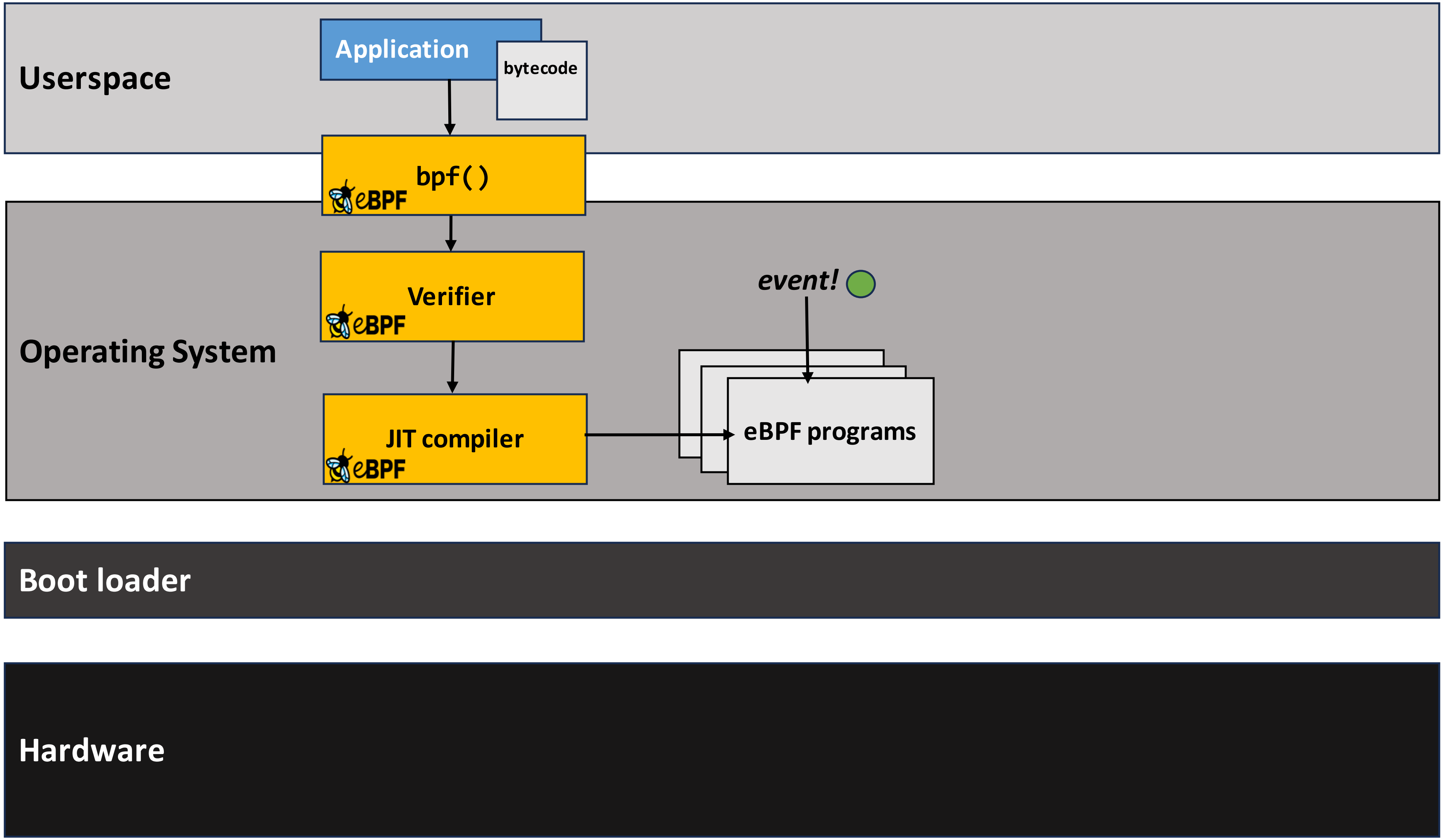
Extending Non-Repudiable Logs with eBPF

Avery Blanchard[1], Gheorghe Almasi[2], James Bottomley[2] and Hubertus Franke[2]

