OpenCore

Reference Manual (0.0.3.4)

[2019.08.10]

Contents

1 Introduction

This document provides information on OpenCore user configuration file format used to setup the correct functioning of macOS operating system.

1.1 Known defects

For OpenCore issues please refer to Acidanthera Bugtracker.

2 ~~Generic Terms~~

1.1 Generic Terms

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

2 ~~Overview~~Configuration

2.1 Configuration Terms

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

2.2 Configuration Processing

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

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

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

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

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

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

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

2.3 Configuration Structure

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

- `Add` provides support for data addition.
- `Block` provides support for data removal or ignorance.
- `Patch` provides support for data modification.
- `Quirks` provides support for specific hacks.

Root configuration entries consist of the following:

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

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

3 Setup

3.1 Directory Structure

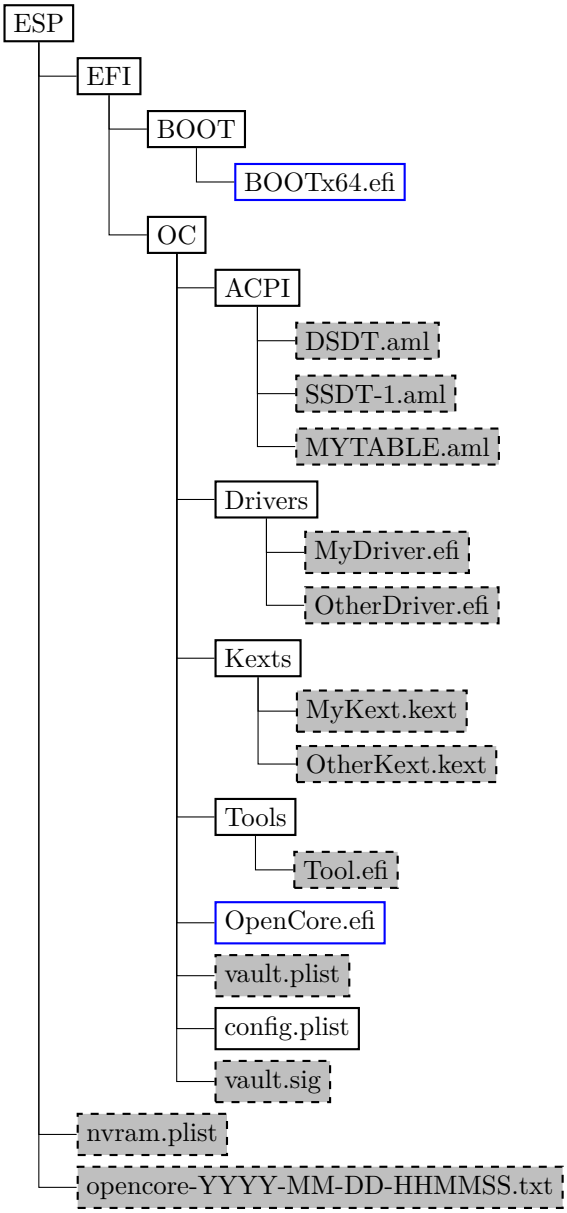

Figure 1. Directory Structure

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

- `BOOTx64.efi`
  Initial booter, which loads `OpenCore.efi` unless it was already started as a driver.
- `ACPI`
  Directory used for storing supplemental ACPI information for `ACPI` section.
- `Drivers`
  Directory used for storing supplemental `UEFI` drivers for `UEFI` section.
- `Kexts`
  Directory used for storing supplemental kernel information for `Kernel` section.
- `Tools`
  Directory used for storing supplemental tools.
- `OpenCore.efi`

Main booter driver responsible for operating system loading.

- `vault.plist`
  Hashes for all files potentially loadable by `OC Config`.
- `config.plist`
  `OC Config`.
- `vault.sig`
  Signature for `vault.plist`.
- `nvram.plist`
  OpenCore variable import file.
- ~~opencore~~opencore-YYYY-MM-DD-HHMMSS.~~log~~txt
  OpenCore log file.

~~Figure 1. Directory Structure~~

3.2 Installation and Upgrade

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

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

For BIOS booting a third-party UEFI environment provider will have to be used. `DuetPkg` is one of the known UEFI environment providers for legacy systems. To run OpenCore on such a legacy system you can install `DuetPkg` with a dedicated tool: BootInstall.

