White Paper

Open Compute - Challenges for UEFI and the Cloud

Mallik Bulusu
Microsoft Corporation

Vincent Zimmer
Intel Corporation

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Executive Summary

This paper talks about the challenges for Cloud computing. The Open Compute Project (OCP) [OCP] vies to provide interoperability between many elements in the data center, pioneering ‘open hardware’ precepts for this market area.

Just as the OCP goal is to have interoperability between all elements of the server complex, UEFI [UEFI-BOOK] attempts to provide similar business interoperability. Specifically, the UEFI/PI/ACPI designs have followed the same spirit, effecting this intent through industry standard API’s. Through these API’s we can have plug and play binaries between different business elements.

UEFI can help open up the boot and management firmware elements of OCP that have traditionally been vendor specific and not fully interoperable.

This paper isn’t exhaustive but instead attempts to highlight some Cloud challenges with corresponding solutions based upon UEFI.

Prerequisite:
This paper assumes that audience has basic EDKII/UEFI firmware development experience.

Table of Contents

Cloud Firmware Challenges

Introduction – the Cloud

When designing a compute engine, one must strive to work around three main constraints, as shown in below Figure, namely –

- Constraints from Physics
- How to deploy the compute engine?
- How to manage the compute?

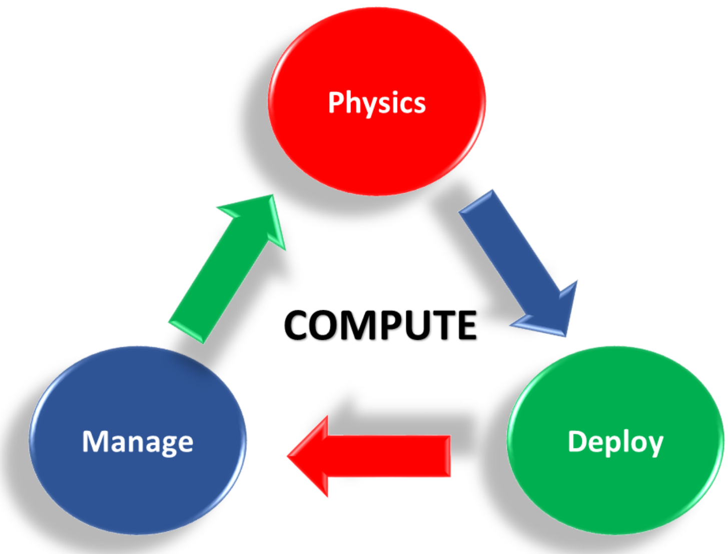


Figure: Challenge Vectors

Hypothetically, let us imagine possibility of an ideal compute node that can cater to all the conceivable compute in the universe. This will simply trivialize the deployment challenges as we have to prepare the hardware once. Then we have to install the firmware stack, OS and software stack exactly once. But this is clearly not viable from the viewpoint of performing compute as there are power delivery challenges, thermal, mechanical and availability challenges etc. The Cloud [CLOUD] server paradigm offers elegant answer to this problem via its inherent scale. In particular, it addresses various challenges such as power deliver, thermal, mechanical, availability, etc. associated with concentration of compute. This is accomplished by distribution of compute across thousands of compute nodes. Such compute nodes are usually symmetric, but that is not a requirement. The advantage of cloud paradigm is that with varying compute needs, the size of Cloud can be changed accordingly. However, this does pose new challenges related to "deploying" the compute as well as "managing" the compute, such as–

- ensuring that firmware updates can be deployed seamlessly on a broad scale
- ensuring that cloud can be provisioned seamlessly as per underlying specifications
- ensuring that cloud is secured both at a node level as well as at datacenter/cloud level
- ensuring that software tools and diagnostics can easily predict and/or detect, root-cause failures

This paper examines the opportunities and challenges that lie ahead with the UEFI, in order to solve above platform construction problems via standards.

Introduction – UEFI

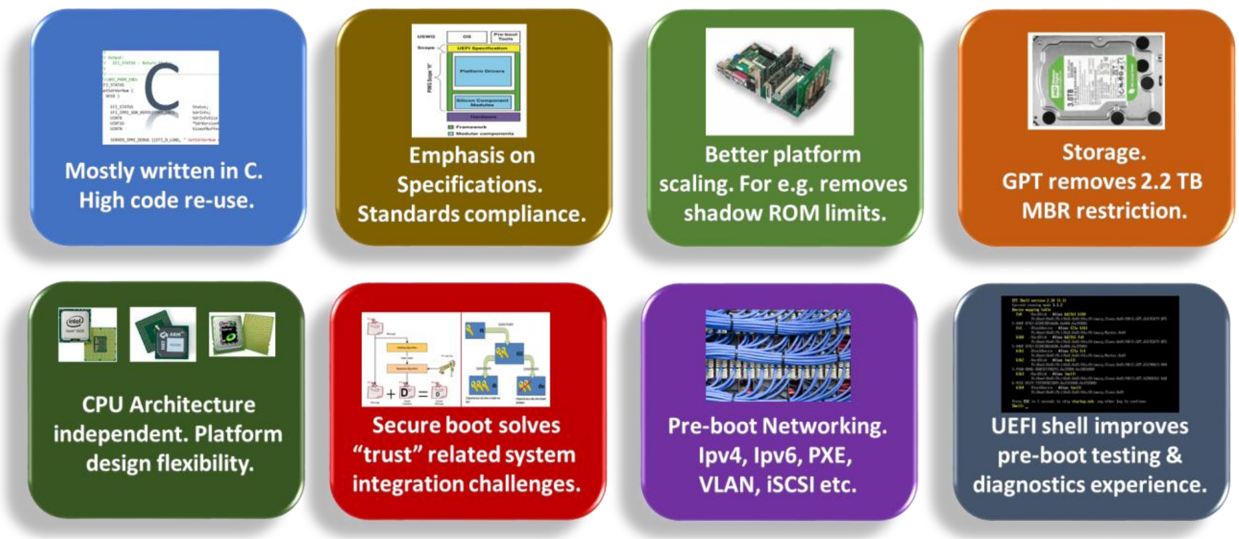
UEFI stands for the "Unified Extensible Firmware Interface." UEFI has several dimensions, including industry standards www.uefi.org for purposes of interoperability between operating system loaders, pre-OS applications, and operating system runtimes. The UEFI Forum governs the UEFI Specification evolution and various companies, including Intel ®, contribute to the open source project.

The salient details of the UEFI specification includes the definition of ANSI C-callable API's that are published by the system board firmware implementation. The figure below describes various facets of UEFI, including the dynamically loadable UEFI drivers that can be installed on host-bus adapters (HBA's). This allows for moving beyond the limitations of PC/AT BIOS wherein option ROM's had to reside in a fixed location. The UEFI Specification defines a set of mandatory capabilities, including boot and runtime services. These services allow for managing memory, timers, events, UEFI variables, capsules, and loading code. Beyond those basic services, chapter 2.6 of the UEFI 2.4 Specification describes the mandatory and optional services. To be a compliant UEFI implementation, you don't need much more than the boot services, runtime services, and loadfile protocol. An example of this diminutive implementation of UEFI can be found in the TinyQuark [TINY-QUARK].

