Securing the EDK II Image Loader

Marvin Häuser
Technische Universität Kaiserslautern;
Ivannikov Institute for System Programming of the Russian Academy of Sciences
mhaeuser@posteo.de

Vitaly Cheptsov
Ivannikov Institute for System Programming of the Russian Academy of Sciences
cheptsov@ispras.ru

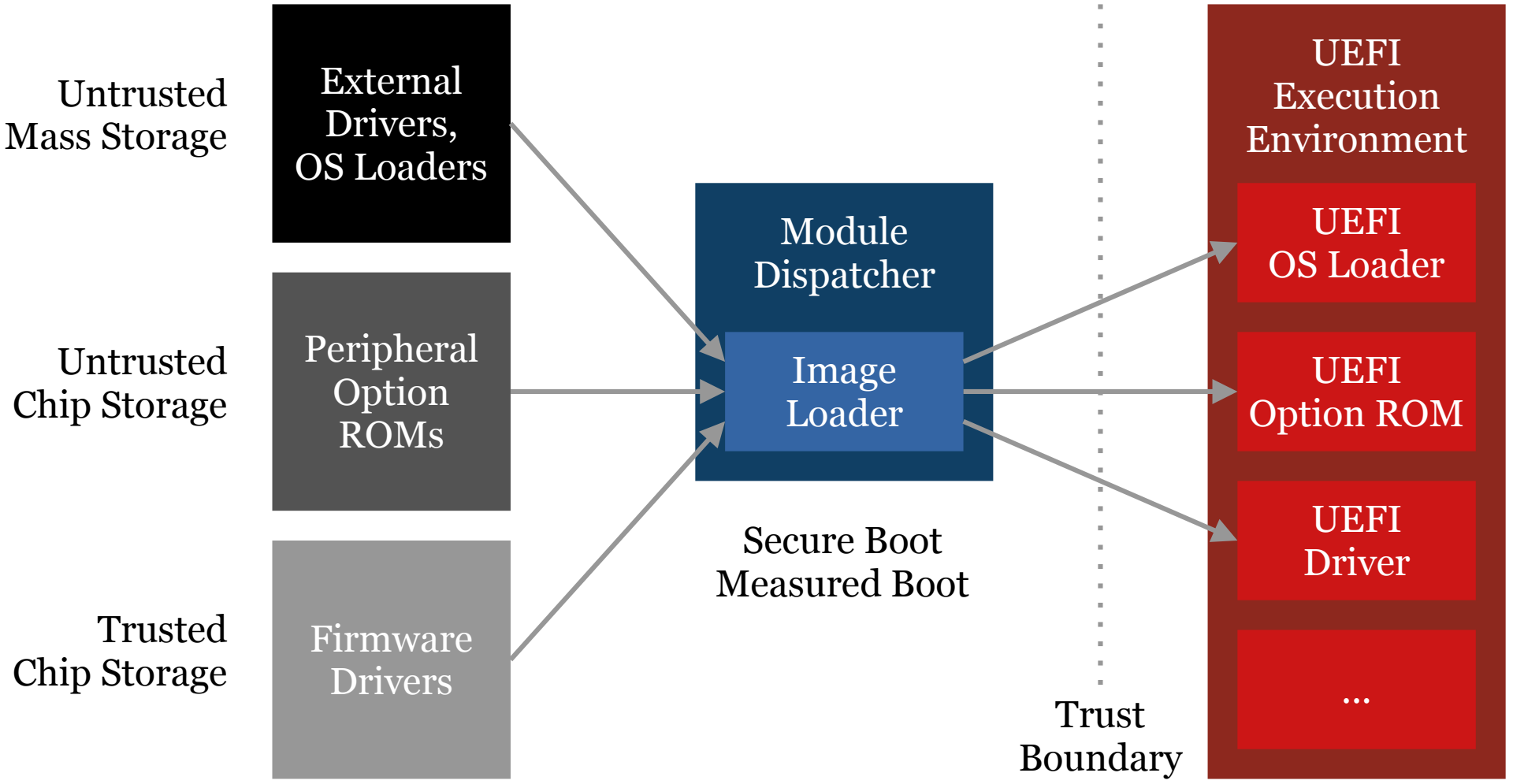

Untrusted
Mass Storage
External
Drivers,
OS Loaders
Untrusted
Chip Storage
Peripheral
Option
ROMs
Trusted
Chip Storage
Firmware
Drivers
Module
Dispatcher
Image
Loader
Secure Boot
Measured Boot
Trust
Boundary
UEFI
Execution
Environment
UEFI
OS Loader
UEFI
Option ROM
UEFI
Driver
...

Image Loader requirements

- Verify raw file conformance to the key parts of the PE specification
- Authenticate raw file (e.g. signature)
- Map the raw file into memory space
- Ensure code safety in the process (e.g. alignment, wraparounds, termination, etc.)

