



OpenCore

Reference Manual (0.7.3)

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Contents

1	Introduction	3
1.1	Generic Terms	3
2	Configuration	4
2.1	Configuration Terms	4
2.2	Configuration Processing	4
2.3	Configuration Structure	5
3	Setup	6
3.1	Directory Structure	6
3.2	Installation and Upgrade	7
3.3	Contribution	8
3.4	Coding conventions	9
3.5	Debugging	10
4	ACPI	11
4.1	Introduction	11
4.2	Properties	11
4.3	Add Properties	12
4.4	Delete Properties	12
4.5	Patch Properties	13
4.6	Quirks Properties	14
5	Booter	16
5.1	Introduction	16
5.2	Properties	16
5.3	MmioWhitelist Properties	17
5.4	Patch Properties	17
5.5	Quirks Properties	18
6	DeviceProperties	23
6.1	Introduction	23
6.2	Properties	23
6.3	Common Properties	23
7	Kernel	25
7.1	Introduction	25
7.2	Properties	25
7.3	Add Properties	26
7.4	Block Properties	27
7.5	Emulate Properties	27
7.6	Force Properties	29
7.7	Patch Properties	29
7.8	Quirks Properties	31
7.9	Scheme Properties	34
8	Misc	37
8.1	Introduction	37
8.2	Properties	38
8.3	Boot Properties	39
8.4	Debug Properties	44
8.5	Security Properties	47
8.6	Entry Properties	53
9	NVRAM	55
9.1	Introduction	55

9.2	Properties	55
9.3	Mandatory Variables	56
9.4	Recommended Variables	56
9.5	Other Variables	57
10	PlatformInfo	61
10.1	Properties	61
10.2	Generic Properties	63
10.3	DataHub Properties	64
10.4	Memory Properties	66
10.5	PlatformNVRAM Properties	69
10.6	SMBIOS Properties	69
11	UEFI	74
11.1	Introduction	74
11.2	Drivers	74
11.3	Tools and Applications	75
11.4	OpenCanopy	76
11.5	OpenRuntime	76
11.6	OpenLinuxBoot	77
11.7	Properties	79
11.8	APFS Properties	80
11.9	AppleInput Properties	81
11.10	Audio Properties	83
11.11	Drivers Properties	85
11.12	Input Properties	85
11.13	Output Properties	87
11.14	ProtocolOverrides Properties	90
11.15	Quirks Properties	92
11.16	ReservedMemory Properties	94
12	Troubleshooting	95
12.1	Legacy Apple OS	95
12.2	UEFI Secure Boot	96
12.3	Windows support	97
12.4	Debugging	98
12.5	Tips and Tricks	99

1 Introduction

This document provides information on the format of the OpenCore user configuration file used to set up the correct functioning of the 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 to be documentation or implementation issues which should be reported via the Acidanthera Bugtracker. An errata sheet is available in OpenCorePkg repository.

This document is structured as a specification and is not meant to provide a step-by-step guide to configuring an end-user Board Support Package (BSP). The intended audience of the document is anticipated to be programmers and engineers with a basic understanding of macOS internals and UEFI functionality. 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 similar, may be more useful for a wider audience as they could provide guide-like material. However, they are subject to their authors' preferences, misinterpretations of this document, and unavoidable obsolescence. In cases of using such sources, such as Dortania's OpenCore Install Guide and related material, please refer back to this document on every decision made and re-evaluate potential implications.

Please note that regardless of the sources used, users are required to fully understand every OpenCore configuration option, and the principles behind them, before posting issues to the Acidanthera Bugtracker.

Note: Creating this document would not have been possible without the invaluable contributions from other people: Andrey1970, Goldfish64, dakanji, PMheart, and several others, with the full list available in OpenCorePkg history.

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 multidata** — 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 (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 provides an extensible way to configure OpenCore and is structured to be separated into multiple named sections situated under the root **plist** dictionary. These sections may 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 the **#** symbol (e.g. **#Hello**) are also considered **valid keys** and while they behave as comments, effectively discarding their values, they are still required to be **valid plist objects**. All other **plist keys** are not valid, and their presence results in **undefined behaviour**.
- **valid value** — **valid plist object** of **OC config** described in this document that matches all the additional requirements in specific **plist object** descriptions 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** descriptions (e.g. value range), or missing from the corresponding collection. **Invalid values** are 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 values**, applying incompatible values to the host system may result in **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. Implementations shall prevent the boot process from continuing until the host system is restarted. It is permitted, but not required, to execute cold reboots or to show warning messages in such cases.
- **undefined behaviour** — behaviour not prescribed by this document. Implementations may take any measures including, but not limited to, measures associated with **fatal behaviour**, assumptions of any state or value, or disregarding any associated states or values. This is however subject to such measures not negatively impacting upon system integrity.

2.2 Configuration Processing

The **OC config** file is guaranteed to be processed at least once if found. Subject to the OpenCore bootstrapping mechanism, the presence of multiple **OC config** files may lead to the reading of any of them. It is permissible for no **OC Config** file to be present on disk. In such cases, if the implementation does not abort the boot process, all values shall follow the rules of **invalid values** and **optional values**.

The **OC config** file has restrictions on size, nesting levels, and number of keys:

- The **OC config** file size shall not exceed **32 MBs**.
- The **OC config** file shall not have more than **32** nesting levels.
- The **OC config** file may have up to **32,768** XML nodes within each **plist object**.
 - One **plist dictionary** item is counted as a pair of nodes

Reading malformed **OC config** files results in **undefined behaviour**. Examples of malformed **OC config** files include the following:

- **OC config** files that do not conform to DTD **PLIST 1.0**.
- **OC config** files with unsupported or non-conformant **plist objects** found in this document.
- **OC config** files violating restrictions on size, nesting levels, and number of keys.

It is recommended, but not required, to abort loading malformed **OC config** files and to continue as if an **OC config** file is not present. For forward compatibility, it is recommended, but not required, for the implementation to warn about the use of **invalid values**.

The recommended approach to interpreting `invalid` values is to conform to the following convention where applicable:

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

2.3 Configuration Structure

The `OC config` file is separated into subsections, as described in separate sections of this document, and is designed so as to attempt not to enable anything by default as well as to provide kill switches via an `Enable` property for `plist dict` entries that represent optional plugins and similar.

The file is structured to group related elements in subsections as follows:

- `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 workarounds.

Root configuration entries consist of the following:

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

Basic validation of an `OC config` file is possible using the `ocvalidate` utility. Please note that the version of `ocvalidate` used must match the OpenCore release and that notwithstanding this, it may not detect all configuration issues present in an `OC config` file.

Note: To maintain system integrity, properties typically have predefined values even when such predefined values are not specified in the `OC config` file. However, all properties must be explicitly specified in the `OC config` file and this behaviour should not be relied on.

3 Setup

3.1 Directory Structure

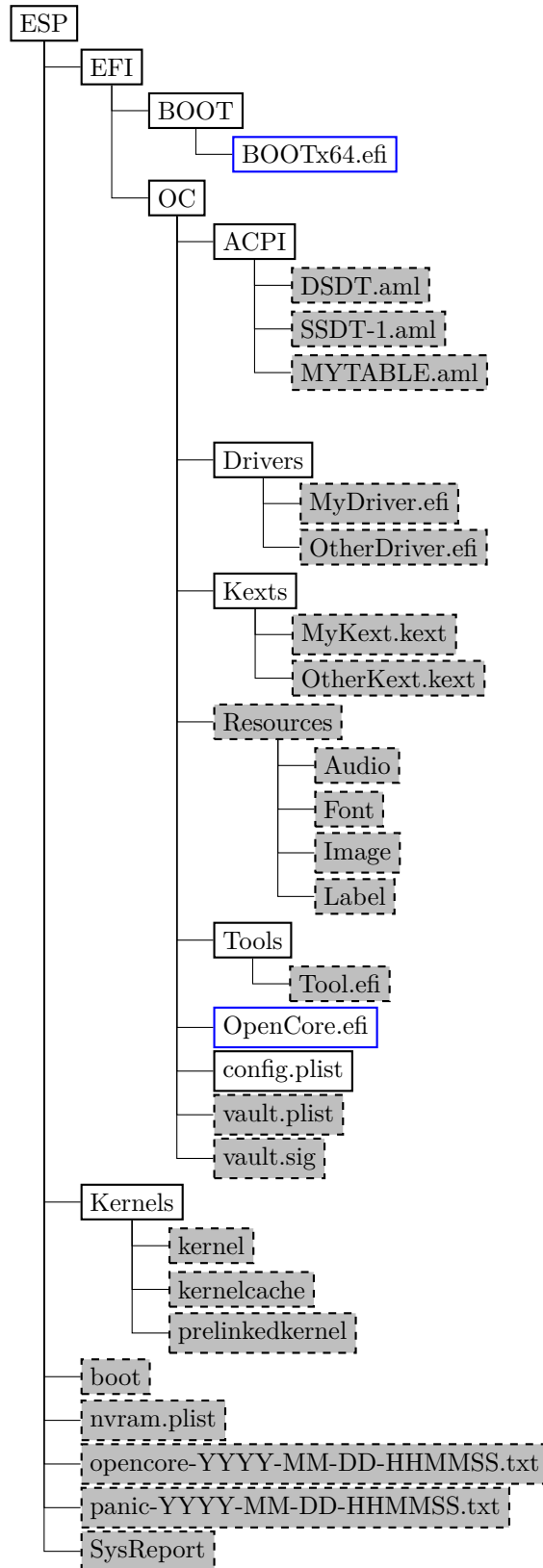


Figure 1. Directory Structure

When directory boot is used, the directory structure used should follow the descriptions in the Directory Structure

figure. Available entries include:

- `BOOTx64.efi` or `BOOTIa32.efi`
Initial bootstrap loaders, which load `OpenCore.efi`. `BOOTx64.efi` is loaded by the firmware by default consistent with the UEFI specification. However, it may also be renamed and put in a custom location to allow OpenCore coexist alongside operating systems, such as Windows, that use `BOOTx64.efi` files as their loaders. Refer to the `LauncherOption` property for details.
- `boot`
Duet bootstrap loader, which initialises the UEFI environment on legacy BIOS firmware and loads `OpenCore.efi` similarly to other bootstrap loaders. A modern Duet bootstrap loader will default to `OpenCore.efi` on the same partition when present.
- `ACPI`
Directory used for storing supplemental ACPI information for the ACPI section.
- `Drivers`
Directory used for storing supplemental UEFI drivers for UEFI section.
- `Kexts`
Directory used for storing supplemental kernel information for the `Kernel` section.
- `Resources`
Directory used for storing media resources such as audio files for screen reader support. Refer to the `UEFI Audio Properties` section for details. This directory also contains image files for graphical user interface. Refer to the `OpenCanopy` section for details.
- `Tools`
Directory used for storing supplemental tools.
- `OpenCore.efi`
Main booter application responsible for operating system loading. The directory `OpenCore.efi` resides in is called the `root` directory, which is set to `EFI\OC` by default. When launching `OpenCore.efi` directly or through a custom launcher however, other directories containing `OpenCore.efi` files are also supported.
- `config.plist`
OC Config.
- `vault.plist`
Hashes for all files potentially loadable by OC Config.
- `vault.sig`
Signature for `vault.plist`.
- `SysReport`
Directory containing system reports generated by `SysReport` option.
- `nvr.am.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 the 0-terminator) will be accessible within OpenCore.

3.2 Installation and Upgrade

To install OpenCore, replicate the Configuration Structure described in the previous section in the EFI volume of a GPT partition. While corresponding sections of this document provide some information regarding external resources such as 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 the OpenCore repository. Vaulting information is provided in the Security Properties section of this document.

The `OC config` file, as with any property list file, can be edited with any text editor, such as `nano` or `vim`. However, specialised software may provide a better experience. On macOS, the preferred GUI application is `Xcode`. For a lightweight cross-platform and open-source alternative, the `ProperTree` editor can be utilised.

It is strongly advised not to use any software that is aware of the internal configuration structure as it constantly gets out of date and will cause incorrect configuration to be generated. If it is a must despite the warning one should make sure to only use stable versions of OpenCore with explicit support for the particular version in the app. The choice of

open-source implementations with transparent binary generation is encouraged (e.g. OCAT), since other tools may contain malware. Remember that a configuration made for a different hardware setup shall never be used on another hardware setup.

For BIOS booting, a third-party UEFI environment provider is required and `OpenDuetPkg` is one such UEFI environment provider for legacy systems. To run OpenCore on such a legacy system, `OpenDuetPkg` can be installed with a dedicated tool — `BootInstall` (bundled with OpenCore). Third-party utilities can be used to perform this on systems other than macOS.

For upgrade purposes, refer to the `Differences.pdf` document which provides information about changes to the configuration (as compared to the previous release) as well as to the `Changelog.md` document (which contains a list of modifications across all published updates).

3.3 Contribution

OpenCore can be compiled as a standard EDK II package and requires the EDK II Stable package. The currently supported EDK II release is hosted in `acidanthera/audk`. Required patches for this package can be found in the `Patches` directory.

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

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

```
git clone --depth=1 https://github.com/acidanthera/audk UDK
cd UDK
git submodule update --init --recommend-shallow
git clone --depth=1 https://github.com/acidanthera/OpenCorePkg
. ./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 using Language Server Protocols. For example, Sublime Text with LSP for Sublime Text plugin. Add `compile_flags.txt` file with similar content to the 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/Nvidia
-I/UefiPackages/OpenCorePkg/Include/VMware
-I/UefiPackages/OvmfPkg/Include
-I/UefiPackages/ShellPkg/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
```

Listing 2: ECC Configuration

Note: `/UefiPackages` in the sample file denotes an absolute path.

Warning: Tool developers modifying `config.plist` or any other OpenCore files must ensure that their tools check the `opencore-version` NVRAM variable (see the Debug Properties section below) and warn users if the version listed is unsupported or prerelease. The OpenCore configuration may change across releases and such tools shall ensure that they carefully follow this document. Failure to do so may result in such tools being considered to be malware and blocked by any means.

3.4 Coding conventions

As with any other project, we have conventions that we follow during development. All third-party contributors are advised to adhere to the conventions listed below before submitting patches. To minimise abortive work and the potential rejection of submissions, third-party contributors should initially raise issues to the Acidanthera Bugtracker for feedback before submitting patches.

Organisation. The codebase is contained in the `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 the EDK II codestyle with a 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 two spaces to indent function arguments when splitting lines.
- Prefix public functions with either `Oc` or another distinct name.
- Do not prefix private `static` functions, but prefix private `non-static` functions with `Internal`.
- 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.

The `git-bisect` functionality may be useful when trying to find problematic changes. Unofficial sources of `per-commit` OpenCore binary builds, such as `Dortania`, may also be useful.

4 ACPI

4.1 Introduction

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

To compile and disassemble ACPI tables, the iASL compiler developed by ACPICA can be used. A 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 (consistent with the ACPI specification, not possible before the operating system boots), operating system chainloading, and difficult ACPI debugging. Hence, more attention may be required when writing changes to `_OSI`.

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.

There are several sources of ACPI tables and workarounds. Commonly used ACPI tables are provided with OpenCore, VirtualSMC, VoodooPS2, and WhateverGreen releases. Besides those, several third-party instructions may be found on the AppleLife Laboratory and DSDT subforums (e.g. Battery register splitting guide). A slightly more user-friendly explanation of some tables included with OpenCore can also be found in Dortania’s Getting started with ACPI guide. For more exotic cases, there are several alternatives such as daliansky’s ACPI sample collection (English Translation by 5T33Z0 et al). Please note however, that suggested solutions from third parties may be outdated or may contain errors.

4.2 Properties

1. Add

Type: `plist array`

Failsafe: Empty

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

To be filled with `plist dict` values, describing each add entry. Refer to the Add Properties section below for details.

2. Delete

Type: `plist array`

Failsafe: Empty

Description: Remove selected tables from the ACPI stack.

To be filled with `plist dict` values, describing each delete entry. Refer to the Delete Properties section below for details.

3. Patch

Type: `plist array`

Failsafe: Empty

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

To be filled with `plist dictionary` values describing each patch entry. Refer to the Patch Properties section below for details.

4. Quirks

Type: `plist dict`

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

4.3 Add Properties

1. **Comment**
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
2. **Enabled**
Type: plist boolean
Failsafe: false
Description: Set to true to add this ACPI table.
3. **Path**
Type: plist string
Failsafe: Empty
Description: File paths meant to be loaded as ACPI tables. Example values include `DSDT.aml`, `SubDir/SSDT-8.aml`, `SSDT-USBX.aml`, etc.

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

Note: All tables apart from tables with a DSDT table identifier (determined by parsing data, not by filename) insert new tables into the ACPI stack. DSDT tables perform a replacement of DSDT tables instead.

4.4 Delete Properties

1. **All**
Type: plist boolean
Failsafe: false (Only delete the first matched table)
Description: Set to true to delete all ACPI tables matching the condition.
2. **Comment**
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
3. **Enabled**
Type: plist boolean
Failsafe: false
Description: Set to true to remove this ACPI table.
4. **OemTableId**
Type: plist data, 8 bytes
Failsafe: All zero (Match any table OEM ID)
Description: Match table OEM ID equal to this value.
5. **TableLength**
Type: plist integer
Failsafe: 0 (Match any table size)
Description: Match table size equal to this value.
6. **TableSignature**
Type: plist data, 4 bytes
Failsafe: All zero (Match any table signature)
Description: Match table signature equal to this value.

Note: Do not use table signatures when the sequence must be replaced in multiple places. This is particularly relevant when performing different types of renames.

4.5 Patch Properties

1. **Base**
Type: plist string
Failsafe: Empty (Ignored)
Description: Selects ACPI path base for patch lookup (or immediate replacement) by obtaining the offset to the provided path.

Only fully-qualified absolute paths are supported (e.g. `_SB.PCI0.LPCB.HPET`). Currently supported object types are: `Device`, `Field`, `Method`.

Note: Use with care, not all OEM tables can be parsed. Use `ACPIe` utility to debug. `ACPIe` compiled with `DEBUG=1` make command produces helpful ACPI lookup tracing.
2. **BaseSkip**
Type: plist integer
Failsafe: 0 (Do not skip any occurrences)
Description: Number of found `Base` occurrences to skip before finds and replacements are applied.
3. **Comment**
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
4. **Count**
Type: plist integer
Failsafe: 0 (Apply patch to all occurrences found)
Description: Number of occurrences to patch.
5. **Enabled**
Type: plist boolean
Failsafe: false
Description: Set to `true` to apply this ACPI patch.
6. **Find**
Type: plist data
Failsafe: Empty
Description: Data to find. Must be equal to `Replace` in size if set.

Note: Can be empty, when `Base` is specified, immediate replacement after `Base` lookup happens in this case.
7. **Limit**
Type: plist integer
Failsafe: 0 (Search entire ACPI table)
Description: Maximum number of bytes to search for.
8. **Mask**
Type: plist data
Failsafe: Empty (Ignored)
Description: Data bitwise mask used during find comparison. Allows fuzzy search by ignoring not masked (set to zero) bits. Must be equal to `Replace` in size if set.
9. **OemTableId**
Type: plist data, 8 bytes
Failsafe: All zero (Match any table OEM ID)
Description: Match table OEM ID equal to this value.
10. **Replace**
Type: plist data
Failsafe: Empty
Description: Replacement data of one or more bytes.

11. **ReplaceMask**
Type: plist data
Failsafe: Empty (Ignored)
Description: Data bitwise mask used during replacement. Allows fuzzy replacement by updating masked (set to non-zero) bits. Must be equal to **Replace** in size if set.
12. **Skip**
Type: plist integer
Failsafe: 0 (Do not skip any occurrences)
Description: Number of found occurrences to skip before replacements are applied.
13. **TableLength**
Type: plist integer
Failsafe: 0 (Match any table size)
Description: Match table size equal to this value.
14. **TableSignature**
Type: plist data, 4 bytes
Failsafe: All zero (Match any table signature)
Description: Match table signature equal to this value.

In most cases, ACPI patches are not useful and are harmful:

- Avoid renaming devices with ACPI patches. This may fail or perform improper renaming of unrelated devices (e.g. **EC** and **ECO**), be unnecessary, or even fail to rename devices in certain tables. For ACPI consistency it is much safer to rename devices at the I/O Registry level, as done by **WhateverGreen**.
- Avoid patching **_OSI** to support a higher feature set level whenever possible. While this enables a number of workarounds on **APTIO** firmware, it typically results in a need for additional patches. These are not usually needed on modern firmware and smaller patches work well on firmware that does. However, laptop vendors often rely on this method to determine the availability of functions such as modern I2C input support, thermal adjustment and custom feature additions.
- Avoid patching embedded controller event **_Qxx** just to enable brightness keys. The conventional process to find these keys typically involves significant modifications to **DSDT** and **SSDT** files and in addition, the debug kext is not stable on newer systems. Please use the built-in brightness key discovery in **BrightnessKeys** instead.
- Avoid making ad hoc changes such as renaming **_PRW** or **_DSM** whenever possible.

Some cases where patching is actually useful 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 a custom method implementation within an **SSDT**, to inject shutdown fixes on certain computers for instance, the original method can be replaced with a dummy name by patching **_PTS** with **ZPTS** and adding a callback to the original method.

The **Tianocore AcpiAml.h** source file may help with better understanding ACPI opcodes.

Note: Patches of different **Find** and **Replace** lengths are unsupported as they may corrupt ACPI tables and make the system unstable due to area relocation. If such changes are needed, the utilisation of “proxy” patching or the padding of **NOP** to the remaining area could be considered.

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.

 Mainly required on legacy hardware and a few newer laptops. Can also fix power-button shortcuts. Not recommended unless required.

2. NormalizeHeaders

Type: plist boolean

Failsafe: false

Description: Cleanup ACPI header fields to workaround macOS ACPI implementation flaws that result in boot crashes. Reference: Debugging AppleACPIPlatform on 10.13 by Alex James (also known as theracermaster). The issue was 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 the underlying firmware implementation. Among the position-independent code, ACPI tables may contain the physical addresses of MMIO areas used for device configuration, typically grouped by region (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 results in the shift of the addresses in the aforementioned `OperationRegion` constructions.

For this reason, the application of modifications to ACPI tables is extremely risky. The best approach is to make as few changes as possible to ACPI tables and to avoid replacing any tables, particularly DSDT tables. When this cannot be avoided, ensure that any custom DSDT tables are based on the most recent DSDT tables or attempt to remove reads and writes 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 is not a magic bullet however, and only works with the most typical cases. Do not use unless absolutely required as it can have the opposite effect on certain platforms and result in boot failures.

