



OpenCore

Reference Manual (0.5.9)

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1 Introduction

This document provides information on OpenCore user configuration file format used to setup the correct functioning of macOS operating system. It is to be read as the official clarification of expected OpenCore behaviour. All deviations, if found in published OpenCore releases, shall be considered documentation or implementation bugs, and are requested to be reported through Acidanthera Bugtracker.

This document is structured as a specification, and is not meant to provide a step by step algorithm for configuring end-user board support package (BSP). The intended audience of the document are programmers and engineers with basic understanding of macOS internals and UEFI functioning. For these reasons this document is available exclusively in English, and all other sources or translations of this document are unofficial and may contain errors.

Third-party articles, utilities, books, and alike may be more useful for a wider audience as they could provide guide-like material. However, they are prone to their authors' preferences, tastes, this document misinterpretation, and essential obsolescence. In case you use these sources, for example, Dortania's OpenCore Desktop Guide and related material, please ensure to follow this document for every made decision and judge its consequences.

Be warned that regardless of the sources used you are required to fully understand every dedicated OpenCore configuration option and concept prior to reporting any issues in Acidanthera Bugtracker.

1.1 Generic Terms

- **plist** — Subset of ASCII Property List format written in XML, also known as XML plist format version 1. Uniform Type Identifier (UTI): `com.apple.property-list`. Plists consist of **plist** objects, which are combined to form a hierarchical structure. Due to plist format not being well-defined, all the definitions of this document may only be applied after plist is considered valid by running `plutil -lint`. External references: <https://www.apple.com/DTDs/PropertyList-1.0.dtd>, `man plutil`.
- **plist type** — plist collections (**plist array**, **plist dictionary**, **plist key**) and primitives (**plist string**, **plist data**, **plist date**, **plist boolean**, **plist integer**, **plist real**).
- **plist object** — definite realisation of **plist type**, which may be interpreted as value.
- **plist array** — array-like collection, conforms to `array`. Consists of zero or more **plist** objects.
- **plist dictionary** — map-like (associative array) collection, conforms to `dict`. Consists of zero or more **plist** keys.
- **plist key** — contains one **plist** object going by the name of **plist key**, conforms to `key`. Consists of printable 7-bit ASCII characters.
- **plist string** — printable 7-bit ASCII string, conforms to `string`.
- **plist data** — base64-encoded blob, conforms to `data`.
- **plist date** — ISO-8601 date, conforms to `date`, unsupported.
- **plist boolean** — logical state object, which is either true (1) or false (0), conforms to `true` and `false`.
- **plist integer** — possibly signed integer number in base 10, conforms to `integer`. Fits in 64-bit unsigned integer in two's complement representation, unless a smaller signed or unsigned integral type is explicitly mentioned in specific **plist** object description.
- **plist real** — floating point number, conforms to `real`, unsupported.
- **plist metadata** — value cast to data by the implementation. Permits passing **plist string**, in which case the result is represented by a null-terminated sequence of bytes (aka C string), **plist integer**, in which case the result is represented by 32-bit little endian sequence of bytes in two's complement representation, **plist boolean**, in which case the value is one byte: 01 for `true` and 00 for `false`, and **plist data** itself. All other types or larger integers invoke undefined behaviour.

2 Configuration

2.1 Configuration Terms

- **OC config** — OpenCore Configuration file in **plist** format named **config.plist**. It has to provide extensible way to configure OpenCore and is structured to be separated into multiple named sections situated in the root **plist** dictionary. These sections are permitted to have **plist array** or **plist dictionary** types and are described in corresponding sections of this document.
- **valid key** — **plist key** object of **OC config** described in this document or its future revisions. Besides explicitly described **valid keys**, keys starting with **#** symbol (e.g. **#Hello**) are also considered **valid keys** and behave as comments, effectively discarding their value, which is still required to be a **valid plist object**. All other **plist keys** are not valid, and their presence yields to **undefined behaviour**.
- **valid value** — **valid plist object** of **OC config** described in this document that matches all the additional requirements in specific **plist object** description if any.
- **invalid value** — **valid plist object** of **OC config** described in this document that is of other **plist type**, does not conform to additional requirements found in specific **plist object** description (e.g. value range), or missing from the corresponding collection. **Invalid value** is read with or without an error message as any possible value of this **plist object** in an undetermined manner (i.e. the values may not be same across the reboots). Whilst reading an **invalid value** is equivalent to reading certain defined **valid value**, applying incompatible value to the host system may yield to **undefined behaviour**.
- **optional value** — **valid value** of **OC config** described in this document that reads in a certain defined manner provided in specific **plist object** description (instead of **invalid value**) when not present in **OC config**. All other cases of **invalid value** do still apply. Unless explicitly marked as **optional value**, any other value is required to be present and reads to **invalid value** if missing.
- **fatal behaviour** — behaviour leading to boot termination. Implementation must stop the boot process from going any further until next host system boot. It is allowed but not required to perform cold reboot or show any warning message.
- **undefined behaviour** — behaviour not prescribed by this document. Implementation is allowed to take any measures including but not limited to **fatal behaviour**, assuming any states or values, or ignoring, unless these measures negatively affect system security in general.

2.2 Configuration Processing

OC config is guaranteed to be processed at least once if it was found. Depending on OpenCore bootstrapping mechanism multiple **OC config** files may lead to reading any of them. No **OC Config** may be present on disk, in which case all the values read follow the rules of **invalid value** and **optional value**.

OC config has size, nesting, and key amount limitations. **OC config** size does not exceed 16 MBs. **OC config** has no more than 8 nesting levels. **OC config** has up to 16384 XML nodes (i.e. one **plist dictionary** item is counted as a pair of nodes) within each **plist object**.

Reading malformed **OC config** file leads to **undefined behaviour**. Examples of malformed **OC config** cover at least the following cases:

- files non-conformant to **plist** DTD
- files with unsupported or non-conformant **plist objects** found in this document
- files violating size, nesting, and key amount limitations

It is recommended but not required to abort loading malformed **OC config** and continue as if no **OC config** was present. For forward compatibility it is recommended but not required for the implementation to warn about the use of **invalid values**. Recommended practice of interpreting **invalid values** is to conform to the following convention where applicable:

Type	Value
plist string	Empty string (<string></string>)
plist data	Empty data (<data></data>)

Type	Value
<code>plist integer</code>	0 (<integer>0</integer>)
<code>plist boolean</code>	False (<false/>)
<code>plist tristate</code>	False (<false/>)

2.3 Configuration Structure

OC `config` is separated into following sections, which are described in separate sections of this document. By default it is tried to not enable anything and optionally provide kill switches with `Enable` property for `plist dict` entries. In general the configuration is written idiomatically to group similar actions in subsections:

- `Add` provides support for data addition. Existing data will not be overridden, and needs to be handled separately with `Delete` if necessary.
- `Delete` provides support for data removal.
- `Patch` provides support for data modification.
- `Quirks` provides support for specific hacks.

Root configuration entries consist of the following:

- `ACPI`
- `Booter`
- `DeviceProperties`
- `Kernel`
- `Misc`
- `NVRAM`
- `PlatformInfo`
- `UEFI`

Note: Currently most properties try to have defined values even if not specified in the configuration for safety reasons. This behaviour should not be relied upon, and all fields must be properly specified in the configuration.

3 Setup

3.1 Directory Structure

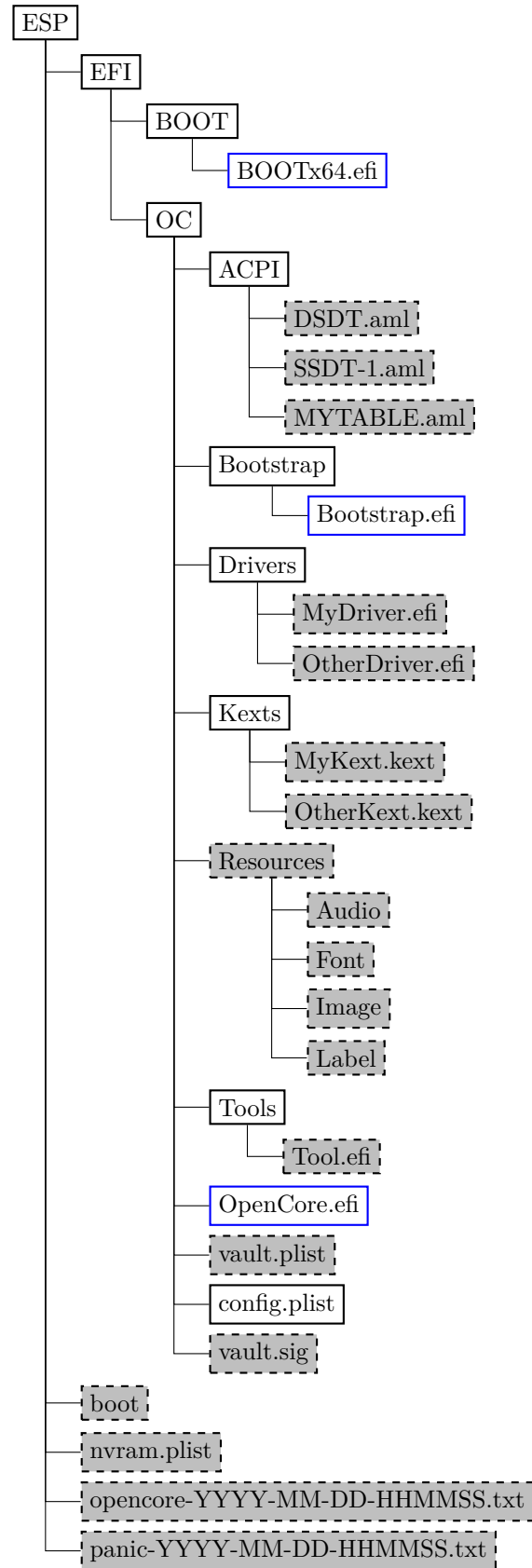


Figure 1. Directory Structure

When directory boot is used the directory structure used should follow the description on Directory Structure figure. Available entries include:

- **BOOTx64.efi** and **Bootstrap.efi**
Initial bootstrap loaders, which loads **OpenCore.efi** unless it was already started as a driver. **BOOTx64.efi** is loaded by the firmware by default according to UEFI specification, and **Bootstrap.efi** can be registered as a custom option to let OpenCore coexist with operating systems using **BOOTx64.efi** as their own loaders (e.g. Windows), see **BootProtect** for more details.
- **boot**
Duet bootstrap loader, which initialises UEFI environment on legacy BIOS firmwares and loads **OpenCore.efi** similarly to other bootstrap loaders. Modern Duet bootstrap loader will default to **OpenCore.efi** on the same partition when present.
- **ACPI**
Directory used for storing supplemental ACPI information for **ACPI** section.
- **Drivers**
Directory used for storing supplemental UEFI drivers for **UEFI** section.
- **Kexts**
Directory used for storing supplemental kernel information for **Kernel** section.
- **Resources**
Directory used for storing media resources, such as audio files for screen reader support. See **UEFI Audio Properties** section for more details. This directory also contains image files for graphical user interface. See **OpenCanopy** section for more details.
- **Tools**
Directory used for storing supplemental tools.
- **OpenCore.efi**
Main booter driver responsible for operating system loading.
- **vault.plist**
Hashes for all files potentially loadable by **OC Config**.
- **config.plist**
OC Config.
- **vault.sig**
Signature for **vault.plist**.
- **nvram.plist**
OpenCore variable import file.
- **opencore-YYYY-MM-DD-HHMMSS.txt**
OpenCore log file.
- **panic-YYYY-MM-DD-HHMMSS.txt**
Kernel panic log file.

Note: It is not guaranteed that paths longer than **OC_STORAGE_SAFE_PATH_MAX** (128 characters including 0-terminator) will be accessible within OpenCore.

3.2 Installation and Upgrade

To install OpenCore reflect the Configuration Structure described in the previous section on a EFI volume of a GPT partition. While corresponding sections of this document do provide some information in regards to external resources like ACPI tables, UEFI drivers, or kernel extensions (kexts), completeness of the matter is out of the scope of this document. Information about kernel extensions may be found in a separate Kext List document available in OpenCore repository. Vaulting information is provided in Security Properties section of this document.

OC config, just like any property lists can be edited with any stock textual editor (e.g. nano, vim), but specialised software may provide better experience. On macOS the preferred GUI application is Xcode. For a lightweight cross-platform and open-source alternative ProperTree editor can be utilised.

For BIOS booting a third-party UEFI environment provider will have to be used. **OpenDuetPkg** is one of the known UEFI environment providers for legacy systems. To run OpenCore on such a legacy system you can install **OpenDuetPkg** with a dedicated tool — **BootInstall** (bundled with OpenCore). Third-party utilities can be used to perform this on systems different from macOS.

For upgrade purposes refer to `Differences.pdf` document, providing the information about the changes affecting the configuration compared to the previous release, and `Changelog.md` document, containing the list of modifications across all published updates.

3.3 Contribution

OpenCore can be compiled as an ordinary EDK II package. Since UDK development was abandoned by TianoCore, OpenCore requires the use of EDK II Stable. Currently supported EDK II release is hosted in acidanthera/audk. The required patches for the package are present in `Patches` directory.

The only officially supported toolchain is `XCODE5`. Other toolchains might work, but are neither supported, nor recommended. Contribution of clean patches is welcome. Please do follow EDK II C Codestyle.

To compile with `XCODE5`, besides Xcode, one should also install NASM and MTOC. The latest Xcode version is recommended for use despite the toolchain name. Example command sequence may look as follows:

```
git clone https://github.com/acidanthera/audk UDK
cd UDK
git clone https://github.com/acidanthera/OpenCorePkg
source edksetup.sh
make -C BaseTools
build -a X64 -b RELEASE -t XCODE5 -p OpenCorePkg/OpenCorePkg.dsc
```

Listing 1: Compilation Commands

For IDE usage Xcode projects are available in the root of the repositories. Another approach could be Sublime Text with EasyClangComplete plugin. Add `.clang_complete` file with similar content to your UDK root:

```
-I/UefiPackages/MdePkg
-I/UefiPackages/MdePkg/Include
-I/UefiPackages/MdePkg/Include/X64
-I/UefiPackages/MdeModulePkg
-I/UefiPackages/MdeModulePkg/Include
-I/UefiPackages/MdeModulePkg/Include/X64
-I/UefiPackages/OpenCorePkg/Include/AMI
-I/UefiPackages/OpenCorePkg/Include/Acidanthera
-I/UefiPackages/OpenCorePkg/Include/Apple
-I/UefiPackages/OpenCorePkg/Include/Apple/X64
-I/UefiPackages/OpenCorePkg/Include/Duet
-I/UefiPackages/OpenCorePkg/Include/Generic
-I/UefiPackages/OpenCorePkg/Include/Intel
-I/UefiPackages/OpenCorePkg/Include/Microsoft
-I/UefiPackages/OpenCorePkg/Include/VMware
-I/UefiPackages/OvmfPkg/Include
-I/UefiPackages/UefiCpuPkg/Include
-IInclude
-include
/UefiPackages/MdePkg/Include/Uefi.h
-fshort-wchar
-Wall
-Wextra
-Wno-unused-parameter
-Wno-missing-braces
-Wno-missing-field-initializers
-Wno-tautological-compare
-Wno-sign-compare
-Wno-varargs
-Wno-unused-const-variable
-DOC_TARGET_NOOPT=1
-DNO_MSABI_VA_FUNCS=1
```

Warning: Tool developers modifying `config.plist` or any other OpenCore files must ensure that their tool checks for `opencore-version` NVRAM variable (see Debug Properties section below) and warn the user if the version listed is unsupported or prerelease. OpenCore configuration may change across the releases and the tool shall ensure that it carefully follows this document. Failure to do so may result in this tool to be considered as malware and blocked with all possible means.

3.4 Coding conventions

Just like any other project we have conventions that we follow during the development. All third-party contributors are highly recommended to read and follow the conventions listed below before submitting their patches. In general it is also recommended to firstly discuss the issue in Acidanthera Bugtracker before sending the patch to ensure no double work and to avoid your patch being rejected.

Organisation. The codebase is contained in `OpenCorePkg` repository, which is the primary EDK II package.

- Whenever changes are required in multiple repositories, separate pull requests should be sent to each.
- Committing the changes should happen firstly to dependent repositories, secondly to primary repositories to avoid automatic build errors.
- Each unique commit should compile with `XCODE5` and preferably with other toolchains. In the majority of the cases it can be checked by accessing the CI interface. Ensuring that static analysis finds no warnings is preferred.
- External pull requests and tagged commits must be validated. That said, commits in master may build but may not necessarily work.
- Internal branches should be named as follows: `author-name-date`, e.g. `vit9696-ballooning-20191026`.
- Commit messages should be prefixed with the primary module (e.g. library or code module) the changes were made in. For example, `OcGuardLib: Add OC_ALIGNED macro`. For non-library changes `Docs` or `Build` prefixes are used.

Design. The codebase is written in a subset of freestanding C11 (C17) supported by most modern toolchains used by EDK II. Applying common software development practices or requesting clarification is recommended if any particular case is not discussed below.

- Never rely on undefined behaviour and try to avoid implementation defined behaviour unless explicitly covered below (feel free to create an issue when a relevant case is not present).
- Use `OcGuardLib` to ensure safe integral arithmetics avoiding overflows. Unsigned wraparound should be relied on with care and reduced to the necessary amount.
- Check pointers for correct alignment with `OcGuardLib` and do not rely on the architecture being able to dereference unaligned pointers.
- Use flexible array members instead of zero-length or one-length arrays where necessary.
- Use static assertions (`STATIC_ASSERT`) for type and value assumptions, and runtime assertions (`ASSERT`) for precondition and invariant sanity checking. Do not use runtime assertions to check for errors as they should never alter control flow and potentially be excluded.
- Assume `UINT32/INT32` to be `int`-sized and use `%u`, `%d`, and `%x` to print them.
- Assume `UINTN/INTN` to be of unspecified size, and cast them to `UINT64/INT64` for printing with `%Lu`, `%Ld` and so on as normal.
- Do not rely on integer promotions for numeric literals. Use explicit casts when the type is implementation-dependent or suffixes when type size is known. Assume `U` for `UINT32` and `ULL` for `UINT64`.
- Do ensure unsigned arithmetics especially in bitwise maths, shifts in particular.
- `sizeof` operator should take variables instead of types where possible to be error prone. Use `ARRAY_SIZE` to obtain array size in elements. Use `L_STR_LEN` and `L_STR_SIZE` macros from `OcStringLib` to obtain string literal sizes to ensure compiler optimisation.
- Do not use `goto` keyword. Prefer early `return`, `break`, or `continue` after failing to pass error checking instead of nesting conditionals.
- Use `EFIAPI`, force `UEFI` calling convention, only in protocols, external callbacks between modules, and functions with variadic arguments.
- Provide inline documentation to every added function, at least describing its inputs, outputs, precondition, postcondition, and giving a brief description.

- Do not use `RETURN_STATUS`. Assume `EFI_STATUS` to be a matching superset that is to be always used when `BOOLEAN` is not enough.
- Security violations should halt the system or cause a forced reboot.

Codestyle. The codebase follows EDK II codestyle with few changes and clarifications.

- Write inline documentation for the functions and variables only once: in headers, where a header prototype is available, and inline for `static` variables and functions.
- Use line length of 120 characters or less, preferably 100 characters.
- Use spaces after casts, e.g. `(VOID *) (UINTN) Variable`.
- Use SPDX license headers as shown in [acidanthera/bugtracker#483](#).

3.5 Debugging

The codebase incorporates EDK II debugging and few custom features to improve the experience.

- Use module prefixes, 2-5 letters followed by a colon (:), for debug messages. For `OpenCorePkg` use `OC:`, for libraries and drivers use their own unique prefixes.
- Do not use dots (.) in the end of debug messages and separate `EFI_STATUS`, printed by `%r`, with a hyphen (e.g. `OCRAM: Allocation of %u bytes failed - %r\n`).
- Use `DEBUG_CODE_BEGIN ()` and `DEBUG_CODE_END ()` constructions to guard debug checks that may potentially reduce the performance of release builds and are otherwise unnecessary.
- Use `DEBUG` macro to print debug messages during normal functioning, and `RUNTIME_DEBUG` for debugging after `EXIT_BOOT_SERVICES`.
- Use `DEBUG_VERBOSE` debug level to leave debug messages for future debugging of the code, which are currently not necessary. By default `DEBUG_VERBOSE` messages are ignored even in `DEBUG` builds.
- Use `DEBUG_INFO` debug level for all non critical messages (including errors) and `DEBUG_BULK_INFO` for extensive messages that should not appear in NVRAM log that is heavily limited in size. These messages are ignored in `RELEASE` builds.
- Use `DEBUG_ERROR` to print critical human visible messages that may potentially halt the boot process, and `DEBUG_WARN` for all other human visible errors, `RELEASE` builds included.

When trying to find the problematic change it is useful to rely on `git-bisect` functionality.

4 ACPI

4.1 Introduction

ACPI (Advanced Configuration and Power Interface) is an open standard to discover and configure computer hardware. ACPI specification defines the standard tables (e.g. `DSDT`, `SSDT`, `FACS`, `DMAR`) and various methods (e.g. `_DSM`, `_PRW`) for implementation. Modern hardware needs little changes to maintain ACPI compatibility, yet some of those are provided as a part of OpenCore.

To compile and disassemble ACPI tables iASL compiler can be used developed by ACPICA. GUI front-end to iASL compiler can be downloaded from Acidanthera/MaciASL.

