EDK II Performance Optimization Guide

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Revision 1.0

Acknowledgements

Revision History

Revision	Revision History	Date
0.1	Initial draft - Measurement Methodologies.	June 2009
0.3.3	Incorporate Review comments	January 2010
1.0	First Release	February 2010

CONTENTS

Figures

Tables

1 Introduction

Failure caused by poor performance renders a system just as useless as failure caused by functional errors, and can be even more expensive to correct. This paper focuses on techniques and methodologies which can be used to characterize and optimize the performance of EDK II based firmware.

Performance Optimization, within the context of this paper, consists of those procedures and techniques needed to identify and remediate problems contributing to excessive boot and execution times.

In order to identify problem areas, one must be able to measure initial performance as well as performance during and after optimization. Depending upon the type of code being measured -- execution phases, device drivers, library routines, etc. -- several different measurement methodologies may be needed.

Once the measurements have been gathered, it is necessary to interpret the data and gain an understanding of what sections of the code are consuming excessive amounts of time. Suspect code must be examined and understood in order to determine if it is, in fact, taking too much time. Often, it will be necessary to take additional measurements, with finer granularity, as one narrows in on the problem.

When the problematic areas of the firmware have been identified, various processes and techniques are employed to reduce the execution time.

This is a highly iterative process, as described in Chapter 7, Strategies, consisting of two major loops:

1. Measure - Analyze; the inner loop which narrows in on the problem
2. Measure - Analyze - Optimize; the outer loop used to validate optimizations and measure the real improvement.

Once an area meets its performance goals, the focus can move to the next most valuable optimization candidate.

1.1 Overview

Within this paper; measurement methodologies, analysis techniques, and firmware optimization strategies will be discussed. Performance measurement tools provided by EDK II will be described as well as how to interpret their output. Finally, a number of Best Known Methods (BKMs) for optimization will be provided.

Factors such as CPU speed, overall system design, FLASH device performance, or other hardware artifacts can affect measured performance as much as algorithm selection and firmware implementation quality. These factors will be discussed further in Chapter 7, Strategies.

This version of the EDK II Performance Optimization Guide describes the *state-of-the-art* of performance measurement in EDK II and introduces the EDK II performance display and reporting utility, “Dp”.

The code base referenced by this document is based upon subversion revision 9680 from the EDK II repository on www.tianocore.org.

1.2 Target Audience

This document is intended for persons doing EFI firmware development and support, using EDK II, as well as development and support for distributable modules. In addition to general information applicable to all developers, specifically targeted information is provided for:

- Silicon Vendors in order to assist with making performance related hardware design trade-offs as well as producing performance optimized drivers.
- Firmware Vendors and development Engineers to help ensure that their products meet performance goals.
- Operating System Vendors to provide visibility into how the firmware affects OS performance and to facilitate the optimization of OS loaders and interactions with EFI Runtime services.

1.3 Document Organization

There are three major parts of this guide: Overview, Infrastructure, and Strategies. Part one, Overview, is composed of Chapter 1 and Chapter 2. These chapters define the scope of the paper as well as providing important background information required for performance measurement or optimization of any firmware system.

Infrastructure, Part two, includes Chapters 3 through 5 and describes the facilities present within the EDK II firmware which facilitate performance measurement and analysis. After describing EDK II's instrumentation features and their relationship to the firmware's execution chronology; the Performance Reporting utility, Dp, is described. Part 2 concludes with a discussion of EDK II's internal constructs relating to performance.

The third and final part of this paper is made up of Chapters 6, 7, and 8; which cover strategies and Best Known Methods for performance measurement and optimization within EDK II.

Chapter 1, Introduction, provides the background information needed to understand key concepts within the remainder of this paper as well as the EDK II firmware. It lays out the scope of information to be presented, and continues with basic definitions. The various firmware and software development roles that the paper targets are then described. Chapter 1 finishes with a description of the typographic conventions which will be encountered throughout the paper.

Chapter 2, Measurement Methodologies, outlines several techniques used for various types of performance measurements.

Chapter 3, EDK II Facilities, describes features provided by EDK II for instrumenting one's code and gathering performance statistics.

Chapter 4, Dp Reporting Utility, is EDK II's performance reporting facility. Dp is described along with general methods for interpreting its output.

Chapter 5, Instrumenting the Code, provides guidance for the changes necessary to add performance instrumentation to existing EDK II based code.

Chapter 6, EDK II Performance Infrastructure, provides an overview of EDK II's low-level performance measurement implementation.

Chapter 7, Strategies, begins by describing the general process for performance optimization. Next, strategies for specific scenarios are provided.

Chapter 8, Lessons Learned, is a collection of techniques developed and used during the development of EDK I which may have applicability to EDK II.

Appendix A, Sample Grouped Report, provides a complete report generated by the Dp utility on a sample platform.

Appendix B, Sample Sequential Report, shows a sequential report with the default interest threshold, `-t`, and record number, `-n`, limits.

Appendix C, Sample Raw Report, illustrates a default raw report. This report type shows the actual values recorded for each measurement record.

Appendix D, Pre-defined Measurements, describes the instrumentation that already exists in the standard EDK II release.

1.4 Related Information

The following publications and sources of information may be useful to you or are referred to by this specification:

- *Unified Extensible Firmware Interface Specification*, Version 2.1, Unified EFI, Inc, 2006, http://www.uefi.org.
- *Platform Initialization Specification*, Version 1.1, Unified EFI, Inc., 2008, http://www.uefi.org.

The following publications are available at www.TianoCore.org:

- *EDK II Module Writers Guide, Intel, 2009*
- *EDK II Module Development Environment Package Library Specification*, Intel, 2009.
- *EDK II Platform Configuration Database Architecture Specification*, Intel, 2006.
- *EDK II C Coding Standards Specification*, Intel, 2009.
- *EDK II DEC File Specification*, Intel, 2008.
- *EDK II DSC File Specification*, Intel, 2008.
- *EDK II Build Specification, Intel*, 2008.
- *EDK II User's Guide*, Intel, 2008.

Code documentation for the MdePkg, MdeModulePkg, IntelFrameworkPkg, and IntelFrameworkModulePkg packages, in CHM format, is available in the EDK II Docs and Files repository under the Releases category. http://sourceforge.net/projects/edk2/files/

1.5 Terms

The following terms are used throughout this document:

BDS

Framework Boot Device Selection phase.

BNF

BNF is an acronym for “Backus Naur Form.” John Backus and Peter Naur introduced, for the first time, a formal notation to describe the syntax of a given language.

Component

An executable image. Components defined in this specification support one of the defined module types.

DXE

Framework Driver Execution Environment phase.

DXE SAL

A special class of DXE module that produces SAL Runtime Services. DXE SAL modules differ from DXE Runtime modules in that the DXE Runtime modules support Virtual mode OS calls at OS runtime and DXE SAL modules support intermixing Virtual or Physical mode OS calls.

DXE SMM

A special class of DXE module that is loaded into the System Management Mode memory.

DXE Runtime

Special class of DXE module that provides Runtime Services

EBNF

Extended “Backus-Naur Form” meta-syntax notation with the following additional constructs: square brackets “[…]” surround optional items, suffix “*” for a sequence of zero or more of an item, suffix “+” for one or more of an item, suffix “?” for zero or one of an item, curly braces “{…}” enclosing a list of alternatives and super/subscripts indicating between n and m occurrences.

EDK Compatibility Package (ECP)

The EDK Compatibility Package (ECP) provides libraries that will permit using most existing EDK drivers with the EDK II build environment and EDK II platforms.

EFI

Generic term that refers to one of the versions of the EFI specification: EFI 1.02, EFI 1.10, UEFI 2.0 or UEFI 2.1.

Framework

Intel® Platform Innovation Framework for EFI consists of the Foundation, plus other modular components that characterize the portability surface for modular components designed to work on any implementation of the Tiano architecture.

GUID

Globally Unique Identifier. A 128-bit value used to name entities uniquely. A unique GUID can be generated by an individual without the help of a centralized authority. This allows the generation of names that will never conflict, even among multiple, unrelated parties. GUID values can be registry format (8-4-4-4-12) or C data structure format.

Library Class

A library class defines the API or interface set for a library. The consumer of the library is coded to the library class definition. Library classes are defined via a library class .h file that is published by a package.

Library Instance

An implementation of one or more library classes.

Module

A module is either an executable image or a library instance. For a list of module types supported by this package, see module type.

Module Type

All libraries and components belong to one of the following module types: BASE, SEC, PEI_CORE, PEIM, DXE_CORE, DXE_DRIVER, DXE_RUNTIME_DRIVER, DXE_SMM_DRIVER, DXE_SAL_DRIVER, UEFI_DRIVER, or UEFI_APPLICATION. These definitions provide a framework that is consistent with a similar set of requirements. A module that is of module type BASE, depends only on headers and libraries provided in the MDE, while a module that is of module type DXE_DRIVER depends on common DXE components. For a definition of the various module types, see module type.

Package

A package is a container. It can hold a collection of files for any given set of modules.

Packages may contain Source Modules, containing all source files and descriptions of a module; or Binary Modules, containing PI FFS Sections and a description file specific to linking and binary editing of features and attributes or both Binary and Source modules.

Multiple modules can also be combined into a package. Multiple Packages can also be Bundled into a single Distribution Package.

Protocol

An API named by a GUID as defined by the EFI specification.

PCD

Platform Configuration Database.

PCD C Name

The symbolic name for a PCD Token that follows the ANSI C naming conventions for the name of a variable.

PCD Element

A single configurable element within the Platform Configuration Database, uniquely identified by a Token Space GUID and Token Number.

PCD Token Space GUID

The GUID value associated with a group of PCD Tokens. Using a GUID allows vendors to allocate their own Token Numbers for configuration elements that apply to their own modules, libraries or platforms without a centralized allocator. Within the Distribution Description file, a PCD Token Space GUID is referred to using the PCD Token Space GUID C Name.

PCD Token Space GUID C Name

A symbolic name for a PCD Token Space GUID value that follows the ANSI C naming conventions for the name of a variable.

PEI

Pre-EFI Initialization Phase.

Platform Configuration Database (PCD)

The collection of PCD elements that can be configured when building modules, libraries, or platform firmware images. These elements are identified by a Token Space GUID and Token Number. PCD elements are declared in packages by Package Developers. Modules Developers use PCD elements in the design of their modules to increase the portability of their modules to a wider array of platform targets. Platform Integrators set the values of PCD elements based on specific platform requirements. A Platform Integrator has many options when configuring PCDs for a specific platform. They may configure PCD elements to be set to static values at build time. They may also configure PCD elements so the binary image of a Module may be patched prior to integration into platform firmware images. They may also configure PCD elements so the binary image of platform firmware may be patched. They may also configure PCD elements so they can be accessed at runtime through the PCD services described in the PI 1.2 Specification.

PPI

A PEIM-to-PEIM Interface that is named by a GUID as defined by the PEI CIS.

Runtime Services

Interfaces that provide access to underlying platform-specific hardware that might be useful during OS runtime, such as time and date services. These services become active during the boot process but also persist after the OS loader terminates boot services.

SEC

Security Phase is the code that contains the processor reset vector and launches PEI. This phase is separate from PEI because some security schemes require ownership of the reset vector.

UEFI Application

An application that follows the UEFI specification. The only difference between a UEFI application and a UEFI driver is that an application is unloaded from memory when it exits regardless of return status, while a driver that returns a successful return status is not unloaded when its entry point exits.

UEFI

Unified Extensible Firmware Interface

UEFI Driver

A driver that follows the UEFI specification.

UEFI Specification

The UEFI Specification describes an interface between the operating system (OS) and the platform firmware. UEFI was preceded by the Extensible Firmware Interface Specification 1.10 (EFI). This specification is released by the Unified EFI Forum.

This document references the UEFI Specification 2.1, with errata.

UEFI Platform Initialization Specification

This specification defines the core code and services that are required for an implementation of UEFI compliant firmware. The Platform Initialization Specification is divided into volumes to enable logical organization, future growth, and printing convenience. The Platform Initialization Specification consists of the following volumes:

- **VOLUME 1**: Pre-EFI Initialization Core Interface, defines the core code and services that are required for an implementation of the Pre-EFI Initialization (PEI) phase of the Platform Initialization (PI) specifications (hereafter referred to as the “PI Architecture”).
- **VOLUME 2:** Driver Execution Environment Core Interface, defines the core code and services that are required for an implementation of the driver execution environment (DXE) phase of the Unified Extensible Firmware Interface (UEFI) Foundation.
- **VOLUME 3:** Shared Architectural Elements, describes the basic concepts behind Platform Initialization (PI) firmware storage and Hand-Off Blocks implementation.
- **VOLUME 4:** System Management Mode, describes the optional SMM phase, which starts during the DXE phase and runs in parallel with the other PI Architecture phases into runtime.
- **VOLUME 5:** Standards, define the core code and services that are required for an implementation of the System Management Bus (SMBus) Host Controller Protocol and System Management Bus (SMBus) PEIM-to-PEIM Interface (PPI).

Each volume should be viewed in the context of all other volumes, and readers are strongly encouraged to consult the entire specification when researching areas of interest.

This document references UEFI PI Specification 1.1.

Unified EFI Forum

A non-profit collaborative trade organization formed to promote and manage the UEFI standard. For more information, see www.uefi.org.

1.6 Conventions Used in this Document

This document uses the typographic and illustrative conventions described below.

1.6.1 Pseudo-Code Conventions

Pseudo code is presented to describe algorithms in a more concise form. None of the algorithms in this document are intended to be compiled directly. The code is presented at a level corresponding to the surrounding text.

In describing variables, a *list* is an unordered collection of homogeneous objects. A *queue* is an ordered list of homogeneous objects. Unless otherwise noted, the ordering is assumed to be FIFO.

Pseudo code is presented in a C-like format, using C conventions where appropriate. The coding style, particularly the indentation style, is used for readability and does not necessarily comply with an implementation of the UEFI Specification.