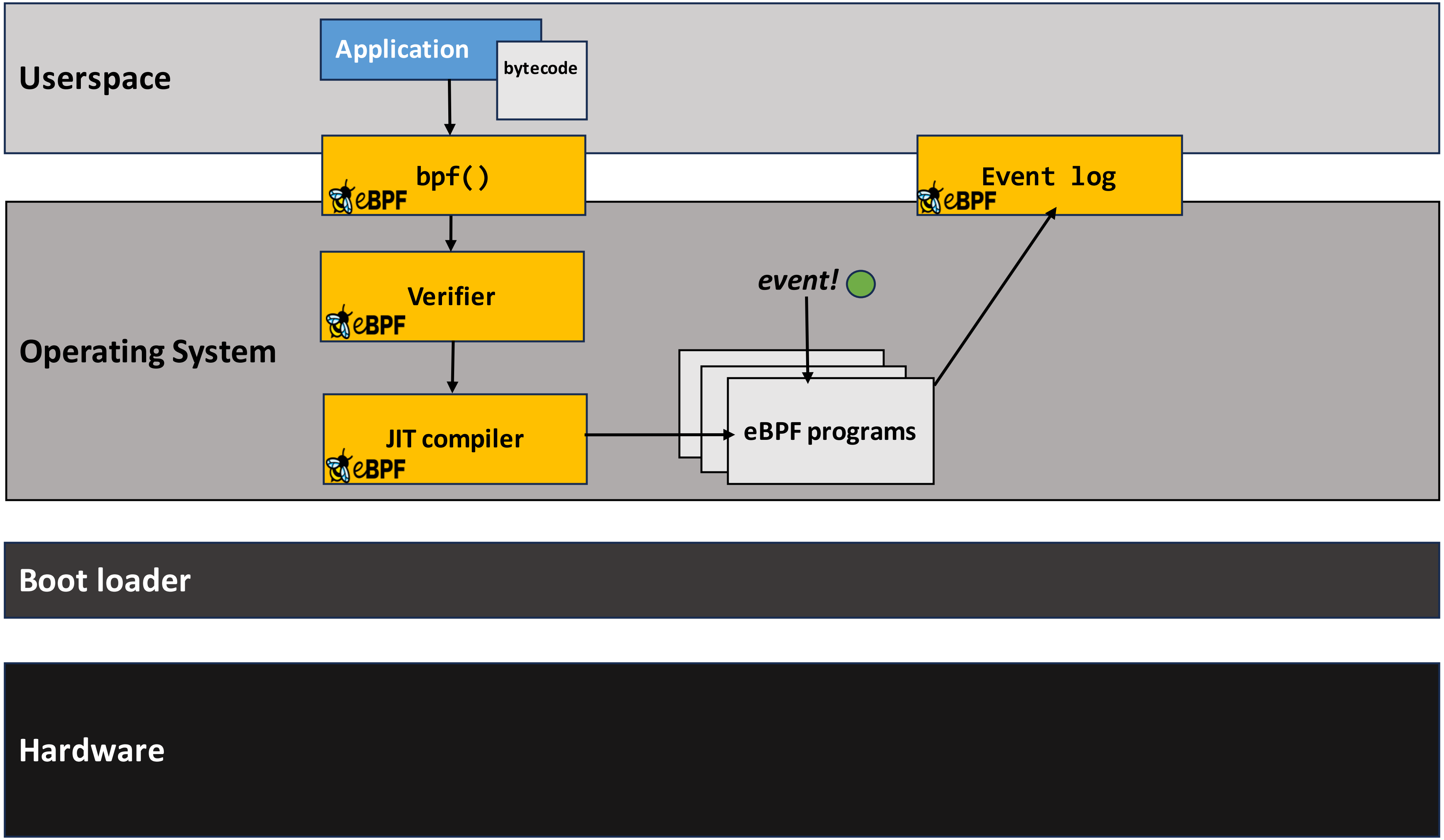
1 Duke University
2 IBM Research

November 13th, 2023

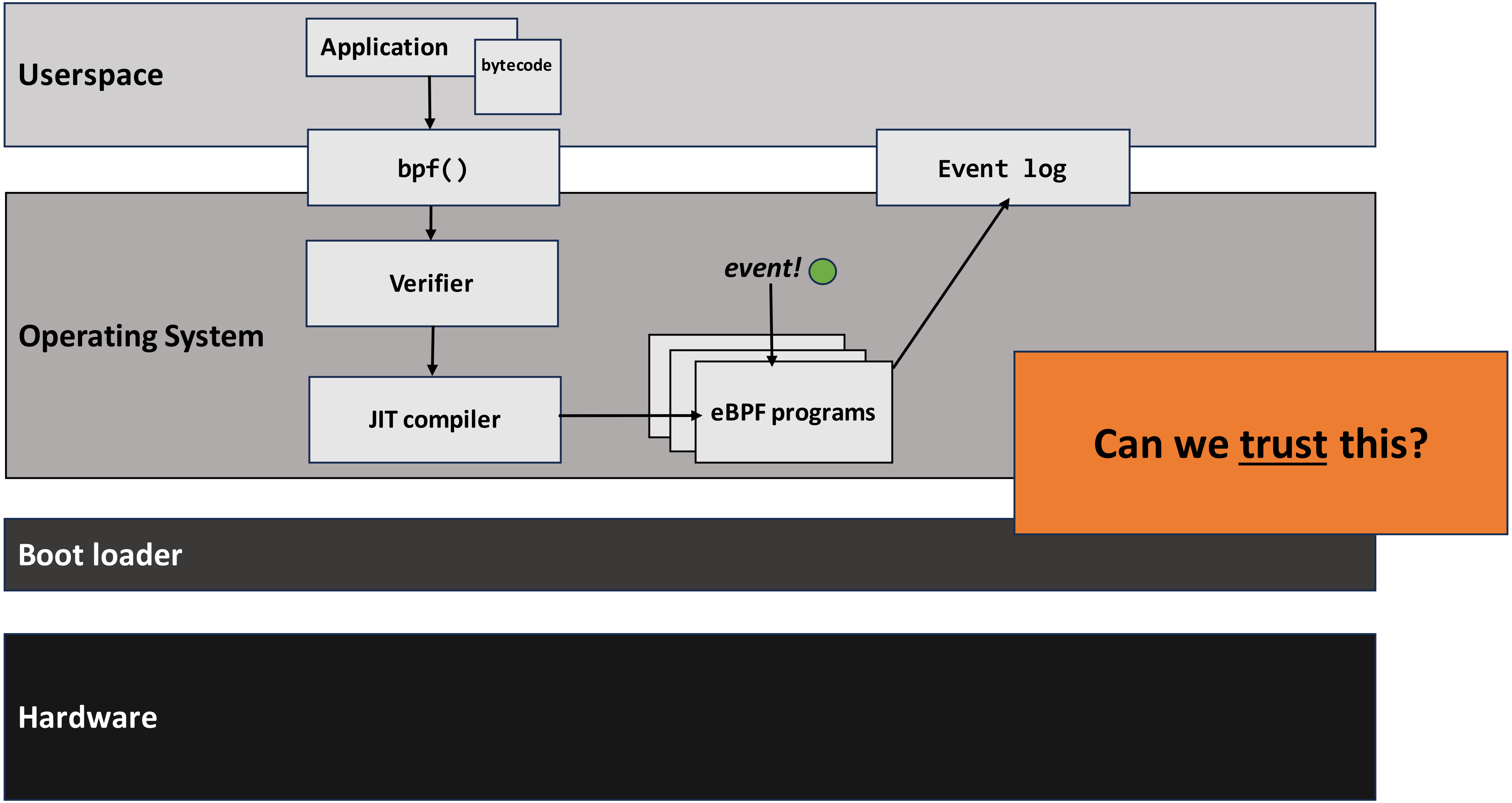
Visibility into System State with eBPF