4. ResetHwSig

Type: plist boolean

Failsafe: false

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

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

6. SyncTableIds

Type: plist boolean

Failsafe: false

Description: Sync table identifiers with the SLIC table.

This works around patched tables becoming incompatible with the SLIC table causing licensing issues in older Windows operating systems.

5 Booter

5.1 Introduction

This section allows the application of different types of UEFI modifications to operating system bootloaders, primarily the Apple bootloader (`boot.efi`). The modifications currently provide various patches and environment alterations for different firmware types. Some of these features were originally implemented as part of `AptioMemoryFix.efi`, which is no longer maintained. Refer to the Tips and Tricks section for instructions on migration.

If this is used for the first time on customised firmware, the following requirements should be met before starting:

- Most up-to-date UEFI firmware (check the 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 the ASUS WS-X299-PRO, this option results in adverse effects and must be disabled. While no other motherboards with the same issue are known, this option should be checked first whenever erratic boot failures are encountered.
- `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 the system cannot be booted at all or `No slide values are usable! Use custom slide!` message can be seen in the log.
- `CFG Lock` (MSR 0xE2 write protection) disabled in firmware settings if present. Refer to the `ControlMsrE2` notes for details.
- `CSM` (Compatibility Support Module) disabled in firmware settings if present. On NVIDIA 6xx/AMD 2xx or older, `GOP ROM` may have to be flashed first. Use `GopUpdate` (see the second post) or `AMD UEFI GOP MAKER` in case of any potential confusion.
- `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 `Thunderbolt support`, `Intel SGX`, and `Intel Platform Trust` may have to be disabled in firmware settings present.

When debugging sleep issues, `Power Nap` and automatic power off (which appear to sometimes cause wake to black screen or boot loop issues on older platforms) may be temporarily disabled. The specific issues may vary, but `ACPI` tables should typically be looked at first.

Here is an example of a defect found on 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 be reset by hardware changes and in certain other circumstances. To view their current state, use the `pmset -g` command in Terminal.

5.2 Properties

1. `MmioWhitelist`
Type: `plist array`
Description: To be filled with `plist dict` values, describing addresses critical for particular firmware functioning when `DevirtualiseMmio` quirk is in use. Refer to the `MmioWhitelist Properties` section below for details.
2. `Patch`
Type: `plist array`
Failsafe: `Empty`
Description: Perform binary patches in booter.

To be filled with `plist dictionary` values, describing each patch. Refer to the `Patch Properties` section below for details.
3. `Quirks`
Type: `plist dict`
Description: Apply individual booter quirks described in the `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. The debug log can be used to find the list of the candidates.

2. Comment

Type: plist string

Failsafe: Empty

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

3. Enabled

Type: plist boolean

Failsafe: false

Description: Exclude MMIO address from the devirtualisation procedure.

5.4 Patch Properties

1. Arch

Type: plist string

Failsafe: Any (Apply to any supported architecture)

Description: Booter patch architecture (`i386`, `x86_64`).

2. Comment

Type: plist string

Failsafe: Empty

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

3. Count

Type: plist integer

Failsafe: 0 (Apply to all occurrences found)

Description: Number of patch occurrences to apply.

4. Enabled

Type: plist boolean

Failsafe: false

Description: Set to `true` to activate this booter patch.

5. Find

Type: plist data

Failsafe: Empty

Description: Data to find. Must be equal to `Replace` in size if set.

6. Identifier

Type: plist string

Failsafe: Any (Match any booter)

Description: Apple for macOS booter (typically `boot.efi`); or a name with a suffix, such as `bootmgfw.efi`, for a specific booter.

7. Limit

Type: plist integer

Failsafe: 0 (Search the entire booter)

Description: Maximum number of bytes to search for.

8. **Mask**
Type: plist data
Failsafe: Empty (Ignored)
Description: Data bitwise mask used during find comparison. Allows fuzzy search by ignoring not masked (set to zero) bits. Must be equal to `Find` in size if set.
9. **Replace**
Type: plist data
Failsafe: Empty
Description: Replacement data of one or more bytes.
10. **ReplaceMask**
Type: plist data
Failsafe: Empty (Ignored)
Description: Data bitwise mask used during replacement. Allows fuzzy replacement by updating masked (set to non-zero) bits. Must be equal to `Replace` in size if set.
11. **Skip**
Type: plist integer
Failsafe: 0 (Do not skip any occurrences)
Description: Number of found occurrences to skip before replacements are applied.

5.5 Quirks Properties

1. **AllowRelocationBlock**
Type: plist boolean
Failsafe: false
Description: Allows booting macOS through a relocation block.

The relocation block is a scratch buffer allocated in the lower 4 GB used for loading the kernel and related structures by `EfiBoot` on firmware where the lower memory region is otherwise occupied by (assumed) non-runtime data. Right before kernel startup, the relocation block is copied back to lower addresses. Similarly, all the other addresses pointing to the relocation block are also carefully adjusted. The relocation block can be used when:

- No better slide exists (all the memory is used)
- `slide=0` is forced (by an argument or safe mode)
- KASLR (`slide`) is unsupported (this is macOS 10.7 or older)

This quirk requires `ProvideCustomSlide` to be enabled and typically also requires enabling `AvoidRuntimeDefrag` to function correctly. Hibernation is not supported when booting with a relocation block, which will only be used if required when the quirk is enabled.

Note: While this quirk is required to run older macOS versions on platforms with used lower memory, it is not compatible with some hardware and macOS 11. In such cases, consider using `EnableSafeModeSlide` instead.

2. **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 firmware that uses SMM backing for certain services such as variable storage. SMM may try to access memory by physical addresses in non-SMM areas but this may sometimes have been moved by `boot.efi`. This option prevents `boot.efi` from moving such data.

Note: Most types of firmware, apart from Apple and VMware, need this quirk.

3. **DevirtualiseMmio**
Type: plist boolean
Failsafe: false
Description: Remove runtime attribute from certain MMIO regions.

This quirk reduces the stolen memory footprint in the memory map by removing the runtime bit for known memory regions. This quirk may result in an increase of KASLR slides available but without additional measures,

it is not necessarily compatible with the target board. This quirk typically frees between 64 and 256 megabytes of memory, present in the debug log, and on some platforms, is the only way to boot macOS, which otherwise fails with allocation errors at the bootloader stage.

This option is useful on all types of firmware, except for some very old ones such as Sandy Bridge. On certain firmware, a list of addresses that need virtual addresses for proper NVRAM and hibernation functionality may be required. Use the `MmioWhitelist` section for this.

4. `DisableSingleUser`

Type: plist boolean

Failsafe: false

Description: Disable single user mode.

This is a security option that restricts the activation of single user mode by ignoring the `CMD+S` hotkey and the `-s` boot argument. The behaviour with this quirk enabled is supposed to match T2-based model behaviour. Refer to this archived article to understand how to use single user mode with this quirk enabled.

5. `DisableVariableWrite`

Type: plist boolean

Failsafe: false

Description: Protect from macOS NVRAM write access.

This is a security option that restricts NVRAM access in macOS. This quirk requires `OC_FIRMWARE_RUNTIME` protocol implemented in `OpenRuntime.efi`.

Note: This quirk can also be used as an ad hoc workaround for defective UEFI runtime services implementations that are unable to write variables to NVRAM and results in operating system failures.

6. `DiscardHibernateMap`

Type: plist boolean

Failsafe: false

Description: Reuse original hibernate memory map.

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

Note: This may be used to workaround defective memory map implementations on older, rare legacy hardware. Examples of such hardware are Ivy Bridge laptops with Insyde firmware such as the Acer V3-571G. Do not use this option without a full understanding of the implications.

7. `EnableSafeModeSlide`

Type: plist boolean

Failsafe: false

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

This option is relevant to users with issues booting to safe mode (e.g. by holding `shift` or with using the `-x` boot argument). By default, safe mode forces 0 slide as if the system was launched with the `slide=0` boot argument.

- This quirk attempts to patch the `boot.efi` file to remove this limitation and to allow using other values (from 1 to 255 inclusive).
- This quirk requires enabling `ProvideCustomSlide`.

Note: The need for this option is dependent on the availability of safe mode. It can be enabled when booting to safe mode fails.

8. `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 `CRO` 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 the firmware supports memory attributes table (MAT). Refer to the `OCABC: MAT support is 1/0` log entry to determine whether MAT is supported.

9. `ForceBooterSignature`

Type: plist boolean

Failsafe: false

Description: Set macOS boot-signature to OpenCore launcher.

Booter signature, essentially a SHA-1 hash of the loaded image, is used by Mac EFI to verify the authenticity of the bootloader when waking from hibernation. This option forces macOS to use OpenCore launcher SHA-1 hash as a booter signature to let OpenCore shim hibernation wake on Mac EFI firmware.

Note: OpenCore launcher path is determined from `LauncherPath` property.

10. `ForceExitBootServices`

Type: plist boolean

Failsafe: false

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

Try to ensure that the `ExitBootServices` call succeeds. If required, an outdated `MemoryMap` key argument can be used by obtaining the current memory map and retrying the `ExitBootServices` call.

Note: The need for this quirk is determined by early boot crashes of the firmware. Do not use this option without a full understanding of the implications.

11. `ProtectMemoryRegions`

Type: plist boolean

Failsafe: false

Description: Protect memory regions from incorrect access.

Some types of firmware incorrectly map certain memory regions:

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

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

Note: The need for this quirk is determined by artifacts, sleep wake issues, and boot failures. This quirk is typically only required by very old firmware.

12. `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 attempts to avoid issues with NVRAM implementations with fragmentation issues, such as on the `MacPro5,1` as well as on certain Insyde firmware without garbage collection or with defective garbage collection.

13. `ProtectUefiServices`

Type: plist boolean

Failsafe: false

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

Some modern firmware, including on virtual machines such as VMware, may update pointers to UEFI services during driver loading and related actions. Consequently, this directly obstructs other quirks that affect memory management, such as `DevirtualiseMmio`, `ProtectMemoryRegions`, or `RebuildAppleMemoryMap`, and may also obstruct other quirks depending on the scope of such.

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

14. ProvideCustomSlide

Type: plist boolean

Failsafe: false

Description: Provide custom KASLR slide on low memory.

This option performs memory map analysis of the 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 cases where potential conflicts exist, this option forces macOS to select a pseudo random value from the available values. This also ensures that the `slide=` argument is never passed to the operating system (for security reasons).

Note: The need for this quirk is determined by the `OCABC: Only N/256 slide values are usable!` message in the debug log.

15. ProvideMaxSlide

Type: plist integer

Failsafe: 0

Description: Provide maximum KASLR slide when higher ones are unavailable.

This option overrides the maximum slide of 255 by a user specified value between 1 and 254 (inclusive) when `ProvideCustomSlide` is enabled. It is assumed that modern firmware allocates pool memory from top to bottom, effectively resulting in free memory when slide scanning is used later as temporary memory during kernel loading. When such memory is not available, this option stops the evaluation of higher slides.

Note: The need for this quirk is determined by random boot failures when `ProvideCustomSlide` is enabled and the randomized slide falls into the unavailable range. When `AppleDebug` is enabled, the debug log typically contains messages such as `AAPL: [EB|'LD:LKC] } Err(0x9)`. To find the optimal value, append `slide=X`, where X is the slide value, to the `boot-args` and select the largest one that does not result in boot failures.

16. RebuildAppleMemoryMap

Type: plist boolean

Failsafe: false

Description: Generate macOS compatible Memory Map.

The Apple kernel has several limitations on parsing the UEFI memory map:

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

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

Note 1: Since several types of firmware come with incorrect memory protection tables, this quirk often comes paired with `SyncRuntimePermissions`.

Note 2: The need for this quirk is determined by early boot failures. This quirk replaces `EnableWriteUnprotector` on firmware supporting Memory Attribute Tables (MAT). This quirk is typically unnecessary when using `OpenDuetPkg` but may be required to boot macOS 10.6, and earlier, for reasons that are as yet unclear.

17. SetupVirtualMap

Type: plist boolean

Failsafe: false

Description: Setup virtual memory at `SetVirtualAddresses`.

Some types of firmware access memory by virtual addresses after a `SetVirtualAddresses` call, resulting in early boot crashes. This quirk workarounds the problem by performing early boot identity mapping of assigned virtual addresses to physical memory.

Note: The need for this quirk is determined by early boot failures.

18. **SignalAppleOS**

Type: plist boolean

Failsafe: false

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

This quirk is useful on Mac firmware, which loads different operating systems with different hardware configurations. For example, it is supposed to enable Intel GPU in Windows and Linux in some dual-GPU MacBook models.

19. **SyncRuntimePermissions**

Type: plist boolean

Failsafe: false

Description: Update memory permissions for the runtime environment.

Some types of firmware 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 attempts to update the memory map and memory attributes table to correct this.