1.6.2 Typographic Conventions

This document uses the typographic and illustrative conventions described below:

Plain text	The normal text typeface is used for the vast majority of the descriptive text in a specification.
Plain text (blue)	Any plain text that is underlined and in blue indicates an active link to the cross-reference. Click on the word to follow the hyperlink.
Bold	In text, a **Bold** typeface identifies a processor register name. In other instances, a **Bold** typeface can be used as a running head within a paragraph.
Italic	In text, an *Italic* typeface can be used as emphasis to introduce a new term or to indicate a manual or specification name.
`BOLD Monospace`	Computer code, example code segments, and all prototype code segments use a **`BOLD Monospace`** typeface with a dark red color. These code listings normally appear in one or more separate paragraphs, though words or segments can also be embedded in a normal text paragraph.
`Bold Monospace`	Words in a **`Bold Monospace`** typeface, that is underlined and in blue, indicate an active hyperlink to the code definition for that function or type definition. Click on the word to follow the hyperlink.
`Italic Monospace`	In code or in text, words in *`Italic Monospace`* indicate placeholder names for variable information that must be supplied (i.e., arguments).
$(VAR)	The symbol VAR defined by the utility or input files.

The following typographic conventions are used in this document to illustrate the Extended Backus-Naur Form.

[item]	Square brackets denote the enclosed item is optional.
{item}	Curly braces denote a choice or selection item, only one of which may occur on a given line.
<item>	Angle brackets denote a name for an item.
(range-range)	Parenthesis with characters and dash characters denote ranges of values, for example, (a-zA-Z0-9) indicates a single alphanumeric character, while (0-9) indicates a single digit.

“item”	Characters within quotation marks are the exact content of an item, as they must appear in the output text file.
?	The question mark denotes zero or one occurrences of an item.
*	The star character denotes zero or more occurrences of an item.
+	The plus character denotes one or more occurrences of an item.
item$^{\{n\}}$	A superscript number, n, is the number of occurrences of the item that must be used. Example: $(0\text{-}9)^8$ indicates that there must be exactly eight digits, so 01234567 is valid, while 1234567 is not valid.
item$^{\{n,\}}$	A superscript number n, followed by a comma “,” and within curly braces, indicates the minimum number of occurrences of item, with no maximum number of occurrences.
item$^{\{,n\}}$	A superscript number, n, preceded by a comma “,” and within curly braces, indicates a maximum number of occurrences of item.
item$^{\{n,m\}}$	A super script number, n, followed by a comma “,“ and a number, m, with both enclosed within curly braces, indicates that the number of occurrences can be from n to m occurrences of item, inclusive.

2
Measurement Methodologies

There is no sense being precise about something
when you do not even know what you are talking about.
John von Neumann

Before one can begin actual firmware optimization, it is necessary to know which areas of the code are consuming unreasonable amounts of time. In order to do this, the system's performance must be measured. The various techniques used to take these measurements are referred to as *measurement methodologies*.

The following seven questions are critical to ensuring the validity of one's measurement data:

1. Who collected these data? (Hopefully people who are trained in proper data collection techniques, or who have at least read this paper.)
2. How were the data collected? (Hopefully by automated means and at the same phase of the process.)
3. When were the data collected? (Hopefully all at the same time on the same day or at the same time in the process.)
4. What do the values presented mean? (Have you changed the process recently? Do these values really tell you what you want or need to know?)
5. How were these values computed from raw inputs? (Have you computed the data to arrive at the results you want, or to accurately depict the true voice of the process?)
6. What formulas were used? (Are they measuring what we need to measure? Are they working? Are they still relevant?)
7. Are we collecting the right data, and are we collecting the data right? (The data collected should be consistent, and the way data are collected should be consistent. Do the data contain the correct information for analysis?)

This chapter provides the basis for answering the first six questions. Question 7 is addressed in Chapter 7, Strategies.

The primary focus of this document will be Software-Based Measurement.

2.1 Software-Based Measurement

Software-based measurement methodologies add specialized software to the code base. This software is then used to instrument the code and gather performance data. There are two main types of software-based performance measurement: Tracing and Profiling. The two predominant types of profiling are *Statistical Profiling* and *Measured Profiling*.

2.1.1 Tracing

Tracing produces a new record for each invocation of the measured code. It can provide chronological, context-specific, information about execution times of measured code regions, whereas profiling collects information for each measured region which is

an aggregate of all invocations of the measured region.

Tracing can potentially consume significant resources depending upon the number of measurement points and how many times each measurement point is invoked.

2.1.2 Statistical Profiling (SW)

Software based statistical profiling uses a periodic interrupt to periodically sample the processor state in order to determine where the processor is executing. That information is then correlated with firmware load maps to identify routines and modules. An advantage of this method is that once the sampling infrastructure is in place, it is not necessary to further modify the code in order to gather information. This allows measurements to be made post-production. Disadvantages include the coarse granularity of both measurement locality and times as well as the necessity of having access to load maps in order for the measurements to be meaningful.

2.1.3 Measured Profiling

Measured profiling relies upon code, inserted at strategic locations within the firmware, which gathers performance information at runtime. Fine grained measurements can be achieved, within the limits of the time source, and correlation of measurements to source code is exact. Two variants of measured profiling are discussed here: *Cumulative Profiling*, and *Min-Max Profiling*.

2.1.3.1 Cumulative Profiling

In Cumulative Profiling, a name, cumulative time and invocation count is kept for each profiled region. Upon entry to the region, a time stamp is collected. When the region is exited, a new time stamp is collected, the starting time subtracted from it, and the remainder added to the cumulative execution time for the named region. For each execution of the region, the invocation count is incremented.

The invocation count allows one to extract two important pieces of information: total time and average time spent executing the measured code.

2.1.3.2 Min-Max Profiling

Min-Max profiling adds Minimum and Maximum time recording to the Cumulative Profiling operations. This type of profiling is suitable for measurement of operations that (may) take a variable amount of time to execute depending upon external factors – e.g. table lookup, device drivers for mechanical devices, …

2.2 Hardware-Based Measurements

Some activities may require greater precision or finer time granularity than the internal timers can provide. In this case there are several techniques that can be used to facilitate time measurements using hardware devices.

2.2.1 Statistical Profiling (HW)

Hardware based statistical profiling uses external hardware to periodically sample the

processor state in order to determine where the processor is executing. That information is then correlated with firmware load maps to identify routines and modules. An advantage of this method is that it is not necessary to modify the code in order to gather information. This allows measurements to be made post-production. Disadvantages include the coarse granularity of both measurement locality and times as well as the necessity of having access to load maps in order for the measurements to be meaningful. These disadvantages are mitigated by certain emulator and debug hardware which can display time information alongside source code listings.

Logic Analyzers and JTAG Based Debuggers are among the most popular tools for hardware based Statistical Profiling.

2.2.2 Logic Analyzers

A logic analyzer, if it can be connected to the correct signals, can be an extremely flexible and useful tool. It can be set up to measure between addresses or almost any other event. The drawback is that all of the address, control, and data lines necessary to recognize the event must be accessible so that the logic analyzer can be connected to them. Logic analyzers also have a relatively limited number of events they can record before new data starts pushing out the old.

In order to make the logic analyzer more selective, it is possible to embed instructions within the code which toggle an easily accessible signal. By measuring or accumulating the duration of each toggle the execution time of the target code can be determined. Drawbacks to this method include the necessity to embed the instructions beforehand; availability of an easily accessible output port, or bit, for this use; and the need to use a different signal for each region to be measured.

The toggled signal can also be used as a trigger input to the logic analyzer. This allows data acquisition to be limited to specific points in time which permits much more relevant data to be stored in the analyzer.

2.2.3 Elapsed Time Counters

Instead of using a logic analyzer, it is possible to use an event or elapsed time counter to measure the duration of the bit toggle. This equipment is easier to manage and set up than a logic analyzer but does not have the same flexibility.

2.2.4 JTAG Based Debuggers

JTAG based debugging solutions can be used to make several different types of timing measurements. Each debugger provides different capabilities ranging from time annotated source code traces to measurement of the time spent executing between two addresses or resource accesses. Some debuggers have provision for external trigger inputs allowing targeted measurement capabilities similar to that provided by Logic Analyzers or Elapsed Time Counters.

3
EDK II Facilities

3.1 Overview

The EDK II firmware provides both *tracing* and *measured profiling* capabilities, each accessed via two macros; one for starting measurement and one for ending the measurement. The start and end times, in timer ticks, for the region between the two macros is then saved in a list in memory which records the measurement's name and times. Each invocation of the pair of **trace** macros creates a new record in the list, thus providing a chronological record of invocation and associated timing. Invocations of the **profiling** macros result in the cumulative time being updated in a single record associated with that measurement.

Use of the trace macros can impose a relatively high overhead during the DXE phase due to the process of searching and managing the list of measurement records. For coarse-grain measurements of code regions that are not executed frequently – tens of invocations as opposed to hundreds or thousands – the overhead is negligible.

Overhead imposed by the profiling macros is less than that of the trace macros, primarily due to a reduction in processing required for each measurement.

The time stamps are taken at the end of the START and beginning of the END macros which minimizes the amount of overhead that is included within the measurement.

Tracing macros, functions, and structures are declared in MdeModulePkg\Include\Guid\Performance.h, and MdePkg\Include\Library\PerformanceLib.h. Profiling macros, functions, and structures are declared in PerformancePkg\Include\Guid\Profile.h, and PerformancePkg\Include\Library\ProfileLib.h. Declarations for the Timer Library are contained within MdePkg\Include\Library\TimerLib.h.

Detailed documentation on these files, functions, macros, and other elements can be found using the resources detailed in Section 1.4.

Subsequent sections of this chapter will describe the instrumentation macros in detail. The Phases of Execution, and their impact on instrumentation and system performance are then described.

3.2 Trace Instrumentation

Trace Instrumentation is added to the code by application of two performance measurement macros: PERF_START and PERF_END. These macros work as a pair with PERF_START creating a new, open, measurement record and PERF_END closing the measurement record. If the PERF_END macro is invoked for a previously closed record, it will return a NOT_FOUND status.

Though optional, it is recommended that one always provide an identifying string for *Token*. This will make it easier to differentiate between the measurement records

when they are analyzed. Use the *Module* parameter to provide additional identifying information so that each macro pair is uniquely identified. When the macro pair occurs inside a loop, such as one of the dispatchers, the *Handle* parameter can be used to provide further differentiation between measurements.

When instrumenting within PEI, the *Token* and *Module* strings are limited to seven significant characters each; more than that will be discarded. This is due to the limited memory resources during PEI before main memory has been initialized.

PEI also places a fixed limit on the number of measurement records that may be collected during that phase. The PCD entry, PcdMaxPeiPerformanceLogEntries, controls the number of measurement records collected during PEI.

During DXE, BDS, or later phases, the Token and Module strings may contain up to 31 characters, each.

The trace instrumentation code is designed to minimize the instrumentation overhead included within each measurement. The overhead incurred by the instrumentation code in order to search tens of thousands of trace records, which occurs on some modern platforms, has a noticeable effect on total execution time. For example, by the time the 27000th trace measurement is added, a minimum of 365 million comparisons have been done for the PERF_END macro alone.

Regardless of execution phase, the performance tracing code can be turned on or off with the use of the PcdPerformanceLibraryPropertyMask PCD entry, described in Section 7. In addition to global control of performance tracing, this PCD entry can be used to limit tracing to specific modules. This will allow the number of active trace measurements to be minimized, reducing the total time required by the instrumentation code.

3.3 Profiling Instrumentation

Profiling Instrumentation is added to the code by application of two performance measurement macros: PROF_START and PROF_END. These macros work as a pair with PROF_START starting a new measurement and PROF_END completing the measurement. If PROF_START is called for a new measurement, a new record is created. Subsequent PROF_END or PROF_START invocations which use the same Token will update the record.

For example:

```
MyFunction( void )
{
  PROF_START( “MyFunction”, 0);
  // Body of the function
  PROF_END( “MyFunction”, 0);
  return;    // The single point of return
}
```

will count the number of times MyFunction is executed and accumulate the time spent in each invocation of the function.

Each profiling measurement will record:

- The number of times the measurement is invoked
- The accumulated duration, in timer ticks, of each invocation
- The shortest duration of all invocations
- The longest duration of all invocations

invocations without an intervening PROF_END, when for the same measurement, will result in the second and subsequent PROF_START invocations for that measurement being ignored. The number of PROF_START invocations is counted with a matching number of PROF_END invocations required. Each PROF_END will extend the duration of that measurement until a matching number have been encountered.

For example:

```
PROF_START( “Foo”, 1);
PROF_END( “Foo”, 10);
...
PROF_START( “Foo”, 21);
PROF_END( “Foo”, 30);
```

will result in two measurements totaling 18 timer ticks being added to measurement “Foo”. The following example:

```
PROF_START( “Foo”, 2);
PROF_START( “Foo”, 3);
PROF_START( “Foo”, 5);
PROF_END( “Foo”, 6);
PROF_START( “Bar”, 8);
PROF_END( “Bar”, 10);
PROF_END( “Foo”, 11);
PROF_END( “Foo”, 19);
...
PROF_START( “Foo”, 29);
PROF_END( “Foo”, 30);
```

also results in two measurements totaling 18 ticks being added to measurement “Foo”. The measurement, “Bar”, is valid and does not affect measurement “Foo”.

Unlike the tracing macros, the Token argument is not optional for profiling. The Token value is the only means of identifying a profiling measurement.

For performance reasons, profiling uses fixed size databases in which to store profiling measurements. There are separate databases for PEI and for DXE and subsequent phases. The PEI and DXE database sizes are specified with the `PcdMaxPeiProfileLogEntries` and `PcdMaxDxeProfileLogEntries` PCD entries respectively.

Similar to performance tracing, profiling code can be turned on or off by use of the `PcdProfileLibraryPropertyMask` PCD entry.

3.4 Instrumenting the Phases

Effective performance instrumentation requires knowledge of the interaction between the instrumentation macros and the firmware's execution phase at the time the instrumented code is executed. The following sections cover these interactions and identify considerations so that the researcher may select the best instrumentation points and methodologies to meet their goals.

3.4.1 SEC

This phase contains the first code executed after power-on or reset. Not only have peripherals not been initialized, but memory may not be available. The SEC phase is not particularly suitable for software-based performance measurement.

Techniques described in section 2.2, Hardware-Based Measurements, are well suited for the SEC phase.

For most platforms, SEC's total elapsed time can be determined by measuring from "the beginning of time" to the start of PEI. This is the mechanism used by EDK II.

3.4.2 PEI

The PEI phase actually consists of two sub-phases: PreMem and PostMem. PreMem is the state before main memory is available for use and PostMem refers to the state after main memory is usable.