ACPI changes apply globally (to every operating system) with the following effective order:

- `Patch` is processed.
- `Delete` is processed.
- `Add` is processed.
- `Quirks` are processed.

Applying the changes globally resolves the problems of incorrect operating system detection, which is not possible before the operating system boots according to the ACPI specification, operating system chainloading, and harder ACPI debugging. For this reason it may be required to carefully use `_OSI` method when writing the changes.

Applying the patches early makes it possible to write so called “proxy” patches, where the original method is patched in the original table and is implemented in the patched table.

4.2 Properties

1. Add

Type: `plist array`

Failsafe: Empty

Description: Load selected tables from `OC/ACPI` directory.

Designed to be filled with `plist dict` values, describing each add entry. See Add Properties section below.

2. Delete

Type: `plist array`

Failsafe: Empty

Description: Remove selected tables from ACPI stack.

Designed to be filled with `plist dict` values, describing each delete entry. See Delete Properties section below.

3. Patch

Type: `plist array`

Failsafe: Empty

Description: Perform binary patches in ACPI tables before table addition or removal.

Designed to be filled with `plist dictionary` values describing each patch entry. See Patch Properties section below.

4. Quirks

Type: `plist dict`

Description: Apply individual ACPI quirks described in Quirks Properties section below.

4.3 Add Properties

1. Comment

Type: `plist string`

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. Its implementation defined whether this value is used.

2. Enabled

Type: `plist boolean`

Failsafe: false

Description: This ACPI table will not be added unless set to **true**.

3. Path

Type: plist string

Failsafe: Empty string

Description: File paths meant to be loaded as ACPI tables. Example values include `DSDT.aml`, `SubDir/SSDT-8.aml`, `SSDT-USBX.aml`, etc.

ACPI table load order follows the item order in the array. All ACPI tables load from `OC/ACPI` directory.

Note: All tables but tables with DSDT table identifier (determined by parsing data not by filename) insert new tables into ACPI stack. DSDT, unlike the rest, performs replacement of DSDT table.

4.4 Delete Properties

1. All

Type: plist boolean

Failsafe: false

Description: If set to **true**, all ACPI tables matching the condition will be deleted. Otherwise only first matched table.

2. Comment

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

3. Enabled

Type: plist boolean

Failsafe: false

Description: This ACPI table will not be removed unless set to **true**.

4. OemTableId

Type: plist data, 8 bytes

Failsafe: All zero

Description: Match table OEM ID to be equal to this value unless all zero.

5. TableLength

Type: plist integer

Failsafe: 0

Description: Match table size to be equal to this value unless 0.

6. TableSignature

Type: plist data, 4 bytes

Failsafe: All zero

Description: Match table signature to be equal to this value unless all zero.

Note: Make sure not to specify table signature when the sequence needs to be replaced in multiple places. Especially when performing different kinds of renames.

4.5 Patch Properties

1. Comment

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

2. Count

Type: plist integer

Failsafe: 0

Description: Number of patch occurrences to apply. 0 applies the patch to all occurrences found.

3. Enabled
Type: plist boolean
Failsafe: false
Description: This ACPI patch will not be used unless set to **true**.
4. Find
Type: plist data
Failsafe: Empty data
Description: Data to find. Must equal to **Replace** in size.
5. Limit
Type: plist integer
Failsafe: 0
Description: Maximum number of bytes to search for. Can be set to 0 to look through the whole ACPI table.
6. Mask
Type: plist data
Failsafe: Empty data
Description: Data bitwise mask used during find comparison. Allows fuzzy search by ignoring not masked (set to zero) bits. Can be set to empty data to be ignored. Must equal to **Replace** in size otherwise.
7. OemTableId
Type: plist data, 8 bytes
Failsafe: All zero
Description: Match table OEM ID to be equal to this value unless all zero.
8. Replace
Type: plist data
Failsafe: Empty data
Description: Replacement data of one or more bytes.
9. ReplaceMask
Type: plist data
Failsafe: Empty data
Description: Data bitwise mask used during replacement. Allows fuzzy replacement by updating masked (set to non-zero) bits. Can be set to empty data to be ignored. Must equal to **Replace** in size otherwise.
10. Skip
Type: plist integer
Failsafe: 0
Description: Number of found occurrences to be skipped before replacement is done.
11. TableLength
Type: plist integer
Failsafe: 0
Description: Match table size to be equal to this value unless 0.
12. TableSignature
Type: plist data, 4 bytes
Failsafe: All zero
Description: Match table signature to be equal to this value unless all zero.

In the majority of the cases ACPI patches are not useful and harmful:

- Avoid renaming devices with ACPI patches. This may fail or perform improper renaming of unrelated devices (e.g. EC and EC0), be unnecessary, or even fail to rename devices in select tables. For ACPI consistency it is much safer to rename devices at I/O Registry level, as done by WhateverGreen.
- Avoid patching `_OSI` to support a higher level of feature sets unless absolutely required. Commonly this enables a number of hacks on APTIO firmwares, which result in the need to add more patches. Modern firmwares generally do not need it at all, and those that do are fine with much smaller patches.
- Try to avoid hacky changes like renaming `_PRW` or `_DSM` whenever possible.

Several cases, where patching actually does make sense, include:

- Refreshing HPET (or another device) method header to avoid compatibility checks by `_OSI` on legacy hardware. `_STA` method with `if ((OSFL () == Zero)) { If (HPTE) ... Return (Zero)` content may be forced to always return `0xF` by replacing `A0 10 93 4F 53 46 4C 00` with `A4 0A 0F A3 A3 A3 A3`.
- To provide custom method implementation with in an SSDT, for instance, to report functional key presses on a laptop, the original method can be replaced with a dummy name by patching `_Q11` with `XQ11`.

Tianocore `AcpiAml.h` source file may help understanding ACPI opcodes.

Note: Patches of different **Find** and **Replace** lengths are unsupported as they may corrupt ACPI tables and make you system unstable due to area relocation. If you need such changes you may utilities “proxy” patching or NOP the remaining area.

4.6 Quirks Properties

1. FadtEnableReset

Type: plist boolean

Failsafe: false

Description: Provide reset register and flag in FADT table to enable reboot and shutdown on legacy hardware. Not recommended unless required.

2. NormalizeHeaders

Type: plist boolean

Failsafe: false

Description: Cleanup ACPI header fields to workaround macOS ACPI implementation bug causing boot crashes. Reference: Debugging AppleACPIPlatform on 10.13 by Alex James aka theracermaster. The issue is fixed in macOS Mojave (10.14).

3. RebaseRegions

Type: plist boolean

Failsafe: false

Description: Attempt to heuristically relocate ACPI memory regions. Not recommended.

ACPI tables are often generated dynamically by underlying firmware implementation. Among the position-independent code, ACPI tables may contain physical addresses of MMIO areas used for device configuration, usually grouped in regions (e.g. **OperationRegion**). Changing firmware settings or hardware configuration, upgrading or patching the firmware inevitably leads to changes in dynamically generated ACPI code, which sometimes lead to the shift of the addresses in aforementioned **OperationRegion** constructions.

For this reason it is very dangerous to apply any kind of modifications to ACPI tables. The most reasonable approach is to make as few as possible changes to ACPI and try to not replace any tables, especially DSDT. When this is not possible, then at least attempt to ensure that custom DSDT is based on the most recent DSDT or remove writes and reads for the affected areas.

When nothing else helps this option could be tried to avoid stalls at **PCI Configuration Begin** phase of macOS booting by attempting to fix the ACPI addresses. It does not do magic, and only works with most common cases. Do not use unless absolutely required.

4. ResetHwSig

Type: plist boolean

Failsafe: false

Description: Reset FACS table **HardwareSignature** value to 0.

This works around firmwares that fail to maintain hardware signature across the reboots and cause issues with waking from hibernation.

5. ResetLogoStatus

Type: plist boolean

Failsafe: false

Description: Reset BGRT table **Displayed** status field to **false**.

This works around firmwares that provide BGRT table but fail to handle screen updates afterwards.

5 Booter

5.1 Introduction

This section allows to apply different kinds of UEFI modifications on Apple bootloader (`boot.efi`). The modifications currently provide various patches and environment alterations for different firmwares. Some of these features were originally implemented as a part of `AptioMemoryFix.efi`, which is no longer maintained. See [Tips and Tricks](#) section for migration steps.

If you are using this for the first time on a customised firmware, there is a list of checks to do first. Prior to starting please ensure that you have:

- Most up-to-date UEFI firmware (check your motherboard vendor website).
- `Fast Boot` and `Hardware Fast Boot` disabled in firmware settings if present.
- `Above 4G Decoding` or similar enabled in firmware settings if present. Note, that on some motherboards (notably ASUS WS-X299-PRO) this option causes adverse effects, and must be disabled. While no other motherboards with the same issue are known, consider this option to be first to check if you have erratic boot failures.
- `DisableIoMapper` quirk enabled, or `VT-d` disabled in firmware settings if present, or `ACPI DMAR` table deleted.
- No ‘slide’ boot argument present in NVRAM or anywhere else. It is not necessary unless you cannot boot at all or see `No slide values are usable! Use custom slide!` message in the log.
- `CFG Lock` (MSR 0xE2 write protection) disabled in firmware settings if present. Consider patching it if you have enough skills and no option is available. See [VerifyMsrE2](#) notes for more details.
- `CSM` (Compatibility Support Module) disabled in firmware settings if present. You may need to flash `GOP ROM` on NVIDIA 6xx/AMD 2xx or older. Use `GopUpdate` (see the second post) or `AMD UEFI GOP MAKER` in case you are not sure how.
- `EHCI/XHCI Hand-off` enabled in firmware settings **only** if boot stalls unless USB devices are disconnected.
- `VT-x`, `Hyper Threading`, `Execute Disable Bit` enabled in firmware settings if present.
- While it may not be required, sometimes you have to disable `Thunderbolt support`, `Intel SGX`, and `Intel Platform Trust` in firmware settings present.

When debugging sleep issues you may want to (temporarily) disable `Power Nap` and automatic power off, which appear to sometimes cause wake to black screen or boot loop issues on older platforms. The particular issues may vary, but in general you should check `ACPI` tables first. Here is an example of a bug found in some Z68 motherboards. To turn `Power Nap` and the others off run the following commands in Terminal:

```
sudo pmset autopoweroff 0
sudo pmset powernap 0
sudo pmset standby 0
```

Note: These settings may reset at hardware change and in certain other circumstances. To view their current state use `pmset -g` command in Terminal.

5.2 Properties

1. `MmioWhitelist`
Type: `plist array`
Description: Designed to be filled with `plist dict` values, describing addresses critical for particular firmware functioning when `DevirtualiseMmio` quirk is in use. See [MmioWhitelist Properties](#) section below.
2. `Quirks`
Type: `plist dict`
Description: Apply individual booter quirks described in [Quirks Properties](#) section below.

5.3 MmioWhitelist Properties

1. `Address`
Type: `plist integer`
Failsafe: 0
Description: Exceptional MMIO address, which memory descriptor should be left virtualised (unchanged) by

`DevirtualiseMmio`. This means that the firmware will be able to directly communicate with this memory region during operating system functioning, because the region this value is in will be assigned a virtual address.

The addresses written here must be part of the memory map, have `EfiMemoryMappedIO` type and `EFI_MEMORY_RUNTIME` attribute (highest bit) set. To find the list of the candidates the debug log can be used.

2. `Comment`

Type: `plist string`

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

3. `Enabled`

Type: `plist boolean`

Failsafe: `false`

Description: This address will be devirtualised unless set to `true`.

5.4 Quirks Properties

1. `AvoidRuntimeDefrag`

Type: `plist boolean`

Failsafe: `false`

Description: Protect from `boot.efi` runtime memory defragmentation.

This option fixes UEFI runtime services (date, time, NVRAM, power control, etc.) support on many firmwares using SMM backing for select services like variable storage. SMM may try to access physical addresses, but they get moved by `boot.efi`.

Note: Most but Apple and VMware firmwares need this quirk.

2. `DevirtualiseMmio`

Type: `plist boolean`

Failsafe: `false`

Description: Remove runtime attribute from select MMIO regions.

This option reduces stolen memory footprint from the memory map by removing runtime bit for known memory regions. This quirk may result in the increase of KASLR slides available, but is not necessarily compatible with the target board without additional measures. In general this frees from 64 to 256 megabytes of memory (present in the debug log), and on some platforms it is the only way to boot macOS, which otherwise fails with allocation error at bootloader stage.

This option is generally useful on all firmwares except some very old ones, like Sandy Bridge. On select firmwares it may require a list of exceptional addresses that still need to get their virtual addresses for proper NVRAM and hibernation functioning. Use `MmioWhitelist` section to do this.

3. `DisableSingleUser`

Type: `plist boolean`

Failsafe: `false`

Description: Disable single user mode.

This is a security option allowing one to restrict single user mode usage by ignoring `CMD+S` hotkey and `-s` boot argument. The behaviour with this quirk enabled is supposed to match T2-based model behaviour. Read this article to understand how to use single user mode with this quirk enabled.

4. `DisableVariableWrite`

Type: `plist boolean`

Failsafe: `false`

Description: Protect from macOS NVRAM write access.

This is a security option allowing one to restrict NVRAM access in macOS. This quirk requires `OC_FIRMWARE_RUNTIME` protocol implemented in `OpenRuntime.efi`.

Note: This quirk can also be used as an ugly workaround to buggy UEFI runtime services implementations that fail to write variables to NVRAM and break the rest of the operating system.

5. `DiscardHibernateMap`

Type: plist boolean

Failsafe: false

Description: Reuse original hibernate memory map.

This option forces XNU kernel to ignore newly supplied memory map and assume that it did not change after waking from hibernation. This behaviour is required to work by Windows, which mandates to preserve runtime memory size and location after S4 wake.

Note: This may be used to workaround buggy memory maps on older hardware, and is now considered rare legacy. Examples of such hardware are Ivy Bridge laptops with Insyde firmware, like Acer V3-571G. Do not use this unless you fully understand the consequences.

6. `EnableSafeModeSlide`

Type: plist boolean

Failsafe: false

Description: Patch bootloader to have KASLR enabled in safe mode.

This option is relevant to the users that have issues booting to safe mode (e.g. by holding `shift` or using `-x` boot argument). By default safe mode forces 0 slide as if the system was launched with `slide=0` boot argument. This quirk tries to patch `boot.efi` to lift that limitation and let some other value (from 1 to 255) be used. This quirk requires `ProvideCustomSlide` to be enabled.

Note: The necessity of this quirk is determined by safe mode availability. If booting to safe mode fails, this option can be tried to be enabled.

7. `EnableWriteUnprotector`

Type: plist boolean

Failsafe: false

Description: Permit write access to UEFI runtime services code.

This option bypasses `RX` permissions in code pages of UEFI runtime services by removing write protection (`WP`) bit from `CR0` register during their execution. This quirk requires `OC_FIRMWARE_RUNTIME` protocol implemented in `OpenRuntime.efi`.

Note: This quirk may potentially weaken firmware security, please use `RebuildAppleMemoryMap` if your firmware supports memory attributes table (MAT).

8. `ForceExitBootServices`

Type: plist boolean

Failsafe: false

Description: Retry `ExitBootServices` with new memory map on failure.

Try to ensure that `ExitBootServices` call succeeds even with outdated `MemoryMap` key argument by obtaining current memory map and retrying `ExitBootServices` call.

Note: The necessity of this quirk is determined by early boot crashes of the firmware. Do not use this unless you fully understand the consequences.

9. `ProtectMemoryRegions`

Type: plist boolean

Failsafe: false

Description: Protect memory regions from incorrect access.

Some firmwares incorrectly map select memory regions:

- CSM region can be marked as boot services code or data, which leaves it as free memory for XNU kernel.
- MMIO regions can be marked as reserved memory and stay unmapped, but may be required to be accessible at runtime for NVRAM support.

This quirk attempts to fix types of these regions, e.g. ACPI NVS for CSM or MMIO for MMIO.

Note: The necessity of this quirk is determined by artifacts, sleep wake issues, and boot failures. In general only very old firmwares need this quirk.

10. **ProtectSecureBoot**

Type: plist boolean

Failsafe: false

Description: Protect UEFI Secure Boot variables from being written.

Reports security violation during attempts to write to `db`, `dbx`, `PK`, and `KEK` variables from the operating system.

Note: This quirk mainly attempts to avoid issues with NVRAM implementations with problematic defragmentation, such as select Insyde or MacPro5,1.

11. **ProtectUefiServices**

Type: plist boolean

Failsafe: false

Description: Protect UEFI services from being overridden by the firmware.

Some modern firmwares including both hardware and virtual machines, like VMware, may update pointers to UEFI services during driver loading and related actions. Consequentially this directly breaks other quirks that affect memory management, like `DevirtualiseMmio`, `ProtectMemoryRegions`, or `RebuildAppleMemoryMap`, and may also break other quirks depending on the effects of these.

Note: On VMware the need for this quirk may be diagnosed by “Your Mac OS guest might run unreliably with more than one virtual core.” message.

12. **ProvideCustomSlide**

Type: plist boolean

Failsafe: false

Description: Provide custom KASLR slide on low memory.

This option performs memory map analysis of your firmware and checks whether all slides (from 1 to 255) can be used. As `boot.efi` generates this value randomly with `rdrand` or pseudo randomly `rdtsc`, there is a chance of boot failure when it chooses a conflicting slide. In case potential conflicts exist, this option forces macOS to use a pseudo random value among the available ones. This also ensures that `slide=` argument is never passed to the operating system for security reasons.

Note: The necessity of this quirk is determined by `OCABC: Only N/256 slide values are usable!` message in the debug log. If the message is present, this option is to be enabled.

13. **RebuildAppleMemoryMap**

Type: plist boolean

Failsafe: false

Description: Generate Memory Map compatible with macOS.

Apple kernel has several limitations in parsing UEFI memory map:

- Memory map size must not exceed 4096 bytes as Apple kernel maps it as a single 4K page. Since some firmwares have very large memory maps (approximately over 100 entries) Apple kernel will crash at boot.
- Memory attributes table is ignored. `EfiRuntimeServicesCode` memory statically gets `RX` permissions, and all other memory types get `RW` permissions. Since some firmware drivers may write to global variables at runtime, Apple kernel will crash at calling UEFI runtime services, unless driver `.data` section has `EfiRuntimeServicesData` type.

To workaround these limitations this quirk applies memory attributes table permissions to memory map passed to Apple kernel and optionally attempts to unify contiguous slots of similar types if the resulting memory map exceeds 4 KB.

Note 1: Since many firmwares come with incorrect memory protection table this quirk often comes in pair with `SyncRuntimePermissions`.

Note 2: The necessity of this quirk is determined by early boot failures. This quirk replaces `EnableWriteUnprotector` on firmwares supporting memory attributes table (MAT).

14. **SetupVirtualMap**

Type: plist boolean

Failsafe: false

Description: Setup virtual memory at `SetVirtualAddresses`.

Select firmwares access memory by virtual addresses after `SetVirtualAddresses` call, which results in early boot crashes. This quirk workarounds the problem by performing early boot identity mapping of assigned virtual addresses to physical memory.

Note: The necessity of this quirk is determined by early boot failures. Currently new firmwares with memory protection support (like OVMF) do not support this quirk due to [acidanthera/bugtracker#719](#).

15. `SignalAppleOS`

Type: plist boolean

Failsafe: false

Description: Report macOS being loaded through OS Info for any OS.

This quirk is useful on Mac firmwares, which behave differently in different OS. For example, it is supposed to enable Intel GPU in Windows and Linux in some dual-GPU MacBook models.

16. `SyncRuntimePermissions`

Type: plist boolean

Failsafe: false

Description: Update memory permissions for runtime environment.

Some firmwares either fail to properly handle runtime permissions:

- They incorrectly mark `OpenRuntime` as not executable in the memory map.
- They incorrectly mark `OpenRuntime` as not executable in the memory attributes table.
- They lose entries from the memory attributes table after `OpenRuntime` is loaded.
- They mark items in the memory attributes table as read-write-execute.

This quirk tries to update memory map and memory attributes table to correct this.

Note: The necessity of this quirk is determined by early boot failures either in macOS or in Linux/Windows. In general only firmwares released in 2018 or later are affected.

6 DeviceProperties

6.1 Introduction

Device configuration is provided to macOS with a dedicated buffer, called `EfiDevicePathPropertyDatabase`. This buffer is a serialised map of DevicePaths to a map of property names and their values.

Property data can be debugged with `gfxutil`. To obtain current property data use the following command in macOS:

```
ioreg -lw0 -p IODeviceTree -n efi -r -x | grep device-properties |  
sed 's/.*<///;s/>.*///' > /tmp/device-properties.hex &&  
gfxutil /tmp/device-properties.hex /tmp/device-properties.plist &&  
cat /tmp/device-properties.plist
```

6.2 Properties

1. Add

Type: `plist dict`

Description: Sets device properties from a map (`plist dict`) of device paths to a map (`plist dict`) of variable names and their values in `plist metadata` format. Device paths must be provided in canonic string format (e.g. `PciRoot(0x0)/Pci(0x1,0x0)/Pci(0x0,0x0)`). Properties will only be set if not present and not deleted.

Note: Currently properties may only be (formerly) added by the original driver, so unless a separate driver was installed, there is no reason to delete the variables.

2. Delete

Type: `plist dict`

Description: Removes device properties from a map (`plist dict`) of device paths to an array (`plist array`) of variable names in `plist string` format.