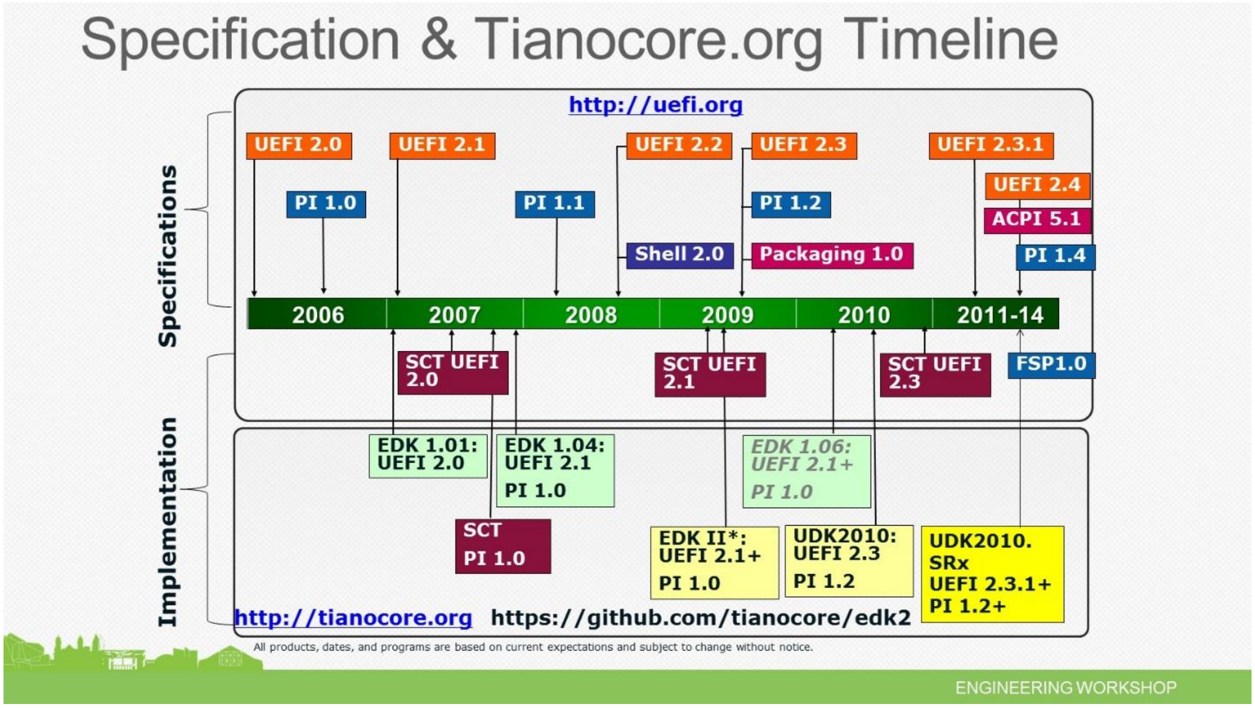
In addition to the API's, the C-callable nature of the UEFI specification allows for platform and CPU architecture flexibility. As of writing this document, the UEFI specification support Intel 32-bit and 64-bit architecture, Intel Itanium ®, and ARM Ltd ® 32-bit and 64-bit CPU's. There are some open source ports to other architectures, such as MIPS ® 32-bit, but they do not have an official binding in the specification. The reason for the binding is that it allows for interoperability between components built but different entities, from the system board vendors, sometimes known as the Original Equipment Manufacturer (OEM) or Original Device Manufacturer (ODM). Leading to the consumers of UEFI services, such as 3rd party UEFI driver extension from an Independent Hardware Vendor (IHV). And finally, there are pre-OS independent software vendors (ISV's) and the hypervisor or operating system vendors. We will club the latter two together as "OSV's" since for purposes of the boot firmware there is no distinction between a virtual machine monitor, such as a type1 VMM or hypervisor, and a static OS. UEFI services can be published by the bare metal motherboard or from within the hypervisor, such as in the case of 'guest firmware.'

Another aspect of UEFI includes the GUIDed Partition Table (GPT). The GPT breaks away from today's MBR and allows for breaking the 2 Terabyte disk limit. Strictly speaking the GPT definition can be used outside of platforms with underlying UEFI firmware implementations, too.

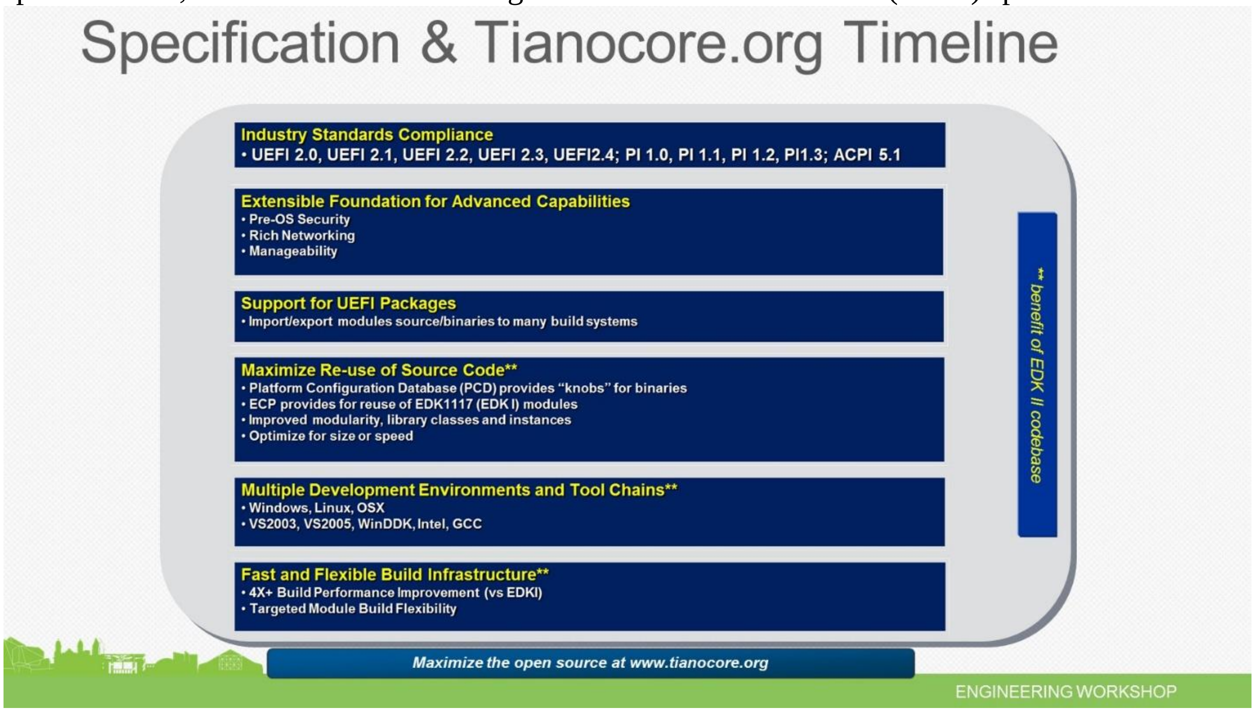
The figure below also highlights other capabilities of UEFI, including the 'UEFI Secure Boot' feature. More will be discussed about this capability, but the gist of the feature is to allow some administrative control of the extensible image loading found in UEFI. And what is potentially of interest to the cloud community includes the integrated networking capability of UEFI, along with a shell. In the spirit of the design-by-interface methodology of UEFI, these API’s for all of the underlying networking interfaces, from the IHV-supplied lowest level wired networking driver up to the software-visible API’s that correspond to the OSI stack, can all be found in the main UEFI Specification document. Correspondingly, the UEFI Shell has a specification hosted on UEFI.org, too, alongside the main UEFI Specification. This mapping to documentation allows for interoperability and investment protection of applications that consume the network stack, shell script, and shell [UEFI-SHELL] applications, respectively.



In addition to the main UEFI specification, though, there is an open source reference implementation at www.tianocore.org. Although the UEFI Forum does not officially endorse any specific implementation, the community has historically attempted to produce a reference implementation of the standard publically available along with the document production. As such, the figure below show how each version of the specification at the top has a corresponding implementation underneath. The underlying software technology used to build these implementations have evolved, from the EFI Development Kit (EDK) of the early UEFI Specifications to the present EDI II project.


Specification & Tianocore.org Timeline
http://uefi.org
Specifications
UEFI 2.0
UEFI 2.1
UEFI 2.2
UEFI 2.3
UEFI 2.3.1
UEFI 2.4
ACPI 5.1
PI 1.0
PI 1.1
PI 1.2
PI 1.4
Shell 2.0
Packaging 1.0
2006
2007
2008
2009
2010
2011-14
SCT UEFI 2.0
SCT UEFI 2.1
SCT UEFI 2.3
FSP1.0
Implementation
EDK 1.01: UEFI 2.0
EDK 1.04: UEFI 2.1 PI 1.0
EDK 1.06: UEFI 2.1+ PI 1.0
SCT PI 1.0
EDK II*: UEFI 2.1+ PI 1.0
UDK2010: UEFI 2.3 PI 1.2
UDK2010. SRx UEFI 2.3.1+ PI 1.2+
http://tianocore.org
https://github.com/tianocore/edk2
All products, dates, and programs are based on current expectations and subject to change without notice.
ENGINEERING WORKSHOP

Speaking of EDK II, this is an open source implementation of the various specifications hosted on tianocore.org. Diagrammatically, the figure below shows the various facets of this project. It provides implementations of the UEFI specifications, the underlying Platform Initialization (PI) specifications, and the Advanced Configuration and Power Interface (ACPI) specification.