After SEC phase transitions to PEI phase, the firmware is in the PreMem state. At this point, some temporary memory is usually available. On some IA platforms the temporary memory is actually a portion of the processor's cache that has been placed in a special mode. While operating in this special mode a number of restrictions exist:

- Temporary memory may only be used for data storage, not instruction execution.
- The size of temporary memory is usually small
- Temporary memory will not survive enabling of caching
- Initialized external or static variables can not be used since they will reside within the read-only firmware device, not temporary memory. Global constants can be used, but they must be declared as CONST and treated as read-only.

In order to store performance tracing measurements made during the PreMem portion of PEI, a HOB, with space for `PcdMaxPeiPerformanceLogEntries` measurement records, is dynamically created in temporary memory. A HOB is also created for profiling measurements with space for `PcdMaxPeiProfileLogEntries` measurement records.

As soon as memory has been initialized and is ready for use, these HOBs, and other PEI data stored in temporary memory, are copied into main memory and the PEI phase continues on in the PostMem state.

Due to memory restrictions during the PreMem state, some differences exist between performance measurements made during PEI and measurements made later.

- The *`Token`* and *`Module`* strings are limited to seven significant characters in trace records. Profiling records always allow up to 15 significant characters for the *`Token`* string.

- Only a fixed number of tracing measurements, specified by the `PcdMaxPeiPerformanceLogEntries` PCD entry, may be made.
- The `PcdMaxPeiProfileLogEntries` PCD entry specifies the number of profiling measurements that may be made.

3.4.3 DXE

One of the first things done after PEI transitions into DXE phase is to copy the PEI Performance tracing HOB into the DXE performance tracing list. As part of the copying operation, the PEI measurement records in the Performance HOB are translated into DXE measurement records within the dynamic DXE measurement list.

The PEI Performance profiling HOB is used to initialize the DXE profiling database. This database is created large enough to contain `PcdMaxPeiProfileLogEntries` + `PcdMaxDxeProfileLogEntries` profiling measurement records.

The differences between PEI and DXE performance measurements include:

- DXE allows tracing measurements to have *`Token`* and *`Module`* strings up to 31 significant characters in length.
- Profiling records always allow up to 15 significant characters for the *`Token`* string.
- The number of performance tracing measurements is limited by the amount of memory available and not by an arbitrary pre-defined number.
- There are (`PcdMaxPeiProfileLogEntries` + `PcdMaxDxeProfileLogEntries`) - `<actual number of PEI profile measurements>` profiling records allowed.

3.4.4 BDS

The instrumentation facilities work the same during the BDS phase as they worked during DXE. The main difference between BDS and DXE, from a performance measurement standpoint, is that a larger number of decisions are made as to which devices to *connect* and use for the boot process.

BDS may also invoke a Setup Browser which is used to set and change configuration and boot options. There are human interface related delays associated with the Setup Browser that can significantly affect performance.

3.4.5 EFI Applications

EFI Applications, of which the EFI Shell is the most commonly known, may also gather performance information. Even if the application itself is not instrumented, the services provided by the firmware may be and will produce additional measurement records as they are accessed.

Instrumenting an EFI Application is no different than instrumenting the DXE or BDS phases.

3.4.6 OS Load and S3 Resume

An OS Loader is a special type of EFI Application. Unlike most applications, an OS loader is expected to eventually call the firmware's `ExitBootServices()` service. Unless something special is done, calling `ExitBootServices()` will result in the loss of the performance measurement services and data. For this reason, EDK II stores a

portion of the trace performance data in a reserved memory area. Unless changed, this area is 16,384 bytes long and begins at the address recorded in EFI variable "PerfDataMemAddr" under Vendor GUID PERFORMANCE_PROTOCOL_GUID.

An S3 Resume is, from a performance measurement standpoint, similar to booting through an OS Loader. The same mechanism is used, as described above, to allow performance data to persist from the firmware into the OS environment. The EDK II firmware, internally, follows a different execution path for an S3 Resume than it does for a normal boot. When adding instrumentation, it is necessary to ensure that the correct code path is instrumented.

Not all performance measurement records are saved for the OS. First, all completed measurement records with a handle value matching one recorded in the handle database are copied into the reserved memory area. Next, completed records with a handle value of zero are copied. Due to the limited size of the storage area, only the first **N** records are saved. At the time of this writing, **N** is 460.

Performance measurement records transferred to the OS using this mechanism consist of a 28 character, NULL terminated, ASCII string and a 32-bit, unsigned, duration in milliseconds. Note that measurements with durations less than 1 millisecond are treated specially based upon the handle value: measurements with a handle value of zero are copied with a duration of zero while measurements with a non-zero handle value are not copied at all.

The techniques described in chapter 5, Instrumenting the Code, show how to restrict performance measurements to specific modules. It is strongly recommended that these techniques be used for both S3 resume and OS Loader measurements in order to ensure that only relevant measurements are made.

An operating system loader, utility, or driver may retrieve the performance data by first reading EFI variable "PerfDataMemAddr" to get the physical address of the saved data, then reading from that address to retrieve the saved performance data. The structure of this data is declared in Include/Guid/Performance.h in MdeModulePkg. The first item is a header, as declared by PERF_HEADER. The header is followed by **N** measurement records where each measurement record is declared by PERF_DATA. **N** is 460, as described above, and calculated by taking the size of the reserved region, subtracting the size of the header, then dividing by the size of PERF_DATA. Unless the EDK II code is modified, this is the same as (16384 - 1644)/ 32, which produces 460 with a few bytes left over.

4
Dp Reporting Utility

4.1 Description

Dp is a Shell application that generates performance reports based upon the performance data recorded by the EDK II performance infrastructure. It will dump all data contained in the performance measurement list, for all phases of execution from PEI through DXE and BDS. The performance infrastructure is responsible for preserving performance data across execution phase boundaries and ensuring that a single measurement record format is used for all records in the performance list.

The Dp application dumps the performance data for:

- Each completed execution phase (SEC, PEI, DXE, BDS, Shell)
- Each completed PEI module, DXE and BDS driver
- Other instrumented code.

Invoking Dp with the '-?' or '-h' option displays the following help information.

```
Display Performance metrics
dp [-b] [-v] [-x] [-s | -A | -R] [-t value] [-n count] [-h | -?]
   -b  display on multiple pages
   -v  display additional information
   -x  prevent display of individual measurements for cumulative items.
   -s  display summary information only
   -A  display all measurements in a list
   -R  display all measurements in raw format
   -t VALUE  Set display threshold to VALUE microseconds
   -n COUNT  Limit display to COUNT lines in All and Raw modes
   -?  display dp help information
```

The most common usage is to invoke Dp without any options or parameters. The default behavior, if no command line options are provided, is to produce a Grouped report with a minimum elapsed time of 1ms.

4.2 Report Structure

Dp produces three types of reports: Grouped, Sequential, and Raw. The *Grouped* report is the default. A *Sequential* report is selected with the '-A' command line option and the *Raw* report is selected with '-R'. See Appendix A for an example of a Grouped report. Appendix B provides a sample of a Sequential report and Appendix C provides a sample of a Raw report.

The Dp utility outputs a line of the form "==[name]==" to mark the beginning of each new section. Possible values for "name" are:

Major Phases	Drivers by Handle	PEIMs
General	Cumulative	Statistics
Sequential Trace Records		RAW Trace

4.3 Common Report Features

All reports track both complete and incomplete measurements. Incomplete measurements are usually major phase measurements where that phase has not completed; such as the Shell phase. Since Dp is a shell application, the shell is still active while Dp is running. For this reason, it is normal for there to be two incomplete measurements. If there are more than two, there may be an error in instrumentation where the measured region exited without encountering an END macro.

There are several report sections and options that are relevant for all report types. These are detailed below.

4.3.1 Options

The `-v`, `-x`, and `-t` options affect the output of all reports.

`-v`	Verbose	When present, this option causes extra information to be displayed. The specific information displayed is covered in the following descriptions for the individual report sections.
`-x`	eXclude	Specifying this option excludes the individual records for cumulative measurements from the report. Accumulated values for these measurements are still given in the *Cumulative* section.
`-t`	Threshold	The -t option must be followed, after one or more spaces, by a number. The number specifies the minimum elapsed time, in microseconds, required for a record to be included in the report. This option is useful for filtering out measurements that are too small to be relevant to the current activity.

4.3.2 Report Heading

All reports begin with the same two lines which identify the version of Dp being run and the frequency of the performance timer used to make the measurements.

If the '*-v*' command line option was specified, additional lines will be displayed specifying the count range of the performance timer as well as the minimum elapsed time value used to filter out measurements too small to be "interesting".

Note that counters can count in two directions, UP or DOWN. This affects the relative magnitude of time stamps, and elapsed time calculations.

```
DP Build Version:       2.2
System Performance Timer Frequency:   2,267,684 (KHz)
System Performance Timer counts UP from 0x0 to 0xFFFFFFFFFFFFFFFF
Measurements less than 1,000 microseconds are not displayed.
```

Figure 1. Report Heading

Dp uses the characteristics of the counter to ensure that elapsed time calculations are done correctly for the type of counter being used.

4.3.3 Statistics

The Statistics section is displayed if either the '-v' or '-s' option is given.

```
==[ Statistics ]========
There were 26389 measurements taken, of which:
       2 are incomplete.
       4 are major execution phases.
  26,319 have non-NULL handles, 70 are NULL.
      15 are PEIMs.
      66 are global measurements.
```

Figure 2. Statistics Report Sample

The values displayed are a summary of all recorded trace measurements, both complete and incomplete.

4.4 Grouped Reports

Grouped Reports are the default reporting format for Dp. As long as the **-A** or **-R** command line options are not specified, a Grouped report will be generated.

The **-s**, or Summary, option results in a report containing only the *Major Phases* and *Statistics* sections. If **-s** is present, the *Statistics* section will be included regardless of whether **-v** was specified or not.

4.4.1 Major Phases

EDK II comes with measurement code in place to gather performance metrics for the major phases of execution: SEC, PEI, DXE, BDS, and SHELL. If the duration of the phase is non-zero, the phase duration information is included in the report.

```
==[ Major Phases ]========
  SEC Phase Duration:        174589 (us)
  PEI Phase Duration:       2910 (ms)
  DXE Phase Duration:      10050 (ms)
  BDS Phase Duration:      12926 (ms)
Total       Duration:      26060 (ms)
```

Figure 3. Major Phases Report Sample

Note that the duration for the SEC phase is given in microseconds, us, while other times are in milliseconds, ms. This is because the SEC phase may vary between less than and greater than one ms. Since it's time is still significant, the time is presented in microseconds to allow greater accuracy.

This section is included in all Grouped Reports. Its contents are not affected by any option.

4.4.2 Drivers by Handles

For this section, each measurement with a handle value is compared to the firmware's handle database. If a match is found a report entry is generated that includes:

1. Index of the matching measurement record

2. Handle from the handle database matching the handle in the measurement record
3. Name of the driver the handle is associated with. This name comes from the Pdb file name which is only included for DEBUG builds. If you want this information included, make sure that you build with "-b DEBUG" or set "TARGET = DEBUG" in the target.txt file.

   If the Pdb file name can not be resolved, "Unknown Driver Name" will be displayed instead.
4. A description which is the value of the Token parameter from the associated performance macros.
5. The elapsed time for this measurement, in microseconds.

```
==[ Drivers by Handle ]========
Index: Handle              Driver Name                Description      Time(us)
-------------------------------------------------------------------------------
 1091: [ AC]                  LegacyBiosDxe               StartImage:    15850
 2355: [ B0]                      PciBusDxe                 DB:Start:     9955
 3431: [ B5]                       UsbKbDxe                 DB:Start:    10650
25924: [123]                                              LoadImage:     3567
25925: [123]                                              StartImage:   544666
```

Figure 4. Drivers by Handle Report Sample

For example, the third line in Figure 4 is interpreted as meaning:

- Measurement **3431**
- is for a driver with handle **B5**
- which is the **USB Keyboard Dxe** driver.
- The measurement is of the **Start** method of the driver's Driver Binding Protocol (**DB**)
- which took **10.65** milliseconds to execute.

The **-x** command-line option has a significant effect in this section since the majority of measurements reported here are covered by the *Cumulative* section.

4.4.3 PEIMs

Every measurement with a *Token* value of "PEIM" and a non-zero ending time is listed in the PEIM section of the report. Instead of a handle value, the physical address of the PEIM being measured is displayed.

```
==[ PEIMs ]========
Index          Pointer Value         Instance Information     Token     ET (us)
-------------------------------------------------------------------------------
   12:  0x0000000000000000              Unknown Driver Name     PEIM        4236
   15:  0x0000000000000000              Unknown Driver Name     PEIM     2338678
```

Figure 5. PEIMs Report Sample

Because there is currently no mechanism in place for determining the human-readable name of a PEIM, one may use the Handle parameter of the performance tracing macros to record identifying information. The Dp utility assumes that the physical address of the PEIM is passed in this parameter.

4.4.4 General

The *General* section lists measurements that:

- Are not execution phases
- Have NULL Handles
- Are complete: Both Start and End times are non-zero

Logically, this section displays all remaining measurements that weren't displayed in the preceding sections.

```
==[ General ]========
Index                        Name(GUID)                  Description     Time(us)
-------------------------------------------------------------------------------
    3:                                                        PreMem      2377641
   16:                                                       PostMem       525775
   23:                           DxeMain                CoreDispatcher     9544115
 2274:                               BDS                   PlatformBds    12905937
```

Figure 6. General Section Report Sample

The Module and Token fields of the performance tracing macros provide the values for the Name and Description fields, respectively, of this report section.

4.4.5 Cumulative

Several measurements are taken hundreds or thousands of times. It is useful to be able to see the overall effect that these measurements have instead of examining each instance. The Cumulative section facilitates this by accumulating statistics from these measurements and presenting each measurement type along with its cumulative values.

```
==[ Cumulative ]========
(Times in microsec.)     Cumulative   Average     Shortest    Longest
   Name         Count     Duration    Duration    Duration    Duration
-------------------------------------------------------------------------------
  LoadImage:       131       39072         298           5        3819
 StartImage:       119    14460491      121516           1     8465003
   DB:Start:       118    11049390       93638           0     5552333
 DB:Support:     25965       11298           0           0          99
```

Figure 7. Cumulative Report Sample

Only complete measurements are accumulated. Be aware that many DB:Start: measurements occur as part of the StartImage: measurement. Because of this, the sum of Cumulative Durations will usually be larger than the total elapsed time. The Raw Trace Report, described in Section 4.6, can be used to determine the temporal relationships between each trace measurement by comparing the start and end counts of the measurements of interest.