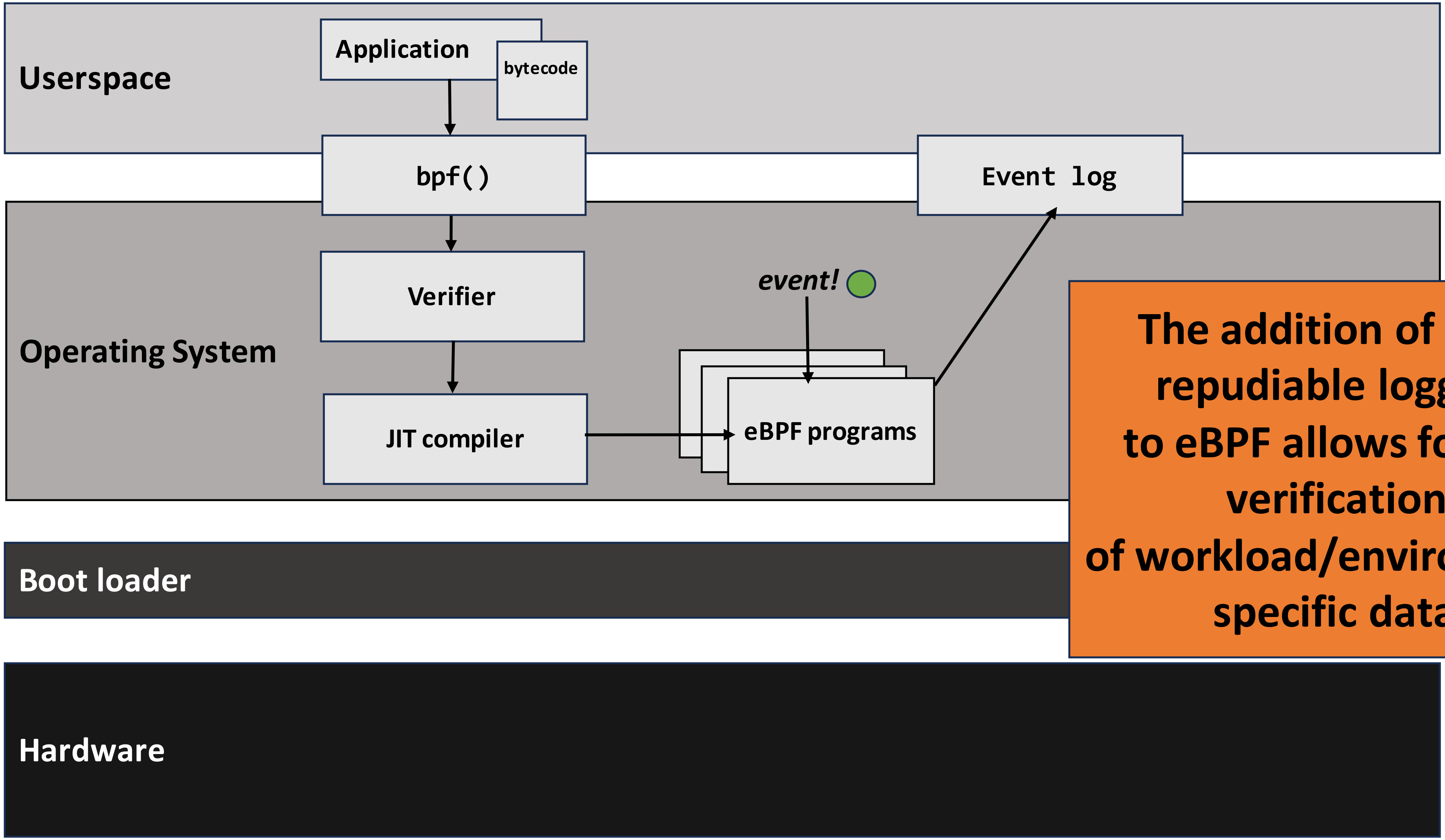
Visibility into System State with eBPF



Visibility into System State with eBPF

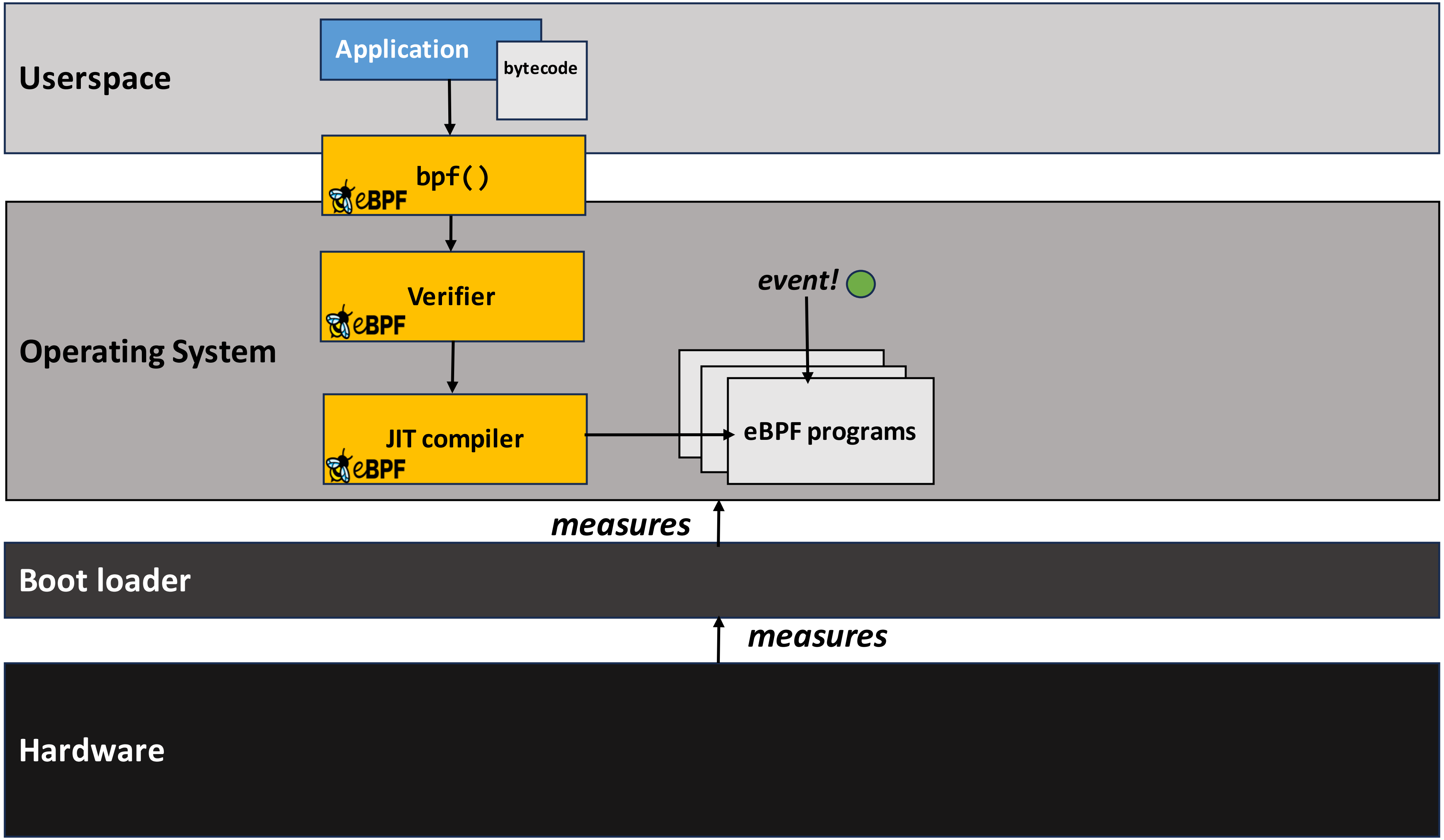