Note: The need for this quirk is indicated by early boot failures. Only firmware released after 2017 is typically 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
```

Device properties are part of the `IODeviceTree` (`gIODT`) plane of the macOS I/O Registry. This plane has several construction stages relevant for the platform initialisation. While the early construction stage is performed by the XNU kernel in the `IODeviceTreeAlloc` method, the majority of the construction is performed by the platform expert, implemented in `AppleACPIPlatformExpert.kext`.

`AppleACPIPlatformExpert` incorporates two stages of `IODeviceTree` construction implemented by calling `AppleACPIPlatformExpert::mergeDeviceProperties`:

1. During ACPI table initialisation through the recursive ACPI namespace scanning by the calls to `AppleACPIPlatformExpert::createDTNubs`.
2. During IOService registration (`IOServices::registerService`) callbacks implemented as a part of `AppleACPIPlatformExpert::platformAdjustService` function and its private worker method `AppleACPIPlatformExpert::platformAdjustPCIDevice` specific to the PCI devices.

The application of the stages depends on the device presence in ACPI tables. The first stage applies very early but exclusively to the devices present in ACPI tables. The second stage applies to all devices much later after the PCI configuration and may repeat the first stage if the device was not present in ACPI.

For all kernel extensions that may inspect the `IODeviceTree` plane without probing, such as `Lilu` and its plugins (e.g. `WhateverGreen`), it is especially important to ensure device presence in the ACPI tables. A failure to do so may result in **erratic behaviour** caused by ignoring the injected device properties as they were not constructed at the first stage. See `SSDT-IMEI.dsl` and `SSDT-BRGO.dsl` for an example.

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 multidata` format.

Note 1: Device paths must be provided in canonic string format (e.g. `PciRoot(0x0)/Pci(0x1,0x0)/Pci(0x0,0x0)`).

Note 2: Existing properties will not be changed unless deleted in the `DeviceProperties Delete` section.

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.

Note: Currently, existing properties may only exist on firmware with `DeviceProperties` drivers (e.g. `Apple`). Hence, there is typically no reason to delete variables unless a new driver has been installed.

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 the application of 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 extensions (kexts) from the `OC/Kexts` directory.

To be filled with `plist dict` values, describing each kext. Refer to the Add Properties section below for details.

Note 1: The load order is based on the order in which the kexts appear in the array. Hence, dependencies must appear before kexts that depend on them.

Note 2: To track the dependency order, inspect the `OSBundleLibraries` key in the `Info.plist` file of the kext being added. Any kext included under the key is a dependency that must appear before the kext being added.

Note 3: Kexts may have inner kexts (`Plugins`) included in the bundle. Such `Plugins` must be added separately and follow the same global ordering rules as other kexts.

2. Block

Type: plist array

Failsafe: Empty

Description: Remove selected kernel extensions (kexts) from the prelinked kernel.

To be filled with `plist dictionary` values, describing each blocked kext. Refer to the Block Properties section below for details.

3. Emulate

Type: plist dict

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

4. Force

Type: plist array

Failsafe: Empty

Description: Load kernel extensions (kexts) from the system volume if they are not cached.

To be filled with `plist dict` values, describing each kext. Refer to the Force Properties section below for details. This section resolves the problem of injecting kexts that depend on other kexts, which are not otherwise cached. The issue typically affects older operating systems, where various dependency kexts, such as `IOAudioFamily` or `IONetworkingFamily` may not be present in the kernel cache by default.

Note 1: The load order is based on the order in which the kexts appear in the array. Hence, dependencies must appear before kexts that depend on them.

Note 2: `Force` happens before `Add`.

Note 3: The signature of the “forced” kext is not checked in any way. This makes using this feature extremely dangerous and undesirable for secure boot.

Note 4: This feature may not work on encrypted partitions in newer operating systems.

5. Patch

Type: plist array

Failsafe: Empty

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

To be filled with `plist dictionary` values, describing each patch. Refer to the Patch Properties section below for details.

- 6. Quirks
Type: plist dict
Description: Apply individual kernel and driver quirks described in the Quirks Properties section below.
- 7. Scheme
Type: plist dict
Description: Define kernelspace operation mode via parameters described in the Scheme Properties section below.

7.3 Add Properties

- 1. Arch
Type: plist string
Failsafe: Any (Apply to any supported architecture)
Description: Kext architecture (i386, x86_64).
- 2. BundlePath
Type: plist string
Failsafe: Empty
Description: Kext bundle path (e.g. Lilu.kext or MyKext.kext/Contents/PlugIns/MySubKext.kext).
- 3. Comment
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
- 4. Enabled
Type: plist boolean
Failsafe: false
Description: Set to true to add this kernel extension.
- 5. ExecutablePath
Type: plist string
Failsafe: Empty
Description: Kext executable path relative to bundle (e.g. Contents/MacOS/Lilu).
- 6. MaxKernel
Type: plist string
Failsafe: Empty
Description: Adds kernel extension 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:

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

$$f(\alpha, \beta, \gamma) = \alpha \leq \gamma \leq \beta$$

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.

7. MinKernel

Type: plist string

Failsafe: Empty

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

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

8. PlistPath

Type: plist string

Failsafe: Empty

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

7.4 Block Properties

1. Arch

Type: plist string

Failsafe: Any (Apply to any supported architecture)

Description: Kext block architecture (`i386`, `x86_64`).

2. Comment

Type: plist string

Failsafe: Empty

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

3. Enabled

Type: plist boolean

Failsafe: false

Description: Set to `true` to block this kernel extension.

4. Identifier

Type: plist string

Failsafe: Empty

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

5. MaxKernel

Type: plist string

Failsafe: Empty

Description: Blocks kernel extension on specified macOS version or older.

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

6. MinKernel

Type: plist string

Failsafe: Empty

Description: Blocks kernel extension on specified macOS version or newer.

Note: Refer to the 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 primarily meets three requirements:

- Enabling support for an unsupported CPU model (e.g. Intel Pentium).
- Enabling support for a CPU model not yet supported by a specific version of macOS (typically old versions).

- Enabling XCPM support for an unsupported CPU variant.

Note 1: It may also be the case that the CPU model is supported but there is no power management supported (e.g. virtual machines). In this case, `MinKernel` and `MaxKernel` can be set to restrict CPU virtualisation and dummy power management patches to the particular macOS kernel version.

Note 2: Only the value of `EAX`, which represents the full CPUID, typically needs to be accounted for and remaining bytes should be left as zeroes. The byte order is Little Endian. For example, `C3 06 03 00` stands for CPUID `0x0306C3` (Haswell).

Note 3: For XCPM support it is recommended to use the following combinations.

- Haswell-E (0x0306F2) 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`
- Rocket Lake (0x0A0670) to Comet Lake (0x0906EB):
`Cpuid1Data: EB 06 09 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`
- Comet Lake U62 (0x0A0660) to Comet Lake U42 (0x0806EC):
`Cpuid1Data: EC 06 08 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`

Note 4: Be aware that the following configurations are unsupported by XCPM (at least out of the box):

- Consumer Ivy Bridge (0x0306A9) as Apple disabled XCPM for Ivy Bridge and recommends legacy power management for these CPUs. `_xcpm_bootstrap` should manually be patched to enforce XCPM on these CPUs instead of this option.
- Low-end CPUs (e.g. Haswell+ Pentium) as they are not supported properly by macOS. Legacy workarounds for older models can be found in the `Special NOTES` section of `acidanthera/bugtracker#365`.

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`.

3. `DummyPowerManagement`

Type: plist boolean

Failsafe: false

Requirement: 10.4

Description: Disables `AppleIntelCpuPowerManagement`.

Note 1: This option is a preferred alternative to `NullCpuPowerManagement.kext` for CPUs without native power management driver in macOS.

Note 2: While this option is typically needed to disable `AppleIntelCpuPowerManagement` on unsupported platforms, it can also be used to disable this kext in other situations (e.g. with `Cpuid1Data` left blank).

4. `MaxKernel`

Type: plist string

Failsafe: Empty

Description: Emulates CPUID and applies `DummyPowerManagement` on specified macOS version or older.

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

5. `MinKernel`

Type: plist string

Failsafe: Empty

Description: Emulates CPUID and applies `DummyPowerManagement` on specified macOS version or newer.

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

7.6 Force Properties

1. Arch
Type: plist string
Failsafe: Any (Apply to any supported architecture)
Description: Kext architecture (i386, x86_64).
2. BundlePath
Type: plist string
Failsafe: Empty
Description: Kext bundle path (e.g. System/Library/Extensions/IONetworkingFamily.kext).
3. Comment
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
4. Enabled
Type: plist boolean
Failsafe: false
Description: Set to true to load this kernel extension from the system volume when not present in the kernel cache.
5. ExecutablePath
Type: plist string
Failsafe: Empty
Description: Kext executable path relative to bundle (e.g. Contents/MacOS/IONetworkingFamily).
6. Identifier
Type: plist string
Failsafe: Empty
Description: Kext identifier to perform presence checking before adding (e.g. com.apple.iokit.IONetworkingFamily). Only drivers which identifiers are not be found in the cache will be added.
7. MaxKernel
Type: plist string
Failsafe: Empty
Description: Adds kernel extension on specified macOS version or older.
Note: Refer to the Add MaxKernel description for matching logic.
8. MinKernel
Type: plist string
Failsafe: Empty
Description: Adds kernel extension on specified macOS version or newer.
Note: Refer to the Add MaxKernel description for matching logic.
9. PlistPath
Type: plist string
Failsafe: Empty
Description: Kext Info.plist path relative to bundle (e.g. Contents/Info.plist).

7.7 Patch Properties

1. Arch
Type: plist string
Failsafe: Any (Apply to any supported architecture)
Description: Kext patch architecture (i386, x86_64).
2. Base
Type: plist string
Failsafe: Empty (Ignored)

Description: Selects symbol-matched base for patch lookup (or immediate replacement) by obtaining the address of the provided symbol name.

3. Comment
 - Type:** plist string
 - Failsafe:** Empty
 - Description:** Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
4. Count
 - Type:** plist integer
 - Failsafe:** 0
 - Description:** Number of patch occurrences to apply. 0 applies the patch to all occurrences found.
5. Enabled
 - Type:** plist boolean
 - Failsafe:** false
 - Description:** This kernel patch will not be used unless set to true.
6. Find
 - Type:** plist data
 - Failsafe:** Empty (Immediate replacement at Base)
 - Description:** Data to find. Must be equal to **Replace** in size if set.
7. Identifier
 - Type:** plist string
 - Failsafe:** Empty
 - Description:** Kext bundle identifier (e.g. `com.apple.driver.AppleHDA`) or `kernel` for kernel patch.
8. Limit
 - Type:** plist integer
 - Failsafe:** 0 (Search entire kext or kernel)
 - Description:** Maximum number of bytes to search for.
9. Mask
 - Type:** plist data
 - Failsafe:** Empty (Ignored)
 - Description:** Data bitwise mask used during find comparison. Allows fuzzy search by ignoring not masked (set to zero) bits. Must be equal to **Replace** in size if set.
10. MaxKernel
 - Type:** plist string
 - Failsafe:** Empty
 - Description:** Patches data on specified macOS version or older.
 - Note:* Refer to the **Add MaxKernel** description for matching logic.
11. MinKernel
 - Type:** plist string
 - Failsafe:** Empty
 - Description:** Patches data on specified macOS version or newer.
 - Note:* Refer to the **Add MaxKernel** description for matching logic.
12. Replace
 - Type:** plist data
 - Failsafe:** Empty
 - Description:** Replacement data of one or more bytes.
13. ReplaceMask
 - Type:** plist data
 - Failsafe:** Empty (Ignored)
 - Description:** Data bitwise mask used during replacement. Allows fuzzy replacement by updating masked (set to non-zero) bits. Must be equal to **Replace** in size if set.

14. Skip

Type: plist integer

Failsafe: 0 (Do not skip any occurrences)

Description: Number of found occurrences to skip before replacements are applied.

7.8 Quirks Properties

1. AppleCpuPmCfgLock

Type: plist boolean

Failsafe: false

Requirement: 10.4

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

Some types of firmware lock the `PKG_CST_CONFIG_CONTROL` MSR register and the bundled `ControlMsrE2` tool can be used to check its state. Note that some types of firmware only have this register locked on some cores. As modern firmware provide a `CFG Lock` setting that allows configuring the `PKG_CST_CONFIG_CONTROL` MSR register lock, this option should be avoided whenever possible.

On APTIO firmware that do not provide a `CFG Lock` setting in the GUI, it is possible to access the option directly:

- (a) Download UEFITool and IFR-Extractor.
- (b) Open the firmware image in UEFITool and find `CFG Lock` unicode string. If it is not present, the firmware may not have this option and the process should therefore be discontinued.
- (c) Extract the `Setup.bin` PE32 Image Section (the UEFITool found) through the `Extract Body` menu option.
- (d) Run IFR-Extractor on the extracted file (e.g. `./ifrextract 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 the 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.

On selected platforms, the `ControlMsrE2` tool can also change such hidden options. Pass desired argument: `lock`, `unlock` for `CFG Lock`. Or pass `interactive` to find and modify other hidden options.

As a last resort, consider patching the BIOS (for advanced users only).

2. AppleXcpmCfgLock

Type: plist boolean

Failsafe: false

Requirement: 10.8 (not required for older)

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. Refer to the `AppleCpuPmCfgLock` description for details.

3. AppleXcpmExtraMsrs

Type: plist boolean

Failsafe: false

Requirement: 10.8 (not required for older)

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

This is typically used in conjunction with the `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

Requirement: 10.8 (not required for older)

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. Only certain Xeon models typically benefit from the patch.

5. CustomSMBIOSGuid

Type: plist boolean

Failsafe: false

Requirement: 10.4

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

6. DisableIoMapper

Type: plist boolean

Failsafe: false

Requirement: 10.8 (not required for older)

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

Note 1: This option is a preferred alternative to deleting DMAR ACPI table and disabling VT-d in firmware preferences, which does not obstruct VT-d support in other systems in case they need this.

Note 2: Misconfigured IOMMU in the firmware may result in broken devices such as ethernet or Wi-Fi adapters. For instance, an ethernet adapter may cycle in link-up link-down state infinitely and a Wi-Fi adapter may fail to discover networks. Gigabyte is one of the most common OEMs with these issues.

7. DisableLinkeditJettison

Type: plist boolean

Failsafe: false

Requirement: 11

Description: Disables __LINKEDIT jettison code.

This option lets Lilu.kext, and possibly other kexts, function in macOS Big Sur at their best performance levels without requiring the keepsyms=1 boot argument.

8. DisableRtcChecksum

Type: plist boolean

Failsafe: false

Requirement: 10.4

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 AppleRtcRam protocol description if this is desired.

9. ExtendBTFeatureFlags

Type: plist boolean

Failsafe: false

Requirement: 10.8-11

Description: Set FeatureFlags to 0x0F for full functionality of Bluetooth, including Continuity.

Note: This option is a substitution for BT4LEContinuityFixup.kext, which does not function properly due to late patching progress.

10. ExternalDiskIcons

Type: plist boolean

Failsafe: false

Requirement: 10.4

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 firmware typically have compatible AHCI controllers.

11. `ForceSecureBootScheme`

Type: plist boolean

Failsafe: false

Requirement: 11

Description: Force x86 scheme for IMG4 verification.

Note: This option is required on virtual machines when using `SecureBootModel` different from `x86legacy`.

12. `IncreasePciBarSize`

Type: plist boolean

Failsafe: false

Requirement: 10.10

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

Note: This option should be avoided whenever possible. A need for this option indicates misconfigured or defective firmware.

13. `LapicKernelPanic`

Type: plist boolean

Failsafe: false

Requirement: 10.6 (64-bit)

Description: Disables kernel panic on LAPIC interrupts.

14. `LegacyCommpage`

Type: plist boolean

Failsafe: false

Requirement: 10.4 - 10.6

Description: Replaces the default 64-bit `commpage` `bcopy` implementation with one that does not require SSSE3, useful for legacy platforms. This prevents a `commpage no match for last panic` due to no available 64-bit `bcopy` functions that do not require SSSE3.

15. `PanicNoKextDump`

Type: plist boolean

Failsafe: false

Requirement: 10.13 (not required for older)

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

16. `PowerTimeoutKernelPanic`

Type: plist boolean

Failsafe: false

Requirement: 10.15 (not required for older)

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.

17. `ProvideCurrentCpuInfo`

Type: plist boolean

Failsafe: false

Requirement: 10.8

Description: Provides current CPU info to the kernel.

This quirk currently provides the correct TSC and FSB values to the kernel, as well as disables CPU topology validation.

Note: These patches currently target Microsoft Hyper-V and may need to be extended for other purposes.

18. SetApfsTrimTimeout

Type: plist integer

Failsafe: -1

Requirement: 10.14 (not required for older)

Description: Set trim timeout in microseconds for APFS filesystems on SSDs.

The APFS filesystem is designed in a way that the space controlled via the spaceman structure is either used or free. This may be different in other filesystems where the areas can be marked as used, free, and *unmapped*. All free space is trimmed (unmapped/deallocated) at macOS startup. The trimming procedure for NVMe drives happens in LBA ranges due to the nature of the DSM command with up to 256 ranges per command. The more fragmented the memory on the drive is, the more commands are necessary to trim all the free space.

Depending on the SSD controller and the level of drive fragmentation, the trim procedure may take a considerable amount of time, causing noticeable boot slowdown. The APFS driver explicitly ignores previously unmapped areas and repeatedly trims them on boot. To mitigate against such boot slowdowns, the macOS driver introduced a timeout (9.999999 seconds) that stops the trim operation when not finished in time.

On several controllers, such as Samsung, where the deallocation process is relatively slow, this timeout can be reached very quickly. Essentially, it means that the level of fragmentation is high, thus macOS will attempt to trim the same lower blocks that have previously been deallocated, but never have enough time to deallocate higher blocks. The outcome is that trimming on such SSDs will be non-functional soon after installation, resulting in additional wear on the flash.

One way to workaroud the problem is to increase the timeout to an extremely high value, which at the cost of slow boot times (extra minutes) will ensure that all the blocks are trimmed. Set this option to a high value, such as 4294967295, to ensure that all blocks are trimmed. Alternatively, use over-provisioning, if supported, or create a dedicated unmapped partition where the reserve blocks can be found by the controller. Conversely, the trim operation can be disabled by setting a very low timeout value. e.g. 999. Refer to this article for details.

19. ThirdPartyDrives

Type: plist boolean

Failsafe: false

Requirement: 10.6 (not required for older)

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.

20. XhciPortLimit

Type: plist boolean

Failsafe: false

Requirement: 10.11 (not required for older)

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 workaroud 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.

7.9 Scheme Properties

These properties are particularly relevant for older macOS operating systems. Refer to the Legacy Apple OS section for details on how to install and troubleshoot such macOS installations.

1. CustomKernel

Type: plist boolean

Failsafe: false

Description: Use customised kernel cache from the `Kernels` directory located at the root of the ESP partition.

Unsupported platforms including `Atom` and `AMD` require modified versions of XNU kernel in order to boot. This option provides the possibility to using a customised kernel cache which contains such modifications from ESP

partition.

2. FuzzyMatch

Type: plist boolean

Failsafe: false

Description: Use `kernelcache` with different checksums when available.

On macOS 10.6 and earlier, `kernelcache` filename has a checksum, which essentially is `adler32` from SMBIOS product name and EfiBoot device path. On certain firmware, the EfiBoot device path differs between UEFI and macOS due to ACPI or hardware specifics, rendering `kernelcache` checksum as always different.

This setting allows matching the latest `kernelcache` with a suitable architecture when the `kernelcache` without suffix is unavailable, improving macOS 10.6 boot performance on several platforms.

3. KernelArch

Type: plist string

Failsafe: Auto (Choose the preferred architecture automatically)

Description: Prefer specified kernel architecture (`i386`, `i386-user32`, `x86_64`) when available.

On macOS 10.7 and earlier, the XNU kernel can boot with architectures different from the usual `x86_64`. This setting will use the specified architecture to boot macOS when it is supported by the macOS and the configuration:

- `i386` — Use `i386` (32-bit) kernel when available.
- `i386-user32` — Use `i386` (32-bit) kernel when available and force the use of 32-bit userspace on 64-bit capable processors if supported by the operating system.
 - On macOS, 64-bit capable processors are assumed to support `SSSE3`. This is not the case for older 64-bit capable Pentium processors, which cause some applications to crash on macOS 10.6. This behaviour corresponds to the `-legacy` kernel boot argument.
 - This option is unavailable on macOS 10.4 and 10.5 when running on 64-bit firmware due to an uninitialised 64-bit segment in the XNU kernel, which causes `AppleEFIRuntime` to incorrectly execute 64-bit code as 16-bit code.
- `x86_64` — Use `x86_64` (64-bit) kernel when available.

The algorithm used to determine the preferred kernel architecture is set out below.

- (a) `arch` argument in image arguments (e.g. when launched via UEFI Shell) or in `boot-args` variable overrides any compatibility checks and forces the specified architecture, completing this algorithm.
- (b) OpenCore build architecture restricts capabilities to `i386` and `i386-user32` mode for the 32-bit firmware variant.
- (c) Determined EfiBoot version restricts architecture choice:
 - 10.4-10.5 — `i386` or `i386-user32` (only on 32-bit firmware)
 - 10.6 — `i386`, `i386-user32`, or `x86_64`
 - 10.7 — `i386` or `x86_64`
 - 10.8 or newer — `x86_64`
- (d) If `KernelArch` is set to `Auto` and `SSSE3` is not supported by the CPU, capabilities are restricted to `i386-user32` if supported by EfiBoot.
- (e) Board identifier (from SMBIOS) based on EfiBoot version disables `x86_64` support on an unsupported model if any `i386` variant is supported. `Auto` is not consulted here as the list is not overridable in EfiBoot.
- (f) `KernelArch` restricts the support to the explicitly specified architecture (when not set to `Auto`) if the architecture remains present in the capabilities.
- (g) The best supported architecture is chosen in this order: `x86_64`, `i386`, `i386-user32`.

Unlike macOS 10.7 (where certain board identifiers are treated as the `i386` only machines), and macOS 10.5 or earlier (where `x86_64` is not supported by the macOS kernel), macOS 10.6 is very special. The architecture choice on macOS 10.6 depends on many factors including not only the board identifier, but also the macOS product type (client vs server), macOS point release, and amount of RAM. The detection of all these is complicated and impractical, as several point releases had implementation flaws resulting in a failure to properly execute the server detection in the first place. For this reason, OpenCore on macOS 10.6 falls back on the `x86_64` architecture whenever it is supported by the board, as it is on macOS 10.7.

A 64-bit Mac model compatibility matrix corresponding to actual EfiBoot behaviour on macOS 10.6.8 and 10.7.5 is outlined below.

Model	10.6 (minimal)	10.6 (client)	10.6 (server)	10.7 (any)
Macmini	4,x (Mid 2010)	5,x (Mid 2011)	4,x (Mid 2010)	3,x (Early 2009)
MacBook	Unsupported	Unsupported	Unsupported	5,x (2009/09)
MacBookAir	Unsupported	Unsupported	Unsupported	2,x (Late 2008)
MacBookPro	4,x (Early 2008)	8,x (Early 2011)	8,x (Early 2011)	3,x (Mid 2007)
iMac	8,x (Early 2008)	12,x (Mid 2011)	12,x (Mid 2011)	7,x (Mid 2007)
MacPro	3,x (Early 2008)	5,x (Mid 2010)	3,x (Early 2008)	3,x (Early 2008)
Xserve	2,x (Early 2008)	2,x (Early 2008)	2,x (Early 2008)	2,x (Early 2008)

Note: 3+2 and 6+4 hotkeys to choose the preferred architecture are unsupported as they are handled by EfiBoot and hence, difficult to detect.

4. KernelCache

Type: plist string

Failsafe: Auto

Description: Prefer specified kernel cache type (Auto, Cacheless, Mkext, Prelinked) when available.

Different variants of macOS support different kernel caching variants designed to improve boot performance. This setting prevents the use of faster kernel caching variants if slower variants are available for debugging and stability reasons. That is, by specifying **Mkext**, **Prelinked** will be disabled for e.g. 10.6 but not for 10.7.

The list of available kernel caching types and its current support in OpenCore is listed below.

macOS	i386 NC	i386 MK	i386 PK	x86_64 NC	x86_64 MK	x86_64 PK	x86_64 KC
10.4	YES	YES (V1)	NO (V1)	—	—	—	—
10.5	YES	YES (V1)	NO (V1)	—	—	—	—
10.6	YES	YES (V2)	YES (V2)	YES	YES (V2)	YES (V2)	—
10.7	YES	—	YES (V3)	YES	—	YES (V3)	—
10.8-10.9	—	—	—	YES	—	YES (V3)	—
10.10-10.15	—	—	—	—	—	YES (V3)	—
11+	—	—	—	—	—	YES (V3)	YES

Note: The first version (V1) of the 32-bit **prelinkedkernel** is unsupported due to the corruption of **kext** symbol tables by the tools. On this version, the **Auto** setting will block **prelinkedkernel** booting. This also results in the **keepsyms=1** boot argument being non-functional for **kext** frames on these systems.

8 Misc

8.1 Introduction

This section contains miscellaneous configuration options affecting OpenCore operating system loading behaviour in addition to other options that do not readily fit into other sections.

OpenCore broadly follows the “bless” model, also known as the “Apple Boot Policy”. The primary purpose of the “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 as compared to the removable media list set out in the UEFI specification.

Partitions can only be booted by OpenCore when they meet the requirements of a predefined `Scan policy`. This policy sets out which specific file systems a partition must have, and which specific device types a partition must be located on, to be made available by OpenCore as a boot option. Refer to the `ScanPolicy` property for details.

The scan process starts with enumerating all available partitions, filtered based on the `Scan policy`. Each partition may generate multiple primary and alternate options. Primary options represent operating systems installed on the media, while alternate options represent recovery options for the operating systems on the media.

- Alternate options may exist without primary options and vice versa.
- Options may not necessarily represent operating systems on the same partition.
- Each primary and alternate option can be an auxiliary option or not.
 - Refer to the `HideAuxiliary` section for details.

The algorithm to determine boot options behaves as follows:

1. Obtain all available partition handles filtered based on the `Scan policy` (and driver availability).
2. Obtain all available boot options from the `BootOrder` UEFI variable.
3. For each boot option found:
 - Retrieve the device path of the boot option.
 - Perform fixups (e.g. NVMe subtype correction) and expansion (e.g. for Boot Camp) of the device path.
 - On failure, if it is an OpenCore custom entry device path, pre-construct the corresponding custom entry and succeed.
 - Obtain the device handle by locating the device path of the resulting device path (ignore it on failure).
 - Locate the 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 for presence on the file system directly.
 - On the OpenCore boot partition, exclude all OpenCore bootstrap files by file 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 the partition handle is marked as *unused*, execute “bless” primary option list retrieval.
In case a `BlessOverride` list is set, both standard and custom “bless” paths will be found.
 - On the OpenCore boot partition, exclude OpenCore bootstrap files using 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 a partition already has any primary options of the “Apple Recovery” type, proceed to the 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, except such pre-constructed previously, are added as primary options without any checks with respect to `Auxiliary`.
6. System entries, such as `Reset NVRAM`, are added as primary auxiliary options.

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

The display order as follows:

- Alternate options follow corresponding primary options. That is, Apple recovery options will follow the relevant macOS option whenever possible.

- Options will be listed in file system handle firmware order to maintain an established order across reboots regardless of the operating system chosen for loading.
- Custom entries, tools, and system entries will be added after all other options.
- Auxiliary options will only be displayed upon entering “Extended Mode” in the OpenCore picker (typically by pressing the Space key).

The boot process is as follows:

- Look up the first valid primary option in the `BootNext` UEFI variable.
- On failure, look up the first valid primary option in the `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 will only work reliably when the `RequestBootVarRouting` option is enabled or the firmware does not control UEFI boot options (`OpenDuetPkg` or custom BDS). When `LauncherOption` is not enabled, other operating systems may overwrite OpenCore settings and this property should therefore be enabled when planning to use other operating systems.

Note 2: UEFI variable boot options boot arguments will be removed, if present, as they may contain arguments that can compromise the operating system, which is undesirable when secure boot is enabled.

Note 3: Some operating systems, such as Windows, may create a boot option and mark it as the topmost option upon first boot or after NVRAM resets from within OpenCore. When this happens, the default boot entry choice will remain changed until the next manual reconfiguration.

8.2 Properties

1. Boot

Type: plist dict

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

2. BlessOverride

Type: plist array

Description: Add custom scanning paths through the bless model.

To be filled with `plist string` entries containing absolute UEFI paths to customised bootloaders such as `\EFI\debian\grubx64.efi` for the Debian bootloader. This allows non-standard boot paths to be automatically discovered by the OpenCore picker. Designwise, they are equivalent to predefined blessed paths, such as `\System\Library\CoreServices\boot.efi` or `\EFI\Microsoft\Boot\bootmgfw.efi`, but unlike predefined bless paths, they have the highest priority.

3. Debug

Type: plist dict

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

4. Entries

Type: plist array

Description: Add boot entries to OpenCore picker.

To be filled with `plist dict` values, describing each load entry. Refer to the Entry Properties section below for details.

5. Security

Type: plist dict

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

6. Tools

Type: plist array

Description: Add tool entries to the OpenCore picker.

To be filled with `plist dict` values, describing each load entry. Refer to the Entry Properties section below for details.

Note: Certain UEFI tools, such as UEFI Shell, can be very dangerous and **MUST NOT** appear in production configurations, particularly in vaulted configurations as well as those protected by secure boot, as such tools can be used to bypass the secure boot chain. Refer to the UEFI section for examples of UEFI tools.

8.3 Boot Properties

1. ConsoleAttributes

Type: plist integer

Failsafe: 0

Description: Sets specific attributes for the console.

The text renderer supports colour arguments as a sum of foreground and background colours based on the UEFI specification. The value for black background and for black foreground, 0, is reserved.

List of colour values and 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 the `System` text renderer. Setting a background different from black could help with testing GOP functionality.

2. HibernateMode

Type: plist string

Failsafe: None

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

- `None` — Ignore hibernation state.
- `Auto` — Use RTC and NVRAM detection.
- `RTC` — Use RTC detection.
- `NVRAM` — Use NVRAM detection.

Note: If the firmware can handle hibernation itself (valid for Mac EFI firmware), then `None` should be specified to hand-off hibernation state as is to OpenCore.

3. HideAuxiliary

Type: plist boolean

Failsafe: false

Description: Set to `true` to hide auxiliary entries from the picker menu.

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. **Reset NVRAM**).

To display all entries, the picker menu can be reloaded into “Extended Mode” by pressing the **Spacebar** key. Hiding auxiliary entries may increase boot performance on multi-disk systems.

4. **LauncherOption**

Type: plist string

Failsafe: Disabled

Description: Register the launcher option in the firmware preferences for persistence.

Valid values:

- **Disabled** — do nothing.
- **Full** — create or update the top priority boot option in UEFI variable storage at bootloader startup.
 - For this option to work, **RequestBootVarRouting** is required to be enabled.
- **Short** — create a short boot option instead of a complete one.
 - This variant is useful for some older types of firmware, typically from Insyde, that are unable to manage full device paths.
- **System** — create no boot option but assume specified custom option is blessed.
 - This variant is useful when relying on **ForceBooterSignature** quirk and OpenCore launcher path management happens through **bless** utilities without involving OpenCore.

This option allows integration with third-party operating system installation and upgrades (which may overwrite the `\EFI\BOOT\BOOTx64.efi` file). The `BOOTx64.efi` file is no longer used for bootstrapping OpenCore if a custom option is created. The custom path used for bootstrapping can be specified by using the **LauncherPath** option.

Note 1: Some types of firmware may have NVRAM implementation flaws, no boot option support, or other incompatibilities. While unlikely, the use of this option may result in boot failures and should only be used exclusively on boards known to be compatible. Refer to [acidanthera/bugtracker#1222](#) for some known issues affecting Haswell and other boards.

Note 2: While NVRAM resets executed from OpenCore would not typically erase the boot option created in **Bootstrap**, executing NVRAM resets prior to loading OpenCore will erase the boot option. Therefore, for significant implementation updates, such as was the case with OpenCore 0.6.4, an NVRAM reset should be executed with **Bootstrap** disabled, after which it can be re-enabled.

5. **LauncherPath**

Type: plist string

Failsafe: Default

Description: Launch path for the **LauncherOption** property.

Default points to `OpenCore.efi`. User specified paths, e.g. `\EFI\SomeLauncher.efi`, can be used to provide custom loaders, which are supposed to load `OpenCore.efi` themselves.

6. **PickerAttributes**

Type: plist integer

Failsafe: 0

Description: Sets specific attributes for the OpenCore picker.

Different OpenCore 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: OpenCore will attempt loading a volume icon by searching as follows, and will fallback to the default icon on failure:

- `.VolumeIcon.icns` file at `Preboot` volume in per-volume directory (`/System/Volumes/Preboot/{GUID}/` when mounted at the default location within macOS) for APFS (if present).
- `.VolumeIcon.icns` file at the `Preboot` volume root (`/System/Volumes/Preboot/`, when mounted at the default location within macOS) for APFS (otherwise).
- `.VolumeIcon.icns` file at the volume root for other filesystems.

Note 1: The Apple picker partially supports placing a volume icon file at the operating system's `Data` volume root, `/System/Volumes/Data/`, when mounted at the default location within macOS. This approach is flawed: the file is neither accessible to OpenCanopy nor to the Apple picker when FileVault 2, which is meant to be the default choice, is enabled. Therefore, OpenCanopy does not attempt supporting Apple's approach. A volume icon file may be placed at the root of the `Preboot` volume for compatibility with both OpenCanopy and the Apple picker, or use the `Preboot` per-volume location as above with OpenCanopy as a preferred alternative to Apple's approach.

Note 2: Be aware that using a volume icon on any drive overrides the normal OpenCore picker behaviour for that drive of selecting the appropriate icon depending on whether the drive is internal or external.

- `0x0002` — `OC_ATTR_USE_DISK_LABEL_FILE`, provides custom prerendered titles for boot entries from `.disk_label` (`.disk_label_2x`) file next to the bootloader for all filesystems. Prerendered labels can be generated via the `disklabel` utility or the `bless` command. When disabled or missing, label text in (`.contentDetails` or `.disk_label.contentDetails`) will be rendered if present instead, otherwise the entry name itself will be rendered.
- `0x0004` — `OC_ATTR_USE_GENERIC_LABEL_IMAGE`, provides predefined label images for boot entries without custom entries. This may however give less detail for the actual boot entry.
- `0x0008` — `OC_ATTR_HIDE_THEMED_ICONS`, prefers builtin icons for certain icon categories to match the theme style. For example, this could force displaying the builtin Time Machine icon. Requires `OC_ATTR_USE_VOLUME_ICON`.
- `0x0010` — `OC_ATTR_USE_POINTER_CONTROL`, enables pointer control in the OpenCore picker when available. For example, this could make use of mouse or trackpad to control UI elements.
- `0x0020` — `OC_ATTR_SHOW_DEBUG_DISPLAY`, enable display of additional timing and debug information, in Builtin picker in `DEBUG` and `NOOPT` builds only.
- `0x0040` — `OC_ATTR_USE_MINIMAL_UI`, use minimal UI display, no Shutdown or Restart buttons, affects OpenCanopy and builtin picker.
- `0x0080` — `OC_ATTR_USE_FLAVOUR_ICON`, provides flexible boot entry content description, suitable for picking the best media across different content sets:

When enabled, the entry icon in OpenCanopy and the audio assist entry sound in OpenCanopy and builtin boot picker are chosen by something called content flavour. To determine content flavour the following algorithm is used:

- For a Tool the value is read from `Flavour` field.
- For an automatically discovered entry it is read from the `.contentFlavour` file next to the bootloader, if present.
- For a custom entry it is read from the `.contentFlavour` file next to the bootloader if `Flavour` is `Auto`, otherwise specified via the `Flavour` value itself.
- If read flavour is `Auto` or there is no `.contentFlavour`, entry flavour is chosen based on the entry type (e.g. Windows automatically gets Windows flavour).

The Flavour value is a sequence of `:` separated names limited to 64 characters of printable 7-bit ASCII. This is designed to support up to approximately five names. Each name refers to a flavour, with the first name having the highest priority and the last name having the lowest priority. Such a structure allows describing an entry in a more specific way, with icons selected flexibly depending on support by the audio-visual pack. A missing audio or icon file means the next flavour should be tried, and if all are missing the choice happens based on the type of the entry. Example flavour values: `BigSur:Apple`, `Windows10:Windows`, `OpenShell:UEFIShell:Shell`.

Using flavours means that you can switch between icon sets easily, with the flavour selecting the best available icons from each set. E.g. specifying icon flavour `Debian:Linux` will use the icon `Debian.icns` if provided, then will try `Linux.icns`, then will fall back to the default for an OS, which is `HardDrive.icns`.

Things to keep in mind:

- For security reasons `Ext<Flavour>.icns` and `<Flavour>.icns` are both supported, and only `Ext<Flavour>.icns` will be used if the entry is on an external drive (followed by default fallback `ExtHardDrive.icns`).
- Where both apply `.VolumeIcon.icns` takes precedence over `.contentFlavour`.

- In order to allow icons and audio assist to work correctly for tools (e.g. for UEFI Shell), system default boot entry icons (see `Docs/Flavours.md`) specified in the `Flavour` setting for `Tools` or `Entries` will continue to apply even when flavour is disabled. Non-system icons will be ignored in this case. In addition, the flavours `UEFIshell` and `NVRAMReset` are given special processing, identifying their respective tools to apply correct audio-assist, default builtin labels, etc.
- A list of recommended flavours is provided in `Docs/Flavours.md`.

7. PickerAudioAssist

Type: plist boolean

Failsafe: false

Description: Enable screen reader by default in the OpenCore picker.

For the macOS bootloader, screen reader preference is set in the `preferences.efires` archive in the `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 the OpenCore picker and the macOS bootloader FileVault 2 login window can also be done by using the `Command + F5` key combination.

Note: The screen reader requires working audio support. Refer to the `UEFI Audio Properties` section for details.

8. PollAppleHotKeys

Type: plist boolean

Failsafe: false

Description: Enable `modifier hotkey` handling in the OpenCore picker.

In addition to `action hotkeys`, which are partially described in the `PickerMode` section and are typically handled by Apple BDS, modifier keys handled by the operating system bootloader (`boot.efi`) also exist. These keys allow changing the behaviour of the operating system by providing different boot modes.

On certain firmware, using modifier keys may be problematic due to driver incompatibilities. To workaroud this problem, this option allows registering certain hotkeys in a more permissive manner from within the OpenCore picker. Such extensions include support for tapping on key combinations before selecting the boot item, and for reliable detection of the `Shift` key when selecting the boot item, in order to work around the fact that hotkeys which are continuously held during boot cannot be reliably detected 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+Enter`, `Shift+Index` — safe mode, may be used in combination with `CTRL+Enter`, `CTRL+Index`.

9. ShowPicker

Type: plist boolean

Failsafe: false

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

10. TakeoffDelay

Type: plist integer, 32 bit

Failsafe: 0

Description: Delay in microseconds executed before handling the OpenCore picker startup and `action hotkeys`.

Introducing a delay may give extra time to hold the right `action hotkey` sequence to, for instance, boot into recovery mode. On some platforms, setting this option to a minimum of 5000–10000 microseconds may be required to access `action hotkeys` due to the nature of the keyboard driver.

11. Timeout

Type: plist integer, 32 bit

Failsafe: 0

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

12. PickerMode

Type: plist string

Failsafe: Builtin

Description: Choose picker used for boot management.

`PickerMode` describes the 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, the **Builtin** mode is used.
- **Apple** — Apple boot management is used if available. Otherwise, the **Builtin** mode is used.

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

The OpenCore built-in picker contains a set of actions chosen during the boot process. The list of supported actions is similar to Apple BDS and typically can be accessed by holding `action hotkeys` during the boot process.

The following actions are currently considered:

- **Default** — this is the default option, and it lets the built-in OpenCore picker load the default boot option as specified in the Startup Disk preference pane.
- **ShowPicker** — this option forces the OpenCore picker to be displayed. This can typically be achieved by holding the `OPT` key during boot. Setting **ShowPicker** to `true` will make **ShowPicker** the default option.
- **ResetNvram** — this option erases certain UEFI variables and is normally executed by holding down the `CMD+OPT+P+R` key combination during boot. Another way to erase UEFI variables is to choose **Reset NVRAM** in the OpenCore picker. This option requires **AllowNvramReset** to be set to `true`.
- **BootApple** — this options performs booting to the first Apple operating system found unless the chosen default operating system is one from Apple. Hold the `X` key down to choose this option.
- **BootAppleRecovery** — this option performs booting into the Apple operating system recovery partition. This is either that related to the default chosen operating system, or first one found when the chosen default operating system is not from Apple or does not have a recovery partition. Hold the `CMD+R` key combination down to choose this option.

Note 1: On non-Apple firmware **KeySupport**, **OpenUsbKbDxe**, or similar drivers are required for key handling. However, not all of the key handling functions can be implemented on several types of firmware.

Note 2: In addition to `OPT`, OpenCore supports using both the **Escape** and **Zero** keys to enter the OpenCore picker when **ShowPicker** is disabled. **Escape** exists to support co-existence with the Apple picker (including OpenCore **Apple** picker mode) and to support firmware that fails to report held `OPT` key, as on some PS/2 keyboards. In addition, **Zero** is provided to support systems on which **Escape** is already assigned to some other pre-boot firmware feature. In systems which do not require **KeySupport**, pressing and holding one of these keys from after power on until the picker appears should always be successful. The same should apply when using **KeySupport** mode if it is correctly configured for the system, i.e. with a long enough **KeyForgetThreshold**. If pressing and holding the key is not successful to reliably enter the picker, multiple repeated keypresses may be tried instead.

Note 3: On Macs with problematic GOP, it may be difficult to access the Apple picker. The **BootKicker** utility can be blessed to workaround this problem even without loading OpenCore. On some Macs however, the **BootKicker** utility cannot be run from OpenCore.

13. PickerVariant

Type: plist string

Failsafe: Auto

Description: Choose specific icon set to be used for boot management.

An icon set is a directory path relative to `Resources\Image`, where the icons and an optional manifest are located. It is recommended for the artists to use provide their sets in the `Vendor\Set` format, e.g.

Acidanthera\GoldenGate.

Sample resources provided as a part of OcBinaryData repository provide the following icon set:

- Acidanthera\GoldenGate — macOS 11 styled icon set.
- Acidanthera\Syrah — macOS 10.10 styled icon set.
- Acidanthera\Chardonnay — macOS 10.4 styled icon set.

For convenience purposes there also are predefined aliases:

- Auto — Automatically select one set of icons based on the `DefaultBackground` colour: `Acidanthera\GoldenGate` for Syrah Black and `Acidanthera\Chardonnay` for Light Gray.
- Default — `Acidanthera\GoldenGate`.

8.4 Debug Properties

1. AppleDebug

Type: plist boolean

Failsafe: false

Description: Enable writing the `boot.efi` debug log to the 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 output to the OpenCore root partition.

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

Development and debug kernels produce more useful kernel panic logs. Consider downloading and installing the `KernelDebugKit` from developer.apple.com when debugging a problem. To activate a development kernel, the boot argument `kcsuffix=development` should be added. Use the `uname -a` command to ensure that the current loaded kernel is a development (or a debug) kernel.

In cases where the OpenCore kernel panic saving mechanism is not used, kernel panic logs may still be found in the `/Library/Logs/DiagnosticReports` directory.

Starting with macOS Catalina, kernel panics are stored in JSON format and thus 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: Some types of firmware may not succeed in booting the operating system quickly, especially in debug mode. This results in the watchdog timer aborting the process. This option turns off the watchdog timer.

4. DisplayDelay

Type: plist integer

Failsafe: 0

Description: Delay in microseconds executed 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. SerialInit

Type: plist boolean

Failsafe: false

Description: Perform serial port initialisation.

This option will perform serial port initialisation within OpenCore prior to enabling (any) debug logging. Serial port configuration is defined via PCDs at compile time in `gEfiMdeModulePkgTokenSpaceGuid` GUID.

Default values as found in `MdeModulePkg.dec` are as follows:

- `PcdSerialBaudRate` — Baud rate: 115200.
- `PcdSerialLineControl` — Line control: no parity, 8 data bits, 1 stop bit.

Refer to the `Debugging` section for details.

7. SysReport

Type: plist boolean

Failsafe: false

Description: Produce system report on ESP folder.

This option will create a `SysReport` directory in the ESP partition unless already present. The directory will contain ACPI, SMBIOS, and audio codec dumps. Audio codec dumps require an audio backend driver to be loaded.

Note: To maintain system integrity, the `SysReport` option is **not** available in `RELEASE` builds. Use a `DEBUG` build if this option is required.

8. Target

Type: plist integer

Failsafe: 0

Description: A bitmask (sum) of enabled logging targets. Logging output is hidden by default and this option must be set when such output is required, such as when debugging.

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

To obtain Data Hub logs, use the following command in macOS (Note that Data Hub logs do not log kernel and kext patches):