6.3 Common Properties

Some known properties include:

- `device-id`
User-specified device identifier used for I/O Kit matching. Has 4 byte data type.
- `vendor-id`
User-specified vendor identifier used for I/O Kit matching. Has 4 byte data type.
- `AAPL,ig-platform-id`
Intel GPU framebuffer identifier used for framebuffer selection on Ivy Bridge and newer. Has 4 byte data type.
- `AAPL,snb-platform-id`
Intel GPU framebuffer identifier used for framebuffer selection on Sandy Bridge. Has 4 byte data type.
- `layout-id`
Audio layout used for AppleHDA layout selection. Has 4 byte data type.

7 Kernel

7.1 Introduction

This section allows to apply different kinds of kernelspace modifications on Apple Kernel (XNU). The modifications currently provide driver (kext) injection, kernel and driver patching, and driver blocking.

7.2 Properties

1. Add

Type: plist array

Failsafe: Empty

Description: Load selected kernel drivers from `OC/Kexts` directory.

Designed to be filled with `plist dict` values, describing each driver. See Add Properties section below. Kernel driver load order follows the item order in the array, thus the dependencies should be written prior to their consumers.

2. Block

Type: plist array

Failsafe: Empty

Description: Remove selected kernel drivers from prelinked kernel.

Designed to be filled with `plist dictionary` values, describing each blocked driver. See Block Properties section below.

3. Emulate

Type: plist dict

Description: Emulate select hardware in kernelspace via parameters described in Emulate Properties section below.

4. Patch

Type: plist array

Failsafe: Empty

Description: Perform binary patches in kernel and drivers prior to driver addition and removal.

Designed to be filled with `plist dictionary` values, describing each patch. See Patch Properties section below.

5. Quirks

Type: plist dict

Description: Apply individual kernel and driver quirks described in Quirks Properties section below.

7.3 Add Properties

1. BundlePath

Type: plist string

Failsafe: Empty string

Description: Kext bundle path (e.g. `Lilu.kext` or `MyKext.kext/Contents/PlugIns/MySubKext.kext`).

2. Comment

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

3. Enabled

Type: plist boolean

Failsafe: false

Description: This kernel driver will not be added unless set to `true`.

4. ExecutablePath

Type: plist string

Failsafe: Empty string

Description: Kext executable path relative to bundle (e.g. `Contents/MacOS/Lilu`).

5. `MaxKernel`

Type: `plist string`

Failsafe: Empty string

Description: Adds kernel driver on specified macOS version or older.

Kernel version can be obtained with `uname -r` command, and should look like 3 numbers separated by dots, for example 18.7.0 is the kernel version for 10.14.6. Kernel version interpretation is implemented as follows:

$$\begin{aligned} ParseDarwinVersion(\kappa, \lambda, \mu) &= \kappa \cdot 10000 && \text{Where } \kappa \in (0, 99) \text{ is kernel version major} \\ &+ \lambda \cdot 100 && \text{Where } \lambda \in (0, 99) \text{ is kernel version minor} \\ &+ \mu && \text{Where } \mu \in (0, 99) \text{ is kernel version patch} \end{aligned}$$

Kernel version comparison is implemented as follows:

$$\begin{aligned} \alpha &= \begin{cases} ParseDarwinVersion(\text{MinKernel}), & \text{If MinKernel is valid} \\ 0 & \text{Otherwise} \end{cases} \\ \beta &= \begin{cases} ParseDarwinVersion(\text{MaxKernel}), & \text{If MaxKernel is valid} \\ \infty & \text{Otherwise} \end{cases} \\ \gamma &= \begin{cases} ParseDarwinVersion(\text{FindDarwinVersion}()), & \text{If valid "Darwin Kernel Version" is found} \\ \infty & \text{Otherwise} \end{cases} \\ f(\alpha, \beta, \gamma) &= \alpha \leq \gamma \leq \beta \end{aligned}$$

Here *ParseDarwinVersion* argument is assumed to be 3 integers obtained by splitting Darwin kernel version string from left to right by the `.` symbol. *FindDarwinVersion* function looks up Darwin kernel version by locating `"Darwin Kernel Version $\kappa.\lambda.\mu$ "` string in the kernel image.

6. `MinKernel`

Type: `plist string`

Failsafe: Empty string

Description: Adds kernel driver on specified macOS version or newer.

Note: Refer to Add `MaxKernel` description for matching logic.

7. `PlistPath`

Type: `plist string`

Failsafe: Empty string

Description: Kext `Info.plist` path relative to bundle (e.g. `Contents/Info.plist`).

7.4 Block Properties

1. `Comment`

Type: `plist string`

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

2. `Enabled`

Type: `plist boolean`

Failsafe: `false`

Description: This kernel driver will not be blocked unless set to `true`.

3. `Identifier`

Type: `plist string`

Failsafe: Empty string

Description: Kext bundle identifier (e.g. `com.apple.driver.AppleTyMCEDriver`).

4. **MaxKernel**
Type: plist string
Failsafe: Empty string
Description: Blocks kernel driver on specified macOS version or older.
Note: Refer to **Add MaxKernel** description for matching logic.

5. **MinKernel**
Type: plist string
Failsafe: Empty string
Description: Blocks kernel driver on specified macOS version or newer.
Note: Refer to **Add MaxKernel** description for matching logic.

7.5 Emulate Properties

1. **Cpuid1Data**
Type: plist data, 16 bytes
Failsafe: All zero
Description: Sequence of EAX, EBX, ECX, EDX values to replace CPUID (1) call in XNU kernel.

This property serves for two needs:

- Enabling support of an unsupported CPU model.
- Enabling XCPM support for an unsupported CPU variant.

Normally it is only the value of **EAX** that needs to be taken care of, since it represents the full CPUID. The remaining bytes are to be left as zeroes. Byte order is Little Endian, so for example, **A9 06 03 00** stands for CPUID 0x0306A9 (Ivy Bridge).

For XCPM support it is recommended to use the following combinations.

- Haswell-E (0x306F2) to Haswell (0x0306C3):
Cpuid1Data: C3 06 03 00 00 00 00 00 00 00 00 00 00 00 00 00
Cpuid1Mask: FF FF FF FF 00 00 00 00 00 00 00 00 00 00 00 00
- Broadwell-E (0x0406F1) to Broadwell (0x0306D4):
Cpuid1Data: D4 06 03 00 00 00 00 00 00 00 00 00 00 00 00 00
Cpuid1Mask: FF FF FF FF 00 00 00 00 00 00 00 00 00 00 00 00

Further explanations can be found at [acidanthera/bugtracker#365](#). See **Special NOTES** for Haswell+ low-end.

2. **Cpuid1Mask**
Type: plist data, 16 bytes
Failsafe: All zero
Description: Bit mask of active bits in **Cpuid1Data**.

When each **Cpuid1Mask** bit is set to 0, the original CPU bit is used, otherwise set bits take the value of **Cpuid1Data**.

7.6 Patch Properties

1. **Base**
Type: plist string
Failsafe: Empty string
Description: Selects symbol-matched base for patch lookup (or immediate replacement) by obtaining the address of provided symbol name. Can be set to empty string to be ignored.
2. **Comment**
Type: plist string
Failsafe: Empty string
Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.
3. **Count**
Type: plist integer

Failsafe: 0

Description: Number of patch occurrences to apply. 0 applies the patch to all occurrences found.

4. Enabled

Type: plist boolean

Failsafe: false

Description: This kernel patch will not be used unless set to **true**.

5. Find

Type: plist data

Failsafe: Empty data

Description: Data to find. Can be set to empty for immediate replacement at **Base**. Must equal to **Replace** in size otherwise.

6. Identifier

Type: plist string

Failsafe: Empty string

Description: Kext bundle identifier (e.g. `com.apple.driver.AppleHDA`) or **kernel** for kernel patch.

7. Limit

Type: plist integer

Failsafe: 0

Description: Maximum number of bytes to search for. Can be set to 0 to look through the whole kext or kernel.

8. Mask

Type: plist data

Failsafe: Empty data

Description: Data bitwise mask used during find comparison. Allows fuzzy search by ignoring not masked (set to zero) bits. Can be set to empty data to be ignored. Must equal to **Replace** in size otherwise.

9. MaxKernel

Type: plist string

Failsafe: Empty string

Description: Patches data on specified macOS version or older.

Note: Refer to **Add MaxKernel** description for matching logic.

10. MinKernel

Type: plist string

Failsafe: Empty string

Description: Patches data on specified macOS version or newer.

Note: Refer to **Add MaxKernel** description for matching logic.

11. Replace

Type: plist data

Failsafe: Empty data

Description: Replacement data of one or more bytes.

12. ReplaceMask

Type: plist data

Failsafe: Empty data

Description: Data bitwise mask used during replacement. Allows fuzzy replacement by updating masked (set to non-zero) bits. Can be set to empty data to be ignored. Must equal to **Replace** in size otherwise.

13. Skip

Type: plist integer

Failsafe: 0

Description: Number of found occurrences to be skipped before replacement is done.

7.7 Quirks Properties

1. AppleCpuPmCfgLock

Type: plist boolean

Failsafe: false

Description: Disables `PKG_CST_CONFIG_CONTROL` (0xE2) MSR modification in `AppleIntelCPUPowerManagement.kext`, commonly causing early kernel panic, when it is locked from writing.

Certain firmwares lock `PKG_CST_CONFIG_CONTROL` MSR register. To check its state one can use bundled `VerifyMsre2` tool. Select firmwares have this register locked on some cores only.

As modern firmwares provide `CFG Lock` setting, which allows configuring `PKG_CST_CONFIG_CONTROL` MSR register lock, this option should be avoided whenever possible. For several APTIO firmwares not displaying `CFG Lock` setting in the GUI it is possible to access the option directly:

- (a) Download UEFITool and IFR-Extractor.
- (b) Open your firmware image in UEFITool and find `CFG Lock` unicode string. If it is not present, your firmware may not have this option and you should stop.
- (c) Extract the `Setup.bin` PE32 Image Section (the one UEFITool found) through `Extract Body` menu option.
- (d) Run IFR-Extractor on the extracted file (e.g. `./ifreextract Setup.bin Setup.txt`).
- (e) Find `CFG Lock, VarStoreInfo (VarOffset/VarName):` in `Setup.txt` and remember the offset right after it (e.g. 0x123).
- (f) Download and run Modified GRUB Shell compiled by brainsucker or use a newer version by datasone.
- (g) Enter `setup_var 0x123 0x00` command, where 0x123 should be replaced by your actual offset, and reboot.

WARNING: Variable offsets are unique not only to each motherboard but even to its firmware version. Never ever try to use an offset without checking.

2. AppleXcpmCfgLock

Type: plist boolean

Failsafe: false

Description: Disables `PKG_CST_CONFIG_CONTROL` (0xE2) MSR modification in XNU kernel, commonly causing early kernel panic, when it is locked from writing (XCPM power management).

Note: This option should be avoided whenever possible. See `AppleCpuPmCfgLock` description for more details.

3. AppleXcpmExtraMsrs

Type: plist boolean

Failsafe: false

Description: Disables multiple MSR access critical for select CPUs, which have no native XCPM support.

This is normally used in conjunction with `Emulate` section on Haswell-E, Broadwell-E, Skylake-SP, and similar CPUs. More details on the XCPM patches are outlined in [acidanthera/bugtracker#365](#).

Note: Additional not provided patches will be required for Ivy Bridge or Pentium CPUs. It is recommended to use `AppleIntelCpuPowerManagement.kext` for the former.

4. AppleXcpmForceBoost

Type: plist boolean

Failsafe: false

Description: Forces maximum performance in XCPM mode.

This patch writes 0xFF00 to `MSR_IA32_PERF_CONTROL` (0x199), effectively setting maximum multiplier for all the time.

Note: While this may increase the performance, this patch is strongly discouraged on all systems but those explicitly dedicated to scientific or media calculations. In general only certain Xeon models benefit from the patch.

5. CustomSMBIOSGuid

Type: plist boolean

Failsafe: false

Description: Performs GUID patching for `UpdateSMBIOSMode Custom` mode. Usually relevant for Dell laptops.

6. DisableIoMapper

Type: plist boolean

Failsafe: false

Description: Disables `IoMapper` support in XNU (VT-d), which may conflict with the firmware implementation.

Note: This option is a preferred alternative to deleting DMAR ACPI table and disabling VT-d in firmware preferences, which does not break VT-d support in other systems in case they need it.

7. `DisableRtcChecksum`

Type: plist boolean

Failsafe: false

Description: Disables primary checksum (0x58-0x59) writing in AppleRTC.

Note 1: This option will not protect other areas from being overwritten, see `RTCMemoryFixup` kernel extension if this is desired.

Note 2: This option will not protect areas from being overwritten at firmware stage (e.g. macOS bootloader), see `AppleRtc` protocol description if this is desired.

8. `DummyPowerManagement`

Type: plist boolean

Failsafe: false

Description: Disables `AppleIntelCpuPowerManagement`.

Note: This option is a preferred alternative to `NullCpuPowerManagement.kext` for CPUs without native power management driver in macOS.

9. `ExternalDiskIcons`

Type: plist boolean

Failsafe: false

Description: Apply icon type patches to `AppleAHCIPort.kext` to force internal disk icons for all AHCI disks.

Note: This option should be avoided whenever possible. Modern firmwares usually have compatible AHCI controllers.

10. `IncreasePciBarSize`

Type: plist boolean

Failsafe: false

Description: Increases 32-bit PCI bar size in `IOPCIFamily` from 1 to 4 GBs.

Note: This option should be avoided whenever possible. In general the necessity of this option means misconfigured or broken firmware.

11. `LapicKernelPanic`

Type: plist boolean

Failsafe: false

Description: Disables kernel panic on LAPIC interrupts.

12. `PanicNoKextDump`

Type: plist boolean

Failsafe: false

Description: Prevent kernel from printing kext dump in the panic log preventing from observing panic details. Affects 10.13 and above.

13. `PowerTimeoutKernelPanic`

Type: plist boolean

Failsafe: false

Description: Disables kernel panic on `setPowerState` timeout.

An additional security measure was added to macOS Catalina (10.15) causing kernel panic on power change timeout for Apple drivers. Sometimes it may cause issues on misconfigured hardware, notably digital audio, which sometimes fails to wake up. For debug kernels `setpowerstate_panic=0` boot argument should be used, which is otherwise equivalent to this quirk.

14. `ThirdPartyDrives`

Type: plist boolean

Failsafe: false

Description: Apply vendor patches to `IOAHCIBlockStorage.kext` to enable native features for third-party drives, such as TRIM on SSDs or hibernation support on 10.15 and newer.

Note: This option may be avoided on user preference. NVMe SSDs are compatible without the change. For AHCI SSDs on modern macOS version there is a dedicated built-in utility called `trimforce`. Starting from 10.15 this utility creates `EnableTRIM` variable in `APPLE_BOOT_VARIABLE_GUID` namespace with `01 00 00 00` value.

15. `XhciPortLimit`

Type: `plist boolean`

Failsafe: `false`

Description: Patch various kexts (`AppleUSBXHCI.kext`, `AppleUSBXHCIPCI.kext`, `IOUSBHostFamily.kext`) to remove USB port count limit of 15 ports.

Note: This option should be avoided whenever possible. USB port limit is imposed by the amount of used bits in `locationID` format and there is no possible way to workaround this without heavy OS modification. The only valid solution is to limit the amount of used ports to 15 (discarding some). More details can be found on [AppleLife.ru](https://applelife.ru).

8 Misc

8.1 Introduction

This section contains miscellaneous configuration affecting OpenCore operating system loading behaviour as well as other entries, which do not go to any other section.

OpenCore tries to follow “bless” model also known as “Apple Boot Policy”. The primary specialty of “bless” model is to allow embedding boot options within the file system (and be accessible through a specialised driver) as well as supporting a broader range of predefined boot paths compared to the removable media list found in the UEFI specification.

Each partition will only be used for booting when it corresponds to “Scan policy”: a set of restrictions to only use partitions with specific file systems and from specific device types. Scan policy behaviour is discussed in `ScanPolicy` property description.

Scan process starts with obtaining all the partitions filtered with “Scan policy”. Each partition may produce multiple primary and alternate options. Primary options describe operating systems installed on this media. Alternate options describe recovery options for the operating systems on the media. It is possible for alternate options to exist without primary options and vice versa. Be warned that the options may not necessarily describe the operating systems on the same partition. Each primary and alternate option can be an auxiliary option or not, refer to `HideAuxiliary` for more details. Algorithm to determine boot options behaves as follows:

1. Obtain all available partition handles filtered by “Scan policy” (and driver availability).
2. Obtain all available boot options from `BootOrder` UEFI variable.
3. For each found boot option:
 - Retrieve device path of the boot option.
 - Perform fixups (e.g. NVMe subtype correction) and expansion (e.g. for Boot Camp) of the device path.
 - Obtain device handle by locating device path of the resulting device path (ignore it on failure).
 - Find device handle in the list of partition handles (ignore it if missing).
 - For disk device paths (not specifying a bootloader) execute “bless” (may return > 1 entry).
 - For file device paths check presence on the file system directly.
 - Exclude options with blacklisted filenames (refer to `BlacklistAppleUpdate` option).
 - On OpenCore boot partition exclude all OpenCore bootstrap files by header checks.
 - Mark device handle as *used* in the list of partition handles if any.
 - Register the resulting entries as primary options and determine their types.
The option will become auxiliary for some types (e.g. Apple HFS recovery).
4. For each partition handle:
 - If partition handle is marked as *unused* execute “bless” primary option list retrieval.
In case `BlessOverride` list is set, not only standard “bless” paths will be found but also custom ones.
 - Exclude options with blacklisted filenames (refer to `BlacklistAppleUpdate` option).
 - On OpenCore boot partition exclude all OpenCore bootstrap files by header checks.
 - Register the resulting entries as primary options and determine their types if found.
The option will become auxiliary for some types (e.g. Apple HFS recovery).
 - If partition already has primary options of “Apple Recovery” type proceed to next handle.
 - Lookup alternate entries by “bless” recovery option list retrieval and predefined paths.
 - Register the resulting entries as alternate auxiliary options and determine their types if found.
5. Custom entries and tools are added as primary options without any checks with respect to `Auxiliary`.
6. System entries (e.g. `Reset NVRAM`) are added as primary auxiliary options.

The display order of the boot options in the picker and the boot process are determined separately from the scanning algorithm. The display order as follows:

- Alternate options follow corresponding primary options, i.e. Apple recovery will be following the relevant macOS option whenever possible.
- Options will be listed in file system handle firmware order to maintain an established order across the reboots regardless of the chosen operating system for loading.
- Custom entries, tools, and system entries will be added after all other options.
- Auxiliary options will only show upon entering “Advanced Mode” in the picker (usually by pressing “Space”).

The boot process is as follows:

- Try looking up first valid primary option through `BootNext` UEFI variable.
- On failure looking up first valid primary option through `BootOrder` UEFI variable.
- Mark the option as the default option to boot.
- Boot option through the picker or without it depending on the `ShowPicker` option.
- Show picker on failure otherwise.

Note 1: This process is meant to work reliably only when `RequestBootVarRouting` option is enabled or the firmware does not control UEFI boot options (`OpenDuetPkg` or custom BDS). Without `BootProtect` it also is possible that other operating systems overwrite `OpenCore`, make sure to enable it if you plan to use them.

Note 2: UEFI variable boot options' boot arguments will be removed if present as they may contain arguments compromising the operating system, which is undesired once secure boot is enabled.

Note 3: Some operating systems, namely Windows, will create their boot option and mark it as top most upon first boot or after NVRAM Reset. When this happens default boot entry choice will update till next manual reconfiguration.

8.2 Properties

1. Boot

Type: plist dict

Description: Apply boot configuration described in Boot Properties section below.

2. BlessOverride

Type: plist array

Description: Add custom scanning paths through bless model.

Designed to be filled with `plist string` entries containing absolute UEFI paths to customised bootloaders, for example, `\EFI\Microsoft\Boot\bootmgfw.efi` for Microsoft bootloader. This allows unusual boot paths to be automatically discovered by the boot picker. Designwise they are equivalent to predefined blessed path, such as `\System\Library\CoreServices\boot.efi`, but unlike predefined bless paths they have highest priority.

3. Debug

Type: plist dict

Description: Apply debug configuration described in Debug Properties section below.

4. Entries

Type: plist array

Description: Add boot entries to boot picker.

Designed to be filled with `plist dict` values, describing each load entry. See Entry Properties section below.

5. Security

Type: plist dict

Description: Apply security configuration described in Security Properties section below.

6. Tools

Type: plist array

Description: Add tool entries to boot picker.

Designed to be filled with `plist dict` values, describing each load entry. See Entry Properties section below.

Note: Select tools, for example, UEFI Shell, are very dangerous and **MUST NOT** appear in production configurations, especially in vaulted ones and protected with secure boot, as they may be used to easily bypass secure boot chain.

8.3 Boot Properties

1. ConsoleAttributes

Type: plist integer

Failsafe: 0

Description: Sets specific attributes for console.