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

3.3 Contribution

OpenCore can be compiled as an ordinary EDK II. Since UDK development was abandoned by TianoCore, OpenCore requires the use of EDK II Stable. Currently supported EDK II release (potentially with patches enhancing the experience) is hosted in acidanthera/audk.

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

Required external package dependencies include EfiPkg, MacInfoPkg, and OcSupportPkg.

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

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

Listing 1: Compilation Commands

~~`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 page. For IDA Pro you will need IDA Pro 7.3 or newer.~~

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

```
-I/UefiPackages/MdePkg
-I/UefiPackages/MdePkg/Include
-I/UefiPackages/MdePkg/Include/X64
-I/UefiPackages/EfiPkg
-I/UefiPackages/EfiPkg/Include
-I/UefiPackages/EfiPkg/Include/X64
-I/UefiPackages/AptioFixPkg/Include
-I/UefiPackages/AppleSupportPkg/Include
-I/UefiPackages/OpenCorePkg/Include
-I/UefiPackages/OcSupportPkg/Include
-I/UefiPackages/MacInfoPkg/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
```

Listing 2: ECC Configuration

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

4 ACPI

4.1 Introduction

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

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

4.2 Properties

1. `Add`
   Type: `plist array`
   Failsafe: Empty
   Description: Load selected tables from `OC/ACPI` directory.

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

2. `Block`
   Type: `plist array`
   Failsafe: Empty
   Description: Remove selected tables from ACPI stack.

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

3. `Patch`
   Type: `plist array`
   Failsafe: Empty
   Description: Perform binary patches in ACPI tables before table addition or removal.

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

4. `Quirks`
   Type: `plist dict`
   Description: Apply individual ACPI quirks described in Quirks Properties section below.

4.3 Add Properties

1. `Comment`
   Type: `plist string`
   Failsafe: Empty string
   Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

2. `Enabled`
   Type: `plist boolean`
   Failsafe: `false`
   Description: This ACPI table will not be added unless set to `true`.

3. `Path`
   Type: `plist string`
   Failsafe: Empty string
   Description: File paths meant to be loaded as ACPI tables. Example values include `DSDT.aml`, `SubDir/SSDT-8.aml`, `SSDT-USBX.aml`, etc.

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

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

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

7. `OemTableId`
   Type: `plist data`, 8 bytes
   Failsafe: All zero
   Description: Match table OEM ID to be equal to this value unless all zero.

8. `Replace`
   Type: `plist data`
   Failsafe: Empty data
   Description: Replacement data of one or more bytes.

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

10. `Skip`
    Type: `plist integer`
    Failsafe: `0`
    Description: Number of found occurrences to be skipped before replacement is done.

11. `TableLength`
    Type: `plist integer`
    Failsafe: `0`
    Description: Match table size to be equal to this value unless `0`.

12. `TableSignature`
    Type:
    textttplist data, 4 bytes
    Failsafe: All zero
    Description: Match table signature to be equal to this value unless all zero.

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

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

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

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

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

4.6 Quirks Properties

1. `FadtEnableReset`
   Type: `plist boolean`

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

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

3. `RebaseRegions`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Attempt to heuristically relocate ACPI memory regions. Not recommended.

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

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

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

4. `ResetHwSig`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Reset `FACS` table `HardwareSignature` value to `0`.

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

5. `ResetLogoStatus`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Reset `BGRT` table `Displayed` status field to `false`.

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

5 Booter

5.1 Introduction

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

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

- Most up-to-date UEFI firmware (check your motherboard vendor website).
- `Fast Boot` and `Hardware Fast Boot` disabled in firmware settings if present.
- `Above 4G Decoding` or similar enabled in firmware settings if present. Note, that on some motherboards (notably ASUS WS-X299-PRO) this option causes adverse effects, and must be disabled. While no other motherboards with the same issue are known, consider this option to be first to check if you have erratic boot failures.
- `DisableIoMapper` quirk enabled, or `VT-d` disabled in firmware settings if present, or ACPI DMAR table dropped.