4.5 Sequential Trace Reports

There is no direct temporal relationship between groups in a Grouped report, only between the individual measurements within a particular group. Sequential Trace Reports are used when the temporal relationship between measurements is desired,

regardless of group. Each measurement displayed starts after measurements with a lower index number and before measurements with a higher index number. Only the starting relationship is shown, not the duration. There are some measurements which overlap others. For example, the following report excerpt shows measurements during the PEI phase.

```
==[ Sequential Trace Records ]========

Index      Handle                 Module                      Token       ET (us)
-------------------------------------------------------------------------------
    2:   0x00000000                                              PEI  2913812
    3:   0x00000000                                           PreMem  2382889
    4:   0x00000000                                             PEIM     1592
   14:   0x00000000                                             PEIM      598
   15:   0x00000000                                             PEIM  2343782
   16:   0x00000000                                          PostMem   524321
   17:   0x00000000                                           DisMem    26343
   19:   0x00000000                                             PEIM     1064
   21:   0x00000000                                              DXE  3322102
```

Figure 8. Temporal Relationships

The measurements in Figure 8 could be visualized as shown in Figure 9 in order to represent hierarchy.

```
+-- PEI  2913812
     +-- PreMem  2382889
            +-- PEIM
            +-- PEIM
            +-- PEIM
     +-- PostMem  524321
            +-- DisMem
                   +-- PEIM
+-- DXE
```

Figure 9. Measurement Hierarchy

This shows that the PEI phase was divided into two main measured units: PreMem and PostMem. Each of these units are comprised of other measurements.

Note that there are approximately 6 ms. unaccounted for between the sum of the PreMem and PostMem measurements and the PEI phase duration. This is because there are two unmeasured time periods: one is between the end of the PreMem measurement and the start of the PostMem measurement, the other is between the end of the PostMem measurement and the end of the PEI measurement.

4.6 Raw Trace Reports

Whether for debugging new measurements or determining fine-grained relationships between measurements, it is desirable to be able to see exactly what is contained in the measurement records. The Raw Trace Report, selected by the `-R` option, is used for this purpose.

The Raw Trace Report can be used to determine the source of the 6 ms. discrepancy described in Section 4.5.

```
==[ RAW Trace ]========

Index    Start Count          End Count               Module
-------------------------------------------------------------------------------
    2: 0000000017992819    00000001A0EE3DE5              PEI
    3: 0000000017992819    0000000158F89595           PreMem
   16: 0000000158FB0CD1    00000001A00BFDD5          PostMem
   21: 00000001A0EE4041    00000006EF701A95              DXE
```

Figure 10. Raw Trace Excerpt

Figure 10, above, presents a compressed form of the relevant measurements from the full report in Appendix C. From this report the unmeasured times during the PEI measurement become clear.

Based upon this information, we see that the unmeasured times account for 14,989,132 counts. Dividing this by the timer frequency in KHz; 2,266,956; gives us the elapsed time in milliseconds, 6. This matches the discrepancy.

5
Instrumenting the Code

This chapter describes the process of adding performance instrumentation to existing EDK II projects. In section 5.1, Establishing a Build Target, the steps for adding performance measurement capabilities to the project's configuration, INF and DSC files are described.

For illustrative purposes, the examples assume that x86 processors are being used. Feel free to modify the examples appropriately to support the intended architecture.

5.1 Establishing a Build Target

Start with a copy of a firmware source tree that you know you can successfully build running firmware from. This will give you a stable base for troubleshooting in case subsequent modifications cause problems.

Create a new directory within your target platform package. This document assumes "Profile" is used. Ex: MyPlatformPkg/Profile

Copy the build files used for your target platform into the new directory. At a minimum, this is the DSC file. You might also include the FDF file if you intend to modify it.

Rename the build files. ex: *MyPlatformPkgProduction* to *MyPlatformPkgProfile*

5.2 Editing the DSC file

Edit the [Defines] section of the DSC file to match the new target. While this is not absolutely necessary, it makes it much easier to keep the profiling builds separate from others. Key areas to focus on are:

```
PLATFORM_NAME                  = MyPlatformPkgProfile
PLATFORM_GUID                  = 12345678-9012-3456-7890-123456789012
OUTPUT_DIRECTORY               = Build/MyPlatformPkgProfile
FLASH_DEFINITION               = MyPlatformPkg/MyPlatformPkg.fdf
```

Before continuing, verify that the firmware can still be built using the build target that was just created. In case of problems, double-check the OUTPUT_DIRECTORY and FLASH_DEFINITION definitions.

```
build -b DEBUG -a IA32 -a X64 -p MyPlatformPkg/Profile/MyPlatformPkgProfile.dsc
```

Note: *The build target, -b, and architecture, -a, options may have already been specified within the source tree's target.txt configuration file. If that is the case, the above example would not have had to include them. It is also possible to edit the target.txt file to point to the desired build target which will eliminate the need for the -p option.*

Still within the DSC file, edit entries within the appropriate [LibraryClasses]

sections to ensure that the correct timer and Performance libraries are used.

- Keep `BasePerformanceLibNull` for the PerformanceLib instance in `[LibraryClasses.common]`. This will take care of any cases where it is not explicitly overridden.
- Add instances of `PeiPerformanceLib` to `[LibraryClasses.common.PEI_CORE]` and `[LibraryClasses.common.PEIM]`
- Add an instance of DxeCorePerformanceLib to `[LibraryClasses.common.DXE_CORE]`
- Add instances of DxePerformanceLib to `[LibraryClasses.common.DXE_DRIVER]`, `[LibraryClasses.common.DXE_SMM_DRIVER]`, `[LibraryClasses.common.UEFI_DRIVER]` and to `[LibraryClasses.common.DXE_RUNTIME_DRIVER]` and `[LibraryClasses.common.UEFI_APPLICATION]` if either of those areas are applicable.
- Determine which area(s) you wish to profile. Ensure that the Timer Library for that area is appropriate. Not all Timer Libraries work for all phases.

NOTE: It is necessary to ensure that all performance measurements are made using the same TimerLib instance.

More detailed information about the PerformanceLib and TimerLib instances is provided in chapter 6, EDK II Performance Infrastructure.

If *Measured Profiling* is to be used, edit the `[LibraryClasses]` sections again to select the correct ProfileLib instances: ProfileLibNull, PeiProfileLib, DxeCoreProfileLib, and DxeProfileLib.

Edit the `[PcdsFixedAtBuild ]` sections to ensure that PcdMaxPeiPerformanceLogEntries is sufficient (40 recommended)[1], PcdPerformanceLibraryPropertyMask is 1 and PcdProfileLibraryPropertyMask is 1. The PropertyMask entries are necessary to enable the tracing and profiling capabilities.

Detailed information on all of the relevant PCD entries is provided in chapter 6. These include settings for controlling debug output as well as entries which can be set to improve performance by removing run-time bounds checking.

At this point you may wish to verify that you can still build functional firmware. If problems do occur, their cause is most likely within the single DSC file that has been edited so far.

5.3 Synchronize DP's Timer Library

Since a timer library has been selected, now is a good time to edit the [LibraryClasses] section of the DP utility's DSC file, PerformancePkg.dsc, so that it uses the same timer library instance as the platform firmware.

1. 40 is a recommended starting value because that is sufficient for all default PEI measurements with room for a few more before the PCD entry needs to be changed. The author uses multiples of 10 for storage sizes in order to allow room for growth.

5.4 Editing a Module's INF file

A module that has not previously been instrumented for performance measurements will probably not have the necessary references in its INF file. The necessary information includes the Packages referenced, Library Classes used, and PCD entries used.

The [Packages] section lists the DEC files for the various packages containing libraries or components used by the module. The trace facility, implemented in the PerformanceLib, is entirely contained within the MdePkg and MdeModulePkg packages. The profiling facility is provided by the PerformancePkg while the various timer libraries will either be provided by one of these packages or possibly other packages depending upon the target platform.

Edit the [Packages] section of the module's INF file, if necessary, to add the relative paths to the required package's DEC files.

```
[Packages]
  MdePkg/MdePkg.dec
  MdeModulePkg/MdeModulePkg.dec
  PerformancePkg/PerformancePkg.dec
```

The [LibraryClasses] section of the INF file may need to have entries added for TimerLib, PerformanceLib, or ProfileLib.

```
[LibraryClasses]
  BaseMemoryLib
  BaseLib
  UefiLib
  MemoryAllocationLib
  UefiBootServicesTableLib
  PerformanceLib
  ProfileLib
  TimerLib
```

When these steps are complete, we are ready to begin instrumenting the module's code.

5.5 Adding Instrumentation

With few exceptions, instrumenting the code consists of surrounding the code to be measured with the appropriate START and END macros as described in chapter 3, EDK II Facilities. One must take care that all code paths are covered so that the measured section can not be exited without encountering an END macro. If a measured section should be exited without encountering a matching END macro, the measurement will be incomplete and will not contribute to the final recorded performance data. Incomplete measurements contribute to inaccurate readings.

An example of instrumentation where the measurement start and stop times are specified can be found in the first measurements made by EDK II. The PeiCore function in MdeModulePkg/Core/Pei/PeiMain contains code similar to the following.

```
 0  if (OldCoreData == NULL) {
 1    Tick = GetPerformanceCounter ();
 2    //
 3    // Report Status Code EFI_SW_PC_INIT
 4    //
 5    REPORT_STATUS_CODE (
 6      EFI_PROGRESS_CODE,
 7      FixedPcdGet32 (PcdStatusCodeValuePeiCoreEntry)
 8    );
 9
10    PERF_START (NULL, "SEC", NULL, 1);
11    PERF_END (NULL, "SEC", NULL, Tick);
12
13    PERF_START (NULL,"PEI", NULL, Tick);
14    //
15    // If first pass, start performance measurement.
16    //
17    PERF_START (NULL,"PreMem", NULL, Tick);
18
19    //
20    // If SEC provided any PPI services to PEI, install them.
21    //
22    if (PpiList != NULL) {
23      Status = PeiServicesInstallPpi (PpiList);
24      ASSERT_EFI_ERROR (Status);
25    }
26  }
```

If `OldCoreData` is `NULL`, this is the first pass, or PreMem, phase of PEI. In line 1 we get the current count from the performance counter. This is done as soon as possible since we will use its value as the starting time for PEI. Lines 10 and 11 are used to determine the time spent in SEC. The tick value of 1 in line 10 specifies that SEC started at “the beginning of time”. The value 1 is used for this because 0 is used to request that the current value of the performance counter be used. Line 11 ends the SEC measurement at the time collected to indicate the beginning of PEI. Thus, the duration of the SEC phase is from processor start until the beginning of PEI.

Line 13 begins the measurement of the PEI phase duration and line 17 starts measuring the PreMem phase of PEI at the same time.

A common use of the performance instrumentation is to measure the duration of a complex function. An example of this can be found in DxeMain where the duration of the DXE CoreDispatcher is measured.

```
1  //
2  // Invoke the DXE Dispatcher
3  //
4  PERF_START (NULL, "CoreDispatcher", "DxeMain", 0);
5  CoreDispatcher ();
6  PERF_END (NULL, "CoreDispatcher", "DxeMain", 0);
```

In both cases, a tick value of 0 is used which starts the measurement just before the call to CoreDispatcher and ends the measurement just after CoreDispatcher returns. Note that the Token and Module strings combine to unambiguously identify the measurement.

5.6 Controlling the Instrumentation

It is possible to specify the desired performance, profiling, or timer libraries for individual modules by editing their entries within the [Components] sections of the project's DSC file. The following example shows how this may be done.

```
[Components]
  MdeModulePkg/Universal/Network/Tcp4Dxe/Tcp4Dxe.inf {
    <PcdsFixedAtBuild>
      gEfiMdePkgTokenSpaceGuid.PcdPerformanceLibraryPropertyMask|0
      gPerformancePkgTokenSpaceGuid.PcdProfileLibraryPropertyMask|0x01
    <LibraryClasses>
      TimerLib|PerformancePkg/Library/TscTimerLib/TscTimerLib.inf
  }
```

In this example, performance tracing is disabled, measured profiling is enabled, and the TSC Timer is used for performance measurements within the Tcp4Dxe module.

If all other instances of PcdProfileLibraryPropertyMask set the value to 0, for example, then only this single module will provide profiling information.

Note that it is required for tracing or profiling to be enabled in DXE_CORE in order to use the associated performance measurement facility. If not enabled in DXE_CORE, the necessary performance infrastructure will not be instantiated and no measurements will be recorded by any module. The migration of performance measurements from the PEI phase is also performed by the performance infrastructure in DXE_CORE. Thus, even PEI performance information will not be available if the appropriate tracing or profiling Property Mask value for DXE_CORE is zero, disabling that type of performance measurement.

6 EDK II Performance Infrastructure

In this chapter, the elements of the EDK II performance infrastructure used for performance instrumentation are summarized. Detailed documentation for these items is available from uefi.org or tianocore.org. See “Related Information” on page 3.

6.1 PCD Entries

A number of PCD entries are used to control and tune performance measurement.

PcdPerformanceLibraryPropertyMask

Set to ZERO to disable performance tracing measurement code. Value definitions are in PerformanceLib.h.

PcdMaxPeiPerformanceLogEntries

Maximum number of performance trace log entries during PEI phase.

PcdProfileLibraryPropertyMask

Set to ZERO to disable performance profiling measurement code. Value definitions are in ProfileLib.h.

PcdMaxPeiProfileLogEntries

Maximum number of performance profiling records during PEI phase.

PcdMaxDxeProfileLogEntries

Maximum number of performance profiling records during DXE phase.

6.2 Library Classes

All instances of a particular library class must provide the same public information and methods. A library class instance does not have to be valid in all execution phases, nor the same phases as other instances of the same class.

6.2.1 PerformanceLib

Performance library instances provide implementations of methods to start, end, and retrieve performance tracing measurements as well as to determine if performance tracing measurements are enabled.

These methods are used by the performance tracing macros, described in Chapter 3. It is intended that the developer use the macros defined in PerformanceLib.h instead of calling the defined methods directly. A brief summary of the performance library instances provided by EDK II follow. See the documentation referenced in Section 1.4 for more detail.

BasePerformanceLibNull

An instance of the Performance Library implementing stub functions that can be used as a template for the implementation of a full performance library instance.

PeiPerformanceLib

This library implements the performance tracing library class for the PEI phase. It is valid for PEI_CORE as well as PEIMs or any other time during PEI phase.

DxeCorePerformanceLib

This library provides infrastructure enabling within DxeCore to log performance trace data. This library instance must be used in DxeCore if one wishes to retrieve performance tracing measurements, regardless of the phase they were taken in.