Text renderer supports colour arguments as a sum of foreground and background colors according to UEFI specification. The value of black background and black foreground (0) is reserved. List of colour names:

- 0x00 — EFI_BLACK
- 0x01 — EFI_BLUE
- 0x02 — EFI_GREEN
- 0x03 — EFI_CYAN
- 0x04 — EFI_RED
- 0x05 — EFI_MAGENTA
- 0x06 — EFI_BROWN
- 0x07 — EFI_LIGHTGRAY
- 0x08 — EFI_DARKGRAY
- 0x09 — EFI_LIGHTBLUE
- 0x0A — EFI_LIGHTGREEN
- 0x0B — EFI_LIGHTCYAN
- 0x0C — EFI_LIGHTRED
- 0x0D — EFI_LIGHTMAGENTA
- 0x0E — EFI_YELLOW
- 0x0F — EFI_WHITE
- 0x10 — EFI_BACKGROUND_BLACK
- 0x11 — EFI_BACKGROUND_BLUE
- 0x12 — EFI_BACKGROUND_GREEN
- 0x13 — EFI_BACKGROUND_CYAN
- 0x14 — EFI_BACKGROUND_RED
- 0x15 — EFI_BACKGROUND_MAGENTA
- 0x16 — EFI_BACKGROUND_BROWN
- 0x17 — EFI_BACKGROUND_LIGHTGRAY

Note: This option may not work well with **System** text renderer. Setting a background different from black could help testing proper GOP functioning.

2. HibernateMode

Type: plist string

Failsafe: None

Description: Hibernation detection mode. The following modes are supported:

- None — Avoid hibernation for your own good.
- Auto — Use RTC and NVRAM detection.
- RTC — Use RTC detection.
- NVRAM — Use NVRAM detection.

3. HideAuxiliary

Type: plist boolean

Failsafe: false

Description: Hides auxiliary entries from picker menu by default.

An entry is considered auxiliary when at least one of the following applies:

- Entry is macOS recovery.
- Entry is macOS Time Machine.
- Entry is explicitly marked as **Auxiliary**.
- Entry is system (e.g. **Clean NVRAM**).

To see all entries picker menu needs to be reloaded in extended mode by pressing **Spacebar** key. Hiding auxiliary entries may increase boot performance for multidisk systems.

4. PickerAttributes

Type: plist integer

Failsafe: 0

Description: Sets specific attributes for picker.

Different pickers may be configured through the attribute mask containing OpenCore-reserved (BIT0~BIT15) and

OEM-specific (BIT16~BIT31) values.

Current OpenCore values include:

- 0x0001 — OC_ATTR_USE_VOLUME_ICON, provides custom icons for boot entries:
 - .VolumeIcon.icns file at Preboot root for APFS.
 - .VolumeIcon.icns file at volume root for other filesystems.
 - <TOOL_NAME>.icns file for Tools.

Volume icons can be set in Finder. Note, that enabling this may result in external and internal icons to be indistinguishable.

- 0x0002 — OC_ATTR_USE_DISK_LABEL_FILE, provides custom rendered titles for boot entries:
 - .disk_label (.disk_label_2x) file near bootloader for all filesystems.
 - <TOOL_NAME>.lbl (<TOOL_NAME>.l2x) file near tool for Tools.

Prerendered labels can be generated via `disklabel` utility or `bless` command. When disabled or missing text labels (`.contentDetails` or `.disk_label.contentDetails`) are to be rendered instead.

- 0x0004 — OC_ATTR_USE_GENERIC_LABEL_IMAGE, provides predefined label images for boot entries without custom entries. May give less detail for the actual boot entry.
- 0x0008 — OC_ATTR_USE_ALTERNATE_ICONS, changes used icon set to an alternate one if it is supported. For example, this could make a use of old-style icons with a custom background colour.

5. PickerAudioAssist

Type: plist boolean

Failsafe: false

Description: Enable screen reader by default in boot picker.

For macOS bootloader screen reader preference is set in `preferences.efires` archive in `isV0Enabled.int32` file and is controlled by the operating system. For OpenCore screen reader support this option is an independent equivalent. Toggling screen reader support in both OpenCore boot picker and macOS bootloader FileVault 2 login window can also be done with `Command + F5` key combination.

Note: screen reader requires working audio support, see `UEFI Audio Properties` section for more details.

6. PollAppleHotKeys

Type: plist boolean

Failsafe: false

Description: Enable modifier hotkey handling in boot picker.

In addition to `action hotkeys`, which are partially described in `PickerMode` section and are normally handled by Apple BDS, there exist modifier keys, which are handled by operating system bootloader, namely `boot.efi`. These keys allow to change operating system behaviour by providing different boot modes.

On some firmwares it may be problematic to use modifier keys due to driver incompatibilities. To workaround this problem this option allows registering select hotkeys in a more permissive manner from within boot picker. Such extensions include the support of tapping on keys in addition to holding and pressing `Shift` along with other keys instead of just `Shift` alone, which is not detectible on many PS/2 keyboards. This list of known `modifier hotkeys` includes:

- `CMD+C+MINUS` — disable board compatibility checking.
- `CMD+K` — boot release kernel, similar to `kcsuffix=release`.
- `CMD+S` — single user mode.
- `CMD+S+MINUS` — disable KASLR slide, requires disabled SIP.
- `CMD+V` — verbose mode.
- `Shift` — safe mode.

7. ShowPicker

Type: plist boolean

Failsafe: false

Description: Show simple boot picker to allow boot entry selection.

8. TakeoffDelay

Type: plist integer, 32 bit

Failsafe: 0

Description: Delay in microseconds performed before handling picker startup and `action hotkeys`.

Introducing a delay may give extra time to hold the right **action hotkey** sequence to e.g. boot to recovery mode. On some platforms setting this option to at least 5000–10000 microseconds may be necessary to access **action hotkeys** at all due to the nature of the keyboard driver.

9. **Timeout**

Type: plist integer, 32 bit

Failsafe: 0

Description: Timeout in seconds in boot picker before automatic booting of the default boot entry. Use 0 to disable timer.

10. **PickerMode**

Type: plist string

Failsafe: Builtin

Description: Choose boot picker used for boot management.

Picker describes underlying boot management with an optional user interface responsible for handling boot options. The following values are supported:

- **Builtin** — boot management is handled by OpenCore, a simple text only user interface is used.
- **External** — an external boot management protocol is used if available. Otherwise **Builtin** mode is used.
- **Apple** — Apple boot management is used if available. Otherwise **Builtin** mode is used.

Upon success **External** mode will entirely disable all boot management in OpenCore except policy enforcement. In **Apple** mode it may additionally bypass policy enforcement. See OpenCanopy plugin for an example of a custom user interface.

OpenCore built-in boot picker contains a set of actions chosen during the boot process. The list of supported actions is similar to Apple BDS and in general can be accessed by holding **action hotkeys** during boot process. Currently the following actions are considered:

- **Default** — this is the default option, and it lets OpenCore built-in boot picker to loads the default boot option as specified in Startup Disk preference pane.
- **ShowPicker** — this option forces picker to show. Normally it can be achieved by holding **OPT** key during boot. Setting **ShowPicker** to **true** will make **ShowPicker** the default option.
- **ResetNvram** — this option performs select UEFI variable erase and is normally achieved by holding **CMD+OPT+P+R** key combination during boot. Another way to erase UEFI variables is to choose **Reset NVRAM** in the picker. This option requires **AllowNvramReset** to be set to **true**.
- **BootApple** — this options performs booting to the first found Apple operating system unless the default chosen operating system is already made by Apple. Hold **X** key to choose this option.
- **BootAppleRecovery** — this option performs booting to Apple operating system recovery. Either the one related to the default chosen operating system, or first found in case default chosen operating system is not made by Apple or has no recovery. Hold **CMD+R** key combination to choose this option.

Note 1: Activated **KeySupport**, **OpenUsbKbDxe**, or similar driver is required for key handling to work. On many firmwares it is not possible to get all the keys function.

Note 2: In addition to **OPT** OpenCore supports **Escape** key to display picker when **ShowPicker** is disabled. This key exists for **Apple** picker mode and for firmwares with PS/2 keyboards that fail to report held **OPT** key and require continual presses of **Escape** key to enter the boot menu.

Note 3: On Macs with problematic **GOP** it may be difficult to access Apple BootPicker. To workaround this problem even without loading OpenCore **BootKicker** utility can be blessed.

8.4 Debug Properties

1. **AppleDebug**

Type: plist boolean

Failsafe: false

Description: Enable **boot.efi** debug log saving to OpenCore log.

Note: This option only applies to 10.15.4 and newer.

2. **ApplePanic**

Type: plist boolean

Failsafe: false

Description: Save macOS kernel panic to OpenCore root partition.

The file is saved as `panic-YYYY-MM-DD-HHMMSS.txt`. It is strongly recommended to have `keepsyms=1` boot argument to see debug symbols in the panic log. In case it was not present `kpdescribe.sh` utility (bundled with OpenCore) may be used to partially recover the stacktrace.

Development and debug kernels produce more helpful kernel panics. Consider downloading and installing `KernelDebugKit` from developer.apple.com when debugging a problem. To activate a development kernel you will need to add a `kcsuffix=development` boot argument. Use `uname -a` command to ensure that your current loaded kernel is a development (or a debug) kernel.

In case OpenCore kernel panic saving mechanism was not used, kernel panics may still be found in `/Library/Logs/Diagnostic` directory. Starting with macOS Catalina kernel panics are stored in JSON format, so they need to be preprocessed before passing to `kpdescribe.sh`:

```
cat Kernel.panic | grep macOSProcessedStackshotData |  
python -c 'import json,sys;print(json.load(sys.stdin)["macOSPanicString"]'
```

3. DisableWatchDog

Type: plist boolean

Failsafe: false

Description: Select firmwares may not succeed in quickly booting the operating system, especially in debug mode, which results in watch dog timer aborting the process. This option turns off watch dog timer.

4. DisplayDelay

Type: plist integer

Failsafe: 0

Description: Delay in microseconds performed after every printed line visible onscreen (i.e. console).

5. DisplayLevel

Type: plist integer, 64 bit

Failsafe: 0

Description: EDK II debug level bitmask (sum) showed onscreen. Unless **Target** enables console (onscreen) printing, onscreen debug output will not be visible. The following levels are supported (discover more in `DebugLib.h`):

- 0x00000002 (bit 1) — `DEBUG_WARN` in `DEBUG`, `NOOPT`, `RELEASE`.
- 0x00000040 (bit 6) — `DEBUG_INFO` in `DEBUG`, `NOOPT`.
- 0x00400000 (bit 22) — `DEBUG_VERBOSE` in custom builds.
- 0x80000000 (bit 31) — `DEBUG_ERROR` in `DEBUG`, `NOOPT`, `RELEASE`.

6. Target

Type: plist integer

Failsafe: 0

Description: A bitmask (sum) of enabled logging targets. By default all the logging output is hidden, so this option is required to be set when debugging is necessary.

The following logging targets are supported:

- 0x01 (bit 0) — Enable logging, otherwise all log is discarded.
- 0x02 (bit 1) — Enable basic console (onscreen) logging.
- 0x04 (bit 2) — Enable logging to Data Hub.
- 0x08 (bit 3) — Enable serial port logging.
- 0x10 (bit 4) — Enable UEFI variable logging.
- 0x20 (bit 5) — Enable non-volatile UEFI variable logging.
- 0x40 (bit 6) — Enable logging to file.

Console logging prints less than all the other variants. Depending on the build type (`RELEASE`, `DEBUG`, or `NOOPT`) different amount of logging may be read (from least to most).

Data Hub log will not log kernel and kext patches. To obtain Data Hub log use the following command in macOS:

```
ioreg -lw0 -p IODeviceTree | grep boot-log | sort | sed 's/.*<\(.*\)>.*\/1/' | xxd -r -p
```

UEFI variable log does not include some messages and has no performance data. For safety reasons log size is limited to 32 kilobytes. Some firmwares may truncate it much earlier or drop completely if they have no memory. Using non-volatile flag will write the log to NVRAM flash after every printed line. To obtain UEFI variable log use the following command in macOS:

```
nvr 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:boot-log |  
  awk '{gsub(/%0d%0a%00/, ""); gsub(/%0d%0a/, "\n")}1'
```

Warning: Some firmwares are reported to have broken NVRAM garbage collection. This means that they may not be able to always free space after variable deletion. Do not use non-volatile NVRAM logging without extra need on such devices.

While OpenCore boot log already contains basic version information with build type and date, this data may also be found in NVRAM in `opencore-version` variable even with boot log disabled.

File logging will create a file named `opencore-YYYY-MM-DD-HHMMSS.txt` at EFI volume root with log contents (the upper case letter sequence is replaced with date and time from the firmware). Please be warned that some file system drivers present in firmwares are not reliable, and may corrupt data when writing files through UEFI. Log is attempted to be written in the safest manner, and thus is very slow. Ensure that `DisableWatchDog` is set to `true` when you use a slow drive.

When interpreting the log, note that the lines are prefixed with a tag describing the relevant location (module) of the log line allowing one to better attribute the line to the functionality. The list of currently used tags is provided below.

Drivers and tools:

- BMF — OpenCanopy, bitmap font
- BS — Bootstrap
- GSTT — GoptStop
- HDA — AudioDxe
- KKT — KeyTester
- MMDD — MmapDump
- OCPAVP — PavpProvision
- OCRST — ResetSystem
- OCUI — OpenCanopy
- OC — OpenCore main

Libraries:

- AAPL — OcDebugLogLib, Apple EfiBoot logging
- OCABC — OcAfterBootCompatLib
- OCAE — OcAppleEventLib
- OCAK — OcAppleKernelLib
- OCAU — OcAudioLib
- OCAV — OcAppleImageVerificationLib
- OCA — OcAcpiLib
- OCBP — OcAppleBootPolicyLib
- OCB — OcBootManagementLib
- OCCL — OcAppleChunkListLib
- OCCPU — OcCpuLib
- OCC — OcConsoleLib
- OCDH — OcDataHubLib
- OCDI — OcAppleDiskImageLib
- OCFSQ — OcFileLib, UnblockFs quirk
- OCFS — OcFileLib
- OCFV — OcFirmwareVolumeLib
- OCHS — OcHashServicesLib
- OCIC — OcImageConversionLib
- OCII — OcInputLib
- OCJS — OcApfsLib

- `OCKM` — `OcAppleKeyMapLib`
- `OCL` — `OcDebugLogLib`
- `OCMCO` — `OcMachoLib`
- `OCME` — `OcHeciLib`
- `OCMM` — `OcMemoryLib`
- `OCPI` — `OcFileLib`, partition info
- `OCPNG` — `OcPngLib`
- `OCRAM` — `OcAppleRamDiskLib`
- `OCRTC` — `OcRtcLib`
- `OCSB` — `OcAppleSecureBootLib`
- `OCSMB` — `OcSmbiosLib`
- `OCSMC` — `OcSmcLib`
- `OCST` — `OcStorageLib`
- `OCS` — `OcSerializedLib`
- `OCTPL` — `OcTemplateLib`
- `OCUC` — `OcUnicodeCollationLib`
- `OCUT` — `OcAppleUserInterfaceThemeLib`
- `OCXML` — `OcXmlLib`

8.5 Security Properties

1. `AllowNvramReset`
Type: `plist boolean`
Failsafe: `false`
Description: Allow `CMD+OPT+P+R` handling and enable showing `NVRAM Reset` entry in boot picker.
2. `AllowSetDefault`
Type: `plist boolean`
Failsafe: `false`
Description: Allow `CTRL+Enter` and `CTRL+Index` handling to set the default boot option in boot picker.
3. `AuthRestart`
Type: `plist boolean`
Failsafe: `false`
Description: Enable `VirtualSMC`-compatible authenticated restart.

Authenticated restart is a way to reboot FileVault 2 enabled macOS without entering the password. To perform authenticated restart one can use a dedicated terminal command: `sudo fdsetup authrestart`. It is also used when installing operating system updates.

`VirtualSMC` performs authenticated restart by saving disk encryption key split in `NVRAM` and `RTC`, which despite being removed as soon as `OpenCore` starts, may be considered a security risk and thus is optional.

4. `BlacklistAppleUpdate`
Type: `plist boolean`
Failsafe: `false`
Description: Ignore boot options trying to update Apple peripheral firmware (e.g. `MultiUpdater.efi`).
5. `BootProtect`
Type: `plist string`
Failsafe: `None`
Description: Attempt to provide bootloader persistence.

Valid values:

- `None` — do nothing.
- `Bootstrap` — create or update top-priority `\EFI\OC\Bootstrap\Bootstrap.efi` boot option (`Boot9696`) in UEFI variable storage at bootloader startup. For this option to work `RequestBootVarRouting` is required to be enabled.

This option provides integration with third-party operating system installation and upgrade at the times they overwrite `\EFI\BOOT\BOOTX64.efi` file. By creating a custom option in `Bootstrap` mode this file path becomes

no longer used for bootstrapping OpenCore.

Note 1: Some firmwares may have broken NVRAM, no boot option support, or various other incompatibilities of any kind. While unlikely, the use of this option may even cause boot failure. Use at your own risk on boards known to be compatible.

Note 2: Be warned that while NVRAM reset executed from OpenCore should not erase the boot option created in **Bootstrap**, executing NVRAM reset prior to loading OpenCore will remove it.

6. ExposeSensitiveData

Type: plist integer

Failsafe: 0x6

Description: Sensitive data exposure bitmask (sum) to operating system.

- 0x01 — Expose printable booter path as an UEFI variable.
- 0x02 — Expose OpenCore version as an UEFI variable.
- 0x04 — Expose OpenCore version in boot picker menu title.
- 0x08 — Expose OEM information as a set of UEFI variables.

Exposed booter path points to OpenCore.efi or its booter depending on the load order. To obtain booter path use the following command in macOS:

```
nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:booter-path
```

To use booter path for mounting booter volume use the following command in macOS:

```
u=$(nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:booter-path | sed 's/.*GPT,\([^,]*\),.*\/1/'); \
if [ "$u" != "" ]; then sudo diskutil mount $u ; fi
```

To obtain OpenCore version use the following command in macOS:

```
nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:opencore-version
```

To obtain OEM information use the following commands in macOS:

```
nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:oem-product # SMBIOS Type1 ProductName
nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:oem-vendor   # SMBIOS Type2 Manufacturer
nvram 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:oem-board    # SMBIOS Type2 ProductName
```

7. HaltLevel

Type: plist integer, 64 bit

Failsafe: 0x80000000 (DEBUG_ERROR)

Description: EDK II debug level bitmask (sum) causing CPU to halt (stop execution) after obtaining a message of HaltLevel. Possible values match DisplayLevel values.

8. Vault

Type: plist string

Failsafe: Secure

Description: Enables vaulting mechanism in OpenCore.

Valid values:

- **Optional** — require nothing, no vault is enforced, insecure.
- **Basic** — require **vault.plist** file present in OC directory. This provides basic filesystem integrity verification and may protect from unintentional filesystem corruption.
- **Secure** — require **vault.sig** signature file for **vault.plist** in OC directory. This includes **Basic** integrity checking but also attempts to build a trusted bootchain.

vault.plist file should contain SHA-256 hashes for all files used by OpenCore. Presence of this file is highly recommended to ensure that unintentional file modifications (including filesystem corruption) do not happen unnoticed. To create this file automatically use **create_vault.sh** script. Regardless of the underlying filesystem, path name and case must match between **config.plist** and **vault.plist**.

`vault.sig` file should contain a raw 256 byte RSA-2048 signature from SHA-256 hash of `vault.plist`. The signature is verified against the public key embedded into `OpenCore.efi`. To embed the public key you should do either of the following:

- Provide public key during the `OpenCore.efi` compilation in `OpenCoreVault.c` file.
- Binary patch `OpenCore.efi` replacing zeroes with the public key between `=BEGIN OC VAULT=` and `==END OC VAULT==` ASCII markers.

RSA public key 520 byte format description can be found in Chromium OS documentation. To convert public key from X.509 certificate or from PEM file use `RsaTool`.

The complete set of commands to:

- Create `vault.plist`.
- Create a new RSA key (always do this to avoid loading old configuration).
- Embed RSA key into `OpenCore.efi`.
- Create `vault.sig`.

Can look as follows:

```
cd /Volumes/EFI/EFI/OC
/path/to/create_vault.sh .
/path/to/RsaTool -sign vault.plist vault.sig vault.pub
off=$((($(strings -a -t d OpenCore.efi | grep "=BEGIN OC VAULT=" | cut -f1 -d' ')+16))
dd of=OpenCore.efi if=vault.pub bs=1 seek=$off count=528 conv=notrunc
rm vault.pub
```

Note 1: While it may appear obvious, but you have to use an external method to verify `OpenCore.efi` and `BOOTx64.efi` for secure boot path. For this you are recommended to at least enable UEFI SecureBoot with a custom certificate, and sign `OpenCore.efi` and `BOOTx64.efi` with your custom key. More details on customising secure boot on modern firmwares can be found in Taming UEFI SecureBoot paper (in Russian).

Note 2: `vault.plist` and `vault.sig` are used regardless of this option when `vault.plist` is present or public key is embedded into `OpenCore.efi`. Setting this option will only ensure configuration sanity, and abort the boot process otherwise.

9. ScanPolicy

Type: plist integer, 32 bit

Failsafe: 0x10F0103

Description: Define operating system detection policy.

This value allows to prevent scanning (and booting) from untrusted source based on a bitmask (sum) of select flags. As it is not possible to reliably detect every file system or device type, this feature cannot be fully relied upon in open environments, and the additional measures are to be applied.

Third party drivers may introduce additional security (and performance) measures following the provided scan policy. Scan policy is exposed in `scan-policy` variable of 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102 GUID for UEFI Boot Services only.