- **No** 'slide' boot argument present in NVRAM or anywhere else. It is not necessary unless you cannot boot at all or see `No slide values are usable! Use custom slide!` message in the log.
- `CFG Lock` (MSR `0xE2` write protection) disabled in firmware settings if present. Cconsider patching it if you have enough skills and no option is available. See VerifyMsrE2 nots for more details.
- `CSM` (Compatibility Support Module) disabled in firmware settings if present. You may need to flash GOP ROM on NVIDIA 6xx/AMD 2xx or older. Use GopUpdate or AMD UEFI GOP MAKER in case you are not sure how.

- `EHCI/XHCI Hand-off` enabled in firmware settings `only` if boot stalls unless USB devices are disconnected.
- `VT-x`, `Hyper Threading`, `Execute Disable Bit` enabled in firmware settings if present.
- While it may not be required, sometimes you have to disable `Thunderbolt support`, `Intel SGX`, and `Intel Platform Trust` in firmware settings present.

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

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

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

5.2 Properties

1. `Quirks`
   Type: `plist dict`
   Description: Apply individual booter quirks described in Quirks Properties section below.

5.3 Quirks Properties

1. `AvoidRuntimeDefrag`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Protect from boot.efi runtime memory defragmentation.

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

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

Note: The necessity of this quirk is determined by artifacts and sleep wake issues. As `AvoidRuntimeDefrag` resolves a similar problem, no known firmwares should need this quirk. Do not use this unless you fully understand the consequences.

8. `ProvideCustomSlide`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Provide custom KASLR slide on low memory.

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

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

9. `SetupVirtualMap`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Setup virtual memory at `SetVirtualAddresses`.

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

   Note: The necessity of this quirk is determined by early boot failures.

10. `ShrinkMemoryMap`
    Type: `plist boolean`
    Failsafe: `false`
    Description: Attempt to join similar memory map entries.

    Select firmwares have very large memory maps, which do not fit Apple kernel, permitting up to `64` slots for runtime memory. This quirk attempts to unify contiguous slots of similar types to prevent boot failures.

    Note: The necessity of this quirk is determined by early boot failures. It is rare to need this quirk on Haswell or newer. Do not use unless you fully understand the consequences.

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

5. `MatchKernel`
Type: `plist string`
Failsafe: Empty string
Description: ~~Blocks~~ Adds kernel driver on selected macOS version only. The selection happens based on prefix match with the kernel version, i.e. `16.7.0` will match macOS 10.12.6 and `16.` will match any macOS 10.12.x version.

6. `PlistPath`
Type: `plist string`
Failsafe: Empty string
Description: Kext `Info.plist` path relative to bundle (e.g. `Contents/Info.plist`).

7.4 Block Properties

1. `Comment`
Type: `plist string`
Failsafe: Empty string
Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

2. `Enabled`
Type: `plist boolean`
Failsafe: `false`
Description: This kernel driver will not be blocked unless set to `true`.

3. `Identifier`
Type: `plist string`
Failsafe: Empty string
Description: Kext bundle identifier (e.g. `com.apple.driver.AppleTyMCEDriver`).

4. `MatchKernel`
Type: `plist string`
Failsafe: Empty string
Description: Blocks kernel driver on selected macOS version only. The selection happens based on prefix match with the kernel version, i.e. `16.7.0` will match macOS 10.12.6 and `16.` will match any macOS 10.12.x version.

7.5 Emulate Properties

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

2. `Cpuid1Mask`
Type: `plist data`, 16 bytes
Failsafe: All zero
Description: Bit mask of active bits in `Cpuid1Data`. When each `Cpuid1Mask` bit is set to 0, the original CPU bit is used, otherwise set bits take the value of `Cpuid1Data`.

7.6 Patch Properties

1. `Base`
Type: `plist string`
Failsafe: Empty string
Description: Selects symbol-matched base for patch lookup (or immediate replacement) by obtaining the address of provided symbol name. Can be set to empty string to be ignored.

7.7 Quirks Properties

1. `AppleCpuPmCfgLock`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Disables `PKG_CST_CONFIG_CONTROL` (`0xE2`) MSR modification in AppleIntelCPUPowerManagement.kext, commonly causing early kernel panic, when it is locked from writing.