DxePerformanceLib

This library provides infrastructure for a DXE driver to log performance tracing data by using the services of the performance protocol.

6.2.2 TimerLib

Timer library instances provide implementations of methods to pause for a specified period of time, retrieve the current count from a timer, and get information about that timer. The TimerLib methods and instances are summarized below.

6.2.2.1 TimerLib Methods

MicroSecondDelay

Stalls the CPU for at least the given number of microseconds.

NanoSecondDelay

Stalls the CPU for at least the given number of nanoseconds.

GetPerformanceCounter

Retrieves the current value of a 64-bit free running performance counter.

GetPerformanceCounterProperties

Retrieves the 64-bit counting frequency of the counter, in Hz, and the range of performance counter values.

6.2.2.2 TimerLib Instances

There are a number of Timer Library instances that take advantage of the different counters provided by a platform. The implementations present in EDK II are summarized below.

BaseTimerLibNull

A non-functional instance of the Timer Library that can be used as a template for the implementation of a functional timer library instance. This library instance can also be used to test the build DXE Runtime, DXE SAL, and DXE SMM modules that require timer services as well as EBC modules that require timer services.

SecPeiDxeTimerLibCpu

Timer Library that only uses CPU resources to provide calibrated delays on IA-32, x64, and IPF.

TscTimerLib

This is an implementation of the Timer Library that uses the TimeStamp Counter (TSC) in Intel Ia32 and X64 CPUs to provide precision time measurements. Beginning with Pentium-4, the TSC in Intel CPUs count at a constant rate regardless of power management state. The only time the counter stops is during reset or when the processor is put into a Deep Sleep state.

6.2.3 ProfileLib

Profiling library instances provide implementations of methods to start, end, and retrieve performance profiling measurements as well as to determine if performance profiling measurements are enabled.

These methods are used by the performance profiling macros, described in Chapter 3. It is intended that the developer use the macros defined in ProfileLib.h in preference to calling the defined methods directly.

BaseProfileLibNull

An instance of the Profile Library implementing stub functions that can be used as a template for the implementation of a full profile library instance.

PeiProfileLib

This library implements the performance Profiling library class for the PEI phase. It is valid for PEI_CORE as well as PEIMs or any other time during PEI phase.

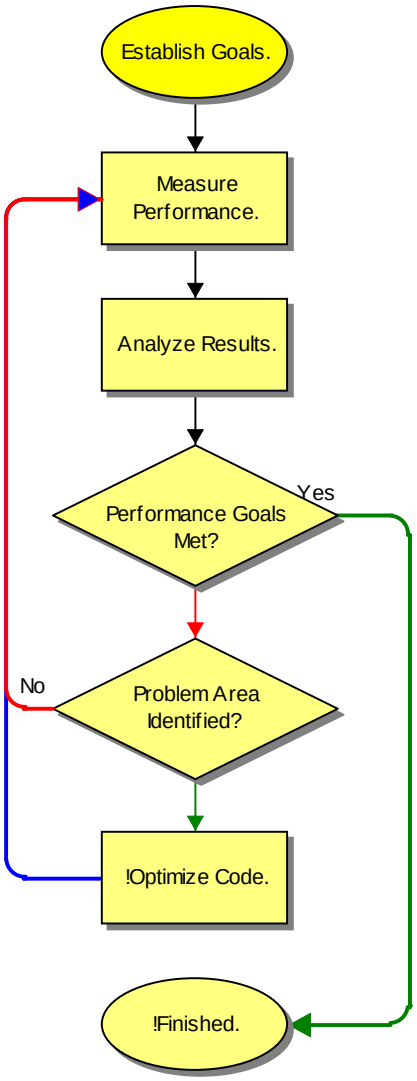
DxeCoreProfileLib

This library provides infrastructure enabling within DxeCore to log performance profiling data. This library instance must be used in DxeCore if one wishes to retrieve performance profiling measurements, regardless of the phase they were taken in.

DxeProfileLib

This library provides infrastructure for a Dxe driver to log performance profiling data by using the services of the profiling protocol.

7
Strategies



The general strategy employed in this document is one of successive refinement: start with the most general investigation and coarsest measurements then successively identify and narrow in on problem areas. Once the problem area is identified, analysis of the code can be performed to discover potential optimizations. Performance is then re-measured and the results analyzed to determine how effective the optimizations were. If needed, more optimizations are performed and the whole process is repeated as many times as needed to achieve the desired results.

This highly iterative process is illustrated by the figure on the left. Subsequent sections will describe the components of this process and how they apply to Performance Optimization in EDK II.

7.1 Establish Goals

Factors such as CPU speed, overall system design, FLASH device performance, or other hardware artifacts can affect measured performance as much as algorithm selection and firmware implementation quality. Performance optimization goals will determine which of these factors will be addressed.

It is crucial that a systematic approach be taken where only one thing changes between any two performance measurement runs. If more than one thing changes, it is difficult to determine which change affected the measurement and by how much.

7.2 Measure Performance

Measuring performance consists of:

1. Identifying what to measure.
2. Instrumenting the code.
3. Gathering the results.

Each of these activities is explained in detail below.

7.2.1 What to Measure

Determining what to measure is at first guided by goals, as established in Section 7.1. The code is then instrumented so that the desired statistics can be gathered. Determining what to measure, though, requires an understanding of the modular structure of EDK II.

- Phases of Execution: SEC, PEI, DXE, BDS, OS Loaders.
  Total elapsed time of the phase. Phases are sequential, only executed once, and mutually exclusive.
- Major functional units: dispatchers, module startup, …
  These functional units have some relatively well defined rules for when they are invoked and their roles within a particular phase – within the context of the specific implementation being instrumented. Measurement is relatively coarse grained with recording and reporting expectations similar to that for the Phases of Execution.
- Boot & Runtime Services
  Services can be invoked many times from diverse locations. Both single execution and cumulative measurements are significant.
- Measure the time to perform the instrumented service. Need one or more of:
  - Minimum time through the service
  - Maximum time through the service
  - Average time for the service
  - Number of times executed
  - Cumulative time for all invocations
- Library functionality
  Library functions can be invoked many times from diverse locations. Both single execution and cumulative measurements are significant.
- Measure the time to perform the instrumented routine. Need one or more of:
  - Minimum time through the routine
  - Maximum time through the routine

  - Average time for the routine
  - Number of times routine
  - Cumulative time for all invocations
- PPI and Protocol methods

  Protocol methods can be invoked many times from diverse locations. Both single execution and cumulative measurements are significant.
- Measure the time to perform the instrumented routine. Need one or more of:
  - Minimum time through the routine
  - Maximum time through the routine
  - Average time for the routine
  - Number of times routine
  - Cumulative time for all invocations
- Driver execution: disk read, console out, …

7.2.2 Instrumenting the Code

Even though one uses the same firmware image each time, the path through the firmware will vary depending upon the firmware's execution mode. These modes include:

- First boot with a new firmware image.
- Boot after power-on.
- Boot after a reset.
- Warm Boot
- Normal boot.
- Resume from S3.
- Resume from S4.

One must be aware of these different boot paths when selecting instrumentation points.

The PCD capability of EDK II can be leveraged to allow relatively fine-grained control of Data Collection. At a minimum, this allows collection or measurement to be selectively enabled or disabled for each Phase of Execution.

7.2.3 Gathering Statistics

Once the code has been instrumented, new firmware is built following guidelines given in Chapter 5. When executed, the firmware will then generate statistics which can be reported by the Dp utility.

7.3 Analyze Results

After the instrumented firmware has been executed and all the measurement data collected, an analysis is performed with the goal of deriving detailed interpretations of the collected data. The analysis is performed by one or more firmware engineers that are familiar with the code base. As a first step, the collected data is assessed for reasonableness and correctness. If any problems regarding the validity of the data are found, the reason has to be determined.

Note: *Any interrupts; such as SMI, PMI, Machine Checks, etc., that occur while a measurement is in progress will add the interrupt handler's time to the measurement. One must be aware of the possibility of this event and take it into account during any analysis.*

Depending on the identified reason, either the planning or the instrumentation may have to be revisited and performed again resulting in new measurement data. Once the validity of the collected data has been confirmed, the initially planned analyses are conducted. The results are interpreted to identify and understand problems in the investigated component. Based on the analysis results, preliminary conclusions and improvement suggestions are derived. If it is necessary, for example to gain confidence in the results or to draw sound conclusions, additional measurement and analyses passes are conducted. This might also include improving measurement definitions, data collection procedures, and analysis techniques as needed to ensure meaningful results that support measurement goals. To prevent misunderstandings of the analysis results and rework, initial and final results should be reviewed with all relevant stakeholders. Once the final analysis results are available, relevant stakeholders should be assisted in understanding and interpreting the results.

8 Lessons Learned

This chapter contains a summary of lessons learned and Best Known Methods (BKMs) acquired during boot performance optimization tuning work on platforms using Intel processors. The performance data mentioned is for normal, minimal and S3 boot modes, not the full configuration boot mode.

8.1 Lessons by Phase

8.1.1 SEC Phase

SEC is a platform-specific phase. On some platforms, SEC does an optional early microcode update for all CPUs, collects BIST of all CPUs, sets MTRR for BSP and enables temporary memory.

SEC operates the same during normal and S3 Resume boot paths.

Relevant sections are:

- 8.2.1, Enable code cache for boot block
- 8.3.4, Enable SPI prefetching
- 8.9.1, Use CPU number for synchronization
- 8.10.1, Code Alignment Issue

8.1.2 PEI Phase

PEI phase is composed of three sub-phases: Pre-Mem (before memory available), Mem-Dis (during memory detection), and Post-Mem (after memory available). The code in Pre-Mem phase and Mem-Dis runs out of the FD device, usually Flash.

If the CPU can't support code cache or the cache size is not large enough, it is recommended to shadow the code to memory in Post-Mem to speed up execution. Sections, 8.5.4 and 8.5.5, describe this performance impact.

It's recommended to cache the entire FV in Post-Mem phase to speed up the FLASH access and copy FvMain to memory (or decompress FvMainCompact).

Sections relevant to PEI are:

- 8.2.2, Configure C,D,E,F segments as WP
- 8.2.3, Enable Caching of Flash
- 8.3.5, Decompress FvMain block in memory
- 8.5.1, Memory operation algorithms
- 8.5.4, Shadow PEIMs after Memory Discovered
- 8.5.5, Shadow the PEI core
- 8.5.6, Run More Code in Post-Mem than in Pre-Mem
- 8.6.1, Reduce the number of FV Hobs
- 8.6.2, Report CPU BIST as a Hob

- 8.8.1, PeiReportStatusCode
- 8.9.1, Use CPU number for synchronization

8.1.3 DXE Phase

Lessons relevant to the DXE phase are:

- 8.4, Drivers
- 8.4.1, Avoid Legacy drivers/devices whenever possible
- 8.5.1, Memory operation algorithms
- 8.8.1, PeiReportStatusCode
- 8.9.1, Use CPU number for synchronization

8.1.4 BDS Phase

BDS phase lessons are:

- 8.4.2, BiosVideo Driver Enhancement
- 8.4.3, Keyboard Driver Enhancement
- 8.5, Memory
- 8.7.1, Minimal Configuration Path for Fast Boot
- 8.8.1, PeiReportStatusCode

8.2 Cache

CPU cache is the fastest memory bank in the system. To make good use of CPU cache is critical for boot performance. For UEFI-compliant firmware development on IA platforms, setting MTRRs is the only way to properly use CPU cache.

It's valuable to check the MTRR settings in each phase to look for potential enhancements.

8.2.1 Enable code cache for boot block

Relevant for SEC Phase and S3 Resume.

When configuring MTRRs, the boot block can be set as WP to enhance the PEI performance.

Note: *The WP mode, in IA processors, does not protect memory from writes. Instead, caching is enabled for reads while writes go directly to memory and the corresponding cache line (if any) is invalidated.*

One should check the CPU type (using cpuid for example) before enabling the code cache. Until recently, IA processors could not support code cache while using Non-Eviction Mode (NEM). If it is supported, enabling the code cache is highly recommended. This can greatly enhance execution performance prior to memory initialization.

Below is the code sample to enable code cache in SEC.

To enable code cache for 2-block FvRecovery (64KB for one block):

```
mov eax, 0FFFE0000h OR MTRR_MEMORY_TYPE_WP
xor edx, edx
mov ecx, CODE_CACHE_MTRR_PHYS_BASE
wrmsr
mov eax, NOT(20000h-1) OR MTRR_PHYSMASK_VALID
mov edx, 0Fh
mov ecx, CODE_CACHE_MTRR_PHYS_MASK
wrmsr
```

To enable code cache for 3-block FvRecovery (64KB for one block):

```
mov eax, 0FFFC0000h OR MTRR_MEMORY_TYPE_WP
xor edx, edx
mov ecx, CODE_CACHE_MTRR_PHYS_BASE_1
wrmsr
mov eax, NOT(40000h-1) OR MTRR_PHYSMASK_VALID
mov edx, 0Fh
mov ecx, CODE_CACHE_MTRR_PHYS_MASK_1
wrmsr
mov eax, 0FFFC0000h OR MTRR_MEMORY_TYPE_UC
xor edx, edx
mov ecx, CODE_CACHE_MTRR_PHYS_BASE_2
wrmsr
mov eax, NOT(10000h-1) OR MTRR_PHYSMASK_VALID
mov edx, 0Fh
mov ecx, CODE_CACHE_MTRR_PHYS_MASK_2
wrmsr
```

8.2.2 Configure C,D,E,F segments as WP

Relevant during PEI phase.

In order to speed up some legacy drivers like BiosVideo, configure the C,D,E,F segments, in the 0xC0000 to 0xFFFFF memory range, as Write Protected (WP).

8.2.3 Enable Caching of Flash

Relevant during PEI phase.

Enabling caching of the FLASH area, for example: 0xFFF0000 – 0xFFFFFFFF, will result in a significant improvement in pre-memory execution. On IA processors, use the MTRRs to select a cache mode such as WP.

8.3 Flash

8.3.1 Be careful of all Flash-access operations

As the access to the Flash device is slow, attention should be paid to all Flash-access operations. Two guidelines might be helpful:

- Never read FVs that we never use.

- Never read the same FV twice from Flash device.

Sections 8.6.1 and 8.4 have more details.

