for true autonomic computing. These analysis tools can be utilized by the executing program in real time to provide autonomic computing, as in the case of end-user screen-error message analysis and action, and by the executing program itself in real-time to correct itself. Similar true autonomic computing analysis and correction could be used in automobile “Black box” program real-time analysis of engine, automatic throttle control, brakes, transmission, seat belt, air bag, electrical, tire pressure and other systems with self-correcting function to stop the car in extreme emergencies such as “run away” cars. Other major software catastrophes such as the “Blackberry” internet routine software update that caused outages of hours and days, could be either prevented with better testing and analysis as in RTPA, or mitigated, instantly found or corrected with true autonomic computing using RTPA audit output.

### **3.6 Vote-Count Tabulation Verification**

Real-time program auditing can be utilized in vote-count tabulation verification [21] to ensure that all votes counted by a computer program, such as mark sensed voting sheets or electronic voting, are verified with a *permanent and unalterable* audit record of *actual votes* as each vote is accumulated. This auditing technique could be very easily implemented, and, if mandated, would eliminate actual and much attempted electronic-voting machine and online voting fraud at every level of voting.

### **3.7 Internet Security and Authentication Verification**

The emergence of the Internet and remote processing technologies such as Cloud Computing [22], has greatly increased the susceptibility of computer programs to hacking, unauthorized use, and the resulting damage by this hacking of computers at every level of business and government, as the computing is external to the corporate location.

Electronic program auditing and analysis provides unalterable and potentially permanent and accessible proof of exactly what was processed at the program executing statement level; what data were processed at the executing statement level; the moment-in-time of the executing statement level; and the user ID or program name and object information responsible for the processing activity. This, the ultimate drilldown for security and authentication, provides real-time audit information for autonomic computing security and authentication, analysis, and corrective action during the execution of the program and later for detailed review and analysis.

### **3.8 Ultra-Fast Trading, time is a huge competitive advantage**

Ultra-fast stock trading [23] and ultra-fast computers with sophisticated quantitative analysis software give computers closest to the source of stock trades (as in the same building) a time advantage in receiving stock trade information faster than those computers farther away who must use communication lines to access the stock trades. This allows ultra fast trading of information not yet available to the public. Real-time program auditing of the actual programs forming the stock trade, before it is sent to a communication line outside of the computer, would allow true autonomic computing of the trade as it is being computed and before it is available to ultra fast trading techniques.

## **4 The Tool: RTPA**

This implementation of full electronic program auditing is the Real-Time Program Audit (RTPA) software tool [11], which is written in the RPG programming language and is implemented for several programming languages, including RPG, COBOL, and the IBM Control Program Language (CLP). The original source program is not altered in any way, and the copy of the source program is audit-enabled without programmer intervention, so that full auditing is output to an audit file when the audit-enabled program is executed.

During execution of the audit-enabled executable object program, the program is intended to execute the original source statements exactly as in the original source program. The inserted RTPA source statements are executed inline with the executing original source program statements, merely and only to record the executing source program statement, the content of program variables in the executing original source statement, and the moment-in-time of execution of the original source program statement. The executable object program of some programming languages such as RPG, COBOL, and CLP have a program template that includes the source program statement and program variable definitions to allow for step through or interactive debugging and program variable analysis. Implementation of full electronic program auditing by software vendors in the operating system compilers would utilize this available information for audit recording, rather than the auditing preprocessor having to save this information in the audit-enabled executable object program. Thus, software vendor-supplied full electronic program auditing capable compilers would provide the capability to output the executing source statement to the audit file when the source statement was executed and the moment-in-time of execution as part of the operating system.

## **5 Empirical Evaluation**

The feasibility and value of full electronic program auditing in the corporate programming environment was first tested by manually inserting the RTPA additional source statements to a copy of a large production original source program. When the resulting expanded source program was compiled to an expanded object program and executed in a normal corporate processing environment, the resulting real-time audit file and audit spool file was extremely useful in the real-time analysis of the program. This manually inserted program auditing was performed on several important source programs and greatly simplified the development and maintenance and support of these programs.

No step-debugging or program rerunning was required to solve programming issues, since the audit file and audit spool file had already produced the information needed for analysis.