- 0x00000001 (bit 0) — `OC_SCAN_FILE_SYSTEM_LOCK`, restricts scanning to only known file systems defined as a part of this policy. File system drivers may not be aware of this policy, and to avoid mounting of undesired file systems it is best not to load its driver. This bit does not affect dmg mounting, which may have any file system. Known file systems are prefixed with `OC_SCAN_ALLOW_FS_`.
- 0x00000002 (bit 1) — `OC_SCAN_DEVICE_LOCK`, restricts scanning to only known device types defined as a part of this policy. This is not always possible to detect protocol tunneling, so be aware that on some systems it may be possible for e.g. USB HDDs to be recognised as SATA. Cases like this must be reported. Known device types are prefixed with `OC_SCAN_ALLOW_DEVICE_`.
- 0x00000100 (bit 8) — `OC_SCAN_ALLOW_FS_APFS`, allows scanning of APFS file system.
- 0x00000200 (bit 9) — `OC_SCAN_ALLOW_FS_HFS`, allows scanning of HFS file system.
- 0x00000400 (bit 10) — `OC_SCAN_ALLOW_FS_ESP`, allows scanning of EFI System Partition file system.
- 0x00000800 (bit 11) — `OC_SCAN_ALLOW_FS_NTFS`, allows scanning of NTFS (Msft Basic Data) file system.
- 0x00001000 (bit 12) — `OC_SCAN_ALLOW_FS_EXT`, allows scanning of EXT (Linux Root) file system.
- 0x00010000 (bit 16) — `OC_SCAN_ALLOW_DEVICE_SATA`, allow scanning SATA devices.

- 0x00020000 (bit 17) — OC_SCAN_ALLOW_DEVICE_SASEX, allow scanning SAS and Mac NVMe devices.
- 0x00040000 (bit 18) — OC_SCAN_ALLOW_DEVICE_SCSI, allow scanning SCSI devices.
- 0x00080000 (bit 19) — OC_SCAN_ALLOW_DEVICE_NVME, allow scanning NVMe devices.
- 0x00100000 (bit 20) — OC_SCAN_ALLOW_DEVICE_ATAPI, allow scanning CD/DVD devices.
- 0x00200000 (bit 21) — OC_SCAN_ALLOW_DEVICE_USB, allow scanning USB devices.
- 0x00400000 (bit 22) — OC_SCAN_ALLOW_DEVICE_FIREWIRE, allow scanning FireWire devices.
- 0x00800000 (bit 23) — OC_SCAN_ALLOW_DEVICE_SDCARD, allow scanning card reader devices.
- 0x01000000 (bit 24) — OC_SCAN_ALLOW_DEVICE_PCI, allow scanning devices directly connected to PCI bus (e.g. VIRTIO).

Note: Given the above description, 0xF0103 value is expected to allow scanning of SATA, SAS, SCSI, and NVMe devices with APFS file system, and prevent scanning of any devices with HFS or FAT32 file systems in addition to not scanning APFS file systems on USB, CD, and FireWire drives. The combination reads as:

- OC_SCAN_FILE_SYSTEM_LOCK
- OC_SCAN_DEVICE_LOCK
- OC_SCAN_ALLOW_FS_APFS
- OC_SCAN_ALLOW_DEVICE_SATA
- OC_SCAN_ALLOW_DEVICE_SASEX
- OC_SCAN_ALLOW_DEVICE_SCSI
- OC_SCAN_ALLOW_DEVICE_NVME

8.6 Entry Properties

1. Arguments

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used as boot arguments (load options) of the specified entry.

2. Auxiliary

Type: plist boolean

Failsafe: false

Description: This entry will not be listed by default when `HideAuxiliary` is set to `true`.

3. Comment

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

4. Enabled

Type: plist boolean

Failsafe: false

Description: This entry will not be listed unless set to `true`.

5. Name

Type: plist string

Failsafe: Empty string

Description: Human readable entry name displayed in boot picker.

6. Path

Type: plist string

Failsafe: Empty string

Description: Entry location depending on entry type.

- **Entries** specify external boot options, and therefore take device paths in `Path` key. These values are not checked, thus be extremely careful. Example: `PciRoot(0x0)/Pci(0x1,0x1)/.../EFI\COOL.EFI`
- **Tools** specify internal boot options, which are part of bootloader vault, and therefore take file paths relative to `OC/Tools` directory. Example: `OpenShell.efi`.

9 NVRAM

9.1 Introduction

Has `plist dict` type and allows to set volatile UEFI variables commonly referred as NVRAM variables. Refer to `man nvram` for more details. macOS extensively uses NVRAM variables for OS — Bootloader — Firmware intercommunication, and thus supplying several NVRAM is required for proper macOS functioning.

Each NVRAM variable consists of its name, value, attributes (refer to UEFI specification), and its GUID, representing which ‘section’ NVRAM variable belongs to. macOS uses several GUIDs, including but not limited to:

- 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14 (APPLE_VENDOR_VARIABLE_GUID)
- 7C436110-AB2A-4BBB-A880-FE41995C9F82 (APPLE_BOOT_VARIABLE_GUID)
- 8BE4DF61-93CA-11D2-AA0D-00E098032B8C (EFI_GLOBAL_VARIABLE_GUID)
- 4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102 (OC_VENDOR_VARIABLE_GUID)

Note: Some of the variables may be added by PlatformNVRAM or Generic subsections of PlatformInfo section. Please ensure that variables of this section never collide with them, as behaviour is undefined otherwise.

For proper macOS functioning it is often required to use `OC_FIRMWARE_RUNTIME` protocol implementation currently offered as a part of `OpenRuntime` driver. While it brings any benefits, there are certain limitations which arise depending on the use.

1. Not all tools may be aware of protected namespaces.
When `RequestBootVarRouting` is used `Boot-`prefixed variable access is restricted and protected in a separate namespace. To access the original variables tools have to be aware of `OC_FIRMWARE_RUNTIME` logic.

9.2 Properties

1. Add
Type: `plist dict`
Description: Sets NVRAM variables from a map (`plist dict`) of GUIDs to a map (`plist dict`) of variable names and their values in `plist metadata` format. GUIDs must be provided in canonic string format in upper or lower case (e.g. 8BE4DF61-93CA-11D2-AA0D-00E098032B8C).

Created variables get `EFI_VARIABLE_BOOTSERVICE_ACCESS` and `EFI_VARIABLE_RUNTIME_ACCESS` attributes set. Variables will only be set if not present or deleted. I.e. to overwrite an existing variable value add the variable name to the `Delete` section. This approach enables to provide default values till the operating system takes the lead.

Note: If `plist` key does not conform to GUID format, behaviour is undefined.

2. Delete
Type: `plist dict`
Description: Removes NVRAM variables from a map (`plist dict`) of GUIDs to an array (`plist array`) of variable names in `plist string` format.
3. LegacyEnable
Type: `plist boolean`
Failsafe: `false`
Description: Enables loading of NVRAM variable file named `nvram.plist` from EFI volume root.

This file must have root `plist dictionary` type and contain two fields:

- `Version` — `plist integer`, file version, must be set to 1.
- `Add` — `plist dictionary`, equivalent to `Add` from `config.plist`.

Variable loading happens prior to `Delete` (and `Add`) phases. Unless `LegacyOverwrite` is enabled, it will not overwrite any existing variable. Variables allowed to be set must be specified in `LegacySchema`. Third-party scripts may be used to create `nvram.plist` file. An example of such script can be found in `Utilities`. The use of third-party scripts may require `ExposeSensitiveData` set to `0x3` to provide `boot-path` variable with OpenCore EFI partition UUID.

WARNING: This feature is very dangerous as it passes unprotected data to your firmware variable services. Use it only when no hardware NVRAM implementation is provided by the firmware or it is incompatible.

4. LegacyOverwrite

Type: plist boolean

Failsafe: false

Description: Permits overwriting firmware variables from `nvr.plist`.

Note: Only variables accessible from the operating system will be overwritten.

5. LegacySchema

Type: plist dict

Description: Allows setting select NVRAM variables from a map (plist dict) of GUIDs to an array (plist array) of variable names in `plist string` format.

You can use `*` value to accept all variables for select GUID.

WARNING: Choose variables very carefully, as `nvr.plist` is not vaulted. For instance, do not put `boot-args` or `csr-active-config`, as this can bypass SIP.

6. WriteFlash

Type: plist boolean

Failsafe: false

Description: Enables writing to flash memory for all added variables.

Note: This value is recommended to be enabled on most firmwares, but is left configurable for firmwares that may have issues with NVRAM variable storage garbage collection or alike.

To read NVRAM variable value from macOS one could use `nvr` by concatenating variable GUID and name separated by `:` symbol. For example, `nvr 7C436110-AB2A-4BBB-A880-FE41995C9F82:boot-args`.

A continuously updated variable list can be found in a corresponding document: [NVRAM Variables](#).

9.3 Mandatory Variables

Warning: These variables may be added by PlatformNVRAM or Generic subsections of PlatformInfo section. Using PlatformInfo is the recommend way of setting these variables.

The following variables are mandatory for macOS functioning:

- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:FirmwareFeatures`
32-bit `FirmwareFeatures`. Present on all Macs to avoid extra parsing of SMBIOS tables
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:FirmwareFeaturesMask`
32-bit `FirmwareFeaturesMask`. Present on all Macs to avoid extra parsing of SMBIOS tables.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:MLB`
`BoardSerialNumber`. Present on newer Macs (2013+ at least) to avoid extra parsing of SMBIOS tables, especially in `boot.efi`.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ROM`
Primary network adapter MAC address or replacement value. Present on newer Macs (2013+ at least) to avoid accessing special memory region, especially in `boot.efi`.

9.4 Recommended Variables

The following variables are recommended for faster startup or other improvements:

- `7C436110-AB2A-4BBB-A880-FE41995C9F82:csr-active-config`
32-bit System Integrity Protection bitmask. Declared in XNU source code in `csr.h`.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ExtendedFirmwareFeatures`
Combined `FirmwareFeatures` and `ExtendedFirmwareFeatures`. Present on newer Macs to avoid extra parsing of SMBIOS tables
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ExtendedFirmwareFeaturesMask`
Combined `FirmwareFeaturesMask` and `ExtendedFirmwareFeaturesMask`. Present on newer Macs to avoid extra parsing of SMBIOS tables.

- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_BID`
Hardware BoardProduct (e.g. `Mac-35C1E88140C3E6CF`). Not present on real Macs, but used to avoid extra parsing of SMBIOS tables, especially in `boot.efi`.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_MLB`
Hardware BoardSerialNumber. Override for MLB. Present on newer Macs (2013+ at least).
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_ROM`
Hardware ROM. Override for ROM. Present on newer Macs (2013+ at least).
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:prev-lang:kbd`
ASCII string defining default keyboard layout. Format is `lang-COUNTRY:keyboard`, e.g. `ru-RU:252` for Russian locale and ABC keyboard. Also accepts short forms: `ru:252` or `ru:0` (U.S. keyboard, compatible with 10.9). Full decoded keyboard list from `AppleKeyboardLayouts-L.dat` can be found here. Using non-latin keyboard on 10.14 will not enable ABC keyboard, unlike previous and subsequent macOS versions, and is thus not recommended in case you need 10.14.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:security-mode`
ASCII string defining FireWire security mode. Legacy, can be found in `IOFireWireFamily` source code in `IOFireWireController.cpp`. It is recommended not to set this variable, which may speedup system startup. Setting to `full` is equivalent to not setting the variable and `none` disables FireWire security.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:UIScale`
One-byte data defining `boot.efi` user interface scaling. Should be `01` for normal screens and `02` for HiDPI screens.
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:DefaultBackgroundColor`
Four-byte BGRA data defining `boot.efi` user interface background colour. Standard colours include `BF BF BF 00` (Light Gray) and `00 00 00 00` (Syrah Black). Other colours may be set at user's preference.

9.5 Other Variables

The following variables may be useful for certain configurations or troubleshooting:

- `7C436110-AB2A-4BBB-A880-FE41995C9F82:boot-args`
Kernel arguments, used to pass configuration to Apple kernel and drivers. There are many arguments, which may be found by looking for the use of `PE_parse_boot_argn` function in the kernel or driver code. Some of the known boot arguments include:
 - `acpi_layer=0xFFFFFFFF`
 - `acpi_level=0xFFFF5F` (implies `ACPI_ALL_COMPONENTS`)
 - `batman=VALUE` (`AppleSmartBatteryManager` debug mask)
 - `batman-nosmc=1` (disable `AppleSmartBatteryManager` SMC interface)
 - `cpus=VALUE` (maximum number of CPUs used)
 - `debug=VALUE` (debug mask)
 - `io=VALUE` (`IOKit` debug mask)
 - `keepsyms=1` (show panic log debug symbols)
 - `kextlog=VALUE` (kernel extension loading debug mask)
 - `nv_disable=1` (disables NVIDIA GPU acceleration)
 - `nvda_drv=1` (legacy way to enable NVIDIA web driver, removed in 10.12)
 - `npci=0x2000` (legacy, disables `kIOPCIConfiguratorPFM64`)
 - `lapic_dont_panic=1`
 - `slide=VALUE` (manually set KASLR slide)
 - `smcdebug=VALUE` (`AppleSMC` debug mask)
 - `-amd_no_dgpu_accel` (alternative to WhateverGreen's `-radvesa` for new GPUs)
 - `-nehalem_error_disable`
 - `-no_compat_check` (disable model checking)
 - `-s` (single mode)
 - `-v` (verbose mode)
 - `-x` (safe mode)

There are multiple external places summarising macOS argument lists: [example 1](#), [example 2](#).

- `7C436110-AB2A-4BBB-A880-FE41995C9F82:bootercfg`
Booter arguments, similar to `boot-args` but for `boot.efi`. Accepts a set of arguments, which are hexadecimal 64-bit values with or without `0x`. At different stages `boot.efi` will request different debugging (logging) modes (e.g. after `ExitBootServices` it will only print to serial). Several booter arguments control whether these requests

will succeed. The list of known requests is covered below:

- 0x00 - INIT.
- 0x01 - VERBOSE (e.g. -v, force console logging).
- 0x02 - EXIT.
- 0x03 - RESET:OK.
- 0x04 - RESET:FAIL (e.g. unknown board-id, hibernate mismatch, panic loop, etc.).
- 0x05 - RESET:RECOVERY.
- 0x06 - RECOVERY.
- 0x07 - REAN:START.
- 0x08 - REAN:END.
- 0x09 - DT (can no longer log to DeviceTree).
- 0x0A - EXITBS:START (forced serial only).
- 0x0B - EXITBS:END (forced serial only).
- 0x0C - UNKNOWN.

In 10.15 debugging support was mostly broken before 10.15.4 due to some kind of refactoring and introduction of a new debug protocol. Some of the arguments and their values below may not be valid for versions prior to 10.15.4. The list of known arguments is covered below:

- **boot-save-log=VALUE** — debug log save mode for normal boot.
 - * 0
 - * 1
 - * 2 — (default).
 - * 3
 - * 4 — (save to file).
- **wake-save-log=VALUE** — debug log save mode for hibernation wake.
 - * 0 — disabled.
 - * 1
 - * 2 — (default).
 - * 3 — (unavailable).
 - * 4 — (save to file, unavailable).
- **breakpoint=VALUE** — enables debug breaks (missing in production `boot.efi`).
 - * 0 — disables debug breaks on errors (default).
 - * 1 — enables debug breaks on errors.
- **console=VALUE** — enables console logging.
 - * 0 — disables console logging.
 - * 1 — enables console logging when debug protocol is missing (default).
 - * 2 — enables console logging unconditionally (unavailable).
- **embed-log-dt=VALUE** — enables DeviceTree logging.
 - * 0 — disables DeviceTree logging (default).
 - * 1 — enables DeviceTree logging.
- **kc-read-size=VALUE** — Chunk size used for buffered I/O from network or disk for prelinkedkernel reading and related. Set to 1MB (0x100000) by default, can be tuned for faster booting.
- **log-level=VALUE** — log level bitmask.
 - * 0x01 — enables trace logging (default).
- **serial=VALUE** — enables serial logging.
 - * 0 — disables serial logging (default).
 - * 1 — enables serial logging for EXITBS:END onwards.
 - * 1 — enables serial logging for EXITBS:START onwards.
 - * 3 — enables serial logging when debug protocol is missing.
 - * 4 — enables serial logging unconditionally.
- **timestamps=VALUE** — enables timestamp logging.
 - * 0 — disables timestamp logging.
 - * 1 — enables timestamp logging (default).
- **log=VALUE** — deprecated starting from 10.15.
 - * 1 — AppleLoggingConOutOrErrSet/AppleLoggingConOutOrErrPrint (classical ConOut/StdErr)
 - * 2 — AppleLoggingStdErrSet/AppleLoggingStdErrPrint (StdErr or serial?)
 - * 4 — AppleLoggingFileSet/AppleLoggingFilePrint (BOOTER.LOG/BOOTER.OLD file on EFI partition)
- **debug=VALUE** — deprecated starting from 10.15.

- * 1 — enables print something to `BOOTER.LOG` (stripped code implies there may be a crash)
- * 2 — enables perf logging to `/efi/debug-log` in the device tree
- * 4 — enables timestamp printing for styled printf calls
- `level=VALUE` — deprecated starting from 10.15. Verbosity level of `DEBUG` output. Everything but `0x80000000` is stripped from the binary, and this is the default value.

Note: To see verbose output from `boot.efi` on modern macOS versions enable `AppleDebug` option. This will save the log to general OpenCore log. For versions before 10.15.4 set `bootercfg` to `log=1`. This will print verbose output onscreen.

- `7C436110-AB2A-4BBB-A880-FE41995C9F82:bootercfg-once`
Booter arguments override removed after first launch. Otherwise equivalent to `bootercfg`.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:efiboot-perf-record`
Enable performance log saving in `boot.efi`. Performance log is saved to physical memory and is pointed by `efiboot-perf-record-data` and `efiboot-perf-record-size` variables. Starting from 10.15.4 it can also be saved to OpenCore log by `AppleDebug` option.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:fmm-computer-name`
Current saved host name. ASCII string.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:nvda_drv`
NVIDIA Web Driver control variable. Takes ASCII digit 1 or 0 to enable or disable installed driver.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:StartupMute`
Mute startup chime sound in firmware audio support. 8-bit integer. The value of `0x00` means unmuted. Missing variable or any other value means muted. This variable only affects Gibraltar machines (T2).
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:SystemAudioVolume`
System audio volume level for firmware audio support. 8-bit integer. The bit of `0x80` means muted. Lower bits are used to encode volume range specific to installed audio codec. The value is capped by `MaximumBootBeepVolume` AppleHDA layout value to avoid too loud audio playback in the firmware.

10 PlatformInfo

Platform information is comprised of several identification fields generated or filled manually to be compatible with macOS services. The base part of the configuration may be obtained from `AppleModels`, which itself generates a set of interfaces based on a database in YAML format. These fields are written to three select destinations:

- SMBIOS
- Data Hub
- NVRAM

Most of the fields specify the overrides in SMBIOS, and their field names conform to EDK2 SmBios.h header file. However, several important fields reside in Data Hub and NVRAM. Some of the values can be found in more than one field and/or destination, so there are two ways to control their update process: manual, where one specifies all the values (the default), and semi-automatic, where (`Automatic`) only select values are specified, and later used for system configuration.

To inspect SMBIOS contents dmidecode utility can be used. Version with macOS specific enhancements can be downloaded from Acidanthera/dmidecode.

10.1 Properties

1. Automatic

Type: plist boolean

Failsafe: false

Description: Generate PlatformInfo based on `Generic` section instead of using values from `DataHub`, `NVRAM`, and `SMBIOS` sections.

Enabling this option is useful when `Generic` section is flexible enough. When enabled `SMBIOS`, `DataHub`, and `PlatformNVRAM` data is unused.

2. UpdateDataHub

Type: plist boolean

Failsafe: false

Description: Update Data Hub fields. These fields are read from `Generic` or `DataHub` sections depending on `Automatic` value.

3. UpdateNVRAM

Type: plist boolean

Failsafe: false

Description: Update NVRAM fields related to platform information.

These fields are read from `Generic` or `PlatformNVRAM` sections depending on `Automatic` value. All the other fields are to be specified with `NVRAM` section.

If `UpdateNVRAM` is set to `false` the aforementioned variables can be updated with `NVRAM` section. If `UpdateNVRAM` is set to `true` the behaviour is undefined when any of the fields are present in `NVRAM` section.

4. UpdateSMBIOS

Type: plist boolean

Failsafe: false

Description: Update SMBIOS fields. These fields are read from `Generic` or `SMBIOS` sections depending on `Automatic` value.

5. UpdateSMBIOSMode

Type: plist string

Failsafe: Create

Description: Update SMBIOS fields approach:

- `TryOverwrite` — `Overwrite` if new size is \leq than the page-aligned original and there are no issues with legacy region unlock. `Create` otherwise. Has issues with some firmwares.
- `Create` — Replace the tables with newly allocated `EfiReservedMemoryType` at `AllocateMaxAddress` without any fallbacks.

- **Overwrite** — Overwrite existing gEfiSmbiosTableGuid and gEfiSmbiosTable3Guid data if it fits new size. Abort with unspecified state otherwise.
- **Custom** — Write SMBIOS tables (gEfiSmbios(3)TableGuid) to gOcCustomSmbios(3)TableGuid to workaround firmwares overwriting SMBIOS contents at ExitBootServices. Otherwise equivalent to **Create**. Requires patching AppleSmbios.kext and AppleACPIPlatform.kext to read from another GUID: "EB9D2D31" - "EB9D2D35" (in ASCII), done automatically by CustomSMBIOSGuid quirk.