8.3.2 Do things in memory rather than in Flash

The experiment shows that to read data or execute code in Flash is much slower than the operations on memory. It's worthwhile to shadow the content from Flash to Memory after the memory is available.

- We can move PEI services to memory by shadowing PEI core. (See Section 8.5.5)
- We can improve the PPI performance by shadowing PEIM to memory. (See Section 8.5.4)
- We can improve the decompression of FvMain by copying the compressed FvMain from Flash to Memory before decompressing. (See Section 8.3.5)

8.3.3 S3 Resume: Access NV Storage as Little as Possible in Pre-Mem

The reason is the same for the code execution. Cache dominates the speed.

8.3.4 Enable SPI prefetching

Relevant during SEC phase.

If the flash chip is SPI, SPI prefetching can be enabled in SEC. (For ICH8, Bus 0, Dev 31, Func 0, Register BIOS_CNTL[3:2]=10b)

8.3.5 Decompress FvMain block in memory

Relevant during PEI phase.

On desktop, FvMain block is compressed as FvMainCompact FV and is decompressed in DxeIpl PEIM. The decompression on Flash is slower than the decompression in memory. So it's recommended to copy the FvMainCompact FV to memory first and then do decompression. If the flash chip is SPI and SPI prefetching is enabled, the performance gap is not that big, but this trick is general for all types of flash chip and chip's configurations.

8.4 Drivers

8.4.1 Avoid Legacy drivers/devices whenever possible

Legacy Option ROMs use 16-bit code and need thunking from and to 32-bit or 64-bit mode resulting in poor performance for these drivers. Native drivers are thus preferred over legacy drivers.

For similar reasons, EFI boot is preferred over Legacy boot.

8.4.2 BiosVideo Driver Enhancement

Relevant during BDS phase.

As was mentioned in Section 8.2.2, if we configure C,D,E,F segments as WP in PEI, some legacy drivers will get improved performance. For BiosVideo, C segment is used for VideoRom and we saw a big improvement on an Integrated Graphics Device (IGD) and also some improvement with an external graphics card.

Table 1. C,D,E,F segments Caching Impact

Video Card	C seg UC (ms)		C seg WP (ms)		Overall Enhancement (ms)
	ROM Dispatch	BiosVideoChild HandleInstall	ROM Dispatch	BiosVideoChild HandleInstall	
IGD	2726	244	487	227	2256
GeForce2 MX400 PCI	4431	921	4308	846	188
Asus PCIe	599	822	453	677	291

8.4.3 Keyboard Driver Enhancement

Relevant during BDS phase.

Do not do a full reset when calling `EFI_SIMPLE_TEXT_IN_PROTOCOL.Reset()` by setting the second parameter to **FALSE**. This will save about 400ms.

Note: *This optimization might leave some keyboards in an abnormal state after initialization.*

8.5 Memory

Memory routines (copy, set and zero) are used in many places in the firmware code. There are several commonly used memory operation algorithms, and the performance analysis shows that different algorithms have different performance results depending upon the boot phase.

8.5.1 Memory operation algorithms

8.5.1.1 MMX

This algorithm uses MMX registers in the processor. The Intel MMX technology was introduced into the IA-32 architecture in the Pentium II processor family and Pentium processor with MMX technology. The registers are 64-bit wide so the data transaction unit is 64-bit (8 bytes).

8.5.1.2 XMM (SSE2)

The streaming SIMD extensions 2 (SSE2) were introduced into the IA-32 architecture in the Pentium 4 and Intel Xeon processors. The registers are 128-bit wide so the data transaction unit is 128-bit (16 bytes).

Note: *XMM feature must be enabled by setting the OSFXSR (CR0[9]) and OSXMMEXCPT (CR0[10]) bits.*

8.5.1.3 REPSTR

The REPSTR algorithms use MOVS or STOS instruction with REP prefix. There are two versions of implementations for REPSTR in regards with the data size. The first version is to move one byte at a time until all data are transferred. The second version is to move N bytes at a time until there are less than N bytes left and to move one byte at a time for the left bytes. The N here could be 2 or 4 bytes on 32-bit mode and 2, 4 or 8 bytes on 64-bit mode. We use REPSTRN to represent the algorithm with N bytes transaction unit.

8.5.2 S3 Resume: Memory-related Operations

8.5.2.1 Problem

The original algorithm used for memory operations uses MMX which is slow in Pre-Mem phase without code cache.

8.5.2.2 Solution

Per investigation result, REPSTR1 is used for memory copy and REPSTR4 is used for memory set and zero memory. This saves about 40ms.

8.5.3 BKMs to choose proper algorithms

Table 2 lists the BKMs summarized from the performance analysis for each phase. The analysis is based on Processor E6850. The algorithm set is described as X (X1) / Y (Y1) where X is the best algorithm for memory copy and X1 is the second best one, Y is the best algorithm for memory set and zero memory, Y1 is the second best one.

Table 2. Recommended Memory Operation Algorithms

	Code Uncached			Code Cached		
	SPI	**FWH**	**Memory**	**SPI**	**FWH**	**Memory**
Data Uncached	N/A[1]	N/A[1]	REPSTR4[5]	N/A[1]	N/A[1]	XMM (MMX)[4]
Data Cached	REPSTR1 (REPSTR4) / REPSTR4 (REPSTR1)[2]	REPSTR1 (REPSTR4) / REPSTR1 (REPSTR4)[2]	N/A[1]	REPSTR4 (MMX) / REPSTR1 (REPSTR4)[2]	REPSTR1 (MMX) / MMX (REPSTR4)[2]	XMM (REPSTR1) / REPSTR4 (XMM)[3]

NOTE:

1. The cache configurations that are marked as N/A cannot be mapped to a particular usage model in Pre-boot environment.
2. The configurations are for Pre-Mem PEI phase.
3. The configuration is for DXE/BDS phase.
4. The configuration is for FvMainCompact shadowing (in DxeIpl) and frame buffer operations.

5. The configuration is for PEI core shadowing.

8.5.4 Shadow PEIMs after Memory Discovered

If a PEIM will be used after memory is discovered, it is better to be shadowed.

Note: *Make sure that PEIMs are NOT shadowed in S3 boot path to avoid S3 failure.*

8.5.4.1 PEIM shadowing without PI support

8.5.4.1.1 PEIM that is loaded after memory available

If the PEIM is ensured to be loaded after memory is available, a private PPI can be installed as a sign indicating whether the PEIM is shadowed.

Please refer to the function `PeimInitializeDxeIpl()` in Edk\Sample\Universal\DxeIpl\Pei\DxeLoad.c or Edk\Sample\Universal\DxeIpl\Pei\DxeLoadX64.c for implementation details.

8.5.4.1.2 PEIM that is loaded before memory available

If the PEIM is loaded before memory is available, a callback can be registered for the installation of PEI FV File Loader PPI (GUID is EFI_PEI_FV_FILE_LOADER_GUID). DxeIpl will install this PPI so memory is available on callback.

8.5.4.2 PEIM shadowing with PI support

With the advent of PI support, the shadowing of PEIM is quite straight-forward. A new PEI service is provided for this purpose: `RegisterForShadow()`. Assume the entry point of PEIM is `MyPeimInit()`.

```
EFI_STATUS
EFIAPI
MyPeimInit (
IN EFI_FFS_FILE_HEADER *FfsHeader,
IN EFI_PEI_SERVICES **PeiServices
);
```

Inside the `MyPeimInit()`, the PEIM can be shadowed like this:

```
(**PeiServices).RegisterForShadow ((EFI_PEI_FILE_HANDLE) FfsHeader);
```

Then when the memory is available, PEI core will shadow the PEIM automatically.

8.5.5 Shadow the PEI core

Note: *PEI core shadowing is implemented in PI-compliant PEI but is not available in non-PI PEI. Also make sure that PEI core is NOT shadowed in S3 boot path to avoid S3 failures.*

As all PEI services are implemented in PEI core, if PEI core is not shadowed, the code of PEI services will still be located on Flash after memory is installed. This will greatly impact the Post-memory performance.

8.5.6 Run More Code in Post-Mem than in Pre-Mem

S3 Resume

In S3 boot path, the code cache will be turned on after the memory is installed. Code will run much faster in Post-Mem.

If the PEIM is dispatched in Post-Mem phase, nothing needs changing as all the code in this PEIM will be executed on cache.

If the PEIM is dispatched in Pre-Mem phase, the simplest way to schedule a piece of code to run in Post-Mem phase is to register a callback notification of MemoryDiscovered PPI.

8.6 HOBs

8.6.1 Reduce the number of FV Hobs

PEI

The FV hob is created in some platform PEIMs and transfers the discovered FV's information to DXE phase. DXE core searches DXE drivers in the FV reported in this FV hob list. It wastes time to search something in FV on Flash, so it is worth to only put necessary Flash-FV into FV hob list or put memory-FV into FV host list.

There are two possible enhancements.

- Only build FV HOBs with FVs that contain DXE drivers. As the Recovery FV and NVStorage FV contains no DXE drivers, Dozens of milliseconds can be saved by removing FvRecovery & NVStorage from the HOB.
- Don't generate FvMainCompact FV or mark it as EFI_HOB_TYPE_UNUSED. As it has already been decompressed and put into memory. This prevents FvMainCompact FV from being decompressed again in DXE, saving hundreds of milliseconds.

PIWG specification gives a chance. It introduce a new protocol `EFI_FIRMWARE_VOLUME2_PROTOCOL` which contains `GetInfo()` interface to get Fv detail information. So the long term solution is that in PEI phase, all FV in flash are reported to Fv hob list but DXE core only search DXE driver in memory based FV in FV hob list by judging `EFI_FIRMWARE_VOLUME2_PROTOCOL.GetInfo()`.

8.6.2 Report CPU BIST as a Hob

The CPU BIST info is collected in SEC and passed to PEI. We can build this hob and pass to DXE so that MpCpu Driver doesn't need to re-calculate the CPU number and can depend on the CPU number to do synchronization.

8.7 Boot Mode Utilization

8.7.1 Minimal Configuration Path for Fast Boot

Relevant during BDS phase.

To make a quick boot, not all devices need to be started. The basic idea of minimal configuration path enhancement is to only start devices that are necessary for booting. For example, during the EFI boot to HD, only the HD, console input and console output devices need to be started even if the USB, CDROM or other devices are also connected to board. Figure 11 shows the minimal configuration path.

The minimal configuration path solution will greatly speed up the boot, especially EFI boot. For example, a test platform with one HD and one USB disk connected was two seconds faster using a minimal configuration as compared with the full configuration boot path.

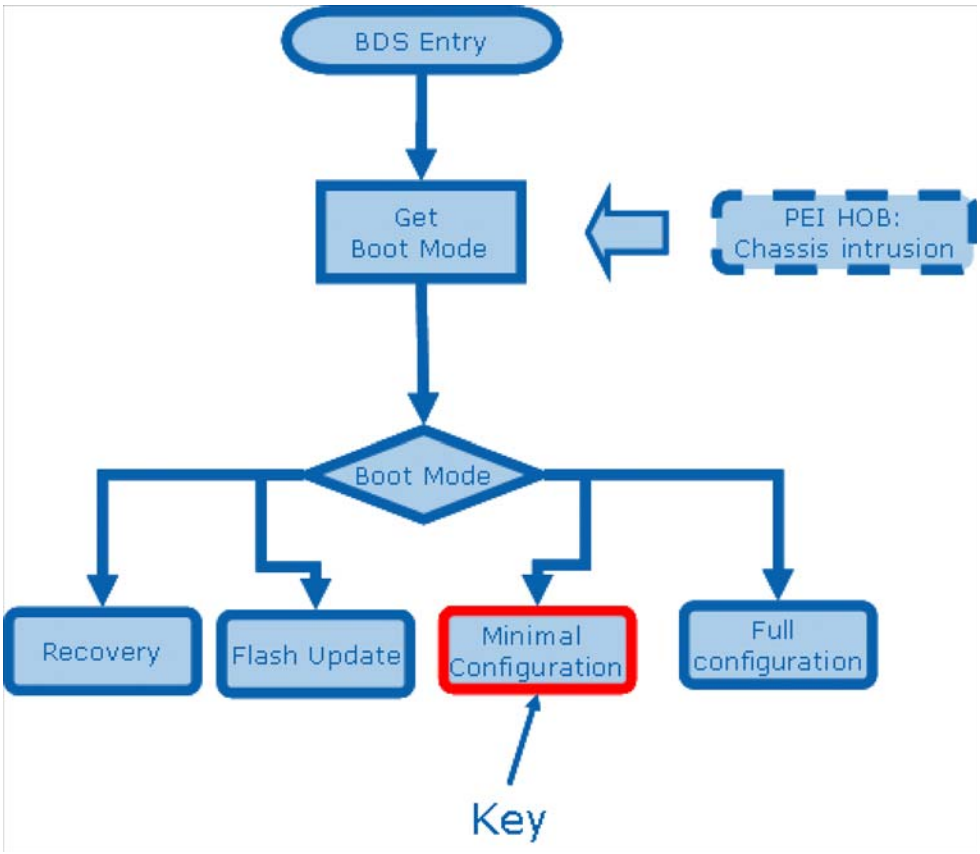


Figure 11. Minimal Configuration Path

8.7.2 S3 Resume Boot Path

The S3 resume boot path is a special boot path that causes the Firmware to take actions different from those in the normal boot path. In this special path, the Firmware derives pre-saved data about the platform's configuration from persistent storage and configures the platform before jumping to the operating system's waking vector.

Platform initialization can be viewed as a flow of the following:

- I/O operations
- Memory operations

- Accessing to the PCI configuration space
- A collection of platform-specific actions that can be abstracted by Pre-EFI Initialization Module (PEIM) PEIM-to-PEIM Interface (PPIs)

The goal of an S3 resume is to restore the platform to its pre-boot configuration.

8.7.2.1 PEI Phase in S3 Resume Boot Path

The PEI phase initializes the platform with the minimum configuration that is needed to enable the execution of DXE phase. During the S3 resume boot path, the Firmware still needs to restore the PEI portion of configuration.

PEIMs can use the `GetBootMode()` PEI service function to become aware of what the current boot path is. This awareness enables the platform to restore more efficiently because the same PEIM can save the configuration during a normal boot path and take advantage of that configuration in the S3 resume boot path.

8.7.2.2 DXE Phase in S3 Resume Boot Path

DXE phase in S3 resume boot path is not actually a DXE. In consideration of efficiency, the I/O and memory operations, the PCI configuration space access and SMBus configurations are saved as EFI Boot Script in normal boot path, retrieved and executed in S3 boot path. The Boot Scripts are executed in S3Resume PEIM.