Once the concept and value of full electronic program auditing was proved, the manual auditing process was generalized and automated as in today's RTPA software implementations, and the automated auditing implementation was generalized for other programming languages.

It has been proven that—through its simplification of programming and analysis and its provision of real-time program data, internal to the program, that had never before been available—full electronic program auditing (as in the RTPA implementations), represents a paradigm shift in programming and computing.

Though the need for structured programming is widely acknowledged and useful to programmers viewing the static program source structure, full electronic program auditing diminishes this need, since all the executing statements from many routines or sub-procedures in a logical application written in several programming languages can be sequenced in the moment-of-time the statement was executed, regardless of program organization. The emergence and astonishing capability of online search engines to almost instantly gather together the widely dispersed information to satisfy a search request is an example of how a logical request for related data created at different times does not rely on the data being stored next to or near each other.

Electronic Program auditing is essential and needed in virtually all corporate processing environments and in virtually all corporate applications, including all financial applications. Virtually all of these corporate applications are processed in

a multiprocessing environment, where multiple independent jobs are running simultaneously in the computer, and where each program is running in a single processing thread [24]

My book “How to Become a Highly Paid Corporate Programmer” [25] illustrates the capability and usefulness of electronic program auditing, the usefulness of breaking programs into logical phases for development and production analysis, and prototyping the programs during development.

Indeed, thousands of original source programs have been audit-enabled using the Real-Time Program Audit (RTPA) software, and then audited using the resulting expanded audit-enabled executable object program in normal processing environments. Typically, an original source program of several thousand source statements is copied, audit-enabled into an audit-enabled source program as in Figure 2 and then compiled into an audit-enabled executable object program as in Figure 4, in less than 5 elapsed seconds on a small corporate computer.

## 6 Related Work

I know of no other implementation of full electronic program auditing software, as in the Real-Time Program Audit (RTPA) software—at least in the corporate programming environment.

The many debuggers and capture-and-replay tools such as SCARPE[15] provide useful tools for program review and analysis, but they sometimes allow program and data modification, and they do not provide a full and complete real-time and permanent audit record of the entire program execution of all executing source statements and all data processed as output of the executed programs.

Large hardware and software vendors, such as IBM, Hewlett-Packard, and Oracle, need a new killer application that implements the immense benefits of full electronic program auditing, and utilizes the largely unused capacity of current technology to fully implement the emerging initiatives of autonomic computing, data as an asset on the balance sheet, and real-time business analysis and optimization (BAO) technology.

## 7 Conclusion

I have described a technique for implementing full electronic program auditing and autonomic computing with the Real-Time Program Audit (RTPA) software. Of the many new applications made possible with electronic program auditing, eight have been suggested. Finally, I have presented the initial implementations of full electronic program auditing in several corporate programming languages, and I have demonstrated how easy, effective, and valuable it is to implement electronic program auditing in a corporate programming language.

One significant conclusion is that the entire world of corporate computing can be made dramatically more productive, auditable, capable, and simple by harnessing the power of the computer to fully electronic program-audit, record, and analyze the execution of all computer programs. Academic computing would also greatly benefit from electronic program auditing, particularly in teaching and learning computer languages and by being capable to fully record and observe the actual statement computations being performed in programs that are often executed only once and that do not have otherwise verifiable results.

Productivity tools that are now conventional—such as the Microsoft Word Spelling and Grammar tool and the security and virus tools that run in the background of Word document processing—are key examples of the significant benefits provided by smarter processing with productivity tools. Full electronic program auditing, as in the Real-time Program Audit (RTPA), provides smarter processing that is revolutionary and more comprehensive—indeed, it will work industry-wide and provide a critical new level of real-time information from the executing program itself.

Mandated standards and regulations in many industries have evolved over the years to provide needed safety and security for all who use cars, such as the automobile industry requirements for airbags and collision protection standards, and health care strict safety standards. These mandated standards have allowed much greater safe use of automobiles worldwide, while greatly reducing risks and accidents. It is now time and feasible that corporate computing and corporate and government develop and implement effective and powerful real-time safety, security and auditing standards and capability for all corporate computing through tools such as full electronic program auditing.

Key next steps are to improve and expand the capability and use of full electronic program auditing into other corporate programming languages, and particularly to expand the use of real-time audit information in autonomic computing and in business analysis and optimization (BAO) tools.

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