   Note: This option should avoided whenever possible. Modern firmwares provide `CFG Lock` setting, disabling which is much cleaner. More details about the issue can be found in VerifyMsrE2 notes.

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

   Note: This option should avoided whenever possible. Modern firmwares provide `CFG Lock` setting, disabling which is much cleaner. More details about the issue can be found in VerifyMsrE2 notes.

3. `AppleXcpmExtraMsrs`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Disables multiple MSR access critical for select CPUs, which have no native XCPM support.

   This is normally used in conjunction with `Emulate` section on Haswell-E, Broadwell-E, Skylake-X, 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. `CustomSMBIOSGuid`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Performs GUID patching for `UpdateSMBIOSMode Custom` mode. Usually relevant for Dell laptops.

5. `DisableIoMapper`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Disables `IOMapper` support in XNU (VT-d), which may conflict with the firmware implementation.

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

6. `ExternalDiskIcons`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Apply icon type patches to AppleAHCIPort.kext to force internal disk icons for all AHCI disks.

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

7. `LapicKernelPanic`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Disables kernel panic on LAPIC interrupts.

8. `PanicNoKextDump`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Prevent kernel from printing kext dump in the panic log preventing from observing panic details. Affects 10.13 and above.

9. `ThirdPartyTrim`
   Type: `plist boolean`

8 Misc

8.1 Introduction

This section contains miscellaneous configuration entries for OpenCore behaviour that does not go to any other sections

8.2 Properties

1. `Boot`
   Type: `plist dict`
   Description: Apply boot configuration described in Boot Properties section below.

2. `BlessOverride`
   Type: `plist array`
   Description: Add custom scanning paths through bless model.

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

3. `Debug`
   Type: `plist dict`
   Description: Apply debug configuration described in Debug Properties section below.

4. `Entries`
   Type: `plist array`
   Description: Add boot entries to boot picker.

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

5. `Security`
   Type: `plist dict`
   Description: Apply security configuration described in Security Properties section below.

6. `Tools`
   Type: `plist array`
   Description: Add ~~new~~ tool entries to boot picker.

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

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

8.3 Boot Properties

1. `ConsoleMode`
   Type: `plist string`
   Failsafe: Empty string
   Description: Sets console output mode as specified with the `WxH` (e.g. `80x24`) formatted string. Set to empty string not to change console mode. Set to `Max` to try to use largest available console mode.

2. `ConsoleBehaviourOs`
   Type: `plist string`
   Failsafe: Empty string
   Description: Set console control behaviour upon operating system load.

   Console control is a legacy protocol used for switching between text and graphics screen output. Some firmwares do not provide it, yet select operating systems require its presence, which is what `ConsoleControl` UEFI protocol is for.

When console control is available, OpenCore can be made console control aware, and and set different modes for the operating system booter (`ConsoleBehaviourOs`), which normally runs in graphics mode, and its own user interface (`ConsoleBehaviourUi`), which normally runs in text mode. Possible behaviours, set as values of these options, include:

- Empty string — Do not modify console control mode.
- `Text` — Switch to text mode.
- `Graphics` — Switch to graphics mode.
- `ForceText` — Switch to text mode and preserve it (requires `ConsoleControl`).
- `ForceGraphics` — Switch to graphics mode and preserve it (require `ConsoleControl`).

Hints:

- Unless empty works, firstly try to set `ConsoleBehaviourOs` to `Graphics` and `ConsoleBehaviourUi` to `Text`.
- On APTIO IV (Haswell and earlier) it is usually enough to have `ConsoleBehaviourOs` set to `Graphics` and `ConsoleBehaviourUi` set to `ForceText` to avoid visual glitches.
- On APTIO V (Broadwell and newer) `ConsoleBehaviourOs` set to `ForceGraphics` and `ConsoleBehaviourUi` set to `ForceText` usually works best.
- On Apple firmwares `ConsoleBehaviourOs` set to `Graphics` and `ConsoleBehaviourUi` set to `Text` is supposed to work best.

Note: `IgnoreTextInGraphics` and `SanitiseClearScreen` may need to be enabled for select firmware implementations. Particularly APTIO firmwares.