Visibility into System State with eBPF

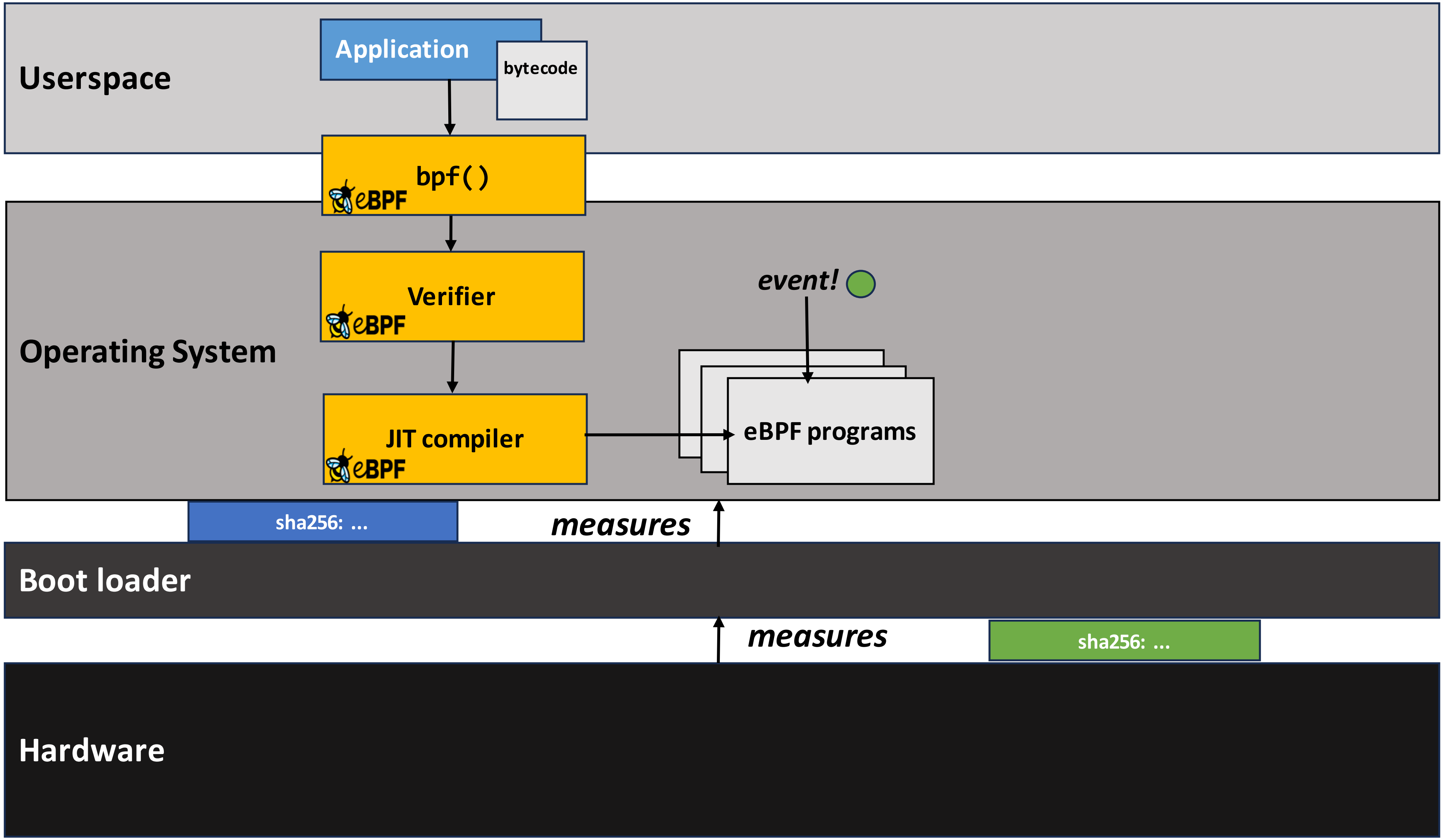


The addition of non-repudiable logging to eBPF allows for the verification of workload/environment specific data.