```
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. To maintain system integrity, the log size is limited to 32 kilobytes. Some types of firmware may truncate it much earlier or drop completely if they have no memory. Using the `non-volatile` flag will cause the log to be written to NVRAM flash after every printed line.

To obtain UEFI variable logs, use the following command in macOS:

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

Warning: Certain firmware appear to have defective NVRAM garbage collection. As a result, they may not be able to always free space after variable deletion. Do not enable `non-volatile` NVRAM logging on such devices unless specifically required.

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

File logging will create a file named `opencore-YYYY-MM-DD-HHMMSS.txt` (in UTC) under the 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 firmware are not reliable and may corrupt data when writing files through UEFI. Log writing is attempted in the safest manner and thus, is very slow. Ensure that `DisableWatchDog` is set to `true` when a slow drive is used. Try to avoid frequent use of this option when dealing with flash drives as large I/O amounts may speed up memory wear and render the flash drive unusable quicker.

When interpreting the log, note that the lines are prefixed with a tag describing the relevant location (module) of the log line allowing better attribution of the line to the functionality.

The list of currently used tags is as follows.

Drivers and tools:

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

Libraries:

- AAPL — OcDebugLogLib, Apple EfiBoot logging
- OCABC — OcAfterBootCompatLib
- OCAE — OcAppleEventLib
- OCAK — OcAppleKernelLib
- OCAU — OcAudioLib
- OCA — OcAcpiLib
- OCBP — OcAppleBootPolicyLib
- OCB — OcBootManagementLib
- OCLBT — OcBlitLib
- OCCL — OcAppleChunkListLib
- OCCPU — OcCpuLib
- OCC — OcConsoleLib
- OCDC — OcDriverConnectionLib
- OCDH — OcDataHubLib
- OCDI — OcAppleDiskImageLib
- OCDM — OcDeviceMiscLib
- OCFS — OcFileLib
- OCFV — OcFirmwareVolumeLib
- OCHS — OcHashServicesLib
- OCI4 — OcAppleImg4Lib
- OCIC — OcImageConversionLib
- OCII — OcInputLib
- OCJS — OcApsLib
- OCKM — OcAppleKeyMapLib
- OCL — OcDebugLogLib

- OCM — OcMiscLib
- OCMCO — OcMachoLib
- OCME — OcHeciLib
- OCMM — OcMemoryLib
- OCPE — OcPeCoffLib, OcPeCoffExtLib
- 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 OpenCore picker.

Note 1: It is known that some Lenovo laptops have a firmware bug, which makes them unbootable after performing NVRAM reset. Refer to [acidanthera/bugtracker#995](https://bugtracker.oxidized.org/view.php?id=995) for details.

Note 2: Resetting NVRAM will also erase any boot options not backed up using the `bless` command. For example, Linux installations to custom locations not specified in `BlessOverride`

2. AllowSetDefault

Type: plist boolean

Failsafe: false

Description: Allow CTRL+Enter and CTRL+Index handling to set the default boot option in the OpenCore picker.

Note 1: May be used in combination with `Shift+Enter` or `Shift+Index` when `PollAppleHotKeys` is enabled.

Note 2: In order to support systems with unresponsive modifiers during preboot (which includes V1 and V2 `KeySupport` mode on some firmware) OpenCore also allows holding the `=/+` key in order to trigger ‘set default’ mode.

3. AllowToggleSip

Type: plist boolean

Failsafe: false

Description: Enable entry for disabling and enabling System Integrity Protection in OpenCore picker.

This will toggle Apple NVRAM variable `csr-active-config` between 0 for SIP Enabled and a practical default value for SIP Disabled (currently `0x26F`).

Note 1: It is strongly recommended not to make a habit of running macOS with SIP disabled. Use of this boot option may make it easier to quickly disable SIP protection when genuinely needed - it should be re-enabled again afterwards.

Note 2: OC uses `0x26F` even though `csrutil disable` on Big Sur sets `0x7F`. To explain the choice:

- `csrutil disable --no-internal` actually sets `0x6F`, and this is preferable because `CSR_ALLOW_APPLE_INTERNAL` (`0x10`) prevents updates (unless you are running an internal build of macOS).
- `CSR_ALLOW_UNAPPROVED_KEXTS` (`0x200`) is generally useful, in the case where you do need to have SIP disabled, as it allows installing unsigned kexts without manual approval in System Preferences.

- `CSR_ALLOW_UNAUTHENTICATED_ROOT` (0x800) is not practical as it prevents incremental (non-full) OTA updates.

Note3: For any other value which you may need to use, it is possible to configure `CsrUtil.efi` as a `TextMode Tools` entry to configure a different value, e.g. use `toggle 0x6F` in `Arguments` to toggle the SIP disabled value set by default by `csrutil disable --no-internal` in Big Sur.

4. ApECID

Type: plist integer, 64 bit

Failsafe: 0

Description: Apple Enclave Identifier.

Setting this value to any non-zero 64-bit integer will allow using personalised Apple Secure Boot identifiers. To use this setting, generate a random 64-bit number with a cryptographically secure random number generator. As an alternative, the first 8 bytes of `SystemUUID` can be used for `ApECID`, this is found in macOS 11 for Macs without the T2 chip.

With this value set and `SecureBootModel` valid (and not `Disabled`), it is possible to achieve `Full Security` of Apple Secure Boot.

To start using personalised Apple Secure Boot, the operating system must be reinstalled or personalised. Unless the operating system is personalised, macOS DMG recovery cannot be loaded. In cases where DMG recovery is missing, it can be downloaded by using the `macrecovery` utility and saved in `com.apple.recovery.boot` as explained in the Tips and Tricks section. Note that DMG loading needs to be set to `Signed` to use any DMG with Apple Secure Boot.

To personalise an existing operating system, use the `bless` command after loading to macOS DMG recovery. Mount the system volume partition, unless it has already been mounted, and execute the following command:

```
bless --folder "/Volumes/Macintosh HD/System/Library/CoreServices" \
  --bootefi --personalize
```

On macOS 11 and newer the dedicated `x86legacy` model always uses `ApECID`. When this configuration setting is left as 0 first 8 bytes of `system-id` variable are used instead.

On macOS versions before macOS 11, which introduced a dedicated `x86legacy` model for models without the T2 chip, personalised Apple Secure Boot may not work as expected. When reinstalling the operating system, the macOS Installer from macOS 10.15 and older will often run out of free memory on the `/var/tmp` partition when trying to install macOS with the personalised Apple Secure Boot. Soon after downloading the macOS installer image, an `Unable to verify macOS` error message will appear.

To workaroud this issue, allocate a dedicated RAM disk of 2 MBs for macOS personalisation by entering the following commands in the macOS recovery terminal before starting the installation:

```
disk=$(hdiutil attach -nomount ram://4096)
diskutil erasevolume HFS+ SecureBoot $disk
diskutil unmount $disk
mkdir /var/tmp/OSPersonalizationTemp
diskutil mount -mountpoint /var/tmp/OSPersonalizationTemp $disk
```

5. 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. A dedicated terminal command can be used to perform authenticated restarts: `sudo fdsetup authrestart`. It is also used when installing operating system updates.

`VirtualSMC` performs authenticated restarts by splitting and saving disk encryption keys between NVRAM and RTC, which despite being removed as soon as `OpenCore` starts, may be considered a security risk and thus is optional.

6. BlacklistAppleUpdate

Type: plist boolean

Failsafe: false

Description: Ignore boot options trying to update Apple peripheral firmware (e.g. `MultiUpdater.efi`).

Note: Certain operating systems, such as macOS Big Sur, are incapable of disabling firmware updates by using the `run-efi-updater` NVRAM variable.

7. DmgLoading

Type: plist string

Failsafe: Signed

Description: Define Disk Image (DMG) loading policy used for macOS Recovery.

Valid values:

- **Disabled** — loading DMG images will fail. The **Disabled** policy will still let the macOS Recovery load in most cases as typically, there are `boot.efi` files compatible with Apple Secure Boot. Manually downloaded DMG images stored in `com.apple.recovery.boot` directories will not load, however.
- **Signed** — only Apple-signed DMG images will load. Due to the design of Apple Secure Boot, the **Signed** policy will let any Apple-signed macOS Recovery load regardless of the Apple Secure Boot state, which may not always be desired. While using signed DMG images is more desirable, verifying the image signature may slightly slow the boot time down (by up to 1 second).
- **Any** — any DMG images will mount as normal filesystems. The **Any** policy is strongly discouraged and will result in boot failures when Apple Secure Boot is active.

8. EnablePassword

Type: plist boolean

Failsafe: false

Description: Enable password protection to facilitate sensitive operations.

Password protection ensures that sensitive operations such as booting a non-default operating system (e.g. macOS recovery or a tool), resetting NVRAM storage, trying to boot into a non-default mode (e.g. verbose mode or safe mode) are not allowed without explicit user authentication by a custom password. Currently, password and salt are hashed with 5000000 iterations of SHA-512.

Note: This functionality is still under development and is not ready for production environments.

9. ExposeSensitiveData

Type: plist integer

Failsafe: 0x6

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

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

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

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

To use a booter path to mount a booter volume, use the following command in macOS:

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

To obtain the current OpenCore version, use the following command in macOS:

```
nvrnm 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

```

10. 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.

11. PasswordHash

Type: plist data 64 bytes

Failsafe: all zero

Description: Password hash used when EnabledPassword is set.

12. PasswordSalt

Type: plist data

Failsafe: empty

Description: Password salt used when EnabledPassword is set.

13. Vault

Type: plist string

Failsafe: Secure

Description: Enables the OpenCore vaulting mechanism.

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.

The `vault.plist` file should contain SHA-256 hashes for all files used by OpenCore. The presence of this file is highly recommended to ensure that unintentional file modifications (including filesystem corruption) do not go unnoticed. To create this file automatically, use the `create_vault.sh` script. Notwithstanding the underlying file system, the path names and cases between `config.plist` and `vault.plist` must match.