3. `ConsoleBehaviourUi`
   Type: `plist string`
   Failsafe: Empty string
   Description: Set console control behaviour upon OpenCore user interface load. Refer to `ConsoleBehaviourOs` description for details.

4. `HibernateMode`
   Type: `plist string`
   Failsafe: `None`
   Description: Hibernation detection mode. The following modes are supported:

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

5. `HideSelf`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Hides own boot entry from boot picker. This may potentially hide other entries, for instance, when another UEFI OS is installed on the same volume and driver boot is used.

6. `Resolution`
   Type: `plist string`
   Failsafe: Empty string
   Description: Sets console output screen resolution.

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

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

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

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

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

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

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

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

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

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

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

8.5 Security Properties

1. `ExposeSensitiveData`
   Type: `plist integer`
   Failsafe: `2`
   Description: Sensitive data exposure bitmask (sum) to operating system.
   - `0x01` — Expose printable booter path as an UEFI variable.
   - `0x02` — Expose OpenCore version as an UEFI variable.

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

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

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

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

   To obtain OpenCore version use the following command in macOS:

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

2. `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.

3. `RequireSignature`
   Type: `plist boolean`
   Failsafe: `true`
   Description: Require `vault.sig` signature file for `vault.plist` in `OC` directory.

- `0x00000001` (bit `0`) — `OC_SCAN_FILE_SYSTEM_LOCK`, restricts scanning to only known file systems defined as a part of this policy. File system drivers may not be aware of this policy, and to avoid mounting of undesired file systems it is best not to load its driver. This bit does not affect dmg mounting, which may have any file system. Known file systems are prefixed with `OC_SCAN_ALLOW_FS_`.
- `0x00000002` (bit `1`) — `OC_SCAN_DEVICE_LOCK`, restricts scanning to only known device types defined as a part of this policy. This is not always possible to detect protocol tunneling, so be aware that on some systems it may be possible for e.g. USB HDDs to be recognised as SATA. Cases like this must be reported. Known device types are prefixed with `OC_SCAN_ALLOW_DEVICE_`.
- `0x00000100` (bit `8`) — `OC_SCAN_ALLOW_FS_APFS`, allows scanning of APFS file system.
- `0x00000200` (bit `9`) — `OC_SCAN_ALLOW_FS_HFS`, allows scanning of HFS file system.
- `0x00000400` (bit `10`) — `OC_SCAN_ALLOW_FS_ESP`, allows scanning of EFI System Partition file system.
- `0x00010000` (bit `16`) — `OC_SCAN_ALLOW_DEVICE_SATA`, allow scanning SATA devices.
- `0x00020000` (bit `17`) — `OC_SCAN_ALLOW_DEVICE_SASEX`, allow scanning SAS and Mac NVMe devices.
- `0x00040000` (bit `18`) — `OC_SCAN_ALLOW_DEVICE_SCSI`, allow scanning SCSI devices.
- `0x00080000` (bit `19`) — `OC_SCAN_ALLOW_DEVICE_NVME`, allow scanning NVMe devices.
- `0x00100000` (bit `20`) — `OC_SCAN_ALLOW_DEVICE_ATAPI`, allow scanning CD/DVD devices.
- `0x00200000` (bit `21`) — `OC_SCAN_ALLOW_DEVICE_USB`, allow scanning USB devices.
- `0x00400000` (bit `22`) — `OC_SCAN_ALLOW_DEVICE_FIREWIRE`, allow scanning FireWire devices.
- `0x00800000` (bit `23`) — `OC_SCAN_ALLOW_DEVICE_SDCARD`, allow scanning card reader devices.

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

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

8.6 ~~Tools~~ Entry Properties

1. `Comment`
   Type: `plist string`
   Failsafe: Empty string
   Description: Arbitrary ASCII string used to provide human readable reference for the entry. It is implementation defined whether this value is used.

2. `Enabled`
   Type: `plist boolean`
   Failsafe: `false`
   Description: This ~~tool~~ entry will not be listed unless set to `true`.

3. `Name`
   Type: `plist string`
   Failsafe: Empty string
   Description: Human readable ~~tool~~ entry name displayed in boot picker.

4. `Path`
   Type: `plist string`
   Failsafe: Empty string
   Description: ~~File path to select UEFI tool~~ Entry location depending on entry type.