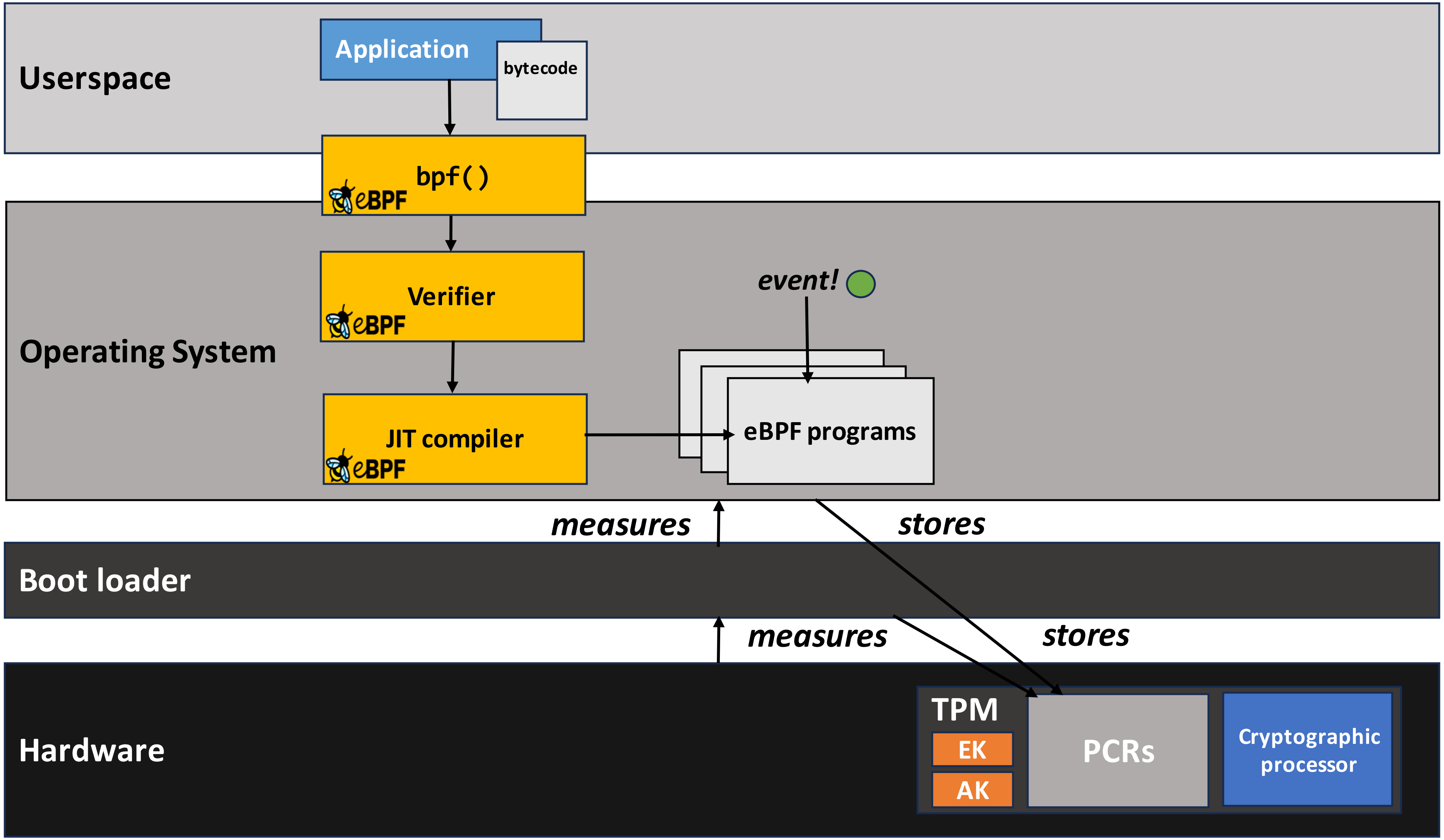
Building a Chain of Trust



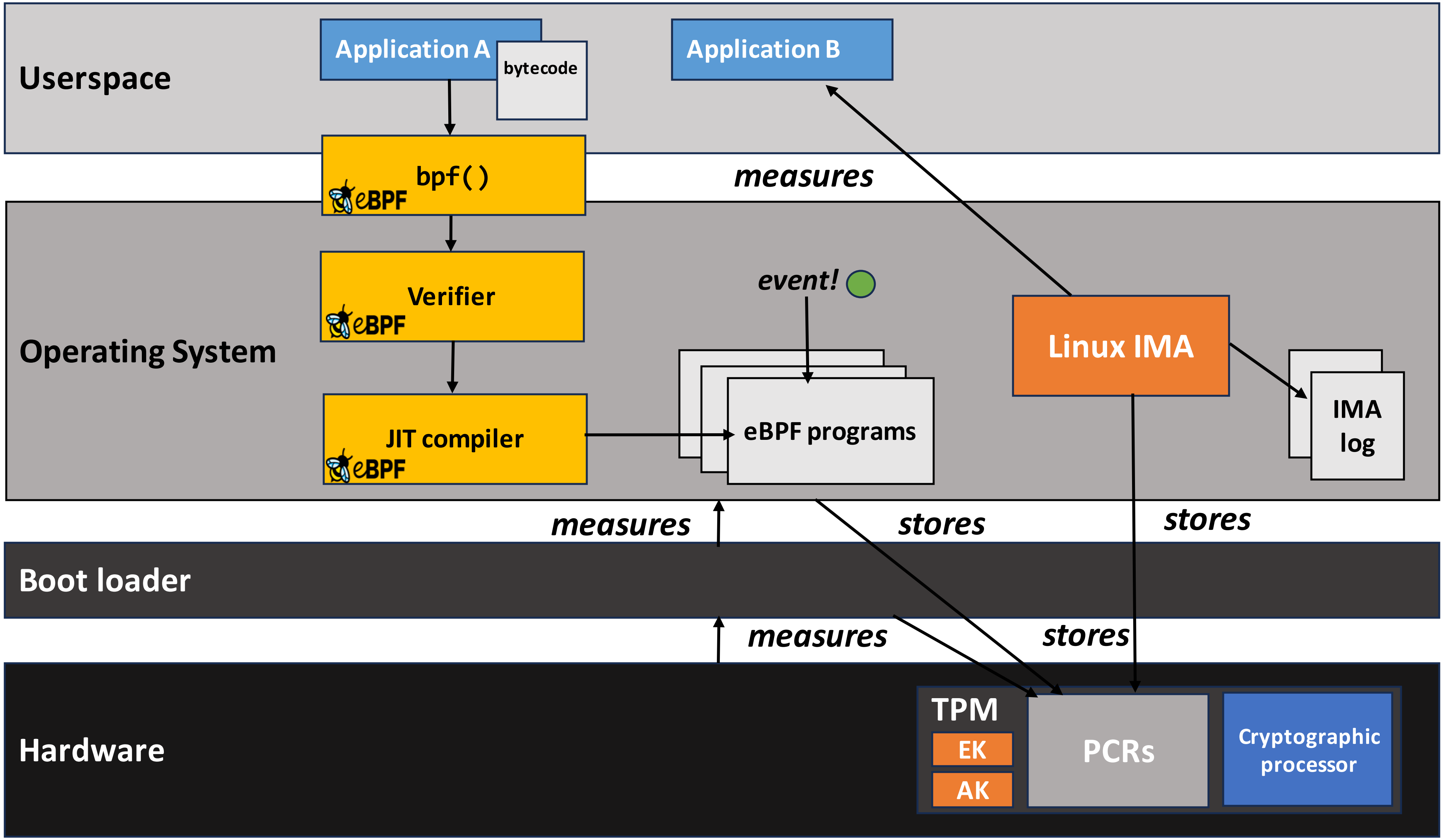
Building a Chain of Trust



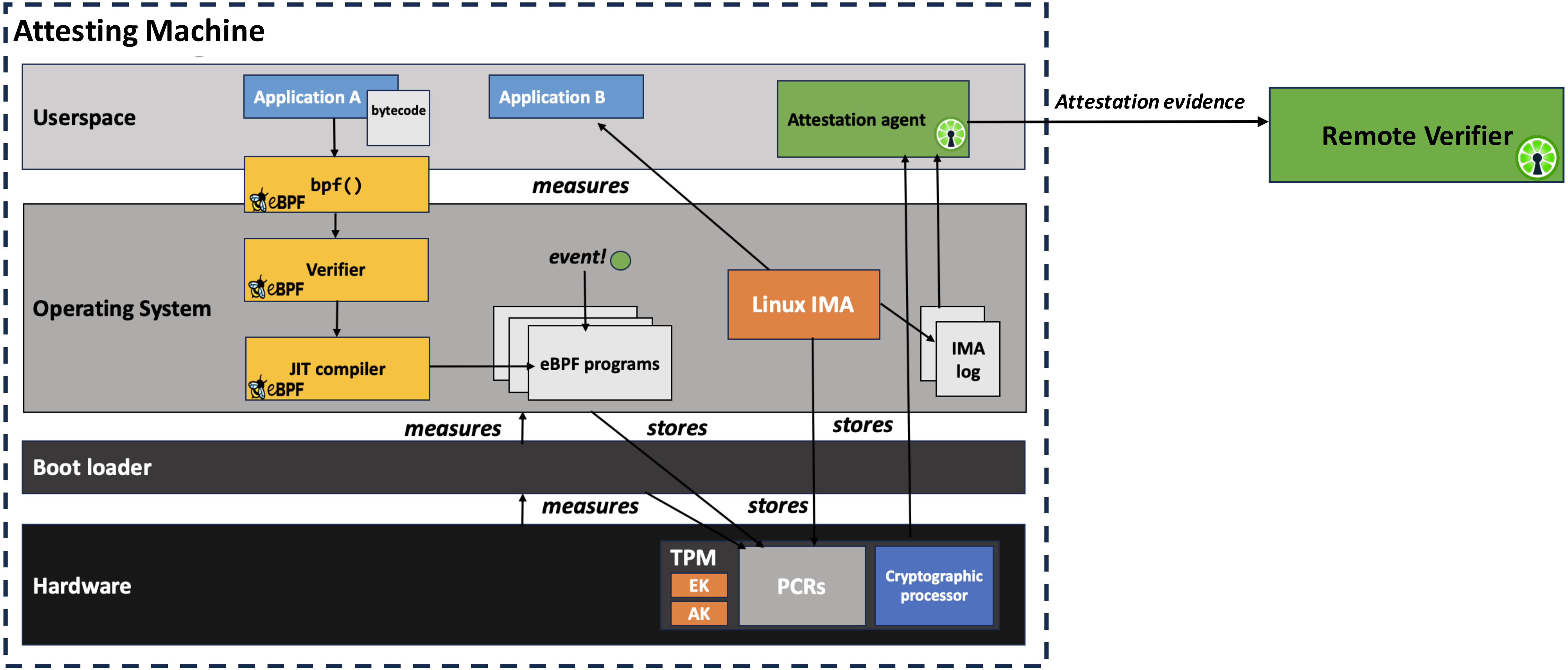