Note: A side effect of using **Custom** approach is making SMBIOS updates exclusive to macOS, avoiding a collision with existing Windows activation and custom OEM software but potentially breaking Apple-specific tools.

6. Generic

Type: plist dictionary

Optional: When Automatic is false

Description: Update all fields. This section is read only when Automatic is active.

7. DataHub

Type: plist dictionary

Optional: When Automatic is true

Description: Update Data Hub fields. This section is read only when Automatic is not active.

8. PlatformNVRAM

Type: plist dictionary

Optional: When Automatic is true

Description: Update platform NVRAM fields. This section is read only when Automatic is not active.

9. SMBIOS

Type: plist dictionary

Optional: When Automatic is true

Description: Update SMBIOS fields. This section is read only when Automatic is not active.

10.2 Generic Properties

1. SpoofVendor

Type: plist boolean

Failsafe: false

Description: Sets SMBIOS vendor fields to Acidanthera.

It is dangerous to use Apple in SMBIOS vendor fields for reasons given in **SystemManufacturer** description. However, certain firmwares may not provide valid values otherwise, which could break some software.

2. AdviseWindows

Type: plist boolean

Failsafe: false

Description: Forces Windows support in FirmwareFeatures.

Added bits to FirmwareFeatures:

- FW_FEATURE_SUPPORTS_CSM_LEGACY_MODE (0x1) - Without this bit it is not possible to reboot to Windows installed on a drive with EFI partition being not the first partition on the disk.
- FW_FEATURE_SUPPORTS_UEFI_WINDOWS_BOOT (0x20000000) - Without this bit it is not possible to reboot to Windows installed on a drive with EFI partition being the first partition on the disk.

3. SystemProductName

Type: plist string

Failsafe: MacPro6,1

Description: Refer to SMBIOS SystemProductName.

4. SystemSerialNumber

Type: plist string

Failsafe: OPENCORE_SN1

Description: Refer to SMBIOS SystemSerialNumber.

5. SystemUUID
Type: plist string, GUID
Failsafe: OEM specified
Description: Refer to SMBIOS SystemUUID.
6. MLB
Type: plist string
Failsafe: OPENCORE_MLB_SN11
Description: Refer to SMBIOS BoardSerialNumber.
7. ROM
Type: plist data, 6 bytes
Failsafe: all zero
Description: Refer to 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ROM.

10.3 DataHub Properties

1. PlatformName
Type: plist string
Failsafe: Not installed
Description: Sets name in gEfiMiscSubClassGuid. Value found on Macs is platform in ASCII.
2. SystemProductName
Type: plist string
Failsafe: Not installed
Description: Sets Model in gEfiMiscSubClassGuid. Value found on Macs is equal to SMBIOS SystemProductName in Unicode.
3. SystemSerialNumber
Type: plist string
Failsafe: Not installed
Description: Sets SystemSerialNumber in gEfiMiscSubClassGuid. Value found on Macs is equal to SMBIOS SystemSerialNumber in Unicode.
4. SystemUUID
Type: plist string, GUID
Failsafe: Not installed
Description: Sets system-id in gEfiMiscSubClassGuid. Value found on Macs is equal to SMBIOS SystemUUID.
5. BoardProduct
Type: plist string
Failsafe: Not installed
Description: Sets board-id in gEfiMiscSubClassGuid. Value found on Macs is equal to SMBIOS BoardProduct in ASCII.
6. BoardRevision
Type: plist data, 1 byte
Failsafe: 0
Description: Sets board-rev in gEfiMiscSubClassGuid. Value found on Macs seems to correspond to internal board revision (e.g. 01).
7. StartupPowerEvents
Type: plist integer, 64-bit
Failsafe: 0
Description: Sets StartupPowerEvents in gEfiMiscSubClassGuid. Value found on Macs is power management state bitmask, normally 0. Known bits read by X86PlatformPlugin.kext:
 - 0x00000001 — Shutdown cause was a PWR0K event (Same as GEN_PMC0N_2 bit 0)
 - 0x00000002 — Shutdown cause was a SYS_PWR0K event (Same as GEN_PMC0N_2 bit 1)
 - 0x00000004 — Shutdown cause was a THRMTRIP# event (Same as GEN_PMC0N_2 bit 3)
 - 0x00000008 — Rebooted due to a SYS_RESET# event (Same as GEN_PMC0N_2 bit 4)
 - 0x00000010 — Power Failure (Same as GEN_PMC0N_3 bit 1 PWR_FLR)

- 0x00000020 — Loss of RTC Well Power (Same as GEN_PMCN_3 bit 2 RTC_PWR_STS)
- 0x00000040 — General Reset Status (Same as GEN_PMCN_3 bit 9 GEN_RST_STS)
- 0xffffffff80 — SUS Well Power Loss (Same as GEN_PMCN_3 bit 14)
- 0x00010000 — Wake cause was a ME Wake event (Same as PRSTS bit 0, ME_WAKE_STS)
- 0x00020000 — Cold Reboot was ME Induced event (Same as PRSTS bit 1 ME_HRST_COLD_STS)
- 0x00040000 — Warm Reboot was ME Induced event (Same as PRSTS bit 2 ME_HRST_WARM_STS)
- 0x00080000 — Shutdown was ME Induced event (Same as PRSTS bit 3 ME_HOST_PWRDN)
- 0x00100000 — Global reset ME Watchdog Timer event (Same as PRSTS bit 6)
- 0x00200000 — Global reset PowerManagement Watchdog Timer event (Same as PRSTS bit 15)

8. InitialTSC

Type: plist integer, 64-bit

Failsafe: 0

Description: Sets InitialTSC in gEfiProcessorSubClassGuid. Sets initial TSC value, normally 0.

9. FSBFrequency

Type: plist integer, 64-bit

Failsafe: Automatic

Description: Sets FSBFrequency in gEfiProcessorSubClassGuid.

Sets CPU FSB frequency. This value equals to CPU nominal frequency divided by CPU maximum bus ratio and is specified in Hz. Refer to MSR_NEHALEM_PLATFORM_INFO (CEh) MSR value to determine maximum bus ratio on modern Intel CPUs.

Note: This value is not used on Skylake and newer but is still provided to follow suit.

10. ARTFrequency

Type: plist integer, 64-bit

Failsafe: Automatic

Description: Sets ARTFrequency in gEfiProcessorSubClassGuid.

This value contains CPU ART frequency, also known as crystal clock frequency. Its existence is exclusive to Skylake generation and newer. The value is specified in Hz, and is normally 24 MHz for client Intel segment, 25 MHz for server Intel segment, and 19.2 MHz for Intel Atom CPUs. macOS till 10.15 inclusive assumes 24 MHz by default.

Note: On Intel Skylake X ART frequency may be a little less (approx. 0.25%) than 24 or 25 MHz due to special EMI-reduction circuit as described in Acidanthera Bugtracker.

11. DevicePathsSupported

Type: plist integer, 32-bit

Failsafe: Not installed

Description: Sets DevicePathsSupported in gEfiMiscSubClassGuid. Must be set to 1 for AppleACPIPlatform.kext to append SATA device paths to Boot#### and efi-boot-device-data variables. Set to 1 on all modern Macs.

12. SmcRevision

Type: plist data, 6 bytes

Failsafe: Not installed

Description: Sets REV in gEfiMiscSubClassGuid. Custom property read by VirtualSMC or FakeSMC to generate SMC REV key.

13. SmcBranch

Type: plist data, 8 bytes

Failsafe: Not installed

Description: Sets RBr in gEfiMiscSubClassGuid. Custom property read by VirtualSMC or FakeSMC to generate SMC RBr key.

14. SmcPlatform

Type: plist data, 8 bytes

Failsafe: Not installed

Description: Sets RPlt in gEfiMiscSubClassGuid. Custom property read by VirtualSMC or FakeSMC to generate SMC RPlt key.

10.4 PlatformNVRAM Properties

1. **BID**
Type: plist string
Failsafe: Not installed
Description: Specifies the value of NVRAM variable 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_BID.
2. **ROM**
Type: plist data, 6 bytes
Failsafe: Not installed
Description: Specifies the values of NVRAM variables 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_ROM and 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ROM.
3. **MLB**
Type: plist string
Failsafe: Not installed
Description: Specifies the values of NVRAM variables 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_MLB and 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:MLB.
4. **FirmwareFeatures**
Type: plist data, 8 bytes
Failsafe: Not installed
Description: This variable comes in pair with **FirmwareFeaturesMask**. Specifies the values of NVRAM variables:
 - 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:FirmwareFeatures
 - 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ExtendedFirmwareFeatures
5. **FirmwareFeaturesMask**
Type: plist data, 8 bytes
Failsafe: Not installed
Description: This variable comes in pair with **FirmwareFeatures**. Specifies the values of NVRAM variables:
 - 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:FirmwareFeaturesMask
 - 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ExtendedFirmwareFeaturesMask

10.5 SMBIOS Properties

1. **BIOSVendor**
Type: plist string
Failsafe: OEM specified
SMBIOS: BIOS Information (Type 0) — Vendor
Description: BIOS Vendor. All rules of **SystemManufacturer** do apply.
2. **BIOSVersion**
Type: plist string
Failsafe: OEM specified
SMBIOS: BIOS Information (Type 0) — BIOS Version
Description: Firmware version. This value gets updated and takes part in update delivery configuration and macOS version compatibility. This value could look like MM71.88Z.0234.B00.1809171422 in older firmwares, and is described in `BiosId.h`. In newer firmwares it should look like 236.0.0.0.0 or 220.230.16.0.0 (**iBridge:** 16.16.2542.0.0,0). **iBridge** version is read from **BridgeOSVersion** variable, and is only present on macs with T2.

Apple ROM Version

BIOS ID: MBP151.88Z.F000.B00.1811142212
Model: MBP151
EFI Version: 220.230.16.0.0
Built by: root@quinoa
Date: Wed Nov 14 22:12:53 2018
Revision: 220.230.16 (B&I)
ROM Version: F000_B00
Build Type: Official Build, RELEASE

Compiler: Apple LLVM version 10.0.0 (clang-1000.2.42)
UUID: E5D1475B-29FF-32BA-8552-682622BA42E1
UUID: 151B0907-10F9-3271-87CD-4BF5DBECACF5

3. BIOSReleaseDate
Type: plist string
Failsafe: OEM specified
SMBIOS: BIOS Information (Type 0) — BIOS Release Date
Description: Firmware release date. Similar to BIOSVersion. May look like 12/08/2017.
4. SystemManufacturer
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — Manufacturer
Description: OEM manufacturer of the particular board. Shall not be specified unless strictly required. Should *not* contain Apple Inc., as this confuses numerous services present in the operating system, such as firmware updates, efichk, as well as kernel extensions developed in Acidanthera, such as Lilu and its plugins. In addition it will also make some operating systems like Linux unbootable.
5. SystemProductName
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1), Product Name
Description: Preferred Mac model used to mark the device as supported by the operating system. This value must be specified by any configuration for later automatic generation of the related values in this and other SMBIOS tables and related configuration parameters. If SystemProductName is not compatible with the target operating system, `-no_compat_check` boot argument may be used as an override.

Note: If SystemProductName is unknown, and related fields are unspecified, default values should be assumed as being set to MacPro6,1 data. The list of known products can be found in AppleModels.
6. SystemVersion
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — Version
Description: Product iteration version number. May look like 1.1.
7. SystemSerialNumber
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — Serial Number
Description: Product serial number in defined format. Known formats are described in macserial.
8. SystemUUID
Type: plist string, GUID
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — UUID
Description: A UUID is an identifier that is designed to be unique across both time and space. It requires no central registration process.
9. SystemSKUNumber
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — SKU Number
Description: Mac Board ID (board-id). May look like Mac-7BA5B2D9E42DDD94 or Mac-F221BEC8 in older models. Sometimes it can be just empty.
10. SystemFamily
Type: plist string
Failsafe: OEM specified
SMBIOS: System Information (Type 1) — Family
Description: Family name. May look like iMac Pro.

11. **BoardManufacturer**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) - Manufacturer
Description: Board manufacturer. All rules of **SystemManufacturer** do apply.
12. **BoardProduct**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) - Product
Description: Mac Board ID (board-id). May look like Mac-7BA5B2D9E42DDD94 or Mac-F221BEC8 in older models.
13. **BoardVersion**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) - Version
Description: Board version number. Varies, may match **SystemProductName** or **SystemProductVersion**.
14. **BoardSerialNumber**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) — Serial Number
Description: Board serial number in defined format. Known formats are described in **macserial**.
15. **BoardAssetTag**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) — Asset Tag
Description: Asset tag number. Varies, may be empty or **Type2 - Board Asset Tag**.
16. **BoardType**
Type: plist integer
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) — Board Type
Description: Either 0xA (Motherboard (includes processor, memory, and I/O) or 0xB (Processor/Memory Module), refer to Table 15 – Baseboard: Board Type for more details.
17. **BoardLocationInChassis**
Type: plist string
Failsafe: OEM specified
SMBIOS: Baseboard (or Module) Information (Type 2) — Location in Chassis
Description: Varies, may be empty or **Part Component**.
18. **ChassisManufacturer**
Type: plist string
Failsafe: OEM specified
SMBIOS: System Enclosure or Chassis (Type 3) — Manufacturer
Description: Board manufacturer. All rules of **SystemManufacturer** do apply.
19. **ChassisType**
Type: plist integer
Failsafe: OEM specified
SMBIOS: System Enclosure or Chassis (Type 3) — Type
Description: Chassis type, refer to Table 17 — System Enclosure or Chassis Types for more details.
20. **ChassisVersion**
Type: plist string
Failsafe: OEM specified
SMBIOS: System Enclosure or Chassis (Type 3) — Version
Description: Should match **BoardProduct**.

- 21. ChassisSerialNumber
 - Type:** plist string
 - Failsafe:** OEM specified
 - SMBIOS:** System Enclosure or Chassis (Type 3) — Version
 - Description:** Should match SystemSerialNumber.
- 22. ChassisAssetTag
 - Type:** plist string
 - Failsafe:** OEM specified
 - SMBIOS:** System Enclosure or Chassis (Type 3) — Asset Tag Number
 - Description:** Chassis type name. Varies, could be empty or MacBook-Aluminum.
- 23. PlatformFeature
 - Type:** plist integer, 32-bit
 - Failsafe:** 0xFFFFFFFF
 - SMBIOS:** APPLE_SMBIOS_TABLE_TYPE133 - PlatformFeature
 - Description:** Platform features bitmask. Refer to AppleFeatures.h for more details. Use 0xFFFFFFFF value to not provide this table.
- 24. SmcVersion
 - Type:** plist data, 16 bytes
 - Failsafe:** All zero
 - SMBIOS:** APPLE_SMBIOS_TABLE_TYPE134 - Version
 - Description:** ASCII string containing SMC version in upper case. Missing on T2 based Macs. Ignored when zero.
- 25. FirmwareFeatures
 - Type:** plist data, 8 bytes
 - Failsafe:** 0
 - SMBIOS:** APPLE_SMBIOS_TABLE_TYPE128 - FirmwareFeatures and ExtendedFirmwareFeatures
 - Description:** 64-bit firmware features bitmask. Refer to AppleFeatures.h for more details. Lower 32 bits match FirmwareFeatures. Upper 64 bits match ExtendedFirmwareFeatures.
- 26. FirmwareFeaturesMask
 - Type:** plist data, 8 bytes
 - Failsafe:** 0
 - SMBIOS:** APPLE_SMBIOS_TABLE_TYPE128 - FirmwareFeaturesMask and ExtendedFirmwareFeaturesMask
 - Description:** Supported bits of extended firmware features bitmask. Refer to AppleFeatures.h for more details. Lower 32 bits match FirmwareFeaturesMask. Upper 64 bits match ExtendedFirmwareFeaturesMask.
- 27. ProcessorType
 - Type:** plist integer, 16-bit
 - Failsafe:** Automatic
 - SMBIOS:** APPLE_SMBIOS_TABLE_TYPE131 - ProcessorType
 - Description:** Combined of Processor Major and Minor types.
- 28. MemoryFormFactor
 - Type:** plist integer, 8-bit
 - Failsafe:** OEM specified
 - SMBIOS:** Memory Device (Type 17) — Form Factor
 - Description:** Memory form factor. On Macs it should be DIMM or SODIMM.

11 UEFI

11.1 Introduction

UEFI (Unified Extensible Firmware Interface) is a specification that defines a software interface between an operating system and platform firmware. This section allows to load additional UEFI modules and/or apply tweaks for the onboard firmware. To inspect firmware contents, apply modifications and perform upgrades UEFITool and supplementary utilities can be used.

11.2 Drivers

Depending on the firmware a different set of drivers may be required. Loading an incompatible driver may lead your system to unbootable state or even cause permanent firmware damage. Some of the known drivers are listed below:

AudioDxe*	HDA audio support driver in UEFI firmwares for most Intel and some other analog audio controllers. Staging driver, refer to acidanthera/bugtracker#740 for known issues in AudioDxe.
ExFatDxe	Proprietary ExFAT file system driver for Bootcamp support commonly found in Apple firmwares. For Sandy Bridge and earlier CPUs ExFatDxeLegacy driver should be used due to the lack of RDRAND instruction support.
HfsPlus	Proprietary HFS file system driver with bless support commonly found in Apple firmwares. For Sandy Bridge and earlier CPUs HfsPlusLegacy driver should be used due to the lack of RDRAND instruction support.
HiiDatabase*	HII services support driver from MdeModulePkg . This driver is included in most firmwares starting with Ivy Bridge generation. Some applications with the GUI like UEFI Shell may need this driver to work properly.
EnhancedFatDxe	FAT filesystem driver from FatPkg . This driver is embedded in all UEFI firmwares, and cannot be used from OpenCore. It is known that multiple firmwares have a bug in their FAT support implementation, which leads to corrupted filesystems on write attempt. Embedding this driver within the firmware may be required in case writing to EFI partition is needed during the boot process.
NvmExpressDxe*	NVMe support driver from MdeModulePkg . This driver is included in most firmwares starting with Broadwell generation. For Haswell and earlier embedding it within the firmware may be more favourable in case a NVMe SSD drive is installed.
OpenCanopy*	OpenCore plugin implementing graphical interface.
OpenRuntime*	OpenCore plugin implementing OC_FIRMWARE_RUNTIME protocol.
OpenUsbKbdDxe*	USB keyboard driver adding the support of AppleKeyMapAggregator protocols on top of a custom USB keyboard driver implementation. This is an alternative to builtin KeySupport , which may work better or worse depending on the firmware.
Ps2KeyboardDxe*	PS/2 keyboard driver from MdeModulePkg . OpenDuetPkg and some firmwares may not include this driver, but it is necessary for PS/2 keyboard to work. Note, unlike OpenUsbKbdDxe this driver has no AppleKeyMapAggregator support and thus requires KeySupport to be enabled.
Ps2MouseDxe*	PS/2 mouse driver from MdeModulePkg . Some very old laptop firmwares may not include this driver, but it is necessary for touchpad to work in UEFI graphical interfaces, such as OpenCanopy .
UsbMouseDxe*	USB mouse driver from MdeModulePkg . Some virtual machine firmwares like OVMF may not include this driver, but it is necessary for mouse to work in UEFI graphical interfaces, such as OpenCanopy .
VBoxHfs	HFS file system driver with bless support. This driver is an alternative to a closed source HfsPlus driver commonly found in Apple firmwares. While it is feature complete, it is approximately 3 times slower and is yet to undergo a security audit.
XhciDxe*	XHCI USB controller support driver from MdeModulePkg . This driver is included in most firmwares starting with Sandy Bridge generation. For earlier firmwares or legacy systems it may be used to support external USB 3.0 PCI cards.

Driver marked with * are bundled with OpenCore. To compile the drivers from UDK (EDK II) use the same command you normally use for OpenCore compilation, but choose a corresponding package:

```
git clone https://github.com/acidanthera/audk UDK
cd UDK
```

```
source edksetup.sh
make -C BaseTools
build -a X64 -b RELEASE -t XCODE5 -p FatPkg/FatPkg.dsc
build -a X64 -b RELEASE -t XCODE5 -p MdeModulePkg/MdeModulePkg.dsc
```

11.3 Tools

Standalone tools may help to debug firmware and hardware. Some of the known tools are listed below. While some tools can be launched from within OpenCore many should be run separately either directly or from **Shell**.

To boot into OpenShell or any other tool directly save **OpenShell.efi** under the name of **EFI\BOOT\BOOTX64.EFI** on a FAT32 partition. In general it is unimportant whether the partition scheme is GPT or MBR.

While the previous approach works both on Macs and other computers, an alternative Mac-only approach to bless the tool on an HFS+ or APFS volume:

```
sudo bless --verbose --file /Volumes/VOLNAME/DIR/OpenShell.efi \
--folder /Volumes/VOLNAME/DIR/ --setBoot
```

Listing 3: Blessing tool

Note 1: You may have to copy **/System/Library/CoreServices/BridgeVersion.bin** to **/Volumes/VOLNAME/DIR**.

Note 2: To be able to use **bless** you may have to disable System Integrity Protection.

Note 3: To be able to boot you may have to disable Secure Boot if present.