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

9 NVRAM

9.1 Introduction

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

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

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

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

9.2 Properties

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

   Created variables get `EFI_VARIABLE_BOOTSERVICE_ACCESS` and `EFI_VARIABLE_RUNTIME_ACCESS` attributes set. Variables will only be set if not present and not blocked. To overwrite a variable add it to `Block` section. This approach enables to provide default values till the operating system takes the lead.

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

2. `Block`
   Type: `plist dict`
   Description: Removes NVRAM variables from a map (`plist dict`) of GUIDs to an array (`plist array`) of variable names in `plist string` format.

3. `LegacyEnable`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Enables loading of NVRAM variable file named `nvram.plist` from EFI volume root.

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

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

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

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

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

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

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

may be found by looking for the use of `PE_parse_boot_argn` function in the kernel or driver code. Some of the known boot arguments include:

  - `acpi_layer=0xFFFFFFFF`
  - `acpi_level=0xFFFF5F` (implies `ACPI_ALL_COMPONENTS`)
  - `batman=VALUE` (`AppleSmartBatteryManager` debug mask)
  - `batman-nosmc=1` (disable `AppleSmartBatteryManager` SMC interface)
  - `cpus=VALUE` (maximum number of CPUs used)
  - `debug=VALUE` (debug mask)
  - `io=VALUE` (`IOKit` debug mask)
  - `keepsyms=1` (show panic log debug symbols)
  - `kextlog=VALUE` (kernel extension loading debug mask)
  - `nv_disable=1` (disables NVIDIA GPU acceleration)
  - `nvda_drv=1` (legacy way to enable NVIDIA web driver, removed in 10.12)
  - `npci=0x2000` (legacy, disables `kIOPCIConfiguratorPFM64`)
  - `lapic_dont_panic=1`
  - `slide=VALUE` (manually set KASLR slide)
  - `smcdebug=VALUE` (`AppleSMC` debug mask)
  - `-amd_no_dgpu_accel` (alternative to WhateverGreen's `-radvesa` for new GPUs)
  - `-nehalem_error_disable`
  - `-no_compat_check` (disable model checking)
  - `-s` (single mode)
  - `-v` (verbose mode)
  - `-x` (safe mode)

  There are multiple external places summarising macOS argument lists: example 1, example 2.

- `7C436110-AB2A-4BBB-A880-FE41995C9F82:bootercfg`
  Booter arguments, similar to `boot-args` but for boot.efi. Accepts a set of arguments, which are hexadecimal 64-bit values with or without 0x prefix primarily for logging control:
  - `log=VALUE`
    * `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`
    * `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` — Verbosity level of DEBUG output. Everything but `0x80000000` is stripped from the binary, and this is the default value.
  - `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.
- `7C436110-AB2A-4BBB-A880-FE41995C9F82:bootercfg-once`
  Booter arguments override removed after first launch. Otherwise equivalent to `bootercfg`.
- `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.

11 UEFI

11.1 Introduction

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

11.2 Properties

1. `ConnectDrivers`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Perform UEFI controller connection after driver loading. This option is useful for loading filesystem drivers, which usually follow UEFI driver model, and may not start by themselves. While effective, this option is not necessary with e.g. APFS loader driver, and may slightly slowdown the boot.

2. `Drivers`
   Type: `plist array`
   Failsafe: None
   Description: Load selected drivers from `OC/Drivers` directory.

   Designed to be filled with string filenames meant to be loaded as UEFI drivers. Depending on the firmware a different set of drivers may be required. Loading an incompatible driver may lead your system to unbootable state or even cause permanent firmware damage. Some of the known drivers include:

   - `ApfsDriverLoader` — APFS file system bootstrap driver adding the support of embedded APFS drivers in bootable APFS containers in UEFI firmwares.
   - `AppleUiSupport` — Apple-specific user interface support driver. This driver brings the support for FileVault 2 GUI, hotkey parsing (shift, cmd+v, etc.), language collation support, and certain other features important for normal macOS functioning. For hotkey support `AppleKeyMapAggregator`-compatible driver is required.
   - `AppleGenericInput` — user input driver adding the support of `AppleKeyMapAggregator` protocols on top of different UEFI input protocols. Additionally resolves mouse input issues on select firmwares. This is an alternative to `UsbKbDxe`, which may work better or worse depending on the firmware.
   - `FwRuntimeServices` — ~~a set of quirks for various firmwares. While it primarily targets APTIO firmwares, other firmwares may be compatible as well. Among the resolved issues are hibernation support, KASLR, Lilu NVRAM security enhancements, NVRAM, and UEFI Boot entry preservation.~~ `OC_FIRMWARE_RUNTIME` protocol implementation that increases the security of OpenCore and Lilu by supporting read-only and write-only NVRAM variables. Some quirks, like `RequestBootVarRouting`, require this driver for proper function. Due to the nature of being a runtime driver, i.e. functioning in parallel with the target operating system, it cannot be implemented within OpenCore itself.
   - `EnglishDxe` — ~~NVRAM emulation driverfrom `MdeModulePkg`.NVRAM is supported by most modern firmwares. For firmwares with macOS incompatible NVRAM implementation an emulated driver may be used. This driver will not preserve NVRAM contents across the reboots.~~
   - ~~—~~Unicode collation driver from `MdeModulePkg`. This driver is a lightweight alternative to `AppleUiSupport`, which contains no Apple-specific code, and only provides unicode collation support. The driver is not recommended for use on any hardware but few original Macs.
   - `EnhancedFatDxe` — FAT filesystem driver from `FatPkg`. This driver is embedded in all UEFI firmwares, and cannot be used from OpenCore. It is known that multiple firmwares have a bug in their FAT support implementation, which leads to corrupted filesystems on write attempt. Embedding this driver within the firmware may be required in case writing to EFI partition is needed during the boot process.
   - `NvmExpressDxe` — NVMe support driver from `MdeModulePkg`. This driver is included in most firmwares starting with Broadwell generation. For Haswell and earlier embedding it within the firmware may be more favourable in case a NVMe SSD drive is installed.
   - `UsbKbDxe` — USB keyboard driver adding the support of `AppleKeyMapAggregator` protocols on top of a custom USB keyboard driver implementation. This is an alternative to `AptioInputFix`, which may work better or worse depending on the firmware.
   - `VirtualSmc` — UEFI SMC driver, required for proper FileVault 2 functionality and potentially other macOS

specifics. An alternative, named `SMCHelper`, is not compatible with `VirtualSmc` and OpenCore, which is unaware of its specific interfaces. In case `FakeSMC` kernel extension is used, manual NVRAM variable addition may be needed and `VirtualSmc` driver should still be used.

- `VBoxHfs` — HFS file system driver with bless support. This driver is an alternative to a closed source `HFSPlus` driver commonly found in Apple firmwares. While it is feature complete, it is approximately 3 times slower and is yet to undergo a security audit.
- `XhciDxe` — XHCI USB controller support driver from `MdeModulePkg`. This driver is included in most firmwares starting with Sandy Bridge generation. For earlier firmwares or legacy systems it may be used to support external USB 3.0 PCI cards.

To compile the drivers from ~~TianoCore UDK~~ UDK (EDK II) use the same command you do normally use for OpenCore compilation, but choose a corresponding package:

```
~~git clone https://github.com/tianocore/edk2 -b UDK2018 UDK~~
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
```

3. `Protocols`
   Type: `plist dict`
   Failsafe: None
   Description: Force builtin versions of select protocols described in Protocols Properties section below.

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

4. `Quirks`
   Type: `plist dict`
   Failsafe: None
   Description: Apply individual firmware quirks described in Quirks Properties section below.

11.3 Protocols Properties

1. `AppleBootPolicy`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Reinstalls Apple Boot Policy protocol with a builtin version. This may be used to ensure APFS compatibility on VMs or legacy Macs.

2. `ConsoleControl`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Replaces Console Control protocol with a builtin version.

   macOS bootloader requires console control protocol for text output, which some firmwares miss. This option is required to be set when the protocol is already available in the firmware, and other console control options are used, such as `IgnoreTextInGraphics`, `SanitiseClearScreen`, and sometimes `ConsoleBehaviourOs` with `ConsoleBehaviourUi`).

3. `DataHub`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Reinstalls Data Hub protocol with a builtin version. This will drop all previous properties if the protocol was already installed.