8.7.3 PEI Dependency Expressions

S3 Resume, PEI

8.7.3.0.1 Problem

Before dispatching each PEIM, the core dispatcher checks whether the prerequisite PPIs have been installed. This procedure provides a sound architecture, however, it burdens S3 resume time if the dependency expression is already satisfied.

8.7.3.0.2 Solution

The PI specification provides a way to impose a dispatching order of PEIMs in PEI phase. An apriori file can be added to the firmware to specify the exact order PEIMs are dispatched as is defined in the PI specification volume 1:

> *The PEI apriori file is a special file that may optionally be present in a firmware volume, and its main purpose is to provide a greater degree of flexibility in the firmware design of a platform. Specifically, the apriori file complements the dependency expression mechanism of PEI by stipulating a series of modules which need be dispatched in a prescribed order.*

Note: *Use extreme care when listing PEIMs in the apriori file since these files will NOT have their dependencies checked. This could potentially result in PEIMs being started that have not had their dependencies satisfied.*

Non-PI builds don't have this feature so PI builds are recommended for performance considerations.

8.7.4 Avoid PEG Training in S3

8.7.4.1 Problem

On some platforms, it is mandatory to poll more than 200ms before MRC to train a PEG. But this is not necessary in S3 resume boot path as no hardware changes occur during S3 from the last normal boot.

8.7.4.2 Solution

- Save the state of PEG, IGD and PCI video card (whether they exist and their mode etc.) in normal boot path to NV storage and retrieve it in S3.
- As there's no restriction for the graphics initialization's execution before MRC, we can put the code to Post-Mem in S3.

8.8 Debug Output

8.8.1 PeiReportStatusCode

8.8.1.1 Problem

This is only for debug purpose and could be removed for production tip.

8.8.1.2 Solution

Disable PEI_REPORT_STATUS_CODE in Config.env.

8.9 MP Configuration

8.9.1 Use CPU number for synchronization

Relevant during SEC, PEI, and DXE phases.

In order to execute the microcode update and collect BIST info, SEC needs to synchronize among all CPUs. We recommend that CPU number is used for synchronization wherever possible. The sequence could be:

- BSP updates microcode
- BSP wakes up all APs to update microcode and collect CPU number at the same time
- BSP busy waits a constant amount of time (~10ms) for APs to finish
- BSP enables Temporary Memory (which will be used for store BIST)
- BSP wakes up all APs to collect BIST info
- BSP uses CPU number for synchronization

8.10 General Coding Issues

8.10.1 Code Alignment Issue

8.10.1.1 Problem

The execution performance of code on SPI FLASH chip without code cache is very sensitive to the code alignment. And it is still unknown how to align the code to make the execution faster.

8.10.1.2 Solution

The loop code is normally a hotspot and more sensitive to alignment issue because it will be executed several times. NOP instructions can be put before the code to adjust the alignment to see if the performance is better.

To avoid writing code with loops is another option but it might enlarge the image size.

A technique to globally adjust the alignment is by putting the APRIORI file list FFS to the top of all PEIMS and declaring APRIORI property for PEIMs in build DSC file. This only applies to PI build tips though. The background is that the size of APRIORI file list FFS depends on the number of PEIMs that have the APRIORI property so the alignment of PEIMs after this FFS varies with the different size of APRIORI file list FFS or the number of PEIMs that have the APRIORI property. More or less APRIORI properties can be put to PEIMs to see if the Pre-Mem phase is faster or not. Normally all PEIMs before MemoryInit PEIM should be declared with APRIORI property and the PEIMs after MemoryInit PEIM could be used for alignment tuning.

The example below shows the way to tune the alignment by adding/removing APRIORI property to the PEIMs. The directory prefix is removed for convenience. Here is the initial declaration in a DSC.

```
AprioriList.inf FV=FvRecovery
PEIM1.inf APRIORI=FvRecovery:1
MemoryInit.inf APRIORI=FvRecovery:2
PEIM2.inf
PEIM3.inf
```

Now we try to add more APRIORIs to PEIMs after MemoryInit PEIM.

```
AprioriList.inf FV=FvRecovery
PEIM1.inf APRIORI=FvRecovery:1
MemoryInit.inf APRIORI=FvRecovery:2
PEIM2.inf APRIORI=FvRecovery:3
PEIM3.inf
```

We assume that it is faster and try to add more.

```
AprioriList.inf FV=FvRecovery
PEIM1.inf APRIORI=FvRecovery:1
MemoryInit.inf APRIORI=FvRecovery:2
PEIM2.inf APRIORI=FvRecovery:3
PEIM3.inf APRIORI=FvRecovery:4
```

We stop at the former configuration if it is slower or we continue the process until we find it slower.

8.10.2 Predicate Expressions

The ordering of terms in predicate expressions can have a significant impact on performance. This is because only enough of the expression has to be evaluated to determine the outcome. For example, the first term in an OR expression that evaluates to TRUE is sufficient to determine that the entire OR expression will be TRUE.

The following code sample consists of a predicate expression within a for loop. The predicate expression is a compound AND expression with four terms. Each term is itself a simple predicate expression.

This is a real example from a previous version of the EDK II code and was used in the implementation of the PERF_END functionality. It finds the first open (EndTimeStamp is zero) performance trace record matching the Handle, Token, and Module parameters of a PERF_END invocation.

```
for (Index = 0; Index < NumberOfEntries; Index++) {
  if ((LogEntryArray[Index].Handle == (EFI_PHYSICAL_ADDRESS) (UINTN) Handle) &&
       AsciiStrnCmp (LogEntryArray[Index].Token, Token, PEI_PERFORMANCE_STRING_LENGTH) == 0 &&
       AsciiStrnCmp (LogEntryArray[Index].Module, Module, PEI_PERFORMANCE_STRING_LENGTH) == 0 &&
       LogEntryArray[Index].EndTimeStamp == 0
     ) {
    break;
  }
}
```

While there is nothing really wrong with this code, a little knowledge of the data it will be working on will allow us to significantly speed things up. Again taking from a real-world example:

1. NumberOfEntries = 25,172
2. Target entry is at Index 25,159
3. There are 532 completed measurement records with the same Handle, Token, and Module values prior to the target.
4. There are 6 measurement records with the same Handle and different Token and Module values prior to the target.
5. There are 25,157 completed entries prior to the target.

From this information, we can see that the terms, in order of importance, are:

1. EndTimeStamp
2. Handle
3. Module
4. Token

We also can determine that this ordering is valid for any measurement. Re-ordering the predicate expression using this information produces:

```
for (Index = 0; Index < NumberOfEntries; Index++) {
  if ( LogEntryArray[Index].EndTimeStamp == 0 &&
       LogEntryArray[Index].Handle == (EFI_PHYSICAL_ADDRESS) (UINTN) Handle &&
       AsciiStrnCmp (LogEntryArray[Index].Module, Module, PEI_PERFORMANCE_STRING_LENGTH) == 0 &&
       AsciiStrnCmp (LogEntryArray[Index].Token, Token, PEI_PERFORMANCE_STRING_LENGTH) == 0
     ) {
    break;
  }
}
```

The new ordering results in 531 fewer 64-bit integer comparisons and 1,069 fewer string comparisons for this single PERF_END invocation. Considering that there will be 25,170 PERF_END invocations one can see how the savings add up to a sizable amount.

8.10.3 Structure Member Alignment

The way structure members are organized can affect both execution performance and code size. Unaligned data accesses incur a performance penalty. Alignment rules can result in additional space, padding, added between members. When data is properly organized there is no performance penalty in accessing it and code is smaller.

By applying some simple rules during the design of data structures, alignment can be maintained and memory use minimized.

The following rules apply to most modern microprocessors. It is easy to add rules for data types not covered here. In particular, pay attention to pointers which may change in length for different processor architectures.

1. Group members by the size of their base type: largest to smallest.
2. Pointers should follow integer members that are the same size, or larger, than the largest size of pointers. For example: on Intel Architecture processors pointers are either 64 bits or 32 bits in length. By placing pointers after INT64 members and before INT32 members the same structure will maintain alignment whether compiled for IA32, X64, or IPF; without wasted space due to padding.

An example of a structure following these rules follows. Any member can be removed and alignment will be maintained without padding. If the rules are followed while adding members, alignment will also be maintained without padding.

```
struct AnExample {
  INT64  BigNum;
  INT64  BigArray[5];
  UCHAR  *CharPtr;            // May be 64 or 32 bit
  INT32  MediumNum;
  INT32  MediumArray[7];
  INT16  ShortNum;
  INT16  ShortArray[9];
  INT8   ByteNum;
  INT8   ByteArray[33];
};
```

Instances of this structure will maintain alignment, without padding.

Appendix A: Sample Grouped Report

```
Shell> dp -v -t 2000

DP Build Version:       2.2
System Performance Timer Frequency:   2,267,684 (KHz)
System Performance Timer counts UP from 0x0 to 0xFFFFFFFFFFFFFFFF
Measurements less than 1,000 microseconds are not displayed.

==[ Major Phases ]========
  SEC Phase Duration:        174589 (us)
  PEI Phase Duration:       2910 (ms)
  DXE Phase Duration:      10050 (ms)
  BDS Phase Duration:      12926 (ms)
Total       Duration:      26060 (ms)

==[ Drivers by Handle ]========
Index: Handle              Driver Name               Description      Time(us)
-------------------------------------------------------------------------------
   81: [ 45]                 FwBlockService               StartImage:     4949
   94: [ 4E]                   MiscSubclass               StartImage:   559927
   97: [ 4F]                        FtwLite               StartImage:    36132
  101: [ 51]             VariableRuntimeDxe               StartImage:    28974
  109: [ 55]     MonotonicCounterRuntimeDxe               StartImage:    31615
  121: [123]                                              StartImage:  8465003
  124: [ 5B]                       Platform               StartImage:     8491
  148: [ 69]                 MemorySubClass               StartImage:    98715
  155: [ 6C]                          MpCpu               StartImage:    33989
  163: [ 70]           GenericMemoryTestDxe               StartImage:   175475
  179: [ 78]                       SmmBase               StartImage:     4434
 1091: [ AC]                  LegacyBiosDxe               StartImage:    15850
 2355: [ B0]                      PciBusDxe                 DB:Start:     9955
 2442: [ 93]                   BiosVideoDxe                 DB:Start:  5552333
 2464: [ 9E]             GraphicsConsoleDxe                 DB:Start:  1522423
 2480: [ 95]                 ConPlatformDxe                 DB:Start:     8394
 2499: [ 99]                 ConSplitterDxe                 DB:Start:  1801058
 2796: [ 9F]                    TerminalDxe                 DB:Start:     5517
 2854: [ 94]                 ConPlatformDxe                 DB:Start:     4842
 2869: [ 95]                 ConPlatformDxe                 DB:Start:     3780
 2901: [ 99]                 ConSplitterDxe                 DB:Start:   420482
 3035: [ B4]                        EhciDxe                 DB:Start:    23926
 3071: [ B9]                     UsbBusDxe                  DB:Start:    23964
 3118: [ B4]                        EhciDxe                 DB:Start:    23924
 3154: [ B9]                     UsbBusDxe                  DB:Start:   346304
 3235: [ B9]                     UsbBusDxe                  DB:Start:    59998
 3316: [ B9]                     UsbBusDxe                  DB:Start:    59999
 3397: [ B9]                     UsbBusDxe                  DB:Start:   287169
 3431: [ B5]                      UsbKbDxe                  DB:Start:    10650
 3628: [ B9]                     UsbBusDxe                  DB:Start:    60002
 3709: [ B9]                     UsbBusDxe                  DB:Start:    60003
 7277: [ 80]           Unknown Driver Name                  DB:Start:   149014
 7355: [ 82]                       SnpDxe                 DB:Start:   147272
 7400: [ 85]                       Ip4Dxe                 DB:Start:     2019
 7442: [ 8C]                     IScsiDxe                 DB:Start:     5861
```

```
 8313: [ 80]            Unknown Driver Name                 DB:Start:   149030
 8391: [ 82]                        SnpDxe                  DB:Start:   147277
 8436: [ 85]                        Ip4Dxe                  DB:Start:     2021
 8478: [ 8C]                     IScsiDxe                   DB:Start:     5875
10876: [ B9]                    UsbBusDxe                   DB:Start:    19080
10928: [ A2]                          Fat                   DB:Start:     2105
10956: [ AF]                PartitionDxe                    DB:Start:     2895
11046: [ A2]                          Fat                   DB:Start:     5030
11162: [ AF]                PartitionDxe                    DB:Start:     2898
11749: [ A6]                   IdeBusDxe                    DB:Start:    43068
11911: [ A6]                   IdeBusDxe                    DB:Start:    43072
21329: [ B9]                   UsbBusDxe                    DB:Start:     2894
21819: [ AF]                PartitionDxe                    DB:Start:     2863
22362: [ A6]                   IdeBusDxe                    DB:Start:     2005
22477: [ A6]                   IdeBusDxe                    DB:Start:     2007
23196: [ AF]                PartitionDxe                    DB:Start:     2895
23949: [ B9]                   UsbBusDxe                    DB:Start:     3261
24332: [120]                       Shell                  LoadImage:     3819
25700: [123]                                              LoadImage:     3532
25701: [123]                                             StartImage:    18024
25924: [123]                                              LoadImage:     3567
25925: [123]                                             StartImage:   544666
25972: [123]                                              LoadImage:     3583
25973: [123]                                             StartImage:  4015088
26020: [123]                                              LoadImage:     3570
26021: [123]                                             StartImage:   110776
26068: [123]                                              LoadImage:     3582
26069: [123]                                             StartImage:    76964
26116: [123]                                              LoadImage:     3592
26117: [123]                                             StartImage:    78441
26164: [123]                                              LoadImage:     3599
26165: [123]                                             StartImage:    78486
26388: [122]            Unknown Driver Name               LoadImage:     3623

==[ PEIMs ]========
Index          Pointer Value         Instance Information     Token     ET (us)
-------------------------------------------------------------------------------
   12:  0x0000000000000000             Unknown Driver Name     PEIM        4236
   15:  0x0000000000000000             Unknown Driver Name     PEIM     2338678

==[ General ]========
Index                       Name(GUID)                 Description     Time(us)
-------------------------------------------------------------------------------
    3:                                                      PreMem     2377641
   12:                                                        PEIM        4236
   15:                                                        PEIM     2338678
   16:                                                     PostMem      525775
   17:                                                      DisMem       26528
   22:                           DxeMain    CoreInitializeDispatcher      506277
   23:                           DxeMain               CoreDispatcher     9544115
 2274:                               BDS                  PlatformBds    12905937
 2275:        PlatformBdsPolicyBehavior                  PlatformBds    12889607
 2276:                      Full Config                PBPB BootMode    12886240
 2277:                                   PlatformBdsConnectConsole    10416684
 2278:        PlatformBdsForceActiveVga               ConnectConsole     8904134
```

```
 2279:                              Top              ForceActiveVga       15844
 2399:                  GetGopDevicePath              ForceActiveVga     8885326
 2400:                              Top           GetGopDevicePath     8885314
 2541:                           Bottom              ForceActiveVga        2947
 2586:        ConnectAllDefaultConsoles              ConnectConsole     1449801
 2986:                              BDS                      ConOut    22564156
 3823:       Diagnostics & Connect Seq.                 Full Config     2205635
 3912:                              BDS                      ConOut    24136123
11750:                              IDE           DiscoverIdeDevice       20481
11752:                              IDE           DiscoverIdeDevice       20480
11754:                              IDE         Finish IDE detection    25021144
11912:                              IDE           DiscoverIdeDevice       20480
11914:                              IDE           DiscoverIdeDevice       20480
11916:                              IDE         Finish IDE detection    25070295
22363:                              IDE         Finish IDE detection    25634842
22478:                              IDE         Finish IDE detection    25644830
23548:                              BDS                      ConOut    25725097
24197:        PlatformBdsEnterFrontPage                 Full Config      249482
24199:                      Zero Timeout                 Full Config       14296

==[ Cumulative ]========
(Times in microsec.)     Cumulative   Average     Shortest    Longest
   Name         Count     Duration    Duration    Duration    Duration
-------------------------------------------------------------------------------
  LoadImage:       131       39072         298           5        3819
 StartImage:       119    14460491      121516           1     8465003
   DB:Start:       118    11049390       93638           0     5552333
 DB:Support:     25965       11298           0           0          99

==[ Statistics ]========
There were 26389 measurements taken, of which:
       2 are incomplete.
       4 are major execution phases.
  26,319 have non-NULL handles, 70 are NULL.
      15 are PEIMs.
      66 are global measurements.
```