Rooting Trust in Hardware



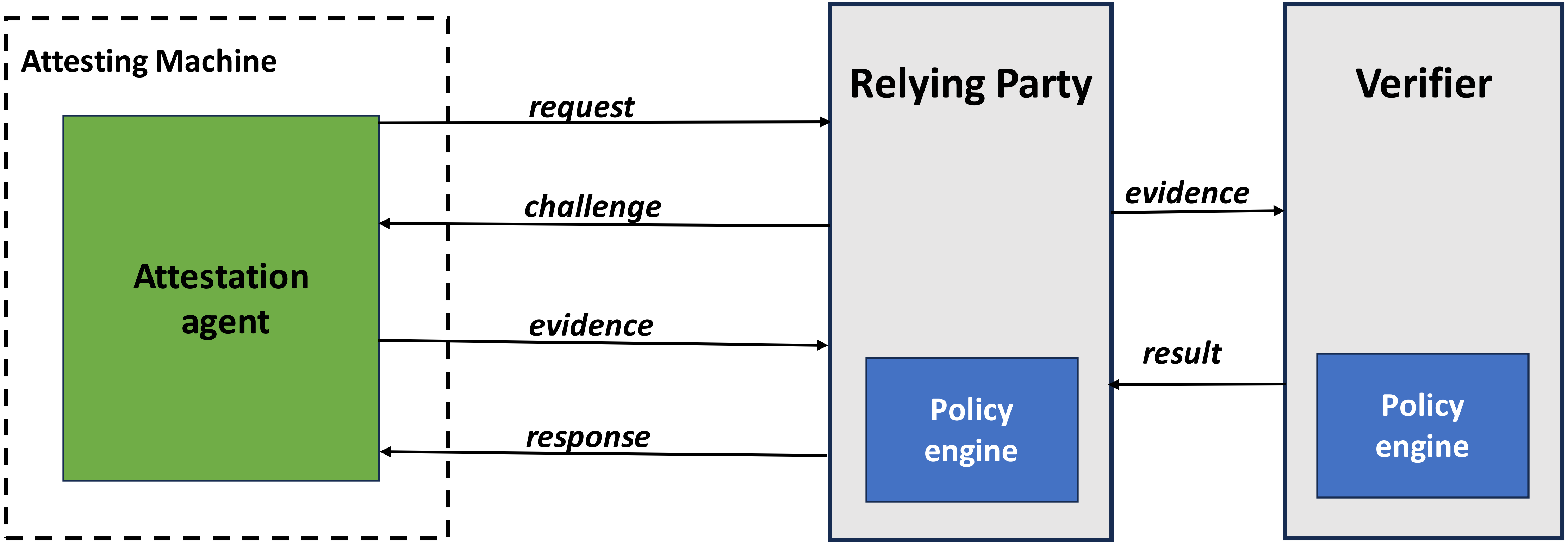
Extending Measurements Through Runtime



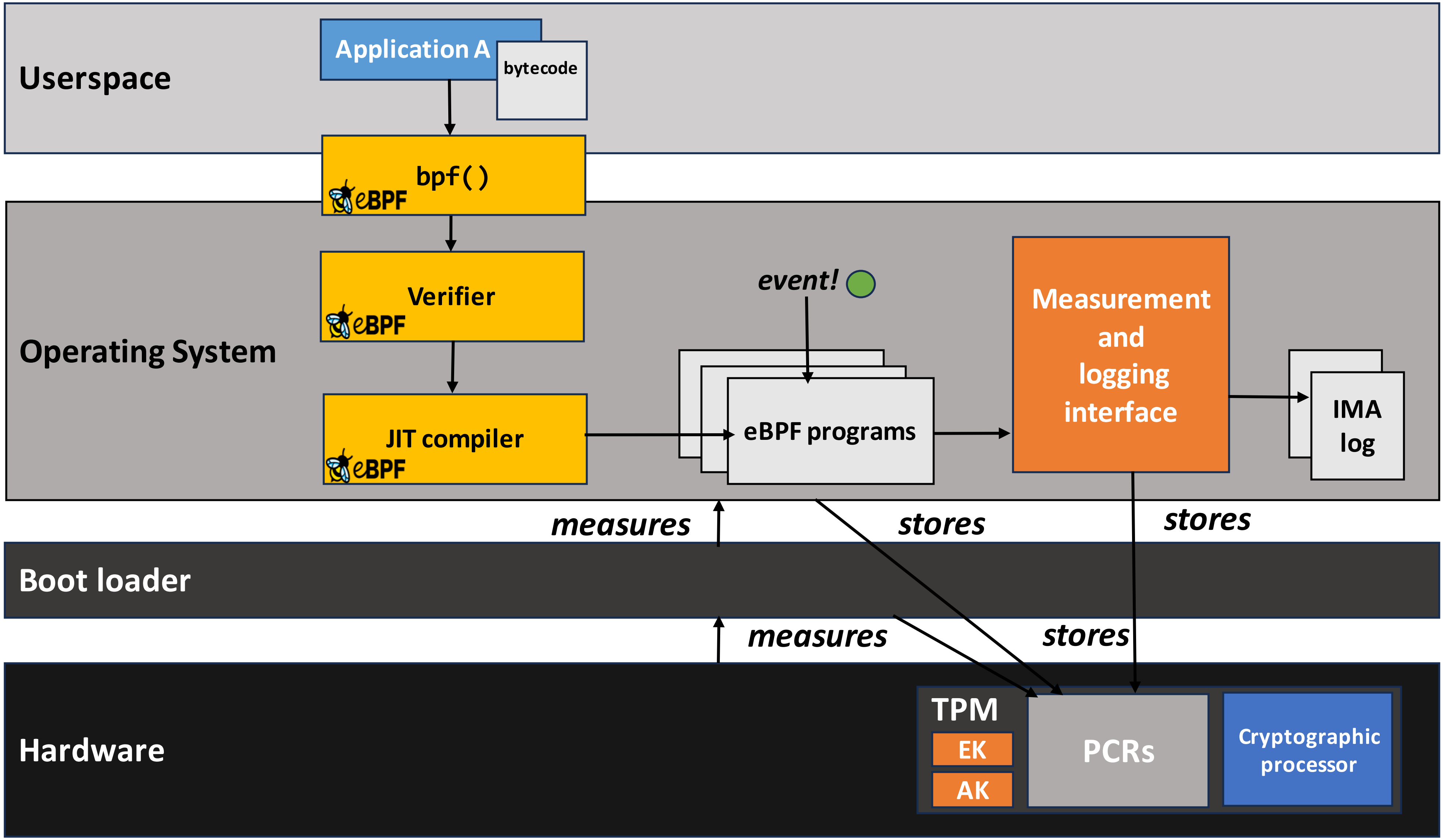