The open source has full implementations of the UEFI core elements, industry standard bus and class drivers, such as PCI, USB, SATA. There are not as many full open source implementations of the underlying PI code, such as memory initialization PEIM's. For that there are hybrid open source platform EDK II code plus binary low-level SI initialization examples, such as use of the Intel Firmware Support Package (FSP) [FSP] [FSP-BOOK].

Summary

The Cloud poses many challenges for platform construction. Given the many business entities involved in deploying the Cloud, from OEM to IHV to ISV to OSV, the ability of UEFI to provide interoperability between the parties bears exploration. The following sections will provide a short, albeit incomplete, map into that exploration.

Firmware Update

Introduction
The cloud platform comprises of various hardware elements such as CPUs, chipset, BMC, ME, on-board PCI devices, add-on PCI devices, storage devices, FPGA based platform extensions etc. as shown in Figure 2. Often, there is an associated firmware stack associated with each of these hardware elements. Thus, in addition to System BIOS which is responsible for booting the platform, host of other firmware elements must be programmed and maintained throughout the life of a platform. In addition, cloud paradigm necessitates voluminous deployment of compute nodes housed within a datacenter.

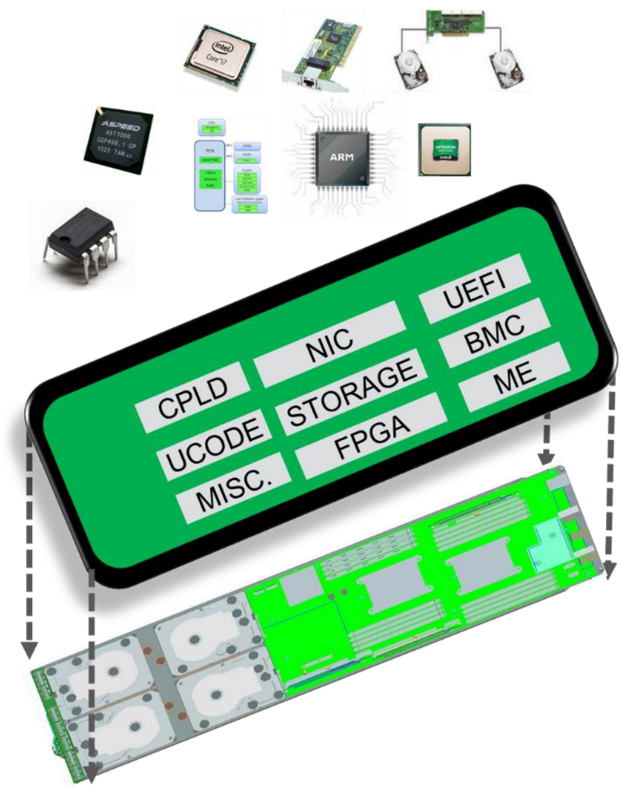


Figure 2: Firmware Composition Challenge

The updateable firmware ingredients can be broadly classified into two categories, viz. system firmware and device firmware. A system firmware is one which is mandatory platform ingredient without which booting of the system is not possible. On the contrary, the device firmware relates to any firmware ingredient that is not required in order to successfully boot the platform. Examples of system firmware include UEFI/BIOS, BMC firmware, ME firmware etc. Examples of device firmware include SSD firmware, RAID firmware etc.

The firmware update process involves three key steps, viz. –

1) verifying the firmware binary integrity
2) updating the firmware
3) verifying update is successful or preform a rollback

These steps are shared by all firmware updates, irrespective of type of the firmware. Refer to Figure 3 for a high level flow chart describing key steps of firmware update.

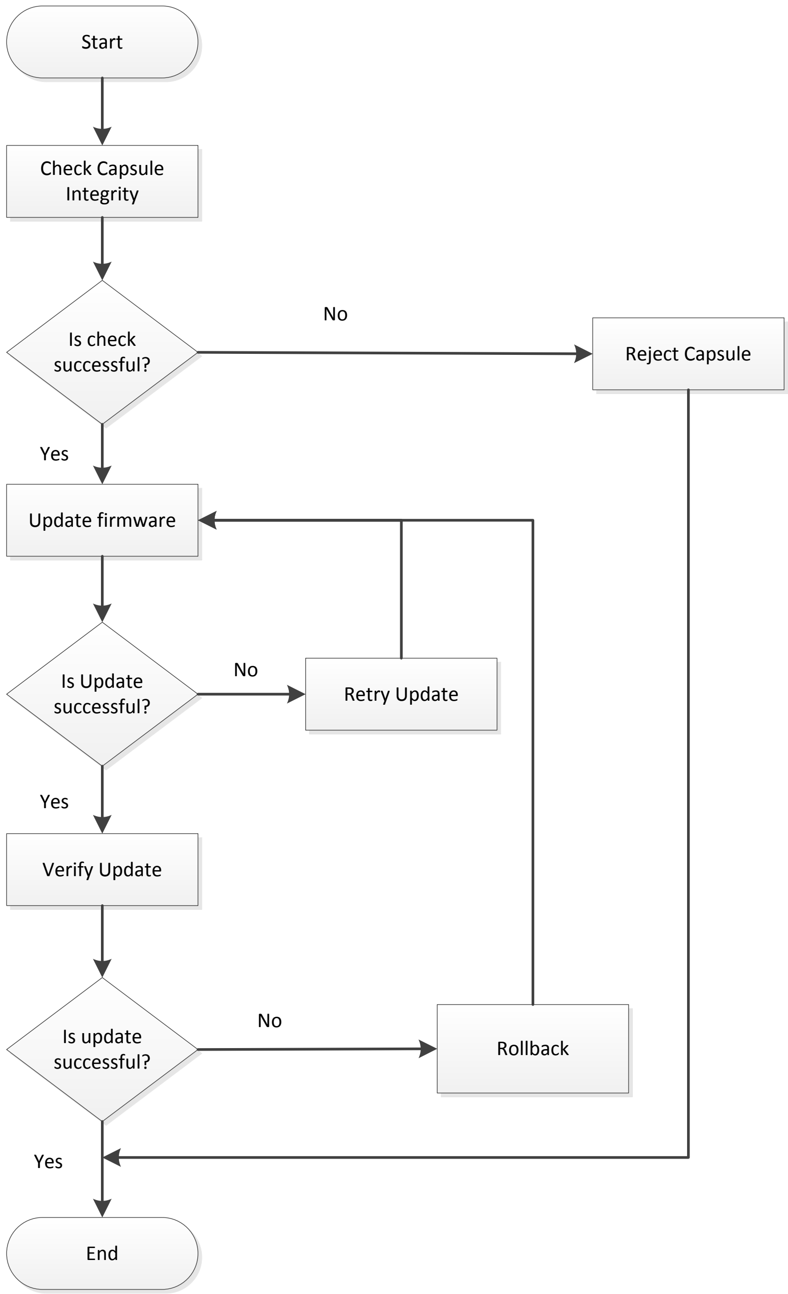


Figure 3: Typical Firmware Update Flow

One of the challenges in asserting firmware binary integrity is lack of a standard way of deploying the firmware. The UEFI specification offers support for capsule format. This specification can be uniformly applied to all updateable firmware ingredients on the platform. Typical layout of the capsule format is as depicted in Figure 4.