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

To embed the public key, either one of the following should be performed:

- 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.

The RSA public key 520 byte format description can be found in Chromium OS documentation. To convert the 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

```

Note 1: While it may appear obvious, an external method is required to verify `OpenCore.efi` and `BOOTx64.efi` for secure boot path. For this, it is recommended to enable UEFI SecureBoot using a custom certificate and to sign `OpenCore.efi` and `BOOTx64.efi` with a custom key. More details on customising secure boot on modern firmware can be found in the 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 a public key is embedded into `OpenCore.efi`. Setting this option will only ensure configuration sanity, and abort the boot process otherwise.

14. ScanPolicy

Type: plist integer, 32 bit

Failsafe: 0x10F0103

Description: Define operating system detection policy.

This value allows preventing scanning (and booting) untrusted sources based on a bitmask (sum) of a set of 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 additional measures are to be applied.

Third party drivers may introduce additional security (and performance) considerations following the provided scan policy. The active Scan policy is exposed in the `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. Hence, to avoid mounting of undesired file systems, drivers for such file systems should not be loaded. 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. It 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 instead. 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_LINUX_ROOT`, allows scanning of Linux Root file systems.
- 0x00002000 (bit 13) — `OC_SCAN_ALLOW_FS_LINUX_DATA`, allows scanning of Linux Data file systems.
- 0x00004000 (bit 14) — `OC_SCAN_ALLOW_FS_XBOOTLDR`, allows scanning the Extended Boot Loader Partition as defined by the Boot Loader Specification.
- 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 and old SATA.
- 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, a value of 0xF0103 is expected to do the following:

- Permit scanning SATA, SAS, SCSI, and NVMe devices with APFS file systems.
- Prevent scanning any devices with HFS or FAT32 file systems.
- Prevent 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`

15. `SecureBootModel`

Type: plist string

Failsafe: Default

Description: Apple Secure Boot hardware model.

Sets Apple Secure Boot hardware model and policy. Specifying this value defines which operating systems will be bootable. Operating systems shipped before the specified model was released will not boot.

Valid values:

- **Default** — Recent available model, currently set to `x86legacy`.
- **Disabled** — No model, Secure Boot will be disabled.
- `j137` — `iMacPro1,1` (December 2017). Minimum macOS 10.13.2 (17C2111)
- `j680` — `MacBookPro15,1` (July 2018). Minimum macOS 10.13.6 (17G2112)
- `j132` — `MacBookPro15,2` (July 2018). Minimum macOS 10.13.6 (17G2112)
- `j174` — `Macmini8,1` (October 2018). Minimum macOS 10.14 (18A2063)
- `j140k` — `MacBookAir8,1` (October 2018). Minimum macOS 10.14.1 (18B2084)
- `j780` — `MacBookPro15,3` (May 2019). Minimum macOS 10.14.5 (18F132)
- `j213` — `MacBookPro15,4` (July 2019). Minimum macOS 10.14.5 (18F2058)
- `j140a` — `MacBookAir8,2` (July 2019). Minimum macOS 10.14.5 (18F2058)
- `j152f` — `MacBookPro16,1` (November 2019). Minimum macOS 10.15.1 (19B2093)
- `j160` — `MacPro7,1` (December 2019). Minimum macOS 10.15.1 (19B88)
- `j230k` — `MacBookAir9,1` (March 2020). Minimum macOS 10.15.3 (19D2064)
- `j214k` — `MacBookPro16,2` (May 2020). Minimum macOS 10.15.4 (19E2269)
- `j223` — `MacBookPro16,3` (May 2020). Minimum macOS 10.15.4 (19E2265)
- `j215` — `MacBookPro16,4` (June 2020). Minimum macOS 10.15.5 (19F96)
- `j185` — `iMac20,1` (August 2020). Minimum macOS 10.15.6 (19G2005)
- `j185f` — `iMac20,2` (August 2020). Minimum macOS 10.15.6 (19G2005)
- `x86legacy` — Macs without T2 chip and VMs. Minimum macOS 11.0.1 (20B29)

Warning: Not all Apple Secure Boot models are supported on all hardware configurations. Starting with macOS 12 `x86legacy` is the only Apple Secure Boot model compatible with software update on hardware without T2 chips.

Apple Secure Boot appeared in macOS 10.13 on models with T2 chips. Since `PlatformInfo` and `SecureBootModel` are independent, Apple Secure Boot can be used with any SMBIOS with and without T2. Setting `SecureBootModel` to any valid value but `Disabled` is equivalent to `Medium Security` of Apple Secure Boot. The `ApECID` value must also be specified to achieve `Full Security`. Check `ForceSecureBootScheme` when using Apple Secure Boot on a virtual machine.

Note that enabling Apple Secure Boot is demanding on invalid configurations, faulty macOS installations, and on unsupported setups.

Things to consider:

- As with T2 Macs, all unsigned kernel extensions as well as several signed kernel extensions, including NVIDIA Web Drivers, cannot be installed.
- The list of cached kernel extensions may be different, resulting in a need to change the list of `Added` or `Forced` kernel extensions. For example, `I080211Family` cannot be injected in this case.
- System volume alterations on operating systems with sealing, such as macOS 11, may result in the operating system being unbootable. Do not try to disable system volume encryption unless Apple Secure Boot is disabled.
- Boot failures might occur when the platform requires certain settings, but they have not been enabled because the associated issues were not discovered earlier. Be extra careful with `IgnoreInvalidFlexRatio` or `HashServices`.
- Operating systems released before Apple Secure Boot was released (e.g. macOS 10.12 or earlier), will still boot until UEFI Secure Boot is enabled. This is so because Apple Secure Boot treats these as incompatible

and they are then handled by the firmware (as Microsoft Windows is).

- (f) On older CPUs (e.g. before Sandy Bridge), enabling Apple Secure Boot might cause slightly slower loading (by up to 1 second).
- (g) As the `Default` value will increase with time to support the latest major released operating system, it is not recommended to use the `ApECID` and the `Default` settings together.
- (h) Installing macOS with Apple Secure Boot enabled is not possible while using HFS+ target volumes. This may include HFS+ formatted drives when no spare APFS drive is available.

The installed operating system may have sometimes outdated Apple Secure Boot manifests on the `Preboot` partition, resulting in boot failures. This is likely to be the case when an “OCB: Apple Secure Boot prohibits this boot entry, enforcing!” message is logged.

When this happens, either reinstall the operating system or copy the manifests (files with `.im4m` extension, such as `boot.efi.j137.im4m`) from `/usr/standalone/i386` to `/Volumes/Preboot/<UUID>/System/Library/CoreServices`. Here, `<UUID>` is the system volume identifier. On HFS+ installations, the manifests should be copied to `/System/Library/CoreServices` on the system volume.

For more details on how to configure Apple Secure Boot with UEFI Secure Boot, refer to the UEFI Secure Boot section.

8.6 Entry Properties

1. Arguments

Type: plist string

Failsafe: Empty

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

2. Auxiliary

Type: plist boolean

Failsafe: false

Description: Set to `true` to hide this entry when `HideAuxiliary` is also set to `true`. Press the `Spacebar` key to enter “Extended Mode” and display the entry when hidden.

3. Comment

Type: plist string

Failsafe: Empty

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

4. Enabled

Type: plist boolean

Failsafe: false

Description: Set to `true` activate this entry.

5. Flavour

Type: plist string

Failsafe: Auto

Description: Specify the content flavour for this entry. See `OC_ATTR_USE_FLAVOUR_ICON` flag for documentation.

6. Name

Type: plist string

Failsafe: Empty

Description: Human readable entry name displayed in the OpenCore picker.

7. Path

Type: plist string

Failsafe: Empty

Description: Entry location depending on entry type.

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

8. RealPath

Type: plist boolean

Failsafe: false

Description: Pass full path to the tool when launching.

This should typically be disabled as passing the tool directory may be unsafe with tools that accidentally attempt to access files without checking their integrity. Reasons to enable this property may include cases where tools cannot work without external files or may need them for enhanced functionality such as `mementest86` (for logging and configuration), or `Shell` (for automatic script execution).

Note: This property is only valid for `Tools` and cannot be specified for `Entries` (is always `true`).

9. TextMode

Type: plist boolean

Failsafe: false

Description: Run the entry in text mode instead of graphics mode.

This setting may be beneficial for some older tools that require text output as all the tools are launched in graphics mode by default. Refer to the Output Properties section below for information on text modes.

9 NVRAM

9.1 Introduction

This section allows setting non-volatile UEFI variables commonly described as NVRAM variables. Refer to `man nvram` for details. The macOS operating system extensively uses NVRAM variables for OS — Bootloader — Firmware intercommunication. Hence, the supply of several NVRAM variables is required for the proper functioning of macOS.

Each NVRAM variable consists of its name, value, attributes (refer to UEFI specification), and its GUID, representing which ‘section’ the NVRAM variable belongs to. The macOS operating system makes use of 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)
- 5EDDA193-A070-416A-85EB-2A1181F45B18 (Apple Hardware Configuration Storage for MacPro7,1)
- 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 the PlatformNVRAM or Generic subsections of the PlatformInfo section. Please ensure that variables set in this section do not conflict with items in those subsections as the implementation behaviour is undefined otherwise.

The OC_FIRMWARE_RUNTIME protocol implementation, currently offered as a part of the OpenRuntime driver, is often required for macOS to function properly. While this brings many benefits, there are some limitations that should be considered for certain use cases.

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 must be aware of the 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 multidata` format. GUIDs must be provided in canonic string format in upper or lower case (e.g. 8BE4DF61-93CA-11D2-AA0D-00E098032B8C).

The EFI_VARIABLE_BOOTSERVICE_ACCESS and EFI_VARIABLE_RUNTIME_ACCESS attributes of created variables are set. Variables will only be set if not present or deleted. That is, to overwrite an existing variable value, add the variable name to the Delete section. This approach enables the provision of default values until the operating system takes the lead.

Note: The implementation behaviour is undefined when the `plist` key does not conform to the GUID format.
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 a NVRAM variable file named `nvram.plist` from EFI volume root.

This file must have a 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 the 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 `nvr.am.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 the OpenCore EFI partition UUID.

Warning: This feature can be dangerous, as it passes unprotected data to firmware variable services. Only use when no hardware NVRAM implementation is provided by the firmware or when the NVRAM implementation is incompatible.

4. LegacyOverwrite

Type: `plist boolean`

Failsafe: `false`

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

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

5. LegacySchema

Type: `plist dict`

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

* value can be used to accept all variables for certain GUID.

WARNING: Choose variables carefully, as the `nvr.am.plist` file is not vaulted. For instance, do not include `boot-args` or `csr-active-config`, as these can be used to bypass SIP.

6. WriteFlash

Type: `plist boolean`

Failsafe: `false`

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

Note: This value should be enabled on most types of firmware but is left configurable to account for firmware that may have issues with NVRAM variable storage garbage collection or similar.

The `nvr.am` command can be used to read NVRAM variable values from macOS by concatenating the GUID and name variables separated by a `:` symbol. For example, `nvr.am 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 the `PlatformNVRAM` or `Generic` subsections of the `PlatformInfo` section. Using `PlatformInfo` is the recommended 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).
- `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:SSN`
Serial number. 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 10.14 is needed.
- `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.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:ForceDisplayRotationInEFI`
32-bit integer defining display rotation. Can be `0` for no rotation or any of `90`, `180`, `270` for matching rotation in degrees.
- `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`)
 - `arch=i386` (force kernel architecture to `i386`, see `KernelArch`)
 - `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)
 - `ioaccel_debug=VALUE` (`IOAccelerator` debug mask)
 - `keepsyms=1` (show panic log debug symbols)
 - `kextlog=VALUE` (kernel extension loading debug mask)
 - `nvrn-log=1` (enables `AppleEFINVRAM` logs)
 - `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` (disable lapic spurious interrupt panic on AP cores)
- `panic_on_display_hang=1` (trigger panic on display hang)
- `panic_on_gpu_hang=1` (trigger panic on GPU hang)
- `slide=VALUE` (manually set KASLR slide)
- `smcdebug=VALUE` (AppleSMC debug mask)
- `spin_wait_for_gpu=1` (reduces GPU timeout on high load)
- `-amd_no_dgpu_accel` (alternative to WhateverGreen's `-radvesa` for new GPUs)
- `-nehalem_error_disable` (disables the AppleTyMCEDriver)
- `-no_compat_check` (disable model checking on 10.7+)
- `-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 defective up to the 10.15.4 release due to refactoring issues as well as the 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.
 - * 2 — 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 three
 - * 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: Enable the `AppleDebug` option to display verbose output from `boot.efi` on modern macOS versions. This will save the log to the general OpenCore log file. 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:csr-data`
Specify sources of kexts which will be approved regardless of SIP `CSR_ALLOW_UNAPPROVED_KEXTS` value.
Example contents:

```
<dict><key>kext-allowed-teams</key><array><string>{DEVELOPER-TEAM-ID}</string></array></dict>%00
```
- `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 to by the `efiboot-perf-record-data` and `efiboot-perf-record-size` variables. Starting from 10.15.4, it can also be saved to the OpenCore log by setting the `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:run-efi-updater`
Override EFI firmware updating support in macOS (MultiUpdater, ThorUtil, and so on). Setting this to No or alternative boolean-castable value will prevent any firmware updates in macOS starting with 10.10 at least.
- `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.
- `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.
- `5EDDA193-A070-416A-85EB-2A1181F45B18:PEXConf`
PCI expansion slot configuration for MacPro7,1. 8-byte sequence describing default PCI slot configuration. Each byte refers to a configuration for a dedicated PCI slot.
 - Slot 1 resides at `IOService:/AppleACPIPlatformExpert/PC01@0/AppleACPIPCI/BR1A@0` and its path is hardcoded. This slot is not behind a muxer.
 - Slot 3 resides at `IOService:/AppleACPIPlatformExpert/PC03@0/AppleACPIPCI/BR3A@0` and its path is hardcoded. This slot is not behind a muxer.
 - Slots 2, 4-8 are dynamic and are matched based on `AAPL,slot-name` property with `Slot-N` value, where N

is the slot number. All these slots are behind the muxer.

Refer to the support page for more details on how MacPro7,1 slots are configured.

- `5EDDA193-A070-416A-85EB-2A1181F45B18:SlotUtilPEXConf`

User PCI expansion slot configuration for MacPro7,1. 8-byte sequence describing user PCI slot configuration.

10 PlatformInfo

Platform information consists 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 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 all the values are specified (the default), and semi-automatic, where (`Automatic`) only certain values are specified, and later used for system configuration.

The `dmidecode` utility can be used to inspect SMBIOS contents and a 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 the `Generic` section instead of using values from the `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.
- When disabled `Generic` section is unused.

Warning: Setting this option to `false` is strongly discouraged when intending to update platform information. A `false` setting is typically only valid for minor corrections to SMBIOS values on legacy Apple hardware. In all other cases, setting `Automatic` to `false` may lead to hard-to-debug errors resulting from inconsistent or invalid settings.

2. `CustomMemory`

Type: plist boolean

Failsafe: false

Description: Use custom memory configuration defined in the `Memory` section. This completely replaces any existing memory configuration in SMBIOS, and is only active when `UpdateSMBIOS` is set to `true`.

3. `UpdateDataHub`

Type: plist boolean

Failsafe: false

Description: Update Data Hub fields. These fields are read from the `Generic` or `DataHub` sections depending on the setting of the `Automatic` property.

Note: The implementation of the Data Hub protocol in EFI firmware on virtually all systems, including Apple hardware, means that existing Data Hub entries cannot be overridden. New entries are added to the end of the Data Hub instead, with macOS ignoring old entries. This can be worked around by replacing the Data Hub protocol using the `ProtocolOverrides` section. Refer to the `DataHub` protocol override description for details.

4. `UpdateNVRAM`

Type: plist boolean

Failsafe: false

Description: Update NVRAM fields related to platform information.

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

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

5. UpdateSMBIOS

Type: plist boolean

Failsafe: false

Description: Update SMBIOS fields. These fields are read from the `Generic` or `SMBIOS` sections depending on the setting of the `Automatic` property.

6. 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 on some types of firmware.
- **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 firmware 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 the `Custom` approach that it makes SMBIOS updates exclusive to macOS, avoiding a collision with existing Windows activation and custom OEM software but potentially obstructing the operation of Apple-specific tools.

7. UseRawUuidEncoding

Type: plist boolean

Failsafe: false

Description: Use raw encoding for SMBIOS UUIDs.

Each UUID `AABBCDD-EEFF-GGHH-IIJJ-KKLLMMNNOOPP` is essentially a hexadecimal 16-byte number. It can be encoded in two ways:

- **Big Endian** — by writing all the bytes as they are without making any order changes (`{AA BB CC DD EE FF GG HH II JJ KK LL MM NN OO PP}`). This method is also known as RFC 4122 encoding or **Raw** encoding.
- **Little Endian** — by interpreting the bytes as numbers and using Little Endian byte representation (`{DD CC BB AA FF EE HH GG II JJ KK LL MM NN OO PP}`).

The SMBIOS specification did not explicitly specify the encoding format for the UUID up to SMBIOS 2.6, where it stated that **Little Endian** encoding shall be used. This led to the confusion in both firmware implementations and system software as different vendors used different encodings prior to that.

- Apple uses the **Big Endian** format everywhere but it ignores SMBIOS UUID within macOS.
- `dmidecode` uses the **Big Endian** format for SMBIOS 2.5.x or lower and the **Little Endian** format for 2.6 and newer. `Acidanthera dmidecode` prints all three.
- Windows uses the **Little Endian** format everywhere, but this only affects the visual representation of the values.

OpenCore always sets a recent SMBIOS version (currently 3.2) when generating the modified DMI tables. If `UseRawUuidEncoding` is enabled, the **Big Endian** format is used to store the `SystemUUID` data. Otherwise, the **Little Endian** format is used.

Note: This preference does not affect UUIDs used in DataHub and NVRAM as they are not standardised and are added by Apple. Unlike SMBIOS, they are always stored in the **Big Endian** format.

8. Generic

Type: plist dictionary

Description: Update all fields in `Automatic` mode.

Note: This section is ignored but may not be removed when `Automatic` is `false`.

9. DataHub

Type: plist dictionary

Description: Update Data Hub fields in non-Automatic mode.

Note: This section is ignored and may be removed when `Automatic` is `true`.

10. Memory

Type: plist dictionary

Description: Define custom memory configuration.

Note: This section is ignored and may be removed when `CustomMemory` is `false`.

11. PlatformNVRAM

Type: plist dictionary

Description: Update platform NVRAM fields in non-Automatic mode.

Note: This section is ignored and may be removed when `Automatic` is `true`.

12. SMBIOS

Type: plist dictionary

Description: Update SMBIOS fields in non-Automatic mode.

Note: This section is ignored and may be removed when `Automatic` is `true`.

10.2 Generic Properties

1. SpoofVendor

Type: plist boolean

Failsafe: false

Description: Sets SMBIOS vendor fields to `Acidanthera`.

It can be dangerous to use “Apple” in SMBIOS vendor fields for reasons outlined in the `SystemManufacturer` description. However, certain firmware may not provide valid values otherwise, which could obstruct the operation of some software.

2. AdviseFeatures

Type: plist boolean

Failsafe: false

Description: Updates `FirmwareFeatures` with supported bits.

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 an EFI partition that is 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 an EFI partition that is the first partition on the disk.
- `FW_FEATURE_SUPPORTS_APFS` (0x00080000) - Without this bit, it is not possible to install macOS on an APFS disk.

Note: On most newer firmwares these bits are already set, the option may be necessary when "upgrading" the firmware with new features.

3. MaxBIOSVersion

Type: plist boolean

Failsafe: false

Description: Sets `BIOSVersion` to `9999.999.999.999.999`, recommended for legacy Macs when using `Automatic PlatformInfo`, to avoid BIOS updates in unofficially supported macOS versions.

4. SystemMemoryStatus

Type: plist string

Failsafe: Auto

Description: Indicates whether system memory is upgradable in `PlatformFeature`. This controls the visibility of the Memory tab in “About This Mac”.

Valid values:

- `Auto` — use the original `PlatformFeature` value.

- `Upgradable` — explicitly unset `PT_FEATURE_HAS_SOLDERED_SYSTEM_MEMORY (0x2)` in `PlatformFeature`.
- `Soldered` — explicitly set `PT_FEATURE_HAS_SOLDERED_SYSTEM_MEMORY (0x2)` in `PlatformFeature`.

Note: On certain Mac models, such as the `MacBookPro10,x` and any `MacBookAir`, `SPMemoryReporter.spreporter` will ignore `PT_FEATURE_HAS_SOLDERED_SYSTEM_MEMORY` and assume that system memory is non-upgradable.

5. `ProcessorType`

Type: `plist integer`

Failsafe: 0 (Automatic)

Description: Refer to SMBIOS `ProcessorType`.

6. `SystemProductName`

Type: `plist string`

Failsafe: Empty (OEM specified or not installed)

Description: Refer to SMBIOS `SystemProductName`.

7. `SystemSerialNumber`

Type: `plist string`

Failsafe: Empty (OEM specified or not installed)

Description: Refer to SMBIOS `SystemSerialNumber`.

Specify special string value `OEM` to extract current value from NVRAM (`SSN` variable) or SMBIOS and use it throughout the sections. This feature can only be used on Mac-compatible firmware.

8. `SystemUUID`

Type: `plist string, GUID`

Failsafe: Empty (OEM specified or not installed)

Description: Refer to SMBIOS `SystemUUID`.

Specify special string value `OEM` to extract current value from NVRAM (`system-id` variable) or SMBIOS and use it throughout the sections. Since not every firmware implementation has valid (and unique) values, this feature is not applicable to some setups, and may provide unexpected results. It is highly recommended to specify the UUID explicitly. Refer to `UseRawUuidEncoding` to determine how SMBIOS value is parsed.

9. `MLB`

Type: `plist string`

Failsafe: Empty (OEM specified or not installed)

Description: Refer to SMBIOS `BoardSerialNumber`.

Specify special string value `OEM` to extract current value from NVRAM (`MLB` variable) or SMBIOS and use it throughout the sections. This feature can only be used on Mac-compatible firmware.

10. `ROM`

Type: `plist multidata, 6 bytes`

Failsafe: Empty (OEM specified or not installed)

Description: Refer to `4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:ROM`.

Specify special string value `OEM` to extract current value from NVRAM (`ROM` variable) and use it throughout the sections. This feature can only be used on Mac-compatible firmware.

10.3 DataHub Properties

1. `PlatformName`

Type: `plist string`

Failsafe: Empty (Not installed)

Description: Sets name in `gEfiMiscSubClassGuid`. The value found on Macs is `platform` in ASCII.

2. `SystemProductName`

Type: `plist string`

Failsafe: Empty (Not installed)

Description: Sets `Model` in `gEfiMiscSubClassGuid`. The value found on Macs is equal to SMBIOS `SystemProductName` in Unicode.

3. **SystemSerialNumber**
Type: plist string
Failsafe: Empty (Not installed)
Description: Sets SystemSerialNumber in gEfiMiscSubClassGuid. The value found on Macs is equal to SMBIOS SystemSerialNumber in Unicode.
4. **SystemUUID**
Type: plist string, GUID
Failsafe: Empty (Not installed)
Description: Sets system-id in gEfiMiscSubClassGuid. The value found on Macs is equal to SMBIOS SystemUUID (with swapped byte order).
5. **BoardProduct**
Type: plist string
Failsafe: Empty (Not installed)
Description: Sets board-id in gEfiMiscSubClassGuid. The 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. The 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. The 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_RESE0T# 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_PMC0N_3 bit 2 RTC_PWR_STS)
 - 0x00000040 — General Reset Status (Same as GEN_PMC0N_3 bit 9 GEN_RST_STS)
 - 0xfffff80 — SUS Well Power Loss (Same as GEN_PMC0N_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: 0 (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: 0 (Automatic)

Description: Sets ARTFrequency in gEfiProcessorSubClassGuid.

This value contains CPU ART frequency, also known as crystal clock frequency. Its existence is exclusive to the Skylake generation and newer. The value is specified in Hz, and is normally 24 MHz for the client Intel segment, 25 MHz for the 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: 0 (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: Empty (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: Empty (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: Empty (Not installed)

Description: Sets RP1t in gEfiMiscSubClassGuid. Custom property read by VirtualSMC or FakeSMC to generate SMC RP1t key.

10.4 Memory Properties

1. DataWidth

Type: plist integer, 16-bit

Failsafe: 0xFFFF (unknown)

SMBIOS: Memory Device (Type 17) — Data Width

Description: Specifies the data width, in bits, of the memory. A DataWidth of 0 and a TotalWidth of 8 indicates that the device is being used solely to provide 8 error-correction bits.

2. Devices

Type: plist array

Failsafe: Empty

Description: Specifies the custom memory devices to be added.

To be filled with plist dictionary values, describing each memory device. Refer to the Memory Devices Properties section below. This should include all memory slots, even if unpopulated.

3. ErrorCorrection

Type: plist integer, 8-bit

Failsafe: 0x03

SMBIOS: Physical Memory Array (Type 16) — Memory Error Correction

Description: Specifies the primary hardware error correction or detection method supported by the memory.

- 0x01 — Other
- 0x02 — Unknown
- 0x03 — None

- 0x04 — Parity
- 0x05 — Single-bit ECC
- 0x06 — Multi-bit ECC
- 0x07 — CRC

4. FormFactor

Type: plist integer, 8-bit

Failsafe: 0x02

SMBIOS: Memory Device (Type 17) — Form Factor

Description: Specifies the form factor of the memory. On Macs, this should typically be DIMM or SODIMM. Commonly used form factors are listed below.

When `CustomMemory` is `false`, this value is automatically set based on Mac product name.

When `Automatic` is `true`, the original value from the the corresponding Mac model will be set if available. Otherwise, the value from `OcMacInfoLib` will be set. When `Automatic` is `false`, a user-specified value will be set if available. Otherwise, the original value from the firmware will be set. If no value is provided, the failsafe value will be set.

- 0x01 — Other
- 0x02 — Unknown
- 0x09 — DIMM
- 0x0D — SODIMM
- 0x0F — FB-DIMM

5. MaxCapacity

Type: plist integer, 64-bit

Failsafe: 0

SMBIOS: Physical Memory Array (Type 16) — Maximum Capacity

Description: Specifies the maximum amount of memory, in bytes, supported by the system.

6. TotalWidth

Type: plist integer, 16-bit

Failsafe: 0xFFFF (unknown)

SMBIOS: Memory Device (Type 17) — Total Width

Description: Specifies the total width, in bits, of the memory, including any check or error-correction bits. If there are no error-correction bits, this value should be equal to `DataWidth`.

7. Type

Type: plist integer, 8-bit

Failsafe: 0x02

SMBIOS: Memory Device (Type 17) — Memory Type

Description: Specifies the memory type. Commonly used types are listed below.

- 0x01 — Other
- 0x02 — Unknown
- 0x0F — SDRAM
- 0x12 — DDR
- 0x13 — DDR2
- 0x14 — DDR2 FB-DIMM
- 0x18 — DDR3
- 0x1A — DDR4
- 0x1B — LPDDR
- 0x1C — LPDDR2
- 0x1D — LPDDR3
- 0x1E — LPDDR4

8. TypeDetail

Type: plist integer, 16-bit

Failsafe: 0x4

SMBIOS: Memory Device (Type 17) — Type Detail

Description: Specifies additional memory type information.

- Bit 0 — Reserved, set to 0
- Bit 1 — Other
- Bit 2 — Unknown
- Bit 7 — Synchronous
- Bit 13 — Registered (buffered)
- Bit 14 — Unbuffered (unregistered)

10.4.1 Memory Device Properties

1. AssetTag

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Asset Tag

Description: Specifies the asset tag of this memory device.

2. BankLocator

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Bank Locator

Description: Specifies the physically labeled bank where the memory device is located.

3. DeviceLocator

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Device Locator

Description: Specifies the physically-labeled socket or board position where the memory device is located.

4. Manufacturer

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Manufacturer

Description: Specifies the manufacturer of this memory device.

For empty slot this must be set to NO DIMM for macOS System Profiler to correctly display memory slots on certain Mac models, e.g. MacPro7,1. MacPro7,1 imposes additional requirements on the memory layout:

- The amount of installed sticks must one of the following: 4, 6, 8, 10, 12. Using any different value will cause an error in the System Profiler.
- The amount of memory slots must equal to 12. Using any different value will cause an error in the System Profiler.
- Memory sticks must be installed in dedicated memory slots as explained on the support page. SMBIOS memory devices are mapped to the following slots: 8, 7, 10, 9, 12, 11, 5, 6, 3, 4, 1, 2.

5. PartNumber

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Part Number

Description: Specifies the part number of this memory device.

6. SerialNumber

Type: plist string

Failsafe: Unknown

SMBIOS: Memory Device (Type 17) — Serial Number

Description: Specifies the serial number of this memory device.

7. Size

Type: plist integer, 32-bit

Failsafe: 0

SMBIOS: Memory Device (Type 17) — Size

Description: Specifies the size of the memory device, in megabytes. 0 indicates this slot is not populated.

8. Speed

Type: plist integer, 16-bit

Failsafe: 0

SMBIOS: Memory Device (Type 17) — Speed

Description: Specifies the maximum capable speed of the device, in megatransfers per second (MT/s). 0 indicates an unknown speed.

10.5 PlatformNVRAM Properties

1. BID

Type: plist string

Failsafe: Empty (Not installed)

Description: Specifies the value of NVRAM variable 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_BID.

2. ROM

Type: plist data, 6 bytes

Failsafe: Empty (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: Empty (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: Empty (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: Empty (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

6. SystemSerialNumber

Type: plist string

Failsafe: Empty (Not installed)

Description: Specifies the values of NVRAM variables 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:HW_SSN and 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:SSN.

7. SystemUUID

Type: plist string

Failsafe: Empty (Not installed)

Description: Specifies the value of NVRAM variable 4D1EDE05-38C7-4A6A-9CC6-4BCCA8B38C14:system-id for boot services only. The value found on Macs is equal to SMBIOS SystemUUID.

10.6 SMBIOS Properties

1. BIOSVendor

Type: plist string

Failsafe: Empty (OEM specified)

SMBIOS: BIOS Information (Type 0) — Vendor

Description: BIOS Vendor. All rules of SystemManufacturer do apply.

2. BIOSVersion

Type: plist string

Failsafe: Empty (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 firmware and is described in BiosId.h. In newer firmware, 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: Empty (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: Empty (OEM specified)

SMBIOS: System Information (Type 1) — Manufacturer

Description: OEM manufacturer of the particular board. Use failsafe unless strictly required. Do not override to contain Apple Inc. on non-Apple hardware, as this confuses numerous services present in the operating system, such as firmware updates, eficheck, as well as kernel extensions developed in Acidanthera, such as Lilu and its plugins. In addition it will also make some operating systems such as Linux unbootable.

5. SystemProductName

Type: plist string

Failsafe: Empty (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: Empty (OEM specified)

SMBIOS: System Information (Type 1) — Version

Description: Product iteration version number. May look like 1.1.

7. SystemSerialNumber

Type: plist string

Failsafe: Empty (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: Empty (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: Empty (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: Empty (OEM specified)
SMBIOS: System Information (Type 1) — Family
Description: Family name. May look like iMac Pro.
11. **BoardManufacturer**
Type: plist string
Failsafe: Empty (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: Empty (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: Empty (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: Empty (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: Empty (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: 0 (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 details.
17. **BoardLocationInChassis**
Type: plist string
Failsafe: Empty (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: Empty (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: 0 (OEM specified)
SMBIOS: System Enclosure or Chassis (Type 3) — Type
Description: Chassis type. Refer to Table 17 — System Enclosure or Chassis Types for details.
20. **ChassisVersion**
Type: plist string
Failsafe: Empty (OEM specified)
SMBIOS: System Enclosure or Chassis (Type 3) — Version
Description: Should match **BoardProduct**.
21. **ChassisSerialNumber**
Type: plist string
Failsafe: Empty (OEM specified)
SMBIOS: System Enclosure or Chassis (Type 3) — Version
Description: Should match **SystemSerialNumber**.
22. **ChassisAssetTag**
Type: plist string
Failsafe: Empty (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 (OEM specified on Apple hardware, do not provide the table otherwise)
SMBIOS: APPLE_SMBIOS_TABLE_TYPE133 - **PlatformFeature**
Description: Platform features bitmask (Missing on older Macs). Refer to **AppleFeatures.h** for details.
24. **SmcVersion**
Type: plist data, 16 bytes
Failsafe: All zero (OEM specified on Apple hardware, do not provide the table otherwise)
SMBIOS: APPLE_SMBIOS_TABLE_TYPE134 - **Version**
Description: ASCII string containing SMC version in upper case. Missing on T2 based Macs.
25. **FirmwareFeatures**
Type: plist data, 8 bytes
Failsafe: 0 (OEM specified on Apple hardware, 0 otherwise)
SMBIOS: APPLE_SMBIOS_TABLE_TYPE128 - **FirmwareFeatures** and **ExtendedFirmwareFeatures**
Description: 64-bit firmware features bitmask. Refer to **AppleFeatures.h** for details. Lower 32 bits match **FirmwareFeatures**. Upper 64 bits match **ExtendedFirmwareFeatures**.
26. **FirmwareFeaturesMask**
Type: plist data, 8 bytes
Failsafe: 0 (OEM specified on Apple hardware, 0 otherwise)
SMBIOS: APPLE_SMBIOS_TABLE_TYPE128 - **FirmwareFeaturesMask** and **ExtendedFirmwareFeaturesMask**
Description: Supported bits of extended firmware features bitmask. Refer to **AppleFeatures.h** for details. Lower 32 bits match **FirmwareFeaturesMask**. Upper 64 bits match **ExtendedFirmwareFeaturesMask**.
27. **ProcessorType**
Type: plist integer, 16-bit
Failsafe: 0 (Automatic)

SMBIOS: APPLE_SMBIOS_TABLE_TYPE131 - ProcessorType

Description: Combined of Processor Major and Minor types.

Automatic value generation attempts to provide the most accurate value for the currently installed CPU. When this fails, please raise an issue and provide `sysctl machdep.cpu` and `dmidecode` output. For a full list of available values and their limitations (the value will only apply if the CPU core count matches), refer to the Apple SMBIOS definitions header [here](#).

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 loading additional UEFI modules as well as applying tweaks to 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 the 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 firmware for most Intel and some other analog audio controllers. Staging driver, refer to acidanthera/bugtracker#740 for known issues in AudioDxe.
btrfs_x64	Open source BTRFS file system driver, required for booting with OpenLinuxBoot from a file system which is now quite commonly used with Linux.
CrScreenshotDxe*	Screenshot making driver saving images to the root of OpenCore partition (ESP) or any available writeable filesystem upon pressing F10. This is a modified version of CrScreenshotDxe driver by Nikolaj Schlej.
ExFatDxe	Proprietary ExFAT file system driver for Bootcamp support commonly found in Apple firmware. For Sandy Bridge and earlier CPUs, the ExFatDxeLegacy driver should be used due to the lack of RDRAND instruction support.
ext4_x64	Open source EXT4 file system driver, required for booting with OpenLinuxBoot from the file system most commonly used with Linux.
HfsPlus	Recommended. Proprietary HFS file system driver with bless support commonly found in Apple firmware. For Sandy Bridge and earlier CPUs, the 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 types of firmware starting with the Ivy Bridge generation. Some applications with GUI, such as UEFI Shell, may need this driver to work properly.
EnhancedFatDxe	FAT filesystem driver from FatPkg. This driver is embedded in all UEFI firmware and cannot be used from OpenCore. Several types of firmware have defective FAT support implementation that may lead to corrupted filesystems on write attempts. Embedding this driver within the firmware may be required in case writing to the EFI partition is needed during the boot process.
NvmExpressDxe*	NVMe support driver from MdeModulePkg. This driver is included in most firmware starting with the 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.
OpenLinuxBoot*	OpenCore plugin implementing OC_BOOT_ENTRY_PROTOCOL to allow direct detection and booting of Linux distributions from OpenCore, without chainloading via GRUB.
OpenUsbKbDxe*	USB keyboard driver adding support for 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.
OpenPartitionDxe*	Partition management driver with Apple Partitioning Scheme support. This driver can be used to support loading older DMG recoveries such as macOS 10.9 using Apple Partitioning Scheme. OpenDuet already includes this driver.
Ps2KeyboardDxe*	PS/2 keyboard driver from MdeModulePkg. OpenDuetPkg and some types of firmware may not include this driver, but it is necessary for PS/2 keyboard to work. Note, unlike OpenUsbKbDxe this driver has no AppleKeyMapAggregator support and thus requires KeySupport to be enabled.
Ps2MouseDxe*	PS/2 mouse driver from MdeModulePkg. Some very old laptop firmware may not include this driver but it is necessary for the touchpad to work in UEFI graphical interfaces such as OpenCanopy.

OpenHfsPlus*	HFS file system driver with bless support. This driver is an alternative to a closed source HfsPlus driver commonly found in Apple firmware. While it is feature complete, it is approximately 3 times slower and is yet to undergo a security audit.
UsbMouseDxe*	USB mouse driver from MdeModulePkg. Some virtual machine firmware such as OVMF may not include this driver but it is necessary for the mouse to work in UEFI graphical interfaces such as OpenCanopy.
XhciDxe*	XHCI USB controller support driver from MdeModulePkg. This driver is included in most types of firmware starting with the Sandy Bridge generation. For earlier firmware 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) the same command used for OpenCore compilation can be taken, 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 and Applications

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 (Refer to the Tools subsection for more details), most 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. It is typically 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: /System/Library/CoreServices/BridgeVersion.bin should be copied to /Volumes/VOLNAME/DIR.

Note 2: To be able to use the bless command, disabling System Integrity Protection is necessary.

Note 3: To be able to boot Secure Boot might be disabled 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.
CsrUtil*	Simple implementation of SIP-related features of Apple csrutil.
GopStop*	Test GraphicsOutput protocol with a simple scenario.
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 firmware.
PavpProvision	Perform EPID provisioning (requires certificate data configuration).
ResetSystem*	Utility to perform system reset. Takes reset type as an argument: coldreset, firmware, shutdown, warmreset. Defaults to coldreset.
RtcRw*	Utility to read and write RTC (CMOS) memory.
ControlMsrE2*	Check CFG Lock (MSR 0xE2 write protection) consistency across all cores and change such hidden options on selected platforms.
TpmInfo*	Check Intel PTT (Platform Trust Technology) capability on the platform, which allows using fTPM 2.0 if enabled. The tool does not check whether fTPM 2.0 is actually enabled.

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. Customised icons can be found over the internet (e.g. [here](#) or [there](#)).

OpenCanopy provides full support for `PickerAttributes` and offers a configurable builtin icon set. The chosen icon set may depend on the `DefaultBackgroundColor` variable value. Refer to `PickerVariant` for more details.

Predefined icons are saved in the `PickerVariant`-derived subdirectory of the `\EFI\OC\Resources\Image` directory. A full list of supported icons (in `.icns` format) is provided below. When optional icons are missing, the closest available icon will be used. External entries will use `Ext`-prefixed icon if available (e.g. `OldExtHardDrive.icns`).

Note: In the following all dimensions are normative for the 1x scaling level and shall be scaled accordingly for other levels.

- `Cursor` — Mouse cursor (mandatory, up to 144x144).
- `Selected` — Selected item (mandatory, 144x144).
- `Selector` — Selecting item (mandatory, up to 144x40).
- `SetDefault` — Selecting default (mandatory, up to 144x40; must be same width as `Selector`).
- `Left` — Scrolling left (mandatory, 40x40).
- `Right` — Scrolling right (mandatory, 40x40).
- `HardDrive` — Generic OS (mandatory, 128x128).
- `Background` — Centred background image.
- `Apple` — Apple OS (128x128).
- `AppleRecv` — Apple Recovery OS (128x128).
- `AppleTM` — Apple Time Machine (128x128).
- `Windows` — Windows (128x128).
- `Other` — Custom entry (see `Entries`, 128x128).
- `ResetNVRAM` — Reset NVRAM system action or tool (128x128).
- `Shell` — Entry with UEFI Shell name for e.g. `OpenShell` (128x128).
- `Tool` — Any other tool (128x128).

Predefined labels are saved in the `\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.
- `SIPDisabled` — Toogle SIP tool with SIP disabled.
- `SIPEnabled` — Toogle SIP tool with SIP enabled.
- `Shell` — Entry with UEFI Shell name (e.g. `OpenShell`).
- `Tool` — Any other tool.

Note: All labels must have a height of exactly 12 px. There is no limit for their width.

Label and icon generation can be performed with bundled utilities: `disklabel` and `icnspack`. 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 `fonverter` to export it to binary format.

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, such as 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 OpenLinuxBoot

`OpenLinuxBoot` is an OpenCore plugin implementing `OC_BOOT_ENTRY_PROTOCOL`. It detects and boots Linux distros which are installed according to the Boot Loader Specification or to the closely related (but not identical, see next paragraph) `systemd` `BootLoaderSpecByDefault`. In effect this means Linux distributions where the available boot options are found in `{ESP}/loader/entries/*.conf` files (for instance `/boot/efi/loader/entries/*.conf`) or in `{boot}/loader/entries/*.conf` files (for instance `/boot/loader/entries/*.conf`). The former layout – pure Boot Loader Specification, using kernel files on the EFI System Partition or Extended Boot Loader Partition – is specific to `systemd-boot`, the latter layout with kernel files typically on the partition which will be mounted as `/boot` applies to most Fedora-related distros including Fedora itself, RHEL and variants.

`BootLoaderSpecByDefault` includes the possibility of expanding GRUB variables in its `*.conf` files – and this is used in practice in certain distros such as CentOS. In order to correctly handle this, `OpenLinuxBoot` extracts all variables from `{boot}/grub2/grubenv` and any unconditionally set variables from `{boot}/grub2/grub.cfg`. This has proved sufficient in practice to extract the required variables seen so far in distros which use this GRUB-specific feature.

For distributions which do not use either of the above schemes, `OpenLinuxBoot` will autodetect and boot `{boot}/vmlinuz*` kernel files directly, after linking these automatically – based on the kernel version in the filename – to their associated `{boot}/init*` ramdisk files, and after searching in `/etc/default/grub` for kernel boot options and `/etc/os-release` for the distro name. This layout applies to most Debian-related distros, including Debian itself, Ubuntu and variants.

The method of starting the kernel relies on it being compiled with EFISTUB, however this applies to almost all modern distros, particularly those which use `systemd`. Most modern distros use `systemd` as their system manager (even though at the same time most do *not* use `systemd-boot` as their bootloader).

The latest kernel version of a given install is always shown in the boot menu. Additional versions, recovery versions, etc. are added as auxiliary boot entries, so depending on OpenCore's `HideAuxiliary` setting may not be shown until the space key is pressed.

Note 1: `OpenLinuxBoot` requires filesystem drivers that may not be available in firmware such as EXT4 and BTRFS drivers. These drivers can be obtained from external sources. Drivers tested in basic scenarios can be downloaded from `OcBinaryData`. Be aware that these drivers are neither tested for reliability in all scenarios, nor underwent any tamper-resistance testing, therefore have may carry potential security or data-loss risks.

Most Linux distributions keep their boot files on the EXT4 file system even when the distribution's main filesystem is something else such as BTRFS, therefore a suitable UEFI EXT4 file system driver such as `ext4_x64` is normally required. A BTRFS driver such as `btrfs_x64` will be required in a somewhat less standard setup where the boot files are on a BTRFS partition, e.g. as by default in openSUSE.

Pure Boot Loader Spec (e.g. as implemented by `systemd-boot`) keeps all kernel and ramdisk images directly on the EFI System Partition (or an Extended Boot Loader Partition), therefore it requires no additional filesystem driver - but it is not widely used except in Arch Linux.

Note 2: `systemd-boot` users (probably almost exclusively Arch Linux users) should be aware that `OpenLinuxBoot` does not support the `systemd-boot`-specific Boot Loader Interface; therefore use `efibootmgr` rather than `bootctl` for any low-level Linux command line interaction with the boot menu.

The default parameter values should work well, but if you need to parameterise this driver the following options may be specified in `UEFI/Drivers/Arguments`:

- `flags` - Default: all flags except `LINUX_BOOT_ADD_DEBUG_INFO` are set.

Available flags are:

- 0x00000001 (bit 0) — `LINUX_BOOT_SCAN_ESP`, Allows scanning for entries on EFI System Partition.
- 0x00000002 (bit 1) — `LINUX_BOOT_SCAN_XBOOTLDR`, Allows scanning for entries on Extended Boot Loader Partition.
- 0x00000004 (bit 2) — `LINUX_BOOT_SCAN_LINUX_ROOT`, Allows scanning for entries on Linux Root filesystems.
- 0x00000008 (bit 3) — `LINUX_BOOT_SCAN_LINUX_DATA`, Allows scanning for entries on Linux Data filesystems.
- 0x00000080 (bit 7) — `LINUX_BOOT_SCAN_OTHER`, Allows scanning for entries on file systems not matched by any of the above.

The following notes apply to all of the above options:

Note 1: Apple filesystems APFS and HFS are never scanned.

Note 2: Regardless of the above flags, a file system must first be allowed by `Misc/Security/ScanPolicy` before it can be seen by `OpenLinuxBoot` or any other `OC_BOOT_ENTRY_PROTOCOL` driver.

Note 3: It is recommended to enable scanning `LINUX_ROOT` and `LINUX_DATA` in both `OpenLinuxBoot` flags and `Misc/Security/ScanPolicy` in order to be sure to detect all valid Linux installs.

- 0x00000100 (bit 8) — `LINUX_BOOT_ALLOW_AUTODETECT`, If set allows autodetecting and linking `vmlinuz*` and `init*` ramdisk files when `loader/entries` files are not found.
- 0x00000200 (bit 9) — `LINUX_BOOT_USE_LATEST`, When a Linux entry generated by `OpenLinuxBoot` is selected as the default boot entry in OpenCore, automatically switch to the latest kernel when a new version is installed.

When this option is set, an internal menu entry id is shared between kernel versions from the same install of Linux. Linux boot options are always sorted highest kernel version first, so this means that the latest kernel version of the same install always shows as the default, with this option set.

Note: This option is recommended on all systems.

- 0x00000400 (bit 10) — `LINUX_BOOT_ADD_RO`, This option applies to autodetected Linux only (i.e. to Debian-style distributions, not to BLSpec and Fedora-style distributions with `/loader/entries/*.conf` files). Some distributions run a filesystem check on loading which requires the root filesystem to initially be mounted read-only via the `ro` kernel option. Set this bit to add this option on autodetected distros; should be harmless but very slightly slow down boot time (due to required remount as read-write) on distros which do not require it. To specify this option for specific distros only, use `partuuidopts:{partuuid}+=ro` instead of this flag.
- 0x00008000 (bit 15) — `LINUX_BOOT_ADD_DEBUG_INFO`, Adds a human readable file system type, followed by the first eight characters of the partition's unique partition uuid, to each generated entry name. Can help with debugging the origin of entries generated by the driver when there are multiple Linux installs on one system.

Flag values can be specified in hexadecimal beginning with 0x or in decimal, e.g. `flags=0x80` or `flags=128`.

- `partuuidopts:{partuuid}[+]="{options}"` - Default: not set.

Allows specifying kernel options for a given partition only. If specified with `+=` then these are used in addition to autodetected options, if specified with `=` they are used instead. Used for autodetected Linux only. Values specified here are never used for entries created from `/loader/entries/*.conf` files.

Note: The `partuuid` value to be specified here is typically the same as the `PARTUUID` seen in `root=PARTUUID=...` in the Linux kernel boot options (view using `cat /proc/cmdline`) for autodetected Debian-style distros, but is NOT the same for Fedora-style distros booted from `/loader/entries/*.conf` files.

Typically you should not need this option in the latter case, but in case you do, to find out the unique partition uuid to use, look for `LNK:` entries in the OpenCore debug log file. Alternatively, and for more advanced scenarios, you may wish to examine how your drives are mounted using the Linux `mount` command, and then find out the `partuuid` of relevant mounted drives by examining the output of `ls -l /dev/disk/by-partuuid`.

- `autoopts[+]="{options}"` - Default: None specified. The kernel options to use for autodetected Linux only. The value here is never used for entries created from `/loader/entries/*.conf` files. `partuuidopts` may be more suitable where there are multiple distros, but `autoopts` with no `PARTUUID` required is more convenient for just one distro. If specified with `+=` then these are used in addition to autodetected options, if specified with `=` they are used instead. As example usage, it is possible to use `+=` format to add a `vt.handoff` options, such

as `autoopts+="vt.handoff=7"` or `autoopts+="vt.handoff=3"` (check `cat /proc/cmdline` when booted via your existing bootloader) on Ubuntu and related distros, in order to add the `vt.handoff` option to the auto-detected GRUB defaults, and avoid a flash of text showing before the distro splash screen.

Users may wish to compare their Linux boot options (shown with `cat /proc/cmdline`) seen when booting via `OpenLinuxBoot` and via their distro's original bootloader, which is normally GRUB (but might also be e.g. `systemd-boot` or `EXTLINUX`). Expect the options generated by `OpenLinuxBoot` not to contain a `BOOT_IMAGE=...` value where GRUB options do, and to contain an `initrd=...` value where the GRUB options do not, since GRUB hands over ramdisks in a different way. All remaining parameters should match, however – perhaps excluding less important graphics handover options, such as in the Ubuntu example given in `autoopts`. `OpenLinuxBoot` will not start a distro unless it can find some configured options to use, therefore in the hopefully unlikely case where no auto-detectable options are available, the user will need to specify the correct options with `partuuidopts` or `autoopts` before the distro will boot. Examine the OpenCore debug log for `LNX`: entries containing further information about what was found.

11.7 Properties

1. APFS

Type: plist dict

Failsafe: None

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

2. Audio

Type: plist dict

Failsafe: None

Description: Configure audio backend support described in the 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 supported audio file formats are MP3 and 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].[audio ext]`. For unlocalised files filename does not include the language code and looks as follows: `[audio type]_[audio path].[audio ext]`. Audio extension can either be `mp3` or `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.mp3`.

Audio localisation is determined separately for macOS bootloader and OpenCore. For macOS bootloader it is set in `preferences.efires` 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 types of firmware, particularly those made by Apple, only connect the boot drive to speed up the boot process. Enable this option to be able to see all the boot options when running multiple drives.

4. Drivers

Type: plist dict

Failsafe: None

Description: Load selected drivers from `OC/Drivers` directory using the settings specified in the Drivers Properties section below.

5. Input

Type: plist dict

Failsafe: None

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

6. Output

Type: plist dict

Failsafe: None

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

7. ProtocolOverrides

Type: plist dict

Failsafe: None

Description: Force builtin versions of certain protocols described in the 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 the Quirks Properties section below.

9. ReservedMemory

Type: plist array

Description: To be filled with `plist dict` values, describing memory areas exclusive to specific firmware and hardware functioning, which should not be used by the operating system. Examples of such memory regions could be the second 256 MB corrupted by the Intel HD 3000 or an area with faulty RAM. Refer to the ReservedMemory Properties section below for details.

11.8 APFS Properties

1. EnableJumpstart

Type: plist boolean

Failsafe: false

Description: Load embedded APFS drivers from APFS containers.

An APFS EFI driver is bundled in all bootable APFS containers. This option performs the loading of signed APFS drivers (consistent with the `ScanPolicy`). Refer to the “EFI Jumpstart” section of the Apple File System Reference for details.

2. GlobalConnect

Type: plist boolean

Failsafe: false

Description: Perform full device connection during APFS loading.

Every handle is connected recursively instead of the partition handle connection typically used for APFS driver loading. This may result in additional time being taken but can sometimes be the only way to access APFS partitions on certain firmware, such as those on older HP laptops.

3. HideVerbose

Type: plist boolean

Failsafe: false

Description: Hide verbose output from APFS driver.

APFS verbose output can be useful for debugging.

4. JumpstartHotPlug

Type: plist boolean

Failsafe: false

Description: Load APFS drivers for newly connected devices.

Permits APFS USB hot plug which enables loading APFS drivers, both at OpenCore startup and during OpenCore picker display. Disable if not required.

5. MinDate

Type: plist integer

Failsafe: 0

Description: Minimal allowed APFS driver date.

The APFS driver date connects the APFS driver with the calendar release date. Apple ultimately drops support for older macOS releases and APFS drivers from such releases may contain vulnerabilities that can be used to compromise a computer if such drivers are used after support ends. This option permits restricting APFS drivers to current macOS versions.

- 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 2021/01/01.
- -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 `OcApfsLib`.

6. MinVersion

Type: plist integer

Failsafe: 0

Description: Minimal allowed APFS driver version.

The APFS driver version connects the APFS driver with the macOS release. Apple ultimately drops support for older macOS releases and APFS drivers from such releases may contain vulnerabilities that can be used to compromise a computer if such drivers are used after support ends. This option permits restricting APFS drivers to current 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 allow macOS Big Sur and newer (1600000000000000).
- -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 `OcApfsLib`.

11.9 AppleInput Properties

1. AppleEvent

Type: plist string

Failsafe: Auto

Description: Determine whether OC builtin or OEM Apple Event protocol is used.

This option determines whether Apple's OEM Apple Event protocol is used (where available), or whether OpenCore's reversed engineered and updated re-implementation is used. In general OpenCore's re-implementation should be preferred, since it contains updates such as noticeably improved fine mouse cursor movement and configurable key repeat delays.

- **Auto** — Use OEM Apple Event implementation if available, connected and recent enough to be used, otherwise use OC reimplementation. On non-Apple hardware this will use the OpenCore builtin implementation. On some Macs (e.g. classic Mac Pro) this will find the Apple implementation. On both older and newer Macs than this, this option will always or often use the OC implementation. On older Macs this is because the implementation available is too old to be used, on newer Macs it is because of optimisations added by Apple which do not connect the Apple Event protocol except when needed – e.g. except when the Apple boot picker is explicitly started. Due to its somewhat unpredictable results, this option is not normally recommended.
- **Builtin** — Always use OpenCore's updated re-implementation of the Apple Event protocol. Use of this setting is recommended even on Apple hardware, due to improvements (better fine mouse control, configurable key delays) made in the OC re-implementation of the protocol.

- **OEM** — Assume Apple’s protocol will be available at driver connection. On all Apple hardware where a recent enough Apple OEM version of the protocol is available – whether or not connected automatically by Apple’s firmware – this option will reliably access the Apple implementation. On all other systems, this option will result in no keyboard or mouse support. For the reasons stated, **Builtin** is recommended in preference to this option in most cases.

2. CustomDelays

Type: plist boolean

Failsafe: false

Description: Enable custom key repeat delays when using the OpenCore implementation of the Apple Event protocol. Has no effect when using the OEM Apple implementation (see **AppleEvent** setting).

- **true** — The values of **KeyInitialDelay** and **KeySubsequentDelay** are used.
- **false** — Apple default values of 500ms (50) and 50ms (5) are used.

3. KeyInitialDelay

Type: plist integer

Failsafe: 50 (500ms before first key repeat)

Description: Configures the initial delay before keyboard key repeats in OpenCore implementation of Apple Event protocol, in units of 10ms.

The Apple OEM default value is 50 (500ms).

Note 1: On systems not using **KeySupport**, this setting may be freely used to configure key repeat behaviour.

Note 2: On systems using **KeySupport**, but which do not show the ‘two long delays’ behavior (see *Note 3*) and/or which always show a solid ‘set default’ indicator (see **KeyForgetThreshold**) then this setting may also be freely used to configure key repeat initial delay behaviour, except that it should never be set to less than **KeyForgetThreshold** to avoid uncontrolled key repeats.

Note 3: On some systems using **KeySupport**, you may find that you see one additional slow key repeat before normal speed key repeat starts, when holding a key down. If so, you may wish to configure **KeyInitialDelay** and **KeySubsequentDelay** according to the instructions at *Note 3* of **KeySubsequentDelay**.

4. KeySubsequentDelay

Type: plist integer

Failsafe: 5 (50ms between subsequent key repeats)

Description: Configures the gap between keyboard key repeats in OpenCore implementation of Apple Event protocol, in units of 10ms.

The Apple OEM default value is 5 (50ms). 0 is an invalid value for this option (will issue a debug log warning and use 1 instead).

Note 1: On systems not using **KeySupport**, this setting may be freely used to configure key repeat behaviour.

Note 2: On systems using **KeySupport**, but which do not show the ‘two long delays’ behaviour (see *Note 3*) and/or which always show a solid ‘set default’ indicator (see **KeyForgetThreshold**) (which should apply to many/most systems using **AMI KeySupport** mode) then this setting may be freely used to configure key repeat subsequent delay behaviour, except that it should never be set to less than **KeyForgetThreshold** to avoid uncontrolled key repeats.

Note 3: On some systems using **KeySupport**, particularly **KeySupport** in non-AMI mode, you may find that after configuring **KeyForgetThreshold** you get one additional slow key repeat before normal speed key repeat starts, when holding a key down. On systems where this is the case, it is an unavoidable artefact of using **KeySupport** to emulate raw keyboard data, which is not made available by UEFI. While this ‘two long delays’ issue has minimal effect on overall usability, nevertheless you may wish to resolve it, and it is possible to do so as follows:

- Set **CustomDelays** to **true**
- Set **KeyInitialDelay** to 0
- Set **KeySubsequentDelay** to at least the value of your **KeyForgetThreshold** setting

The above procedure works as follows:

- Setting **KeyInitialDelay** to 0 cancels the Apple Event initial repeat delay (when using the OC builtin Apple Event implementation with **CustomDelays** enabled), therefore the only long delay you will see is the

the non-configurable and non-avoidable initial long delay introduced by the BIOS key support on these machines.

- Key-smoothing parameter `KeyForgetThreshold` effectively acts as the shortest time for which a key can appear to be held, therefore a key repeat delay of less than this will guarantee at least one extra repeat for every key press, however quickly the key is physically tapped.
- In the unlikely event that you still get frequent, or occasional, double key responses after setting `KeySubsequentDelay` equal to your system's value of `KeyForgetThreshold`, then increase `KeySubsequentDelay` by one or two more until this effect goes away.

5. GraphicsInputMirroring

Type: plist boolean

Failsafe: false

Description: Apple's own implementation of `AppleEvent` prevents keyboard input during graphics applications from appearing on the basic console input stream.

With the default setting of `false`, OC's builtin implementation of `AppleEvent` replicates this behaviour.

On non-Apple hardware this can stop keyboard input working in graphics-based applications such as Windows BitLocker which use non-Apple key input methods.

The recommended setting on all hardware is `true`.

Note: `AppleEvent`'s default behaviour is intended to prevent unwanted queued keystrokes from appearing after exiting graphics-based UEFI applications; this issue is already handled separately within `OpenCore`.

- `true` — Allow keyboard input to reach graphics mode apps which are not using Apple input protocols.
- `false` — Prevent key input mirroring to non-Apple protocols when in graphics mode.

6. PointerSpeedDiv

Type: plist integer

Failsafe: 1

Description: Configure pointer speed divisor in `OpenCore` implementation of Apple Event protocol. Has no effect when using the OEM Apple implementation (see `AppleEvent` setting).

Configures the divisor for pointer movements. The Apple OEM default value is 1. 0 is an invalid value for this option.

Note: The recommended value for this option is 1. This value may optionally be modified in combination with `PointerSpeedMul`, according to user preference, to achieve customised mouse movement scaling.

7. PointerSpeedMul

Type: plist integer

Failsafe: 1

Description: Configure pointer speed multiplier in `OpenCore` implementation of Apple Event protocol. Has no effect when using the OEM Apple implementation (see `AppleEvent` setting).

Configures the multiplier for pointer movements. The Apple OEM default value is 1.

Note: The recommended value for this option is 1. This value may optionally be modified in combination with `PointerSpeedDiv`, according to user preference, to achieve customised mouse movement scaling.

11.10 Audio Properties

1. AudioCodec

Type: plist integer

Failsafe: 0

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

This typically contains the 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-italic):