Some of the known tools are listed below (builtin tools are marked with *):

BootKicker*	Enter Apple BootPicker menu (exclusive for Macs with compatible GPUs).
ChipTune*	Test BeepGen protocol and generate audio signals of different style and length.
CleanNvram*	Reset NVRAM alternative bundled as a standalone tool.
GopStop*	Test GraphicsOutput protocol with a simple scenario.
HdaCodecDump*	Parse and dump High Definition Audio codec information (requires AudioDxe).
KeyTester*	Test keyboard input in SimpleText mode.
MemTest86	Memory testing utility.
OpenControl*	Unlock and lock back NVRAM protection for other tools to be able to get full NVRAM access when launching from OpenCore.
OpenShell*	OpenCore-configured UEFI Shell for compatibility with a broad range of firmwares.
PavpProvision	Perform EPID provisioning (requires certificate data configuration).
ResetSystem*	Utility to perform system reset. Takes reset type as an argument: ColdReset , WarmReset , Shutdown . Defaults to ColdReset .
RtcRw*	Utility to read and write RTC (CMOS) memory.
VerifyMsrE2*	Check CFG Lock (MSR 0xE2 write protection) consistency across all cores.

11.4 OpenCanopy

OpenCanopy is a graphical OpenCore user interface that runs in **External PickerMode** and relies on **OpenCorePkg** **OcBootManagementLib** similar to the builtin text interface.

OpenCanopy requires graphical resources located in **Resources** directory to run. Sample resources (fonts and images) can be found in **OcBinaryData** repository.

OpenCanopy provides full support for **PickerAttributes** and offers a configurable builtin icon set. The default chosen icon set depends on the **DefaultBackgroundColor** variable value. For **Light Gray Old** icon set will be used, for other colours — the one without a prefix.

Predefined icons are put to **\EFI\OC\Resources\Image** directory. Full list of supported icons (in **.icns** format) is provided below. Missing optional icons will use the closest available icon. External entries will use **Ext**-prefixed icon if available (e.g. **OldExtHardDrive.icns**).

- **Cursor** — Mouse cursor (mandatory).
- **Selected** — Selected item (mandatory).
- **Selector** — Selecting item (mandatory).

- **HardDrive** — Generic OS (mandatory).
- **Apple** — Apple OS.
- **AppleRecv** — Apple Recovery OS.
- **AppleTM** — Apple Time Machine.
- **Windows** — Windows.
- **Other** — Custom entry (see **Entries**).
- **ResetNVRAM** — Reset NVRAM system action or tool.
- **Shell** — Entry with UEFI Shell name (e.g. **OpenShell**).
- **Tool** — Any other tool.

Predefined labels are put to `\EFI\OC\Resources\Label` directory. Each label has `.1b1` or `.12x` suffix to represent the scaling level. Full list of labels is provided below. All labels are mandatory.

- **EFIBoot** — Generic OS.
- **Apple** — Apple OS.
- **AppleRecv** — Apple Recovery OS.
- **AppleTM** — Apple Time Machine.
- **Windows** — Windows.
- **Other** — Custom entry (see **Entries**).
- **ResetNVRAM** — Reset NVRAM system action or tool.
- **Shell** — Entry with UEFI Shell name (e.g. **OpenShell**).
- **Tool** — Any other tool.

Label and icon generation can be performed with bundled utilities: **disklabel** and **icnspack**. Please refer to sample data for the details about the dimensions. Font is Helvetica 12 pt times scale factor.

Font format corresponds to AngelCode binary BMF. While there are many utilities to generate font files, currently it is recommended to use **dpFontBaker** to generate bitmap font (using **CoreText** produces best results) and **fconverter** to export it to binary format.

WARNING: OpenCanopy is currently considered experimental and is not recommended for everyday use. Refer to [acidanthera/bugtracker#759](#) for more details regarding the current limitations.

11.5 OpenRuntime

OpenRuntime is an OpenCore plugin implementing `OC_FIRMWARE_RUNTIME` protocol. This protocol implements multiple features required for OpenCore that are otherwise not possible to implement in OpenCore itself as they are needed to work in runtime, i.e. during operating system functioning. Feature highlights:

- NVRAM namespaces, allowing to isolate operating systems from accessing select variables (e.g. **RequestBootVarRouting** or **ProtectSecureBoot**).
- Read-only and write-only NVRAM variables, enhancing the security of OpenCore, Lilu, and Lilu plugins, like VirtualSMC, which implements **AuthRestart** support.
- NVRAM isolation, allowing to protect all variables from being written from an untrusted operating system (e.g. **DisableVariableWrite**).
- UEFI Runtime Services memory protection management to workaround read-only mapping (e.g. **EnableWriteUnprotector**).

11.6 Properties

1. APFS

Type: plist dict

Failsafe: None

Description: Provide APFS support as configured in APFS Properties section below.

2. Audio

Type: plist dict

Failsafe: None

Description: Configure audio backend support described in Audio Properties section below.

Audio support provides a way for upstream protocols to interact with the selected hardware and audio resources. All audio resources should reside in `\EFI\OC\Resources\Audio` directory. Currently the only supported audio file format is WAVE PCM. While it is driver-dependent which audio stream format is supported, most common audio cards support 16-bit signed stereo audio at 44100 or 48000 Hz.

Audio file path is determined by audio type, audio localisation, and audio path. Each filename looks as follows: `[audio type]_[audio localisation]_[audio path].wav`. For unlocalised files filename does not include the language code and looks as follows: `[audio type]_[audio path].wav`.

- Audio type can be `OCEFIAudio` for OpenCore audio files or `AXEFIAudio` for macOS bootloader audio files.
- Audio localisation is a two letter language code (e.g. `en`) with an exception for Chinese, Spanish, and Portuguese. Refer to `APPLE_VOICE_OVER_LANGUAGE_CODE` definition for the list of all supported localisations.
- Audio path is the base filename corresponding to a file identifier. For macOS bootloader audio paths refer to `APPLE_VOICE_OVER_AUDIO_FILE` definition. For OpenCore audio paths refer to `OC_VOICE_OVER_AUDIO_FILE` definition. The only exception is OpenCore boot chime file, which is `OCEFIAudio_VoiceOver_Boot.wav`.

Audio localisation is determined separately for macOS bootloader and OpenCore. For macOS bootloader it is set in `preferences.efi` archive in `systemLanguage.utf8` file and is controlled by the operating system. For OpenCore the value of `prev-lang:kbd` variable is used. When native audio localisation of a particular file is missing, English language (`en`) localisation is used. Sample audio files can be found in OcBinaryData repository.

3. ConnectDrivers

Type: plist boolean

Failsafe: false

Description: Perform UEFI controller connection after driver loading.

This option is useful for loading drivers following UEFI driver model as they may not start by themselves. Examples of such drivers are filesystem or audio drivers. While effective, this option may not be necessary for drivers performing automatic connection, and may slightly slowdown the boot.

Note: Some firmwares, made by Apple in particular, only connect the boot drive to speedup the boot process. Enable this option to be able to see all the boot options when having multiple drives.

4. Drivers

Type: plist array

Failsafe: None

Description: Load selected drivers from `OC/Drivers` directory.

Designed to be filled with string filenames meant to be loaded as UEFI drivers.

5. Input

Type: plist dict

Failsafe: None

Description: Apply individual settings designed for input (keyboard and mouse) in Input Properties section below.

6. Output

Type: plist dict

Failsafe: None

Description: Apply individual settings designed for output (text and graphics) in Output Properties section below.

7. ProtocolOverrides

Type: plist dict

Failsafe: None

Description: Force builtin versions of select protocols described in ProtocolOverrides Properties section below.

Note: all protocol instances are installed prior to driver loading.

8. Quirks

Type: plist dict

Failsafe: None

Description: Apply individual firmware quirks described in Quirks Properties section below.

9. ReservedMemory

Type: plist array

Description: Designed to be filled with **plist dict** values, describing memory areas exquisite to particular firmware and hardware functioning, which should not be used by the operating system. An example of such memory region could be second 256 MB corrupted by Intel HD 3000 or an area with faulty RAM. See ReservedMemory Properties section below.

11.7 APFS Properties

1. EnableJumpstart

Type: plist boolean

Failsafe: false

Description: Load embedded APFS drivers from APFS containers.

APFS EFI driver is bundled in all bootable APFS containers. This option performs loading of signed APFS drivers with respect to **ScanPolicy**. See more details in “EFI Jumpstart” section of Apple File System Reference.

2. HideVerbose

Type: plist boolean

Failsafe: false

Description: Hide verbose output from APFS driver.

APFS verbose output can be useful for debugging.

3. JumpstartHotPlug

Type: plist boolean

Failsafe: false

Description: Load APFS drivers for newly connected devices.

Performs APFS driver loading not only at OpenCore startup but also during boot picker. This permits APFS USB hot plug. Disable if not required.

4. MinDate

Type: plist integer

Failsafe: 0

Description: Minimal allowed APFS driver date.

APFS driver date connects APFS driver with the calendar release date. Older versions of APFS drivers may contain unpatched vulnerabilities, which can be used to inflict harm on your computer. This option permits restricting APFS drivers to only recent releases.

- 0 — require the default supported release date of APFS in OpenCore. The default release date will increase with time and thus this setting is recommended. Currently set to 2018/06/21.
- -1 — permit any release date to load (strongly discouraged).
- Other — use custom minimal APFS release date, e.g. 20200401 for 2020/04/01. APFS release dates can be found in OpenCore boot log and **0cApfsLib**.

5. MinVersion

Type: plist integer

Failsafe: 0

Description: Minimal allowed APFS driver version.

APFS driver version connects APFS driver with the macOS release. APFS drivers from older macOS releases will become unsupported and thus may contain unpatched vulnerabilities, which can be used to inflict harm on your computer. This option permits restricting APFS drivers to only modern macOS versions.

- 0 — require the default supported version of APFS in OpenCore. The default version will increase with time and thus this setting is recommended. Currently set to the latest point release from High Sierra from App Store (748077008000000).
- -1 — permit any version to load (strongly discouraged).
- Other — use custom minimal APFS version, e.g. 1412101001000000 from macOS Catalina 10.15.4. APFS versions can be found in OpenCore boot log and **0cApfsLib**.

11.8 Audio Properties

1. AudioCodec

Type: plist integer

Failsafe: 0

Description: Codec address on the specified audio controller for audio support.

Normally this contains first audio codec address on the builtin analog audio controller (HDEF). Audio codec addresses, e.g. 2, can be found in the debug log (marked in bold):

OCAU: 1/3 PciRoot(0x0)/Pci(0x1,0x0)/Pci(0x0,0x1)/VenMsg(<redacted>,00000000) (4 outputs)

OCAU: 2/3 PciRoot(0x0)/Pci(0x3,0x0)/VenMsg(<redacted>,00000000) (1 outputs)

OCAU: 3/3 PciRoot(0x0)/Pci(0x1B,0x0)/VenMsg(<redacted>,02000000) (7 outputs)

As an alternative this value can be obtained from IOHDACodecDevice class in I/O Registry containing it in IOHDACodecAddress field.

2. AudioDevice

Type: plist string

Failsafe: empty string

Description: Device path of the specified audio controller for audio support.

Normally this contains builtin analog audio controller (HDEF) device path, e.g. PciRoot(0x0)/Pci(0x1b,0x0). The list of recognised audio controllers can be found in the debug log (marked in bold):

OCAU: 1/3 PciRoot(0x0)/Pci(0x1,0x0)/Pci(0x0,0x1)/VenMsg(<redacted>,00000000) (4 outputs)

OCAU: 2/3 PciRoot(0x0)/Pci(0x3,0x0)/VenMsg(<redacted>,00000000) (1 outputs)

OCAU: 3/3 PciRoot(0x0)/Pci(0x1B,0x0)/VenMsg(<redacted>,02000000) (7 outputs)

As an alternative `gfxutil -f HDEF` command can be used in macOS. Specifying empty device path will result in the first available audio controller to be used.

3. AudioOut

Type: plist integer

Failsafe: 0

Description: Index of the output port of the specified codec starting from 0.

Normally this contains the index of the green out of the builtin analog audio controller (HDEF). The number of output nodes (N) in the debug log (marked in bold):

OCAU: 1/3 PciRoot(0x0)/Pci(0x1,0x0)/Pci(0x0,0x1)/VenMsg(<redacted>,00000000) (4 outputs)

OCAU: 2/3 PciRoot(0x0)/Pci(0x3,0x0)/VenMsg(<redacted>,00000000) (1 outputs)

OCAU: 3/3 PciRoot(0x0)/Pci(0x1B,0x0)/VenMsg(<redacted>,02000000) (7 outputs)

The quickest way to find the right port is to bruteforce the values from 0 to N - 1.

4. AudioSupport

Type: plist boolean

Failsafe: false

Description: Activate audio support by connecting to a backend driver.

Enabling this setting routes audio playback from builtin protocols to a dedicated audio port (AudioOut) of the specified codec (AudioCodec) located on the audio controller (AudioDevice).

5. MinimumVolume

Type: plist integer

Failsafe: 0

Description: Minimal heard volume level from 0 to 100.

Screen reader will use this volume level, when the calculated volume level is less than MinimumVolume. Boot chime sound will not play if the calculated volume level is less than MinimumVolume.

6. PlayChime

Type: plist boolean

Failsafe: false

Description: Play chime sound at startup.

Enabling this setting plays boot chime through builtin audio support. Volume level is determined by `MinimumVolume` and `VolumeAmplifier` settings and `SystemAudioVolume` NVRAM variable.

Note: this setting is separate from `StartupMute` NVRAM variable to avoid conflicts when the firmware is able to play boot chime.

7. `VolumeAmplifier`

Type: plist integer

Failsafe: 0

Description: Multiplication coefficient for system volume to raw volume linear translation from 0 to 1000.

Volume level range read from `SystemAudioVolume` varies depending on the codec. To transform read value in `[0, 127]` range into raw volume range `[0, 100]` the read value is scaled to `VolumeAmplifier` percents:

$$RawVolume = MIN(\frac{SystemAudioVolume * VolumeAmplifier}{100}, 100)$$

Note: the transformation used in macOS is not linear, but it is very close and this nuance is thus ignored.

11.9 Input Properties

1. `KeyFiltering`

Type: plist boolean

Failsafe: false

Description: Enable keyboard input sanity checking.

Apparently some boards like GA Z77P-D3 may return uninitialised data in `EFI_INPUT_KEY` with all input protocols. This option discards keys that are neither ASCII, nor are defined in the UEFI specification (see tables 107 and 108 in version 2.8).

2. `KeyForgetThreshold`

Type: plist integer

Failsafe: 0

Description: Remove key unless it was submitted during this timeout in milliseconds.

`AppleKeyMapAggregator` protocol is supposed to contain a fixed length buffer of currently pressed keys. However, the majority of the drivers only report key presses as interrupts and pressing and holding the key on the keyboard results in subsequent submissions of this key with some defined time interval. As a result we use a timeout to remove once pressed keys from the buffer once the timeout expires and no new submission of this key happened.

This option allows to set this timeout based on your platform. The recommended value that works on the majority of the platforms is 5 milliseconds. For reference, holding one key on VMware will repeat it roughly every 2 milliseconds and the same value for APTIO V is 3-4 milliseconds. Thus it is possible to set a slightly lower value on faster platforms and slightly higher value on slower platforms for more responsive input.

3. `KeyMergeThreshold`

Type: plist integer

Failsafe: 0

Description: Assume simultaneous combination for keys submitted within this timeout in milliseconds.

Similarly to `KeyForgetThreshold`, this option works around the sequential nature of key submission. To be able to recognise simultaneously pressed keys in the situation when all keys arrive sequentially, we are required to set a timeout within which we assume the keys were pressed together.

Holding multiple keys results in reports every 2 and 1 milliseconds for VMware and APTIO V respectively. Pressing keys one after the other results in delays of at least 6 and 10 milliseconds for the same platforms. The recommended value for this option is 2 milliseconds, but it may be decreased for faster platforms and increased for slower.

4. `KeySupport`

Type: plist boolean

Failsafe: false

Description: Enable internal keyboard input translation to `AppleKeyMapAggregator` protocol.

This option activates the internal keyboard interceptor driver, based on `AppleGenericInput` aka (`AptioInputFix`), to fill `AppleKeyMapAggregator` database for input functioning. In case a separate driver is used, such as `OpenUsbKbDxe`, this option should never be enabled.

5. `KeySupportMode`

Type: plist string

Failsafe: empty string

Description: Set internal keyboard input translation to `AppleKeyMapAggregator` protocol mode.

- **Auto** — Performs automatic choice as available with the following preference: `AMI`, `V2`, `V1`.
- **V1** — Uses UEFI standard legacy input protocol `EFI_SIMPLE_TEXT_INPUT_PROTOCOL`.
- **V2** — Uses UEFI standard modern input protocol `EFI_SIMPLE_TEXT_INPUT_EX_PROTOCOL`.
- **AMI** — Uses APTIO input protocol `AMI_EFIKEYCODE_PROTOCOL`.

Note: Currently `V1`, `V2`, and `AMI` unlike `Auto` only do filtering of the particular specified protocol. This may change in the future versions.

6. `KeySwap`

Type: plist boolean

Failsafe: false

Description: Swap `Command` and `Option` keys during submission.

This option may be useful for keyboard layouts with `Option` key situated to the right of `Command` key.

7. `PointerSupport`

Type: plist boolean

Failsafe: false

Description: Enable internal pointer driver.

This option implements standard UEFI pointer protocol (`EFI_SIMPLE_POINTER_PROTOCOL`) through select OEM protocols. The option may be useful on Z87 ASUS boards, where `EFI_SIMPLE_POINTER_PROTOCOL` is broken.

8. `PointerSupportMode`

Type: plist string

Failsafe: empty string

Description: Set OEM protocol used for internal pointer driver.

Currently the only supported variant is `ASUS`, using specialised protocol available on select Z87 and Z97 ASUS boards. More details can be found in `LongSoft/UefiTool#116`.

9. `TimerResolution`

Type: plist integer

Failsafe: 0

Description: Set architecture timer resolution.

This option allows to update firmware architecture timer period with the specified value in 100 nanosecond units. Setting a lower value generally improves performance and responsiveness of the interface and input handling.

The recommended value is 50000 (5 milliseconds) or slightly higher. Select ASUS Z87 boards use 60000 for the interface. Apple boards use 100000. You may leave it as 0 in case there are issues.

11.10 Output Properties

1. `TextRenderer`

Type: plist string

Failsafe: `BuiltinGraphics`

Description: Chooses renderer for text going through standard console output.

Currently two renderers are supported: `Builtin` and `System`. `System` renderer uses firmware services for text rendering. `Builtin` bypassing firmware services and performs text rendering on its own. Different renderers support a different set of options. It is recommended to use `Builtin` renderer, as it supports HiDPI mode and uses full screen resolution.

UEFI firmwares generally support `ConsoleControl` with two rendering modes: `Graphics` and `Text`. Some firmwares do not support `ConsoleControl` and rendering modes. OpenCore and macOS expect text to only be

shown in **Graphics** mode and graphics to be drawn in any mode. Since this is not required by UEFI specification, exact behaviour varies.

Valid values are combinations of text renderer and rendering mode:

- **BuiltinGraphics** — Switch to **Graphics** mode and use **Builtin** renderer with custom **ConsoleControl**.
- **SystemGraphics** — Switch to **Graphics** mode and use **System** renderer with custom **ConsoleControl**.
- **SystemText** — Switch to **Text** mode and use **System** renderer with custom **ConsoleControl**.
- **SystemGeneric** — Use **System** renderer with system **ConsoleControl** assuming it behaves correctly.

The use of **BuiltinGraphics** is generally straightforward. For most platforms it is necessary to enable **ProvideConsoleGop**, set **Resolution** to **Max**.

The use of **System** protocols is more complicated. In general the preferred setting is **SystemGraphics** or **SystemText**. Enabling **ProvideConsoleGop**, setting **Resolution** to **Max**, enabling **ReplaceTabWithSpace** is useful on almost all platforms. **SanitiseClearScreen**, **IgnoreTextInGraphics**, and **ClearScreenOnModeSwitch** are more specific, and their use depends on the firmware.

Note: Some Macs, namely **MacPro5,1**, may have broken console output with newer GPUs, and thus only **BuiltinGraphics** may work for them.

2. ConsoleMode

Type: plist string

Failsafe: Empty string

Description: Sets console output mode as specified with the **WxH** (e.g. **80x24**) formatted string.

Set to empty string not to change console mode. Set to **Max** to try to use largest available console mode. Currently **Builtin** text renderer supports only one console mode, so this option is ignored.

Note: This field is best to be left empty on most firmwares.

3. Resolution

Type: plist string

Failsafe: Empty string

Description: Sets console output screen resolution.

- Set to **WxH@Bpp** (e.g. **1920x1080@32**) or **WxH** (e.g. **1920x1080**) formatted string to request custom resolution from GOP if available.
- Set to empty string not to change screen resolution.
- Set to **Max** to try to use largest available screen resolution.

On HiDPI screens **APPLE_VENDOR_VARIABLE_GUID UIScale** NVRAM variable may need to be set to **02** to enable HiDPI scaling in **Builtin** text renderer, FileVault 2 UEFI password interface, and boot screen logo. Refer to Recommended Variables section for more details.

Note: This will fail when console handle has no GOP protocol. When the firmware does not provide it, it can be added with **ProvideConsoleGop** set to **true**.

4. ClearScreenOnModeSwitch

Type: plist boolean

Failsafe: false

Description: Some firmwares clear only part of screen when switching from graphics to text mode, leaving a fragment of previously drawn image visible. This option fills the entire graphics screen with black color before switching to text mode.