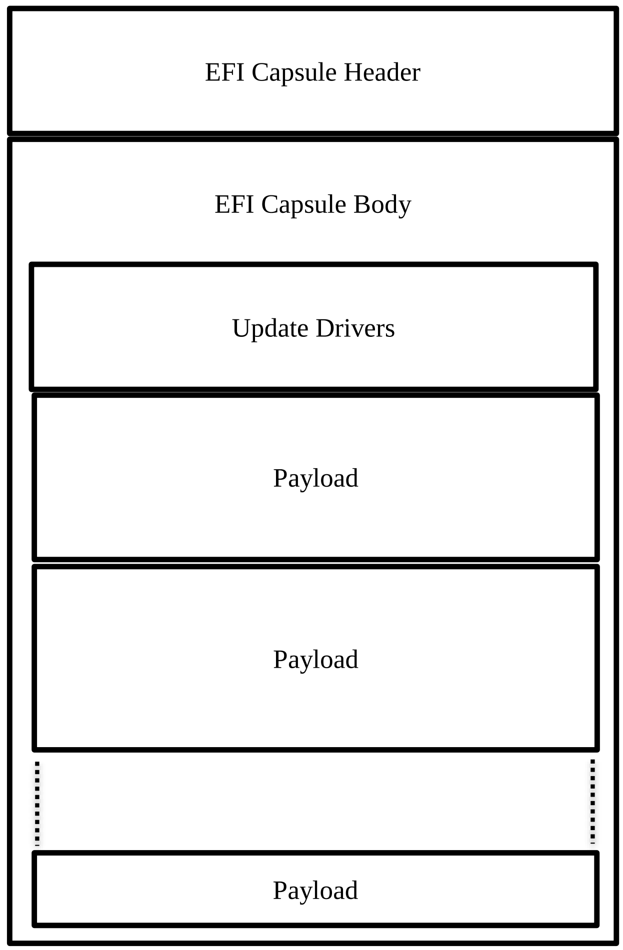


Figure 4: Capsule Format

Once the capsule format is adhered to by all platform firmware ingredients, the integrity check mechanism can be standardized. Also, the format is flexible and self-contained. In other words, the capsule format allows inclusion of update drivers within the capsule body. This approach has advantage as the update driver writer can use core BIOS support for various bus protocols for reading/writing to devices on buses such as SPI, HECI, KCS, I2C etc. Another advantage of capsule format is that multiple firmware images can be included in one capsule. Thus, both discrete as well as composite updates can be applied using EFI capsule format. The reference implementation of UEFI/PI includes tools for generation of capsules.

Another aspect of firmware updates is the ability to query the system for all the installed versions of various firmware elements on the system. This will be useful for both OS based as well as pre-boot based update mechanisms. A standard way to accomplish this is to publish EFI System Resource Table comprising of entries for each type of firmware update (Figure 5). The schema of such a table captures such information as a unique GUID entry denoting type of the firmware, current firmware version, and lowest version to which rollback is permissible, update status etc.

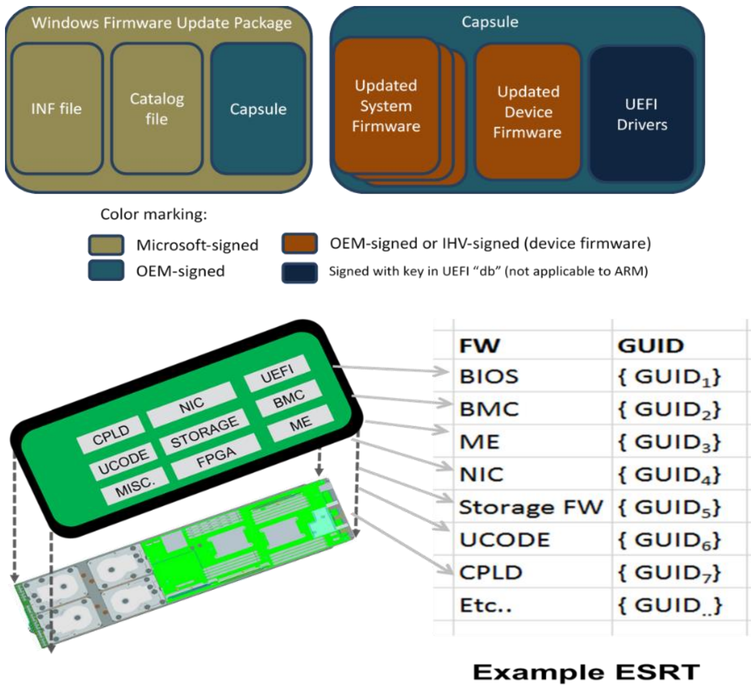


Figure 5: EFI System Resource Table

After a firmware update, one must verify that on-board chips are programmed correctly. If the update fails, typically an update is retried. If the update failures are persistent, a rollback must be attempted in order to reinstate the system into an operable condition. The UEFI 2.3 specification defines Firmware Management protocol which offers interfaces to validate, read and write firmware. The read interface, in particular, can be used to enact a rollback, if need be.

Summary

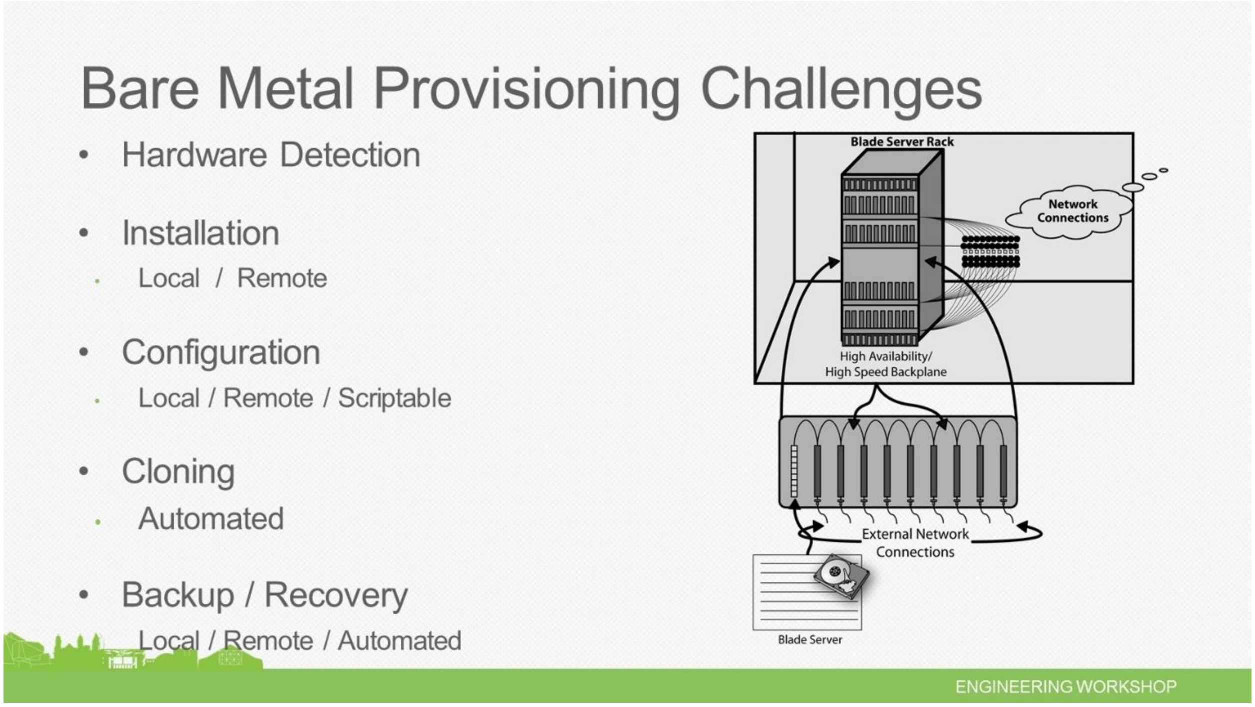
This section has provided an overview of firmware update.

Bare Metal Provisioning

This section will give an overview of bare metal provisioning.

Introduction

As shown in the figure below, the Cloud and warehouse-scale computes poses unique challenges for platform deployment. These challenges include how to detect the hardware, how to coordinate installation between an OEM system board and OSV operating system, configuring the system board, cloning the server so that an image can be mass-deployed to thousands of machines, and backing up settings in case of having to recover or re-deploy a machine. Given the scale of the machines, these tasks should be automated since having a user in front of each machine to do manual configuration is not economic.



The platform firmware has integral roles in provisioning. Whether it is the installation of an operating system during the factory or repurposing a data center, UEFI has many elements that come into play. There is the boot-strapping problem of how to get the OS or hypervisor onto the system board, or the chick-and-the-egg problem. UEFI was designed to allow for ease of OS installation and multi-booting. The mechanism put in place with UEFI provides a software environment for installation agents and OS loaders includes supplying mechanism to orchestrate discovery of boot code, managing policy of 'from where to boot' and 'which console to use' via the UEFI variables.