4. `DeviceProperties`
   Type: `plist boolean`
   Failsafe: `false`
   Description: Reinstalls Device Property protocol with a builtin version. This will drop all previous properties if it was already installed. This may be used to ensure full compatibility on VMs or legacy Macs.

11.4 Quirks Properties

1. AvoidHighAlloc
   Type: plist boolean
   Failsafe: false
   Description: Advises allocators to avoid allocations above first 4 GBs of RAM.

   This is a workaround for select board firmwares, namely GA-Z77P-D3 (rev. 1.1), failing to properly access higher memory in UEFI Boot Services. On these boards this quirk is required for booting entries that need to allocate large memory chunks, such as macOS DMG recovery entries. On unaffected boards it may cause boot failures, and thus strongly not recommended. For known issues refer to acidanthera/bugtracker#449.

2. ExitBootServicesDelay
   Type: plist integer
   Failsafe: 0
   Description: Adds delay in microseconds after EXIT_BOOT_SERVICES event.

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

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

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

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

   Note: While the option is not supposed to induce harm on unaffected firmwares, its usage is not recommended when it is not required. This option may hide onscreen error messages. ConsoleControl may need to be set to true for this to work.

5. ProvideConsoleGop
   Type: plist boolean
   Failsafe: false
   Description: macOS bootloader requires GOP (Graphics Output Protocol) to be present on console handle. This option will install it if missing.

   ~~*Note*: Some drivers, like AptioMemoryFix, may provide equivalent functionality. These drivers are not guaranteed to adhere to the same logic, and if a quirk is necessary, this option is preferred.~~

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

7. RequestBootVarRouting
   Type: plist boolean
   Failsafe: false
   Description: Request ~~NVRAM driver (or AptioMemoryFix) to~~ redirectBoot prefixed variables from EFI_GLOBAL_VARIABLE_G to OC_VENDOR_VARIABLE_GUID.

12 Troubleshooting

12.1 Windows support

Can I install Windows?

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

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

What additional software do I need?

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

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

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

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

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

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

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

Command (? for help): p
Disk \\.\physicaldrive0: 419430400 sectors, 200.0 GiB
Sector size (logical): 512 bytes
```

```
Disk identifier (GUID): DEC57EB1-B3B5-49B2-95F5-3B8C4D3E4E12
Partition table holds up to 128 entries
Main partition table begins at sector 2 and ends at sector 33
First usable sector is 34, last usable sector is 419430366
Partitions will be aligned on 2048-sector boundaries
Total free space is 4029 sectors (2.0 MiB)

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

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

Command (? for help): w

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

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

Listing 3: Relabeling Windows volume

How to choose Windows BOOTCAMP with custom NTFS drivers?

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

12.2 Debugging

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

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

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

12.3 Tips and Tricks

1. **How to debug boot failure?**

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

   - You have a `DEBUG` or `NOOPT` version of OpenCore.
   - Logging is enabled (`1`) and shown onscreen (`2`): `Misc` → `Debug` → `Target` = `3`.

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

If there is no obvious error, check the available hacks in `Quirks` sections one by one.

2. **How to customise boot entries?**

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

3. **What is the simplest way to install macOS?**

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

   To download recovery online you may use Recovery tool from OcSupportPkg.

4. **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. Another cause may be buggy firmware allocator, which can be worked around with `AvoidHighAlloc` UEFI quirk.

5. **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 in acidanthera/bugtracker#377.

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

   For machine code (x86 code) it is not possible to do such 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.

7. **How can I migrate from `AptioMemoryFix`?**

   Behaviour similar to that of `AptioMemoryFix` can be obtained by installing `FwRuntimeServices` driver and enabling the quirks listed below. Please note, that most of these are not necessary to be enabled. Refer to their individual descriptions in this document for more details.

   - `ProvideConsoleGop` (UEFI quirk)
   - `AvoidRuntimeDefrag`
   - `DiscardHibernateMap`
   - `EnableSafeModeSlide`
   - `EnableWriteUnprotector`
   - `ForceExitBootServices`
   - `ProtectCsmRegion`
   - `ProvideCustomSlide`
   - `SetupVirtualMap`
   - `ShrinkMemoryMap`