EDK II as a UEFI platform core

- Contains most platform-agnostic drivers
- Manual code review by the maintainers
- Gradual but slow improvements
- Dozens of “defects” reaching production
  - “Design defects”: Design that provokes bugs
  - “Functional defects”: Implementation bugs
  - Insufficient treatment of critical modules

Terse Executables

- Stripped PE executable to reduce size
- Poor specification makes tight models hard
- Only suitable internally due to lack of signing
- Not updated fields overcomplicate the Loader

The EDK II Image Loader

- It encourages TOC/TOU-vulnerable loading
- It accesses many unchecked offsets
- It does not consider data alignment at all
- It often does not report failures
- It misaligns TE Images in some cases
- It does not fully initialise the image destination

Deductive verification in practice

- C comiler (CompCert) with Coq by INRIA
- Microkernel (seL4) with Isabelle by OK Labs
- Cryptography (HACL *) with F* by Proj. Everest
- Hypervisor (Hyper-V) with VCC by Microsoft
- Avionics software with Frama-C by Airbus

AstraVer Toolset

- Based on established Frama-C technology
- Extended support for binary arithmetic
- Real-world usability showcased by verifying Astra Linux Security Module
- ACSL: First-Order Logic with C-like syntax
- Automatic and manual proving with Why3

Environment formal model

- Own definitions required to extend AV (Jessie)
- Memory model based on CompCert, Version 2, Type model based on C constraints
  - Compatible with common compilers
  - Honours common culprits like Strict Aliasing

PE formal model

- Modelled in ACSL, file adherence proven
  - File Headers and Relocation Directory
  - Sane values (offsets, sizes, etc.)
- Derived from PE specification constraints
  - Adapted by us towards real-world binaries to increase performance, security, and compatibility
- Incomplete, but sufficient to prove the goals

Authenticode Signature

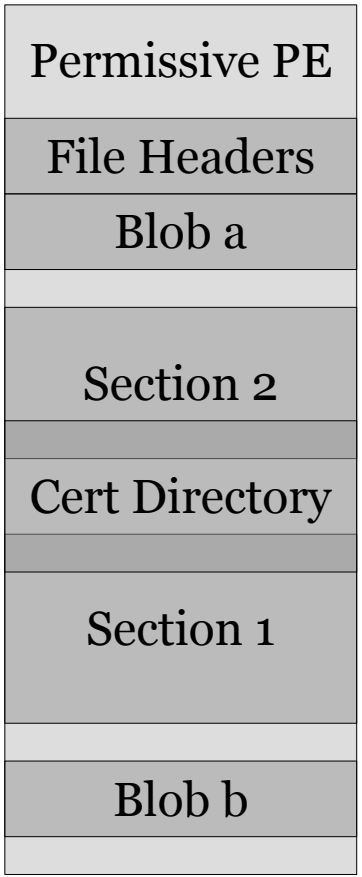
- Overcomplicated hashing algorithm
  - Sorts sections, bookkeeps number of hashed bytes
- Requires dynamic memory allocation
- Windows implementation does not follow specs
- Permits trailing data in the real world

Tightening the model

- Sane alignment rules for offsets
- Sane values (e.g. at least one section)
- Avoid uncommon, ambiguous constructs
  - Compund Base Relocations improperly defined
- Adjacent, sorted file sections
  - Simplifies Authenticode into almost a linear hash

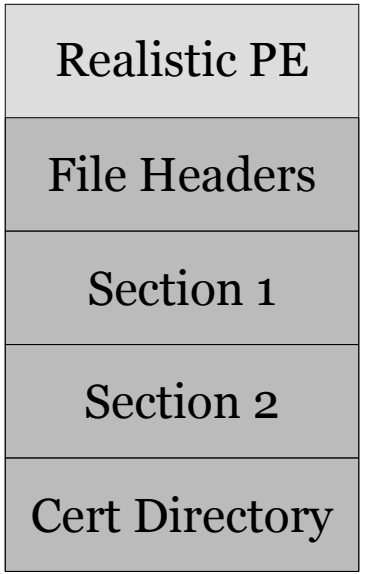
Tightening the model (Cont'd)

✗



- Gaps and Blobs increase the risk for unhashed data
- Intersections allow for easy increase of hashing expense
- Unsorted sections require Authenticode to dynamically allocate memory and sort
- Non-trailing Cert Directory risks accidentially hashing it and covercomplicates the Authenticode algorithm

✓



ACSL proving

- Predicates describe model properties
  - File bounds, alignment, disjunct sections, etc.
- Functions and statements are annotated with preconditions and postconditions
  - Two-way relation: model adherence ⇔ success

```
logic integer image_sect_correct_address (EFI_IMAGE_SECTION_HEADER *Sections, int
SectIndex == 0 ?
    image_loaded_hdr_virtual_size (Sections, SizeOfHeaders, SectionAlignment) :
    align_up (image_sect_top (Sections + SectIndex - 1), SectionAlignment);
```

Culprits

- The AstraVer memory model is limited
  - Additional axioms required for extension
- The solvers' binary arithmetic are limited
  - Interactive proof work required
- Complex expressions are impractical
  - No FOL "counting", no exponents, no HOL

Conventional validation

- Manual code review for common culprits
- Static analysis using SVACE and Coverity
- Dynamic tooling with libFuzzer, ASan/UBSan
  - 100 % coverage excluding defensive code
- Real-world test booting Microsoft Windows, Apple macOS, and GNU Linux bootloaders

Conclusion

- Re-implemented a fully-featured Image Loader
- EDK II implementation issues fully addressed
- 100% C safety proof coverage for core code
- Correctness proofs cover most core code
  - “Fully proven” execution possible on IA32 and X64
- So far no single bug found in proven code ☺

Future work

- Proving of image-embedded signature handler
- Allowing for tighter format constraints
  - Trailing data to header, sections or Cert Directory
- Integeration with the EDK II core modules
- Submission of the project to TianoCore

Material available at: github.com/mhaeuser/ISPRASOpen-SecurePE

Thank you.
Questions?

ISP RAS: Project Amaranth

- Restricted UEFI specification subset
- Focused on security
- Open-source community collaboration
- Incorporates formal methods
- Targets virtual machines and real hardware
- In active development since 2020