The bare metal provisioning scenarios where UEFI comes into play. For purposes of no touch automated installation, the UEFI Forum is now the maintainer of standards based network boot, such as PXE. PXE is both a wire protocol and API's. The API's to support IPV4, TFTP-based PXE can be found in the UEFI specification, and UEFI has also evolved those API's and the wire protocol to include IPV6. One key element of this evolution is RFC 5970 where the DHCP-based discovery of PXE has been extended to go from a file path to a URI. 5970 allowed for a discoverable IPV4 or IPV6 network boot to become:

- 'iscsi://address/bootfilename.efi'
- 'tftp://address/….'

Or HTTP. Or NFS. More information can be found at [UEFI-NETBOOT-BLOG].

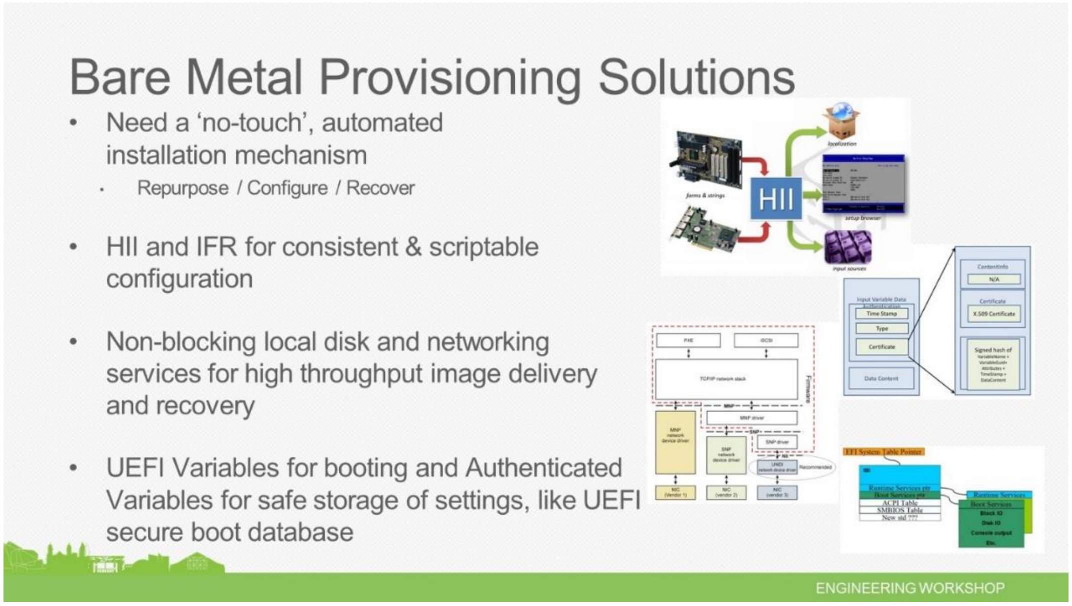
This allows for evolving the boot experience, especially as there have been historical scaling issues and timeouts with connectionless protocols like UDP-based TFTP. Connection oriented platforms based upon TCP offer the future for scaling the network deployment of these large server deployments.

The UEFI specification provides blocking and non-blocking local block storage and networking API's to allow for high performance provisioning actions, such as reading an OS image from the network, overlapping I/O with compute like decompression, and writing to the local system board storage.

In addition, UEFI provides a very stylized means of configuration. [UEFI-CONFIG] describes some of the usages of the Human Interface Infrastructure (HII), which is a forms-based mechanism for configuration. Think of this as a richer variant of PC/AT BIOS CMOS settings. HII allows for having a set of internationalized questions or strings with corresponding settings in a binary format called IFR. HII forms can be presented by the system board for the equivalent of today's set, and the IHV drivers can also post HII. This allows for interoperable configuration. The forms also allow for scripting and cloning.

Finally, UEFI allows for mandatory persistent storage in the platform by way of the UEFI Variable interface. UEFI variables include mandatory elements to describe the boot policy, language, and settings. The authenticated variables include the ability to have owner control of updates via asymmetric cryptography. The binary encoding and storage medium of variables is not dictated by the specification, so options include local SPI NOR flash, BMC's, or other durable, protected stores in the system board.

More information on Authenticated Variables can be found in the "UEFI Networking and Pre-OS Security" paper [UEFI-ITJ].



Below is a figure depicting the implementation of the network stack in UEFI. In addition, [UEFI-NET] provides a historical overview of the UEFI network stack.

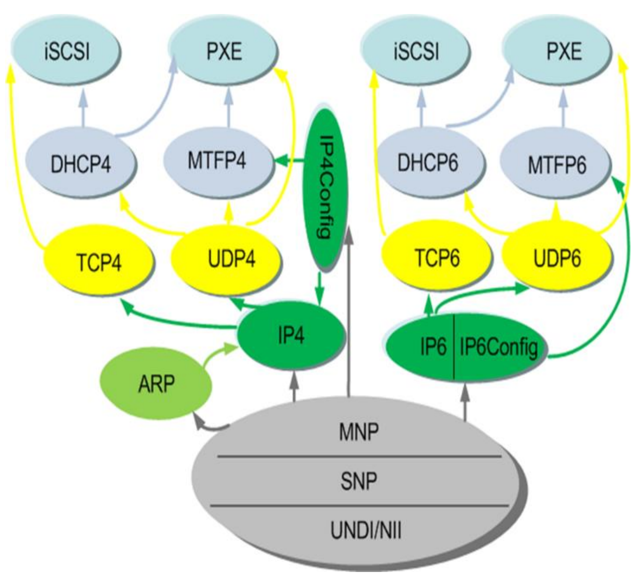


Figure: Network Stack in UEFI

The UEFI specification defines API’s for both IPV4 and IPV6 networking. Other elements include VLAN, IPsec, ISCSI, TCP, and UDP. These API’s are for pre-OS applications, such as deployment agents, OS loaders, and pre-OS applications. The UEFI specification also defines some wire protocols, such as netboot6, as the UEFI owns evolution of PXE.

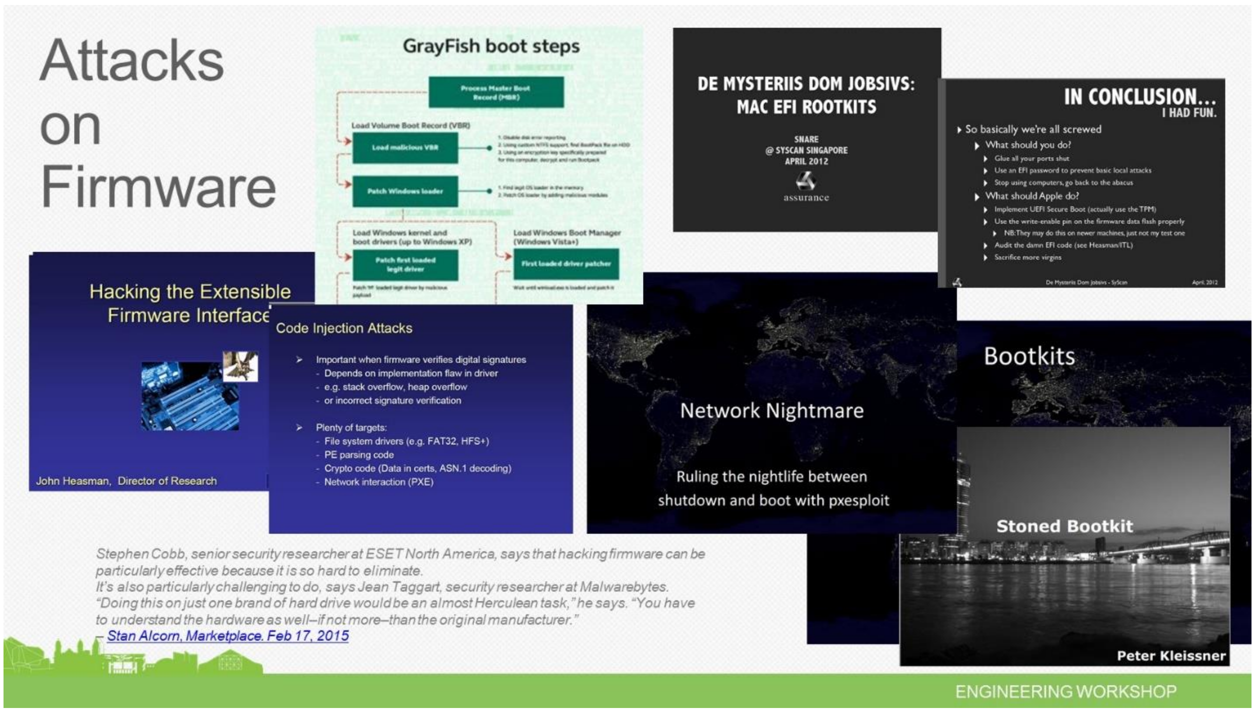
Summary
This section gives brief introduction UEFI and how it can help with provisioning.