```
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

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

This typically 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-italic):

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 an empty device path will result in the first available audio controller being used.

3. AudioOut

Type: plist integer

Failsafe: 0

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

This typically 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-italic):

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.

The screen reader will use this volume level when the calculated volume level is lower than `MinimumVolume` and the boot chime will not play if the calculated volume level is lower than `MinimumVolume`.

6. PlayChime

Type: plist string

Failsafe: Auto

Description: Play chime sound at startup.

Enabling this setting plays the boot chime using the builtin audio support. The volume level is determined by the `MinimumVolume` and `VolumeAmplifier` settings as well as the `SystemAudioVolume` NVRAM variable. Possible values include:

- `Auto` — Enables chime when `StartupMute` NVRAM variable is not present or set to 00.
- `Enabled` — Enables chime unconditionally.
- `Disabled` — Disables chime unconditionally.

Note: `Enabled` can be used in separate from `StartupMute` NVRAM variable to avoid conflicts when the firmware is able to play the boot chime.

7. ResetTrafficClass

Type: plist boolean

Failsafe: false

Description: Set HDA Traffic Class Select Register to TC0.

AppleHDA kext will function correctly only if TCSEL register is configured to use TC0 traffic class. Refer to Intel I/O Controller Hub 9 (ICH9) Family Datasheet (or any other ICH datasheet) for more details about this register.

Note: This option is independent from `AudioSupport`. If AppleALC is used it is preferred to use AppleALC `alctsel` property instead.

8. SetupDelay

Type: plist integer

Failsafe: 0

Description: Audio codec reconfiguration delay in microseconds.

Some codecs require a vendor-specific delay after the reconfiguration (e.g. volume setting). This option makes it configurable. A typical delay can be up to 0.5 seconds.

9. 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:

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

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

11.11 Drivers Properties

1. Path

Type: plist string

Failsafe: Empty

Description: Path of file to be loaded as a UEFI driver from `OC/Drivers` directory.

2. Enabled

Type: plist boolean

Failsafe: false

Description: If false this driver entry will be ignored.

3. Arguments

Type: plist string

Failsafe: Empty

Description: Some OC plugins accept optional additional arguments which may be specified as a string here.

11.12 Input Properties

1. KeyFiltering

Type: plist boolean

Failsafe: false

Description: Enable keyboard input sanity checking.

Apparently some boards such as the 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: Treat duplicate key presses as held keys if they arrive during this timeout, in 10 ms units. Only applies to systems using `KeySupport`.

`AppleKeyMapAggregator` protocol is supposed to contain a fixed length buffer of currently pressed keys. However, the majority of the drivers which require `KeySupport` report key presses as interrupts, with automatically generated key repeat behaviour with some defined initial and subsequent delay. As a result, to emulate the raw key behaviour required by several Apple boot systems, we use a timeout to merge multiple repeated keys which are submitted within a small timeout window.

This option allows setting this timeout based on the platform. The recommended value for the majority of platforms is from 5 (50 milliseconds) to 7 (70 milliseconds), although values up to 9 (90 milliseconds) have been observed to be required on some PS/2 systems. For reference, holding a key on VMware will repeat roughly every 20 milliseconds and the equivalent value for APTIO V is 30-40 milliseconds. `KeyForgetThreshold` should be configured to be longer than this. Thus, it is possible to configure a lower `KeyForgetThreshold` value on platforms with a faster native driver key repeat rate, for more responsive input, and it is required to set a higher value on slower platforms.

Pressing keys one after the other results in delays of at least 60 and 100 milliseconds for the same platforms. Ideally, `KeyForgetThreshold` should remain lower than this value, to avoid merging real key presses.

Tuning the value of `KeyForgetThreshold` is necessary for accurate and responsive keyboard input on systems on which `KeySupport` is enabled, and it is recommended to follow the instructions below to tune it correctly for your system.

Note 1: To tune `KeyForgetThreshold`, you may use the ‘set default’ indicator within either OpenCanopy or the builtin picker. If `KeyForgetThreshold` is too low then the ‘set default’ indicator will continue to flicker while CTRL or =/+ is held down. You should configure the lowest value which avoids this flicker. On some systems (e.g. Aptio IV and potentially other systems using AMI `KeySupport` mode) you will be able to find a minimum `KeyForgetThreshold` value at which the ‘set default’ indicator goes on and stays on with no flicker at all - if so, use this value. On most other systems using `KeySupport`, you will find that the ‘set default’ indicator will flicker once, when first pressing and holding the CTRL or =/+ key, and then after a further very brief interval will go on and stay on. On such systems, you should chose the lowest value of `KeyForgetThreshold` at which you see only one initial flicker and then no subsequent flickering. (Where this happens, it is an unavoidable artefact on those systems of using `KeySupport` to emulate raw keyboard data, which is not made available by UEFI.)

Note 2: `KeyForgetThreshold` should never need to be more than about 9 or 10 at most. If it is set to a value much higher than this, it will result in noticeably unresponsive keyboard input. Therefore, for overall key responsiveness, it is strongly recommended to configure a relatively lower value, at which the ‘set default’ indicator flickers once and then does not flicker, rather than using a much higher value (i.e. significantly greater than 10), which you may be able to find but should not use, where the ‘set default’ indicator does not flicker at all.

3. `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`, also known as `AptioInputFix`, to fill the `AppleKeyMapAggregator` database for input functioning. In cases where a separate driver such as `OpenUsbKbDxe` is used, this option should never be enabled. Additionally, this option is not required and should not be enabled with Apple firmware.

4. `KeySupportMode`

Type: plist string

Failsafe: Auto

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.

5. `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.

6. PointerSupport

Type: plist boolean

Failsafe: false

Description: Enable internal pointer driver.

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

7. PointerSupportMode

Type: plist string

Failsafe: Empty

Description: Set OEM protocol used for internal pointer driver.

Currently the only supported variant is ASUS, using specialised protocol available on certain Z87 and Z97 ASUS boards. More details can be found in LongSoft/UefiTool#116. The value of this property cannot be empty if PointerSupport is enabled.

8. TimerResolution

Type: plist integer

Failsafe: 0

Description: Set architecture timer resolution.

This option allows updating the firmware architecture timer period with the specified value in 100 nanosecond units. Setting a lower value typically 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. In case of issues, this option can be left as 0.

11.13 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 firmware typically supports **ConsoleControl** with two rendering modes: **Graphics** and **Text**. Some types of firmware 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**.
- **BuiltinText** — Switch to **Text** 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 straightforward. For most platforms, it is necessary to enable **ProvideConsoleGop** and set **Resolution** to **Max**. The **BuiltinText** variant is an alternative **BuiltinGraphics** for some very old and defective laptop firmware, which can only draw in **Text** mode.

The use of **System** protocols is more complicated. Typically, 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, such as the `MacPro5,1`, may have incompatible console output when using modern GPUs, and thus only `BuiltinGraphics` may work for them in such cases. NVIDIA GPUs may require additional firmware upgrades.

2. `ConsoleMode`

Type: `plist string`

Failsafe: Empty (Maintain current console mode)

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

Set to `Max` to attempt using the largest available console mode. This option is currently ignored as the `Builtin` text renderer only supports one console mode.

Note: This field is best left empty on most types of firmware.