Note: This option only applies to **System** renderer.

5. DirectGopRendering

Type: plist boolean

Failsafe: false

Description: Use builtin graphics output protocol renderer for console.

On some firmwares this may provide better performance or even fix rendering issues, like on **MacPro5,1**. However, it is recommended not to use this option unless there is an obvious benefit as it may even result in slower scrolling.

6. IgnoreTextInGraphics

Type: plist boolean

Failsafe: false

Description: Select firmwares output text onscreen in both graphics and text mode. This is normally unexpected, because random text may appear over graphical images and cause UI corruption. Setting this option to **true** will discard all text output when console control is in mode different from **Text**.

Note: This option only applies to **System** renderer.

7. ReplaceTabWithSpace

Type: plist boolean

Failsafe: false

Description: Some firmwares do not print tab characters or even everything that follows them, causing difficulties or inability to use the UEFI Shell builtin text editor to edit property lists and other documents. This option makes the console output spaces instead of tabs.

Note: This option only applies to **System** renderer.

8. ProvideConsoleGop

Type: plist boolean

Failsafe: false

Description: Ensure GOP (Graphics Output Protocol) on console handle.

macOS bootloader requires GOP to be present on console handle, yet the exact location of GOP is not covered by the UEFI specification. This option will ensure GOP is installed on console handle if it is present.

Note: This option will also replace broken GOP protocol on console handle, which may be the case on **MacPro5,1** with newer GPUs.

9. ReconnectOnResChange

Type: plist boolean

Failsafe: false

Description: Reconnect console controllers after changing screen resolution.

On some firmwares when screen resolution is changed via GOP, it is required to reconnect the controllers, which produce the console protocols (simple text out). Otherwise they will not produce text based on the new resolution.

Note: On several boards this logic may result in black screen when launching OpenCore from Shell and thus it is optional. In versions prior to 0.5.2 this option was mandatory and not configurable. Please do not use this unless required.

10. SanitiseClearScreen

Type: plist boolean

Failsafe: false

Description: Some firmwares reset screen resolution to a failsafe value (like 1024x768) on the attempts to clear screen contents when large display (e.g. 2K or 4K) is used. This option attempts to apply a workaround.

Note: This option only applies to **System** renderer. On all known affected systems **ConsoleMode** had to be set to empty string for this to work.

11.11 ProtocolOverrides Properties

1. AppleAudio

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple audio protocols with builtin versions.

Apple audio protocols allow macOS bootloader and OpenCore to play sounds and signals for screen reading or audible error reporting. Supported protocols are beep generation and VoiceOver. VoiceOver protocol is specific to Gibraltar machines (T2) and is not supported before macOS High Sierra (10.13). Instead older macOS versions use AppleHDA protocol, which is currently not implemented.

Only one set of audio protocols can be available at a time, so in order to get audio playback in OpenCore user interface on Mac system implementing some of these protocols this setting should be enabled.

Note: Backend audio driver needs to be configured in UEFI **Audio** section for these protocols to be able to stream audio.

2. AppleBootPolicy

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple Boot Policy protocol with a builtin version. This may be used to ensure APFS compatibility on VMs or legacy Macs.

Note: Some Macs, namely **MacPro5,1**, do have APFS compatibility, but their Apple Boot Policy protocol contains recovery detection issues, thus using this option is advised on them as well.

3. AppleDebugLog

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple Debug Log protocol with a builtin version.

4. AppleEvent

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple Event protocol with a builtin version. This may be used to ensure File Vault 2 compatibility on VMs or legacy Macs.

5. AppleImageConversion

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple Image Conversion protocol with a builtin version.

6. AppleKeyMap

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple Key Map protocols with builtin versions.

7. AppleRtcRam

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple RTC RAM protocol with builtin version.

Note: Builtin version of Apple RTC RAM protocol may filter out I/O attempts to select RTC memory addresses. The list of addresses can be specified in **4D1FDA02-38C7-4A6A-9CC6-4BCCA8B30102:rtc-blacklist** variable as a data array.

8. AppleSmcIo

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple SMC I/O protocol with a builtin version.

This protocol replaces legacy **VirtualSmc** UEFI driver, and is compatible with any SMC kernel extension. However, in case **FakeSMC** kernel extension is used, manual NVRAM key variable addition may be needed.

9. AppleUserInterfaceTheme

Type: plist boolean

Failsafe: false

Description: Reinstalls Apple User Interface Theme protocol with a builtin version.

10. DataHub

Type: plist boolean

Failsafe: false

Description: Reinstalls Data Hub protocol with a builtin version. This will delete all previous properties if the protocol was already installed.

11. DeviceProperties

Type: plist boolean

Failsafe: false

Description: Reinstalls Device Property protocol with a builtin version. This will delete all previous properties if it was already installed. This may be used to ensure full compatibility on VMs or legacy Macs.

12. **FirmwareVolume**

Type: plist boolean

Failsafe: false

Description: Forcibly wraps Firmware Volume protocols or installs new to support custom cursor images for File Vault 2. Should be set to **true** to ensure File Vault 2 compatibility on everything but VMs and legacy Macs.

Note: Several virtual machines including VMware may have corrupted cursor image in HiDPI mode and thus may also require this setting to be enabled.

13. **HashServices**

Type: plist boolean

Failsafe: false

Description: Forcibly reinstalls Hash Services protocols with builtin versions. Should be set to **true** to ensure File Vault 2 compatibility on platforms providing broken SHA-1 hashing. Can be diagnosed by invalid cursor size with **UIScale** set to 02, in general platforms prior to APTIO V (Haswell and older) are affected.

14. **OSInfo**

Type: plist boolean

Failsafe: false

Description: Forcibly reinstalls OS Info protocol with builtin versions. This protocol is generally used to receive notifications from macOS bootloader, by the firmware or by other applications.

15. **UnicodeCollation**

Type: plist boolean

Failsafe: false

Description: Forcibly reinstalls unicode collation services with builtin version. Should be set to **true** to ensure UEFI Shell compatibility on platforms providing broken unicode collation. In general legacy Insyde and APTIO platforms on Ivy Bridge and earlier are affected.

11.12 Quirks Properties

1. **DeduplicateBootOrder**

Type: plist boolean

Failsafe: false

Description: Remove duplicate entries in **BootOrder** variable in **EFI_GLOBAL_VARIABLE_GUID**.

This quirk requires **RequestBootVarRouting** to be enabled and therefore **OC_FIRMWARE_RUNTIME** protocol implemented in **OpenRuntime.efi**.

By redirecting **Boot** prefixed variables to a separate GUID namespace with the help of **RequestBootVarRouting** quirk we achieve multiple goals:

- Operating systems are jailed and only controlled by OpenCore boot environment to enhance security.
- Operating systems do not mess with OpenCore boot priority, and guarantee fluent updates and hibernation wakes for cases that require reboots with OpenCore in the middle.
- Potentially incompatible boot entries, such as macOS entries, are not deleted or anyhow corrupted.

However, some firmwares do their own boot option scanning upon startup by checking file presence on the available disks. Quite often this scanning includes non-standard locations, such as Windows Bootloader paths. Normally it is not an issue, but some firmwares, ASUS firmwares on APTIO V in particular, have bugs. For them scanning is implemented improperly, and firmware preferences may get accidentally corrupted due to **BootOrder** entry duplication (each option will be added twice) making it impossible to boot without cleaning NVRAM.

To trigger the bug one should have some valid boot options (e.g. OpenCore) and then install Windows with **RequestBootVarRouting** enabled. As Windows bootloader option will not be created by Windows installer, the firmware will attempt to create it itself, and then corrupt its boot option list.

This quirk removes all duplicates in **BootOrder** variable attempting to resolve the consequences of the bugs upon OpenCore loading. It is recommended to use this key along with **BootProtect** option.

2. ExitBootServicesDelay

Type: plist integer

Failsafe: 0

Description: Adds delay in microseconds after EXIT_BOOT_SERVICES event.

This is a very ugly quirk to circumvent "Still waiting for root device" message on select APTIO IV firmwares, namely ASUS Z87-Pro, when using FileVault 2 in particular. It seems that for some reason they execute code in parallel to EXIT_BOOT_SERVICES, which results in SATA controller being inaccessible from macOS. A better approach should be found in some future. Expect 3-5 seconds to be enough in case the quirk is needed.

3. IgnoreInvalidFlexRatio

Type: plist boolean

Failsafe: false

Description: Select firmwares, namely APTIO IV, may contain invalid values in MSR_FLEX_RATIO (0x194) MSR register. These values may cause macOS boot failure on Intel platforms.

Note: While the option is not supposed to induce harm on unaffected firmwares, its usage is not recommended when it is not required.

4. ReleaseUsbOwnership

Type: plist boolean

Failsafe: false

Description: Attempt to detach USB controller ownership from the firmware driver. While most firmwares manage to properly do that, or at least have an option for, select firmwares do not. As a result, operating system may freeze upon boot. Not recommended unless required.

5. RequestBootVarRouting

Type: plist boolean

Failsafe: false

Description: Request redirect of all Boot prefixed variables from EFI_GLOBAL_VARIABLE_GUID to OC_VENDOR_VARIABLE_GUID.

This quirk requires OC_FIRMWARE_RUNTIME protocol implemented in OpenRuntime.efi. The quirk lets default boot entry preservation at times when firmwares delete incompatible boot entries. Simply said, you are required to enable this quirk to be able to reliably use Startup Disk preference pane in a firmware that is not compatible with macOS boot entries by design.

6. UnblockFsConnect

Type: plist boolean

Failsafe: false

Description: Some firmwares block partition handles by opening them in By Driver mode, which results in File System protocols being unable to install.

Note: The quirk is mostly relevant for select HP laptops with no drives listed.

11.13 ReservedMemory Properties

1. Address

Type: plist integer

Failsafe: 0

Description: Start address of the reserved memory region, which should be allocated as reserved effectively marking the memory of this type inaccessible to the operating system.

The addresses written here must be part of the memory map, have EfiConventionalMemory type, and page-aligned (4 KBs).

2. Comment

Type: plist string

Failsafe: Empty string

Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

3. Size

Type: plist integer

Failsafe: 0

Description: Size of the reserved memory region, must be page-aligned (4 KBs).

4. Enabled

Type: plist boolean

Failsafe: false

Description: This region will not be reserved unless set to **true**.

12 Troubleshooting

12.1 Windows support

Can I install Windows?

While no official Windows support is provided, 64-bit UEFI Windows installations (Windows 8 and above) prepared with Boot Camp are supposed to work. Third-party UEFI installations as well as systems partially supporting UEFI boot, like Windows 7, might work with some extra precautions. Things to keep in mind:

- MBR (Master Boot Record) installations are legacy and will not be supported.
- To install Windows, macOS, and OpenCore on the same drive you can specify Windows bootloader path (`\EFI\Microsoft\Boot\bootmgfw.efi`) in `BlessOverride` section.
- All the modifications applied (to ACPI, NVRAM, SMBIOS, etc.) are supposed to be operating system agnostic, i.e. apply equally regardless of the OS booted. This enables Boot Camp software experience on Windows.
- macOS requires the first partition to be EFI System Partition, and does not support the default Windows layout. While OpenCore does have a workaround for this, it is highly recommend not to rely on it and install properly.
- Windows may need to be reactivated. To avoid it consider setting `SystemUUID` to the original firmware UUID. Be warned, on old firmwares it may be invalid, i.e. not random. In case you still have issues, consider using `HWID` or `KMS38` license or making the use `Custom UpdateSMBIOSMode`. Other nuances of Windows activation are out of the scope of this document and can be found online.

What additional software do I need?

To enable operating system switching and install relevant drivers in the majority of cases you will need Windows support software from Boot Camp. For simplicity of the download process or when configuring an already installed Windows version a third-party utility, Brigadier, can be used successfully. Note, that you may have to download and install 7-Zip prior to using Brigadier.

Remember to always use the latest version of Windows support software from Boot Camp, as versions prior to 6.1 do not support APFS, and thus will not function correctly. To download newest software pass most recent Mac model to Brigadier, for example `./brigadier.exe -m iMac19,1`. To install Boot Camp on an unsupported Mac model afterwards run PowerShell as Administrator and enter `msiexec /i BootCamp.msi`. In case you already have a previous version of Boot Camp installed you will have to remove it first by running `msiexec /x BootCamp.msi` command. `BootCamp.msi` file is located in `BootCamp/Drivers/Apple` directory and can be reached through Windows Explorer.

While Windows support software from Boot Camp solves most of compatibility problems, sometimes you may have to address some of them manually:

- To invert mouse wheel scroll direction `FlipFlopWheel` must be set to 1 as explained on SuperUser.
- `RealTimeIsUniversal` must be set to 1 to avoid time desync between Windows and macOS as explained on SuperUser (this one is usually not needed).
- To access Apple filesystems like HFS and APFS separate software may need to be installed. Some of the known utilities are: Apple HFS+ driver (hack for Windows 10), HFSExplorer, MacDrive, Paragon APFS, Paragon HFS+, TransMac, etc. Remember to never ever attempt to modify Apple file systems from Windows as this often leads to irrecoverable data loss.

Why do I see Basic data partition in Boot Camp Startup Disk control panel?

Boot Camp control panel uses GPT partition table to obtain each boot option name. After installing Windows separately you will have to relabel the partition manually. This can be done with many utilities including open-source `gdisk` utility. Reference example:

```
PS C:\gdisk> .\gdisk64.exe \\.\\physicaldrive0
GPT fdisk (gdisk) version 1.0.4
```

```
Command (? for help): p
Disk \\.\\physicaldrive0: 419430400 sectors, 200.0 GiB
Sector size (logical): 512 bytes
Disk identifier (GUID): DEC57EB1-B3B5-49B2-95F5-3B8C4D3E4E12
```

Partition table holds up to 128 entries
Main partition table begins at sector 2 and ends at sector 33
First usable sector is 34, last usable sector is 419430366
Partitions will be aligned on 2048-sector boundaries
Total free space is 4029 sectors (2.0 MiB)

Number	Start (sector)	End (sector)	Size	Code	Name
1	2048	1023999	499.0 MiB	2700	Basic data partition
2	1024000	1226751	99.0 MiB	EF00	EFI system partition
3	1226752	1259519	16.0 MiB	0C01	Microsoft reserved ...
4	1259520	419428351	199.4 GiB	0700	Basic data partition

Command (? for help): c
Partition number (1-4): 4
Enter name: BOOTCAMP

Command (? for help): w

Final checks complete. About to write GPT data. THIS WILL OVERWRITE EXISTING PARTITIONS!!

Do you want to proceed? (Y/N): Y
OK; writing new GUID partition table (GPT) to \\.\physicaldrive0.
Disk synchronization succeeded! The computer should now use the new partition table.
The operation has completed successfully.

Listing 4: Relabeling Windows volume

How to choose Windows BOOTCAMP with custom NTFS drivers?

Third-party drivers providing NTFS support, such as NTFS-3G, Paragon NTFS, Tuxera NTFS or Seagate Paragon Driver break certain macOS functionality, including Startup Disk preference pane normally used for operating system selection. While the recommended option remains not to use such drivers as they commonly corrupt the filesystem, and prefer the driver bundled with macOS with optional write support (command or GUI), there still exist vendor-specific workarounds for their products: Tuxera, Paragon, etc.

12.2 Debugging

Similar to other projects working with hardware OpenCore supports auditing and debugging. The use of NOOPT or DEBUG build modes instead of RELEASE can produce a lot more debug output. With NOOPT source level debugging with GDB or IDA Pro is also available. For GDB check OpenCore Debug page. For IDA Pro you will need IDA Pro 7.3 or newer, refer to Debugging the XNU Kernel with IDA Pro for more details.

To obtain the log during boot you can make the use of serial port debugging. Serial port debugging is enabled in Target, e.g. 0xB for onscreen with serial. OpenCore uses 115200 baud rate, 8 data bits, no parity, and 1 stop bit. For macOS your best choice are CP2102-based UART devices. Connect motherboard TX to USB UART RX, and motherboard GND to USB UART GND. Use screen utility to get the output, or download GUI software, such as CoolTerm.

Note: On several motherboards (and possibly USB UART dongles) PIN naming may be incorrect. It is very common to have GND swapped with RX, thus you have to connect motherboard “TX” to USB UART GND, and motherboard “GND” to USB UART RX.

Remember to enable COM port in firmware settings, and never use USB cables longer than 1 meter to avoid output corruption. To additionally enable XNU kernel serial output you will need debug=0x8 boot argument.

12.3 Tips and Tricks

1. How to debug boot failure?

Normally it is enough to obtain the actual error message. For this ensure that:

- You have a DEBUG or NOOPT version of OpenCore.

- Logging is enabled (1) and shown onscreen (2): `Misc → Debug → Target = 3`.
- Logged messages from at least `DEBUG_ERROR` (0x80000000), `DEBUG_WARN` (0x00000002), and `DEBUG_INFO` (0x00000040) levels are visible onscreen: `Misc → Debug → DisplayLevel = 0x80000042`.
- Critical error messages, like `DEBUG_ERROR`, stop booting: `Misc → Security → HaltLevel = 0x80000000`.
- Watch Dog is disabled to prevent automatic reboot: `Misc → Debug → DisableWatchDog = true`.
- Boot Picker (entry selector) is enabled: `Misc → Boot → ShowPicker = true`.

If there is no obvious error, check the available hacks in **Quirks** sections one by one. For early boot troubleshooting, for instance, when OpenCore menu does not appear, using `UEFI Shell` (bundled with OpenCore) may help to see early debug messages.

2. How to debug macOS boot failure?

- Refer to `boot-args` values like `debug=0x100`, `keepsym=1`, `-v`, and similar.
- Do not forget about `AppleDebug` and `ApplePanic` properties.
- Take care of `Booter`, `Kernel`, and `UEFI` quirks.
- Consider using serial port to inspect early kernel boot failures. For this you may need `debug=0x108`, `serial=5`, and `msgbuf=1048576` arguments. Refer to the patches in `Sample.plist` when dying before serial init.
- Always read the logs carefully.

3. How to customise boot entries?

OpenCore follows standard Apple Bless model and extracts the entry name from `.contentDetails` and `.disk_label.contentDetails` files in the booter directory if present. These files contain an ASCII string with an entry title, which may then be customised by the user.

4. How to choose the default boot entry?

OpenCore uses the primary UEFI boot option to select the default entry. This choice can be altered from UEFI Setup, with the macOS Startup Disk preference, or the Windows Boot Camp Control Panel. Since choosing OpenCore's `BOOTx64.EFI` as a primary boot option limits this functionality in addition to several firmwares deleting incompatible boot options, potentially including those created by macOS, you are strongly encouraged to use the `RequestBootVarRouting` quirk, which will preserve your selection made in the operating system within the OpenCore variable space. Note, that `RequestBootVarRouting` requires a separate driver for functioning.

5. What is the simplest way to install macOS?

Copy online recovery image (`*.dmg` and `*.chunklist` files) to `com.apple.recovery.boot` directory on a FAT32 partition with OpenCore. Load OpenCore Boot Picker and choose the entry, it will have a `(dmg)` suffix. Custom name may be created by providing `.contentDetails` file.

To download recovery online you may use `macrecovery.py`, builtin tool.

For offline installation refer to [How to create a bootable installer for macOS](#) article. Apart from App Store and `softwareupdate` utility there also are third-party utilities to download an offline image.

6. Why do online recovery images (*.dmg) fail to load?

This may be caused by missing HFS+ driver, as all presently known recovery volumes have HFS+ filesystem.

7. Can I use this on Apple hardware or virtual machines?

Sure, most relatively modern Mac models including `MacPro5,1` and virtual machines are fully supported. Even though there are little to none specific details relevant to Mac hardware, some ongoing instructions can be found on [MacRumors.com](#).

8. Why do Find&Replace patches must equal in length?

For machine code (x86 code) it is not possible to do differently sized replacements due to relative addressing. For ACPI code this is risky, and is technically equivalent to ACPI table replacement, thus not implemented. More detailed explanation can be found on [AppleLife.ru](#) or in the **ACPI** section of this document.

9. How can I decide which Booter quirks to use?

These quirks originate from `AptioMemoryFix` driver but provide a wider set of changes specific to modern systems. Note, that `OpenRuntime` driver is required for most configurations. To get a configuration similar to `AptioMemoryFix` you may try enabling the following set of quirks:

- `ProvideConsoleGop` (UEFI quirk)
- `AvoidRuntimeDefrag`
- `DiscardHibernateMap`
- `EnableSafeModeSlide`
- `EnableWriteUnprotector`
- `ForceExitBootServices`
- `ProtectMemoryRegions`
- `ProvideCustomSlide`
- `RebuildAppleMemoryMap`
- `SetupVirtualMap`

However, as of today such set is strongly discouraged as some of these quirks are not necessary to be enabled or need additional quirks. For example, `DevirtualiseMmio` and `ProtectUefiServices` are often required, while `DiscardHibernateMap` and `ForceExitBootServices` are rarely necessary.

Unfortunately for some quirks like `RebuildAppleMemoryMap`, `EnableWriteUnprotector`, `ProtectMemoryRegions`, `RebuildAppleMemoryMap`, `SetupVirtualMap`, and `SyncRuntimePermissions` there is no definite approach even on similar systems, so trying all their combinations may be required for optimal setup. Refer to individual quirk descriptions in this document for more details.