Security

This section provides an overview of platform security in UEFI.

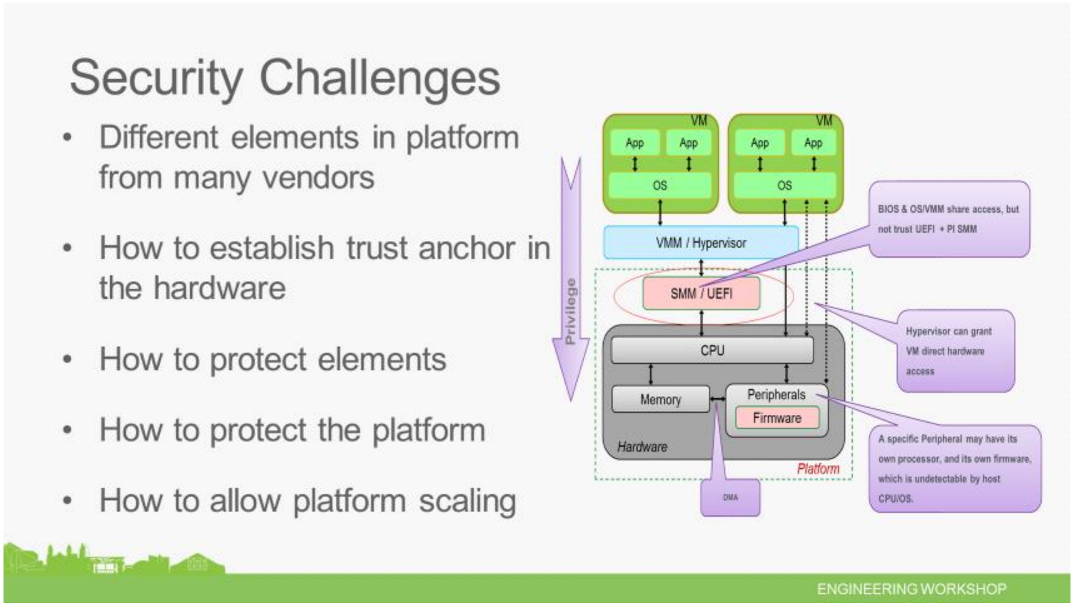
Attack climate

The climate for platform attacks is ever increasing. As operating systems become successively more hardened, attacks have been migrating into the platform firmware. Below is a short example of some attacks against firmware, including 'boot kits', which are attacks on the first stage OS loader. UEFI Secure boot was primarily designed to combat this attack since the first stage loader and the platform firmware and a trust boundary between the system board OEM and OSV.

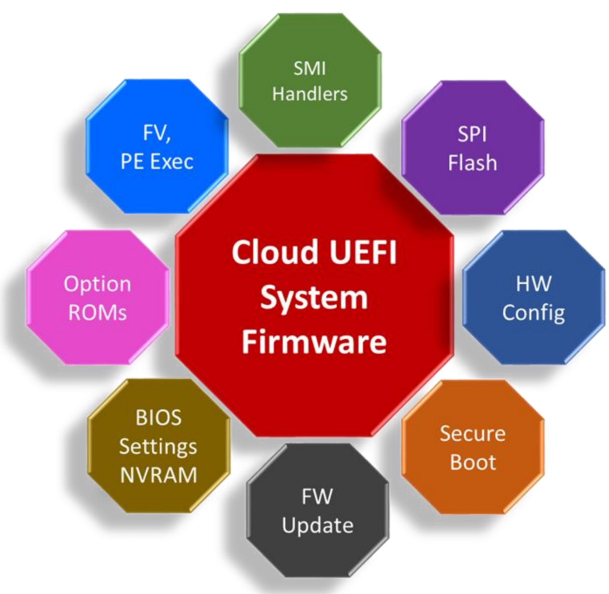


The challenges in constructing the platform firmware for purposes of security are manifold. These include the fact that the platform firmware needs to correctly configure the system board hardware, discover and execute 3rd party code from HBA's, discovery and execute the operating system hand-off. In addition, portions of the firmware persist into the OS runtime via the UEFI rutnime services or OS transparent execution modes like IA32/X64 System Management Mode (SMM). The OEM needs to protect the UEFI implementation from attacks since features like UEFI Secure boot are only of value if their controls and behaviors, as defined in the UEFI specification, are met by the implementation.

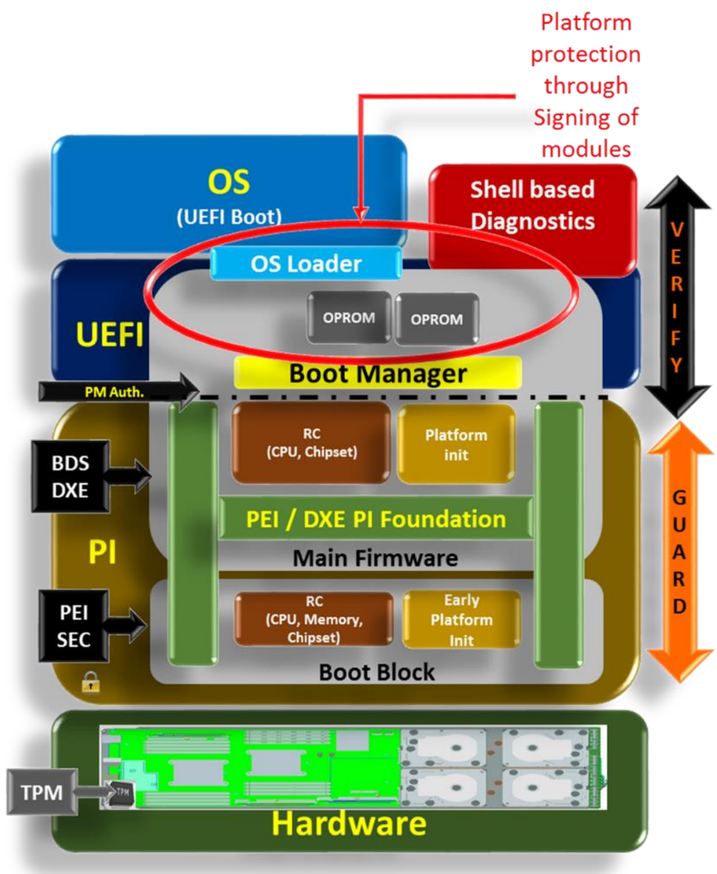
These security controls also need to scale in implementation and deployment. Any protection that needs local user access or cannot be scripted will inhibit deployment.