3. `Resolution`

Type: `plist string`

Failsafe: Empty (Maintain current screen resolution)

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 `Max` to attempt using the 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 the Recommended Variables section for 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. `ForceResolution`

Type: `plist boolean`

Failsafe: `false`

Description: Forces `Resolution` to be set in cases where the desired resolution is not available by default, such as on legacy Intel GMA and first generation Intel HD Graphics (Ironlake/Arrandale). Setting `Resolution` to `Max` will try to pull the largest available resolution from the connected display's EDID.

Note: This option depends on the `OC_FORCE_RESOLUTION_PROTOCOL` protocol being present. This protocol is currently only supported by `OpenDuetPkg`. The `OpenDuetPkg` implementation currently only supports Intel iGPUs.

5. `ClearScreenOnModeSwitch`

Type: `plist boolean`

Failsafe: `false`

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

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

6. `DirectGopRendering`

Type: `plist boolean`

Failsafe: `false`

Description: Use builtin graphics output protocol renderer for console.

On certain firmware, such as on the `MacPro5,1`, this may provide better performance or fix rendering issues. However, this option is not recommended unless there is an obvious benefit as it may result in issues such as slower scrolling.

This renderer fully supports `AppleEg2Info` protocol and will provide screen rotation for all EFI applications. In order to provide seamless rotation compatibility with `EfiBoot`, builtin `AppleFramebufferInfo` should also be used, i.e. it may need to be overridden on Mac EFI.

7. `GopPassThrough`

Type: plist string

Failsafe: Disabled

Description: Provide GOP protocol instances on top of UGA protocol instances.

This option provides the GOP protocol via a UGA-based proxy for firmware that do not implement the protocol. The supported values for the option are as follows:

- `Enabled` — provide GOP for all UGA protocols.
- `Apple` — provide GOP for `AppleFramebufferInfo`-enabled protocols.
- `Disabled` — do not provide GOP.

Note: This option requires `ProvideConsoleGop` to be enabled.

8. `IgnoreTextInGraphics`

Type: plist boolean

Failsafe: false

Description: Some types of firmware output text onscreen in both graphics and text mode. This is typically unexpected as 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 a different mode from `Text`.

Note: This option only applies to the `System` renderer.

9. `ReplaceTabWithSpace`

Type: plist boolean

Failsafe: false

Description: Some types of firmware do not print tab characters or everything that follows them, causing difficulties in using the UEFI Shell's 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.

10. `ProvideConsoleGop`

Type: plist boolean

Failsafe: false

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

macOS bootloader requires GOP or UGA (for 10.4 EfiBoot) to be present on console handle, yet the exact location of the graphics protocol is not covered by the UEFI specification. This option will ensure GOP and UGA, if present, are available on the console handle.

Note: This option will also replace incompatible implementations of GOP on the console handle, as may be the case on the `MacPro5,1` when using modern GPUs.

11. `ReconnectOnResChange`

Type: plist boolean

Failsafe: false

Description: Reconnect console controllers after changing screen resolution.

On certain firmware, the controllers that produce the console protocols (simple text out) must be reconnected when the screen resolution is changed via GOP. 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.

12. `SanitiseClearScreen`

Type: plist boolean

Failsafe: false

Description: Some types of firmware reset screen resolutions to a failsafe value (such as 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 the `System` renderer. On all known affected systems, `ConsoleMode` must be set to an empty string for this option to work.

13. UgaPassThrough

Type: plist boolean

Failsafe: false

Description: Provide UGA protocol instances on top of GOP protocol instances.

Some types of firmware do not implement the legacy UGA protocol but this may be required for screen output by older EFI applications such as EfiBoot from 10.4.

11.14 ProtocolOverrides Properties

1. AppleAudio

Type: plist boolean

Failsafe: false

Description: Replaces Apple audio protocols with builtin versions.

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

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

Note: The 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: Replaces the Apple Boot Policy protocol with a builtin version. This may be used to ensure APFS compatibility on VMs and legacy Macs.

Note: This option is advisable on certain Macs, such as the **MacPro5,1**, that are APFS compatible but on which the Apple Boot Policy protocol has recovery detection issues.

3. AppleDebugLog

Type: plist boolean

Failsafe: false

Description: Replaces the Apple Debug Log protocol with a builtin version.

4. AppleEg2Info

Type: plist boolean

Failsafe: false

Description: Replaces the Apple EFI Graphics 2 protocol with a builtin version.

Note 1: This protocol allows newer **EfiBoot** versions (at least 10.15) to expose screen rotation to macOS. Refer to **ForceDisplayRotationInEFI** variable description on how to set screen rotation angle.

Note 2: On systems without native support for **ForceDisplayRotationInEFI**, **DirectGopRendering=true** is also required for this setting to have an effect.

5. AppleFramebufferInfo

Type: plist boolean

Failsafe: false

Description: Replaces the Apple Framebuffer Info protocol with a builtin version. This may be used to override framebuffer information on VMs and legacy Macs to improve compatibility with legacy EfiBoot such as the one in macOS 10.4.

Note: The current implementation of this property results in it only being active when GOP is available (it is always equivalent to **false** otherwise).

6. AppleImageConversion

Type: plist boolean

Failsafe: false

Description: Replaces the Apple Image Conversion protocol with a builtin version.

7. **AppleImg4Verification**

Type: plist boolean

Failsafe: false

Description: Replaces the Apple IMG4 Verification protocol with a builtin version. This protocol is used to verify im4m manifest files used by Apple Secure Boot.

8. **AppleKeyMap**

Type: plist boolean

Failsafe: false

Description: Replaces Apple Key Map protocols with builtin versions.

9. **AppleRtcRam**

Type: plist boolean

Failsafe: false

Description: Replaces the Apple RTC RAM protocol with a builtin version.

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

10. **AppleSecureBoot**

Type: plist boolean

Failsafe: false

Description: Replaces the Apple Secure Boot protocol with a builtin version.

11. **AppleSmcIo**

Type: plist boolean

Failsafe: false

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

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

12. **AppleUserInterfaceTheme**

Type: plist boolean

Failsafe: false

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

13. **DataHub**

Type: plist boolean

Failsafe: false

Description: Replaces the Data Hub protocol with a builtin version.

Note: This will discard all previous entries if the protocol was already installed, so all properties required for the safe operation of the system must be specified in the configuration file.

14. **DeviceProperties**

Type: plist boolean

Failsafe: false

Description: Replaces the Device Property protocol with a builtin version. This may be used to ensure full compatibility on VMs and legacy Macs.

Note: This will discard all previous entries if the protocol was already installed, so all properties required for safe operation of the system must be specified in the configuration file.

15. **FirmwareVolume**

Type: plist boolean

Failsafe: false

Description: Wraps Firmware Volume protocols, or installs a new version, to support custom cursor images for FileVault 2. Set to `true` to ensure FileVault 2 compatibility on anything other than on VMs and legacy Macs.

Note: Several virtual machines, including VMware, may have corrupted cursor images in HiDPI mode and thus, may also require enabling this setting.

16. HashServices

Type: plist boolean

Failsafe: false

Description: Replaces Hash Services protocols with builtin versions. Set to **true** to ensure FileVault 2 compatibility on platforms with defective SHA-1 hash implementations. This can be determined by an invalid cursor size when `UIScale` is set to 02. Platforms earlier than APTIO V (Haswell and older) are typically affected.

17. OSInfo

Type: plist boolean

Failsafe: false

Description: Replaces the OS Info protocol with a builtin version. This protocol is typically used by the firmware and other applications to receive notifications from the macOS bootloader.

18. UnicodeCollation

Type: plist boolean

Failsafe: false

Description: Replaces unicode collation services with builtin versions. Set to **true** to ensure UEFI Shell compatibility on platforms with defective unicode collation implementations. Legacy Insyde and APTIO platforms on Ivy Bridge, and earlier, are typically affected.

11.15 Quirks Properties

1. ActivateHpetSupport

Type: plist boolean

Failsafe: false

Description: Activates HPET support.

Older boards like ICH6 may not always have HPET setting in the firmware preferences, this option tries to force enable it.

2. EnableVectorAcceleration

Type: plist boolean

Failsafe: false

Description: Enable AVX vector acceleration of SHA-512 and SHA-384 hashing algorithms.

3. DisableSecurityPolicy

Type: plist boolean

Failsafe: false

Description: Disable platform security policy.

Note: This setting disables various security features of the firmware, defeating the purpose of any kind of Secure Boot. Do NOT enable if using UEFI Secure Boot.

4. ExitBootServicesDelay

Type: plist integer

Failsafe: 0

Description: Adds delay in microseconds after `EXIT_BOOT_SERVICES` event.

This is a very rough workaround to circumvent the **Still waiting for root device** message on some APTIO IV firmware (ASUS Z87-Pro) particularly when using FileVault 2. It appears that for some reason, they execute code in parallel to `EXIT_BOOT_SERVICES`, which results in the SATA controller being inaccessible from macOS. A better approach is required and Acidanthera is open to suggestions. Expect 3 to 5 seconds to be adequate when this quirk is needed.

5. ForgeUefiSupport

Type: plist boolean

Failsafe: false

Description: Implement partial UEFI 2.x support on EFI 1.x firmware.

This setting allows running some software written for UEFI 2.x firmware like NVIDIA GOP Option ROMs on hardware with older EFI 1.x firmware like MacPro5,1.

6. IgnoreInvalidFlexRatio

Type: plist boolean

Failsafe: false

Description: Some types of firmware (such as APTIO IV) may contain invalid values in the MSR_FLEX_RATIO (0x194) MSR register. These values may cause macOS boot failures on Intel platforms.

Note: While the option is not expected to harm unaffected firmware, its use is recommended only when specifically required.

7. ReleaseUsbOwnership

Type: plist boolean

Failsafe: false

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

8. ReloadOptionRoms

Type: plist boolean

Failsafe: false

Description: Query PCI devices and reload their Option ROMs if available.

For example, this option allows reloading NVIDIA GOP Option ROM on older Macs after the firmware version is upgraded via ForgeUefiSupport.

9. 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 the firmware deletes incompatible boot entries. In summary, this quirk is required to reliably use the Startup Disk preference pane in firmware that is not compatible with macOS boot entries by design.

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 corrupted in any way.

10. TscSyncTimeout

Type: plist integer

Failsafe: 0

Description: Attempts to perform TSC synchronisation with a specified timeout.

The primary purpose of this quirk is to enable early bootstrap TSC synchronisation on some server and laptop models when running a debug XNU kernel. For the debug kernel the TSC needs to be kept in sync across the cores before any next could kick in rendering all other solutions problematic. The timeout is specified in microseconds and depends on the amount of cores present on the platform, the recommended starting value is 500000.

This is an experimental quirk, which should only be used for the aforementioned problem. In all other cases, the quirk may render the operating system unstable and is not recommended. The recommended solution in the other cases is to install a kernel extension such as VoodooTSCSync, TSCAdjustReset, or CpuTscSync (a more specialised variant of VoodooTSCSync for newer laptops).

Note: This quirk cannot replace the kernel extension because it cannot operate in ACPI S3 (sleep wake) mode and because the UEFI firmware only provides very limited multicore support which prevents precise updates of the MSR registers.

11. UnblockFsConnect
Type: plist boolean
Failsafe: false
Description: Some types of firmware block partition handles by opening them in By Driver mode, resulting in an inability to install File System protocols.
Note: This quirk is useful in cases where unsuccessful drive detection results in an absence of boot entries.

11.16 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 a EfiConventionalMemory type, and be page-aligned (4 KBs).
Note: Some types of firmware may not allocate memory areas used by S3 (sleep) and S4 (hibernation) code unless CSM is enabled causing wake failures. After comparing the memory maps with CSM disabled and enabled, these areas can be found in the lower memory and can be fixed up by doing the reservation. Refer to the Sample.plist file for details.
2. Comment
Type: plist string
Failsafe: Empty
Description: Arbitrary ASCII string used to provide human readable reference for the entry. Whether this value is used is implementation defined.
3. Size
Type: plist integer
Failsafe: 0
Description: Size of the reserved memory region, must be page-aligned (4 KBs).
4. Type
Type: plist string
Failsafe: Reserved
Description: Memory region type matching the UEFI specification memory descriptor types. Mapping:
 - Reserved — EfiReservedMemoryType
 - LoaderCode — EfiLoaderCode
 - LoaderData — EfiLoaderData
 - BootServiceCode — EfiBootServicesCode
 - BootServiceData — EfiBootServicesData
 - RuntimeCode — EfiRuntimeServicesCode
 - RuntimeData — EfiRuntimeServicesData
 - Available — EfiConventionalMemory
 - Persistent — EfiPersistentMemory
 - UnusableMemory — EfiUnusableMemory
 - ACPIReclaimMemory — EfiACPIReclaimMemory
 - ACPIMemoryNVS — EfiACPIMemoryNVS
 - MemoryMappedIO — EfiMemoryMappedIO
 - MemoryMappedIOPortSpace — EfiMemoryMappedIOPortSpace
 - PalCode — EfiPalCode
5. Enabled
Type: plist boolean
Failsafe: false
Description: This region will not be reserved unless set to true.

12 Troubleshooting

12.1 Legacy Apple OS

Older operating systems may be more complicated to install, but are sometimes necessary for various reasons. While a compatible board identifier and CPUID are the obvious requirements for proper functioning of an older operating system, there are many other less obvious things to consider. This section covers a common set of issues relevant to installing older macOS operating systems.

While newer operating systems can be downloaded over the internet, older operating systems did not have installation media for every minor release. For compatible distributions of such, download a device-specific image and modify it if necessary. Visit this archived Apple Support article for a list of the bundled device-specific builds for legacy operating systems. However, as this may not always be accurate, the latest versions are listed below.

12.1.1 macOS 10.8 and 10.9

- Disk images on these systems use the Apple Partitioning Scheme and require the `OpenPartitionDxe` driver to run DMG recovery and installation (included in `OpenDuet`). It is possible to set `DmgLoading` to `Disabled` to run the recovery without DMG loading avoiding the need for `OpenPartitionDxe`.
- Cached kernel images often do not contain family drivers for networking (`IONetworkingFamily`) or audio (`IOAudioFamily`) requiring the use of `Force` loading in order to inject networking or audio drivers.

12.1.2 macOS 10.7

- All previous issues apply.
- SSSE3 support (not to be confused with SSE3 support) is a hard requirement for macOS 10.7 kernel.
- Many kexts, including `Lilu` when 32-bit kernel is used and a lot of `Lilu` plugins, are unsupported on macOS 10.7 and older as they require newer kernel APIs, which are not part of the macOS 10.7 SDK.
- Prior to macOS 10.8 KASLR sliding is not supported, which will result in memory allocation failures on firmware that utilise lower memory for their own purposes. Refer to `acidanthera/bugtracker#1125` for tracking.

12.1.3 macOS 10.6

- All previous issues apply.
- SSSE3 support is a requirement for macOS 10.6 kernel with 64-bit userspace enabled. This limitation can mostly be lifted by enabling the `LegacyCommpage` quirk.
- Last released installer images for macOS 10.6 are macOS 10.6.7 builds `10J3250` (for `MacBookPro8,x`) and `10J4139` (for `iMac12,x`), without Xcode). These images are limited to their target model identifiers and have no `-no_compat_check` boot argument support. Modified images (with `ACDT` suffix) without model restrictions can be found here (MEGA Mirror), assuming macOS 10.6 is legally owned. Refer to the `DIGEST.txt` file for details. Note that these are the earliest tested versions of macOS 10.6 with `OpenCore`.

Model checking may also be erased by editing `OSInstall.mpkg` with e.g. `Flat Package Editor` by making `Distribution` script to always return `true` in `hwbeModelCheck` function. Since updating the only file in the image and not corrupting other files can be difficult and may cause slow booting due to kernel cache date changes, it is recommended to script image rebuilding as shown below:

```
#!/bin/bash
# Original.dmg is original image, OSInstall.mpkg is patched package
mkdir RO
hdiutil mount Original.dmg -noverify -noautoopen -noautoopenrw -noautofsck -mountpoint RO
cp RO/.DS_Store DS_STORE
hdiutil detach RO -force
rm -rf RO
hdiutil convert Original.dmg -format UDRW -o ReadWrite.dmg
mkdir RW
xattr -c OSInstall.mpkg
```



```
hdiutil mount ReadWrite.dmg -noverify -noautoopen -noautoopenrw -noautofsck -mountpoint RW
cp OSInstall.mpkg RW/System/Installation/Packages/OSInstall.mpkg
killall Finder fsevents
rm -rf RW/.fsevents
cp DS_STORE RW/.DS_Store
hdiutil detach RW -force
rm -rf DS_STORE RW
hdiutil convert ReadWrite.dmg -format UDZO -o ReadOnly.dmg
```

12.1.4 macOS 10.5

- All previous issues apply.
- This macOS version does not support `x86_64` kernel and requires `i386` kernel extensions and patches.
- This macOS version uses the first (V1) version of `prelinkedkernel`, which has `kext` symbol tables corrupted by the `kext` tools. This nuance renders `prelinkedkernel` `kext` injection impossible in OpenCore. `Mkext` `kext` injection will still work without noticeable performance drain and will be chosen automatically when `KernelCache` is set to `Auto`.
- Last released installer image for macOS 10.5 is macOS 10.5.7 build `9J3050` (for `MacBookPro5,3`). Unlike the others, this image is not limited to the target model identifiers and can be used as is. The original `9J3050` image can be found here (MEGA Mirror), assuming macOS 10.5 is legally owned. Refer to the `DIGEST.txt` file for details. Note that this is the earliest tested version of macOS 10.5 with OpenCore.

12.1.5 macOS 10.4

- All previous issues apply.
- This macOS version has a hard requirement to access all the optional packages on the second DVD disk installation media, requiring either two disks or USB media installation.
- Last released installer images for macOS 10.4 are macOS 10.4.10 builds `8R4061a` (for `MacBookPro3,1`) and `8R4088` (for `iMac7,1`). These images are limited to their target model identifiers as on newer macOS versions. Modified `8R4088` images (with `ACDT` suffix) without model restrictions can be found here (MEGA Mirror), assuming macOS 10.4 is legally owned. Refer to the `DIGEST.txt` file for details. Note that these are the earliest tested versions of macOS 10.4 with OpenCore.

12.2 UEFI Secure Boot

OpenCore is designed to provide a secure boot chain between firmware and operating system. On most x86 platforms trusted loading is implemented via UEFI Secure Boot model. Not only OpenCore fully supports this model, but it also extends its capabilities to ensure sealed configuration via vaulting and provide trusted loading to the operating systems using custom verification, such as Apple Secure Boot. Proper secure boot chain requires several steps and careful configuration of certain settings as explained below:

1. Enable Apple Secure Boot by setting `SecureBootModel` to run macOS. Note, that not every macOS is compatible with Apple Secure Boot and there are several other restrictions as explained in Apple Secure Boot section.
2. Disable DMG loading by setting `DmgLoading` to `Disabled` if users have concerns of loading old vulnerable DMG recoveries. This is **not** required, but recommended. For the actual tradeoffs see the details in DMG loading section.
3. Make sure that APFS JumpStart functionality restricts the loading of old vulnerable drivers by setting `MinDate` and `MinVersion` to 0. More details are provided in APFS JumpStart section. An alternative is to install `apfs.efi` driver manually.
4. Make sure that `Force` driver loading is not needed and all the operating systems are still bootable.
5. Make sure that `ScanPolicy` restricts loading from undesired devices. It is a good idea to prohibit all removable drivers or unknown filesystems.

6. Sign all the installed drivers and tools with the private key. Do not sign tools that provide administrative access to the computer, such as UEFI Shell.
7. Vault the configuration as explained Vaulting section.
8. Sign all OpenCore binaries (`BOOTX64.efi`, `BOOTIa32.efi`, `OpenCore.efi`, custom launchers) used on this system with the same private key.
9. Sign all third-party operating system (not made by Microsoft or Apple) bootloaders if needed. For Linux there is an option to install Microsoft-signed Shim bootloader as explained on e.g. Debian Wiki.
10. Enable UEFI Secure Boot in firmware preferences and install the certificate with a private key. Details on how to generate a certificate can be found in various articles, such as this one, and are out of the scope of this document. If Windows is needed one will also need to add the Microsoft Windows Production CA 2011. To launch option ROMs or to use signed Linux drivers, Microsoft UEFI Driver Signing CA will also be needed.
11. Password-protect changing firmware settings to ensure that UEFI Secure Boot cannot be disabled without the user's knowledge.

12.3 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, such as Windows 7, might work with some extra precautions. Things to consider:

- MBR (Master Boot Record) installations are legacy and will not be supported.
- 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 aware that it may be invalid on old firmware, i.e., not random. If there still are 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 Windows support software from Boot Camp is required. 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 7-Zip may be downloaded and installed 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`. If there is a previous version of Boot Camp installed it should be removed 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, the rest may still have to be addressed 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 is typically not required).
- To access Apple filesystems such as HFS+ and APFS, separate software may need to be installed. Some of the known utilities are: Apple HFS+ driver (workaround 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 the Boot Camp Startup Disk control panel?

The Boot Camp control panel uses the GPT partition table to obtain each boot option name. After installing Windows separately, the partition has to be relabelled manually. This can be done with many utilities including the 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 do I 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 disrupt certain macOS functionality, including the 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.

12.4 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, version 7.3 or newer is needed, and Debugging the XNU Kernel with IDA Pro may also help.

To obtain the log during boot serial port debugging can be used. Serial port debugging is enabled in `Target`, e.g. `0xB` for onscreen with serial. To initialise serial within OpenCore use `SerialInit` configuration option. For macOS the best choice is 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, motherboard “TX” must be connected 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 `debug=0x8` boot argument is needed.

12.5 Tips and Tricks

1. How do I debug boot failures?

Obtaining the actual error message is usually adequate. For this, ensure that:

- A DEBUG or NOOPT version of OpenCore is used.
- 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, such as `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 workarounds in the 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 do I debug macOS boot failures?

- Refer to `boot-args` values such as `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 `debug=0x108`, `serial=5`, and `msgbuf=1048576` boot arguments are needed. Refer to the patches in `Sample.plist` when dying before serial init.
- Always read the logs carefully.

3. How do I 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 do I 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 types of firmware deleting incompatible boot options, potentially including those created by macOS, users are strongly encouraged to use the `RequestBootVarRouting` quirk, which will preserve the 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 the OpenCore picker and choose the entry, it will have a `(dmg)` suffix. Custom name may be created by providing `.contentDetails` file.

To download recovery online `macrecovery.py` can be used.

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 must Find&Replace patches be equal in size?

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 the following set of quirks should be enabled:

- 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 such as RebuildAppleMemoryMap, EnableWriteUnprotector, ProtectMemoryRegions, 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 details.