Appendix B: Sample Sequential Report

```
Shell> dp -A

DP Build Version:       2.2
System Performance Timer Frequency:   2,266,972 (KHz)

==[ Sequential Trace Records ]========

Index      Handle                 Module                      Token       ET (us)
-------------------------------------------------------------------------------
    1:   0x00000000                                              SEC   174644
    2:   0x00000000                                              PEI  2910941
    3:   0x00000000                                           PreMem  2378388
    4:   0x00000000                                             PEIM     1592
    5:   0x00000000                                             PEIM     1281
    6:   0x00000000                                             PEIM     1250
    7:   0x00000000                                             PEIM     1313
    8:   0x00000000                                             PEIM     1312
    9:   0x00000000                                             PEIM       31
   10:   0x00000000                                             PEIM     1247
   11:   0x00000000                                             PEIM      279
   12:   0x00000000                                             PEIM     4238
   13:   0x00000000                                             PEIM     1406
   14:   0x00000000                                             PEIM      597
   15:   0x00000000                                             PEIM  2339412
   16:   0x00000000                                          PostMem   525940
   17:   0x00000000                                           DisMem    26537
   19:   0x00000000                                             PEIM     1064
   21:   0x00000000                                              DXE 10053926
   22:   0x00000000                        DxeMain CoreInitializeDisp   506436
   23:   0x00000000                        DxeMain     CoreDispatcher  9547112
   24:   0xBE90FF98                         PcdDxe        LoadImage:       10
   25:   0xBE90FF98                         PcdDxe       StartImage:     1005
   26:   0xBE90F898                  DxeStatusCode        LoadImage:        9
   27:   0xBE90F898                  DxeStatusCode       StartImage:     1036
   28:   0xBE90F318            SectionExtractionDxe        LoadImage:        6
   29:   0xBE90F318            SectionExtractionDxe       StartImage:     1003
   30:   0xBE8BED98                  FvToFv2Thunk        LoadImage:        6
   31:   0xBE8BED98                  FvToFv2Thunk       StartImage:     1004
   32:   0xBE8BE498                      CpuIoDxe        LoadImage:        6
   33:   0xBE8BE498                      CpuIoDxe       StartImage:     1003
   34:   0xBE8BCF18                   HiiDatabase        LoadImage:       24
   35:   0xBE8BCF18                   HiiDatabase       StartImage:     1005
   36:   0xBE8BC598                    DataHubDxe        LoadImage:        6
   37:   0xBE8BC598                    DataHubDxe       StartImage:     1003
   38:   0xBE8BC018                    Legacy8259        LoadImage:        6
   39:   0xBE8BC018                    Legacy8259       StartImage:     1021
   40:   0xBE8A9A98                    RuntimeDxe        LoadImage:        6
   41:   0xBE8A9A98                    RuntimeDxe       StartImage:     1086
   42:   0xBE8A9598                  MemoryEccInit        LoadImage:        6
   43:   0xBE8A9598                  MemoryEccInit       StartImage:        1
   44:   0xBE8A9198                SecurityStubDxe        LoadImage:        5
   45:   0xBE8A9198                SecurityStubDxe       StartImage:        4
```

```
46:   0xBE8A6C98                      DpcDxe        LoadImage:        7
47:   0xBE8A6C98                      DpcDxe       StartImage:     1003
48:   0xBE8A6718               DevicePathDxe        LoadImage:       19
49:   0xBE8A6718               DevicePathDxe       StartImage:     1004
50:   0xBE87DF98                                   LoadImage:        8
51:   0xBE87DF98                                  StartImage:       20
52:   0xBE87DF18                      IchSpi        LoadImage:       10
```

Appendix C: Sample Raw Report

```
Shell> dp -R

DP Build Version:       2.2
System Performance Timer Frequency:   2,266,956 (KHz)

==[ RAW Trace ]========
```

Index	Handle	Start Count	End Count	Token	Module
1:	0000000000000000	0000000000000000	0000000017992819	SEC	
2:	0000000000000000	0000000017992819	00000001A0EE3DE5	PEI	
3:	0000000000000000	0000000017992819	0000000158F89595	PreMem	
4:	0000000000000000	000000001859EBC1	00000000189100AD	PEIM	
5:	0000000000000000	00000000189CDAC1	0000000018C92F8D	PEIM	
6:	0000000000000000	0000000018D1D349	0000000018FD12B1	PEIM	
7:	0000000000000000	0000000019016801	000000000192ED371	PEIM	
8:	0000000000000000	0000000019354DCD	000000001962B145	PEIM	
9:	0000000000000000	0000000019681BE1	00000000196931BD	PEIM	
10:	0000000000000000	00000000196FAA4D	00000000199ACD81	PEIM	
11:	0000000000000000	00000000199CFB19	0000000019A6AA61	PEIM	
12:	0000000000000000	0000000019AAFF1D	000000001A3D9925	PEIM	
13:	0000000000000000	000000001A4304A1	000000001A73A985	PEIM	
14:	0000000000000000	000000001A790E21	000000001A8DBD1D	PEIM	
15:	0000000000000000	000000001A9435A5	00000000156AF6A1D	PEIM	
16:	0000000000000000	0000000158FB0CD1	00000001A00BFDD5	PostMem	
17:	0000000000000000	0000000158FC1BF5	000000015C921031	DisMem	
19:	0000000000000000	000000015DFE7BFD	000000015E235151	PEIM	
21:	0000000000000000	00000001A0EE4041	00000006EF701A95	DXE	
22:	0000000000000000	00000001A0FB3D8D	00000001E5697FD1	CoreInitializeDispatcher	DxeMain
23:	0000000000000000	00000001E5698669	00000006EF7012B1	CoreDispatcher	DxeMain
24:	00000000BE90FF98	00000001E56B2415	00000001E56B84A5	LoadImage:	
25:	00000000BE90FF98	00000001E56B87C1	00000001E58E5379	StartImage:	
26:	00000000BE90F898	00000001E58E5491	00000001E58EA55D	LoadImage:	
27:	00000000BE90F898	00000001E58EA815	00000001E5B28499	StartImage:	
28:	00000000BE90F318	00000001E5B285AD	00000001E5B2C111	LoadImage:	
29:	00000000BE90F318	00000001E5B2C371	00000001E5D57AB1	StartImage:	
30:	00000000BE8BED98	00000001E5D57BA1	00000001E5D5B1A1	LoadImage:	
31:	00000000BE8BED98	00000001E5D5B3B5	00000001E5F874C9	StartImage:	
32:	00000000BE8BE498	00000001E5F87599	00000001E5F8B009	LoadImage:	
33:	00000000BE8BE498	00000001E5F8B289	00000001E61B69B1	StartImage:	
34:	00000000BE8BCF18	00000001E61B6AAD	00000001E61C44B1	LoadImage:	
35:	00000000BE8BCF18	00000001E61C478D	00000001E63F0BC5	StartImage:	
36:	00000000BE8BC598	00000001E63F0C95	00000001E63F4949	LoadImage:	
37:	00000000BE8BC598	00000001E63F4BA1	00000001E66201F1	StartImage:	
38:	00000000BE8BC018	00000001E66202CD	00000001E6623ED1	LoadImage:	
39:	00000000BE8BC018	00000001E6624135	00000001E6859AA1	StartImage:	
40:	00000000BE8A9A98	00000001E6859B7D	00000001E685D96D	LoadImage:	
41:	00000000BE8A9A98	00000001E685DC2D	00000001E6AB6D5D	StartImage:	
42:	00000000BE8A9598	00000001E6AB6E75	00000001E6ABA3A9	LoadImage:	
43:	00000000BE8A9598	00000001E6ABA689	00000001E6ABB6E9	StartImage:	
44:	00000000BE8A9198	00000001E6ABB7D1	00000001E6ABE8CD	LoadImage:	

```
45: 00000000BE8A9198 00000001E6ABF1C5 00000001E6AC1761                  StartImage:
46: 00000000BE8A6C98 00000001E6AC18B1 00000001E6AC5A4D                   LoadImage:
47: 00000000BE8A6C98 00000001E6AC5D25 00000001E6CF1401                  StartImage:
48: 00000000BE8A6718 00000001E6CF1509 00000001E6CFBD65                   LoadImage:
49: 00000000BE8A6718 00000001E6CFC06D 00000001E6F27BD9                  StartImage:
50: 00000000BE87DF98 00000001E6F27CDD 00000001E6F2C911                   LoadImage:
51: 00000000BE87DF98 00000001E6F2CC19 00000001E6F384C9                  StartImage:
52: 00000000BE87DF18 00000001E6F3862D 00000001E6F3E5CD                   LoadImage:
```

Appendix D: Pre-defined Measurements

The following tables list, by package, the measurement points which are pre-defined in EDK II. Platform-specific measurement points may also be present depending upon the codebase being used and are beyond the scope of this document.

Table 3. MdeModulePkg Measurement Points

Token	Module	Description
Core/Dxe/DxeMain.c		
PEI		The end of the PEI phase, and beginning of the DXE phase is in the DxeMain function following the point where all PEI data has been copied into Dxe and all of the Library constructors have been called.
DXE		
CoreInitializeDispatcher	DxeMain	In the DxeMain function, the duration of the call to CoreInitializeDispatcher is measured.
CoreDispatcher	DxeMain	In the DxeMain function, the duration of the call to CoreDispatcher is measured.
Core/Dxe/Hand/DriverSupport.c		
DB:Support		Measurement from within the CoreConnectSingleController function of the duration of the call to DriverBinding-->Supported()
DB:Start		Measurement from within the CoreConnectSingleController function of the duration of the call to DriverBinding-->Start()
Core/Dxe/Image/Image.c		
LoadImage:		Duration of the CoreLoadImageCommon() call from CoreLoadImage()
StartImage:		CoreStartImage() duration, minus the time for the call to CoreLoadedImageInfo() at the beginning. There are two PERF_END macros used for this measurement in order to cover both the successful and failure returns.
Core/Pei/Dispatcher/Dispatcher.c		
PEIM	Shadow	PEIM's entry point duration when the PEIM is shadowed into main memory.
PEIM	Dispatch	PEIM's entry point duration when the PEIM is dispatched due to a satisfied dependency expression.
PEIM	PeimFileHandle	PEIM's entry point duration when the PEIM is dispatched due to a processing of notifies.
Core/Pei/PeiMain/PeiMain.c		
PreMem		Duration of the first invocation of PeiCore(), before main memory has been discovered and configured.

Table 3. MdeModulePkg Measurement Points

Token	Module	Description
PostMem		Duration of the second invocation of PeiCore(), after main memory has been discovered and configured.
DisMem		Time, during the second invocation of PeiCore(), to install the MemoryDiscoveredPpi and alert listeners that main memory is available.
SEC		Duration of the SEC phase. Measured from the beginning of time to the start of PeiCore().
PEI		Duration of the PEI phase. Measured from the start of PeiCore() to the start of DxeMain().

Table 4. IntelFrameworkModulePkg Measurement Points

Token	Module	Description
Bus/Pci/IdeBusDxe/IdeBus.c		
DiscoverIdeDevice	IDE	Duration of the DiscoverIdeDevice() call from within IDEBusDriverBindingStart().
Finish IDE detection	IDE	Time from system start to the end of the IDEBusDriverBindingStart() function.
Library/GenericBdsLib/BdsConsole.c		
ConOut	BDS	Time from system start until the console is connected in the BdsLibConnectConsoleVariable() function when called by BdsLibConnectAllDefaultConsoles().
Universal/BdsDxe/BdsEntry.c		
DXE		Duration of the DXE phase. Measured from the beginning of DxeMain() to the beginning of BdsEntry().
BDS		Measurement of the duration of the BDS phase begins at the beginning of BdsEntry().
PlatformBds	BDS	Platform portion of BDS as measured from PlatformBdsInit() until after PlatformBdsPolicyBehavior() but before BdsBootDeviceSelect().
Library/GenericBdsLib/BdsBoot.c		
BDS		Duration of the BDS phase. Measured from the beginning of BdsEntry() to the beginning of BdsLibBootViaBootOption().
Universal/BdsDxe/FrontPage.c		
BdsTimeOut	BDS	The time from entry to PlatformBdsEnterFrontPage() until exit. The PERF_END macro is only executed upon Auto Boot.