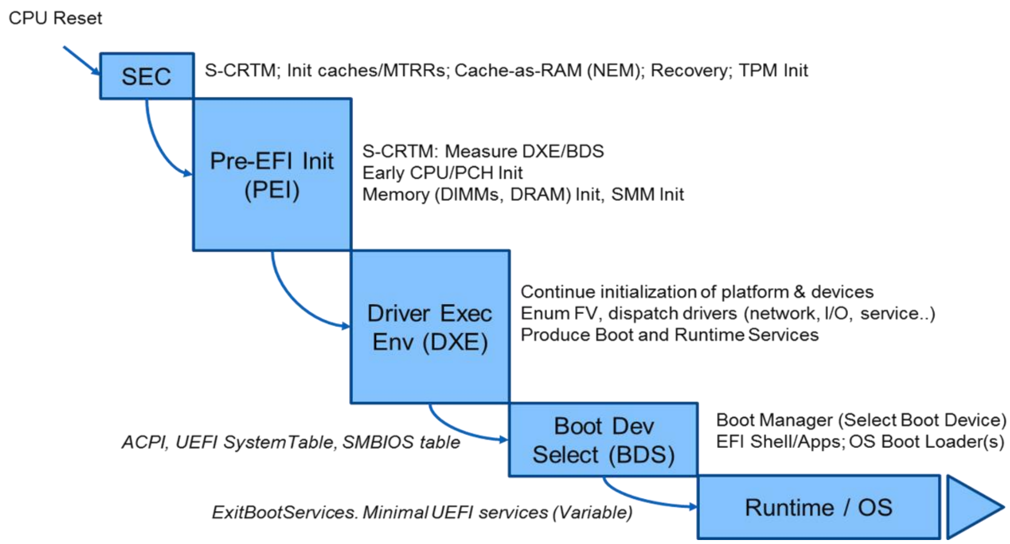
So in the context of platform security, UEFI brings many ingredients to the table as shown in below figure. These include a modular mechanism to load SMI handlers along with rules for their resource usage. In addition, UEFI provides mechanisms for exposing cryptographic hashing, secure boot of images, enveloping binary objects with cryptographic signatures, and authenticating the variables. The Trusted Computing Group (TCG) provides API's and guidance on how to integrate a Trusted Platform Module (TPM) in the platform. More information can be found at [UEFI-TRUST] , [UEFI-TRUST2] and [UEFI-TRUST3], too.



And when discussing security, you need to have a threat model in mind, including the assets in the platform and how they are to be protected. The presentation [UEFI-THREAT] describes a threat model for UEFI based systems. UEFI Secure Boot, as described in the UEFI 2.4b specification, is a critical capability in that it allows for protecting the underlying platform from possible pre-OS malware. In addition, the existence of the feature and a record of its usage in the TPM can inform the operating system or hypervisor that the machine was handed off in a trustworthy state. But as noted earlier, the implementation of the firmware and its protection from unwanted updates is imperative, and UEFI signed capsule updates and signed firmware images can help address that concern, including adherence to [NIST]. The figure below shows these protections in practice in a spatial, or layered view.



In addition to the spatial view shown above, a temporal view of platform security is in order. The figure below shows the UEFI Platform Initialization (PI) based boot flow. The SEC, PEI, and DXE are responsible for doing the basic platform initialization and germinating the UEFI services. In fact, you can think of DXE as the "UEFI Core". All of these PI elements should be under the control of the platform supplier (PS) who will serve in the PS_Admin role. The Platform Owner (PO), who typically administers the operating system or hypervisor, services as the PO_Admin. For a vertically integrated supplier, the PS may be the same as the PO. After invoking BDS, the machine will admit 3rd party code. At this point, typically signaled by the End of Dxe Event, the DXE platform code should lock down the registers, flash parts, and any other elements that may be perturbed by untrusted third party code. The code prior to the BDS can be thought of as OEM-extensible, and the latter to the right is third-party extensible. UEFI on the right provides for the rich interoperability between OEM, OSV, IHV, and ISV. To the left, the interoperability is typically between the CPU, SI component, board manufacturer, and the OEM. The latter extensibility should only be exposed in the factory or in the field view cryptographically signed updates, as described in the earlier firmware update chapter of this paper.



Summary
This section gives brief introduction of security for UEFI. This spans from the UEFI extensible environment down into the UEFI PI elements. Specific technologies and the intent of the specification, when reduced to practice, is also described.

Tools and Diagnostics

Introduction

Verifying compliance of a compute node to the underlying specifications before deployment is vital to commissioning of a datacenter. Also, any node / component failures during the operation of a datacenter must be identified in a timely manner before they can be repaired and restored to operation. Otherwise, there will be an impact to the overall capacity of the datacenter. Thus, one must invest in tools and diagnostics to address these issues.

Constructing platform as per well-defined specifications holds key to a viable story for developing tools and diagnostics (see below Figure).

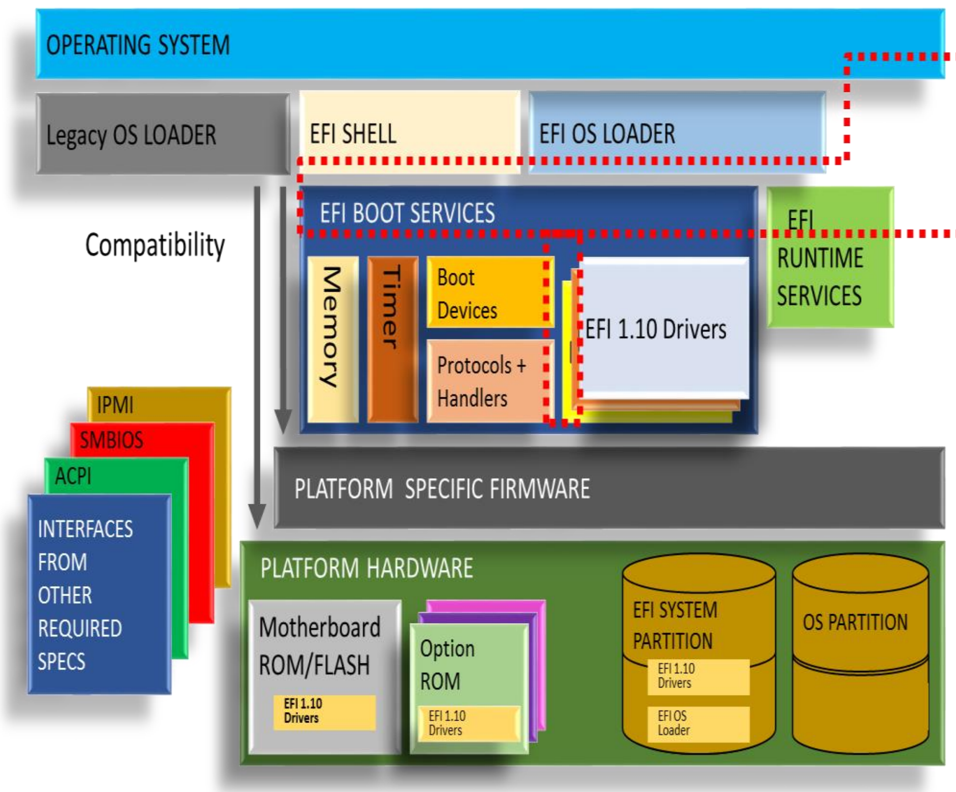


Figure: UEFI Stack overview

The UEFI specification provides a well-defined interactive execution environment for running tools and diagnostics by way of the UEFI Shell. The UEFI compliant BIOS can optionally include the UEFI shell. In addition, the shell comes with built-in commands for accessing memory, driver management, device access, and PCI configuration dump, file handling, etc. The UEFI also allows scripting, which can be used in automation.

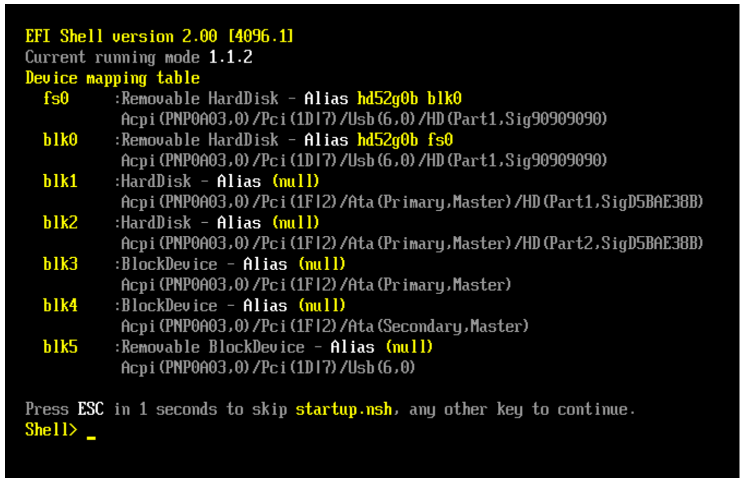


Figure: UEFI Shell command environment

Some of the tools that we can employ for specific

- UEFI SCT
- PI SCT
- ACPI Compliance
- SMBIOS Compliance

In addition, for the purposes of risk assessment, the chipsec [CHIPSEC] tool can be employed. This tool can be extended to meet specific platform concerns. The supported environments for this tool include Windows, Linux, and UEFI over Python.

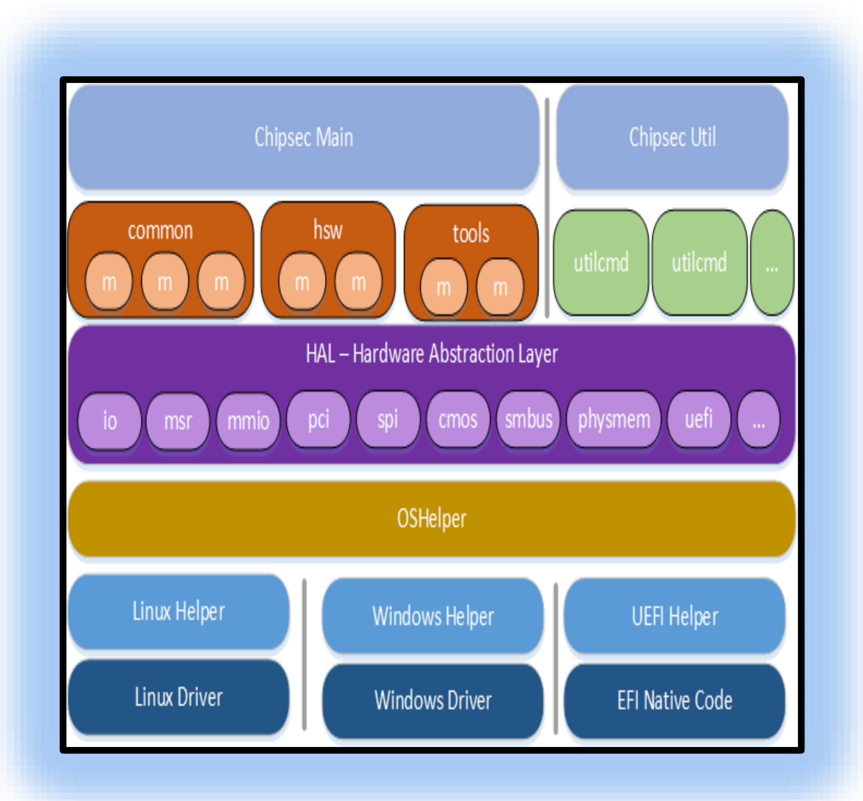


Figure: Chipsec tool architecture

The UEFI boot flow allows implementation of diagnostics OS (see Figure) as a last resort or terminal boot option. One instance of such a diagnostics operating system could be the Linux UEFI Validation environment that can either be hosted from service partition the local disk or over a network from a PXE service location.

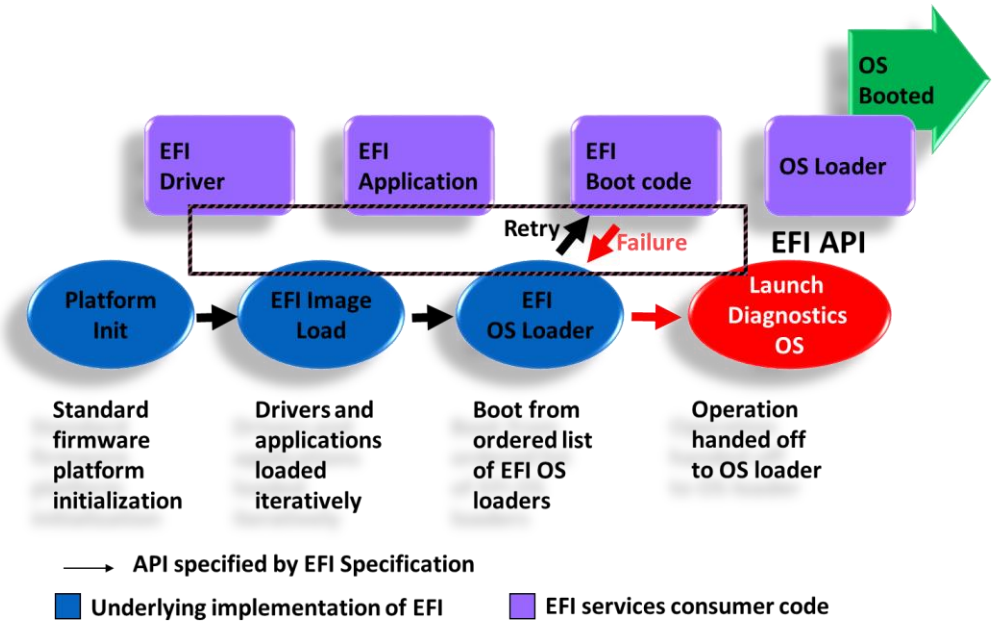


Figure: Example flow for launching diagnostics OS in UEFI

The platform BIOS can also use auxiliary processors such as BMC to log error records to SEL or report status codes using UEFI defined interfaces. This is one way a system can be diagnosed on a real-time basis. Optionally, the platform BIOS can implement BIOS Firmware Volume based logging to capture runtime errors. Tools can be easily developed to extract such errors to determine if a node needs to be serviced.

Conclusion

This paper has provided a brief overview the Cloud and the challenges that such scale-out environments pose. And it is in the face of such challenges that UEFI based technology could be brought to bear. These challenges and possible solutions include firmware update, diagnostics, provisioning, and security.

Glossary

ACPI – Advanced Configuration and Power Interface. The specification defines a new interface to the system board that enables the operating system to implement operating system-directed power management and system configuration. For more information on ACPI specification, visit http://acpi.info/

CHIPSEC: Platform Security Assessment Framework. The CHIPSEC is a framework for analyzing security of PC platforms including hardware, system firmware including BIOS/UEFI and the configuration of platform components. For more information on CHIPSEC, visit https://github.com/chipsec/chipsec

HECI – Host Embedded Controller Interface. The HECI is a technology used in Active Management Technology in Intel chipsets.

I2C - I2C is a serial protocol for two-wire interface to connect low-speed devices like microcontrollers, EEPROMs, A/D and D/A converters, I/O interfaces and other similar peripherals in embedded systems. For more information on I2C, visit http://i2c.info/

IPMI – Intelligent Platform Management Interface. The Intelligent Platform Management Interface (IPMI) defines common platform instrumentation to enable interoperability, extensibility, and scalability with intelligent hardware for enterprise-wide mission critical applications. For more information on IPMI, visit http://www.intel.com/content/www/us/en/servers/ipmi/ipmi-home.html

KCS – Keyboard Controller Style. The KCS is an interface used for communication between BMC and payload coprocessor in IPMI architecture.

OCP – Open Compute Project. The Open Compute Project Foundation is a community of engineers around the world whose mission is to design and enable the delivery of the most efficient server, storage and data center hardware designs for scalable computing. For more information on OCP, visit http://www.opencompute.org/

PCI – Peripheral Component Interconnect. The PCI bus is a local computer bus for attaching hardware devices in a computer. For more information on PCI, visit https://www.pcisig.com/home

PI – Platform Initialization. Volume 1-5 of the UEFI PI specifications. For more information on PI, visit http://www.uefi.org/specifications

SMBIOS – System Management BIOS. The System Management BIOS (SMBIOS) is the premier standard for delivering management information via system firmware. Since its release in 1995, the widely implemented SMBIOS standard has simplified the management of more than two billion client and server systems. For more information on SMBIOS, visit http://www.dmtf.org/standards/smbios

TPM – Trusted Platform Module. Trusted Platform Module (TPM) is an international standard for a secure crypto-processor, which is a dedicated microprocessor designed to secure hardware by integrating cryptographic keys into devices. For additional information on TPM, visit http://www.trustedcomputinggroup.org/developers/trusted_platform_module

UEFI – Unified Extensible Firmware Interface. Firmware interface between the platform and the operating system. Predominate interfaces are in the boot services (BS) or pre-OS. Few runtime (RT) services. For more information on UEFI, visit http://uefi.org/

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Authors

Mallik Bulusu (mallikb@microsoft.com) is a UEFI lead in the Cloud Server Infrastructure team at Microsoft Corporation

Vincent Zimmer (vincent.zimmer@intel.com) is a Sr. Principal Engineer in the Software & Services Group at Intel Corporation