Building Trust in Environments



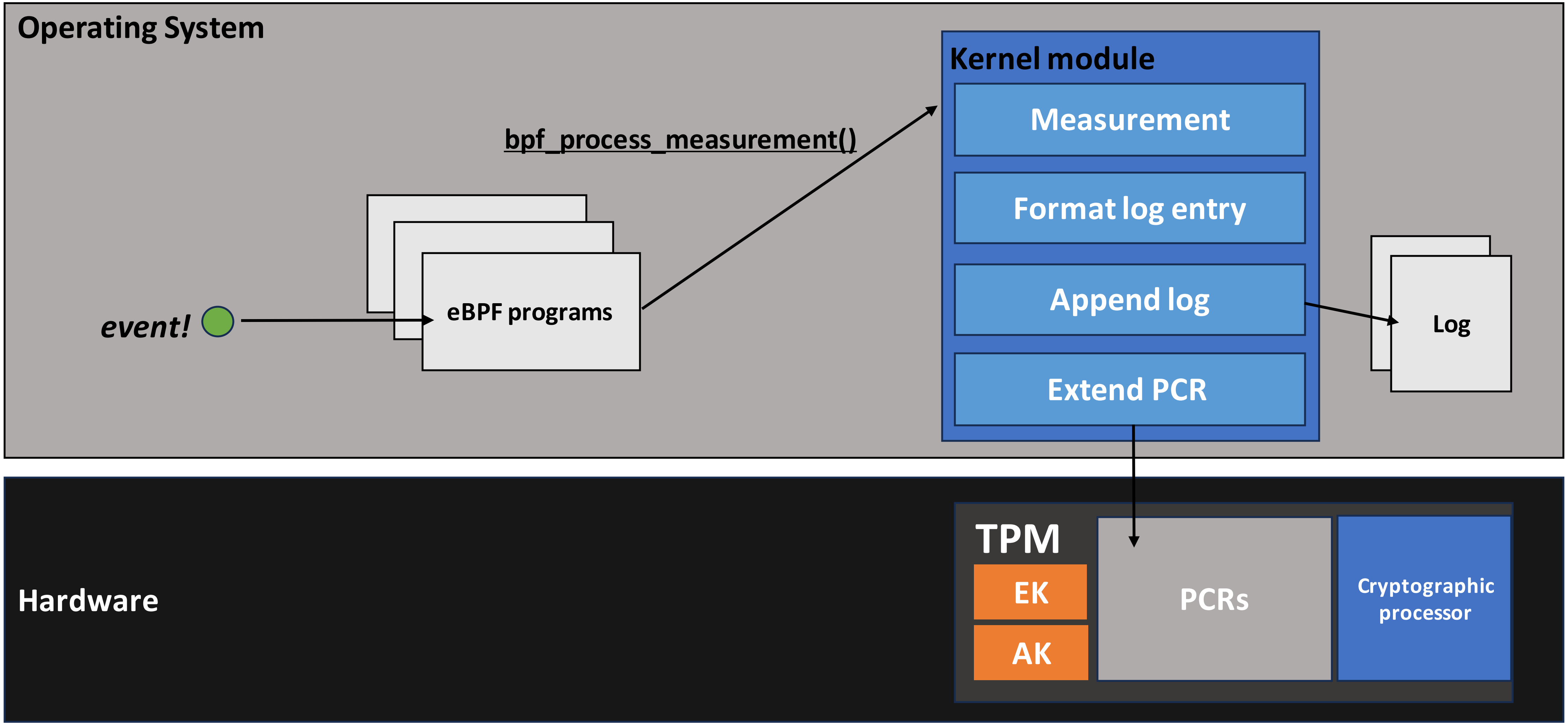
Attesting System Properties



Non-repudiable Logging in eBPF Programs



Measurement Interface



From the eBPF side

- Available to sleepable eBPF programs
- Programs can provoke the measurement and storage of formatted data and files

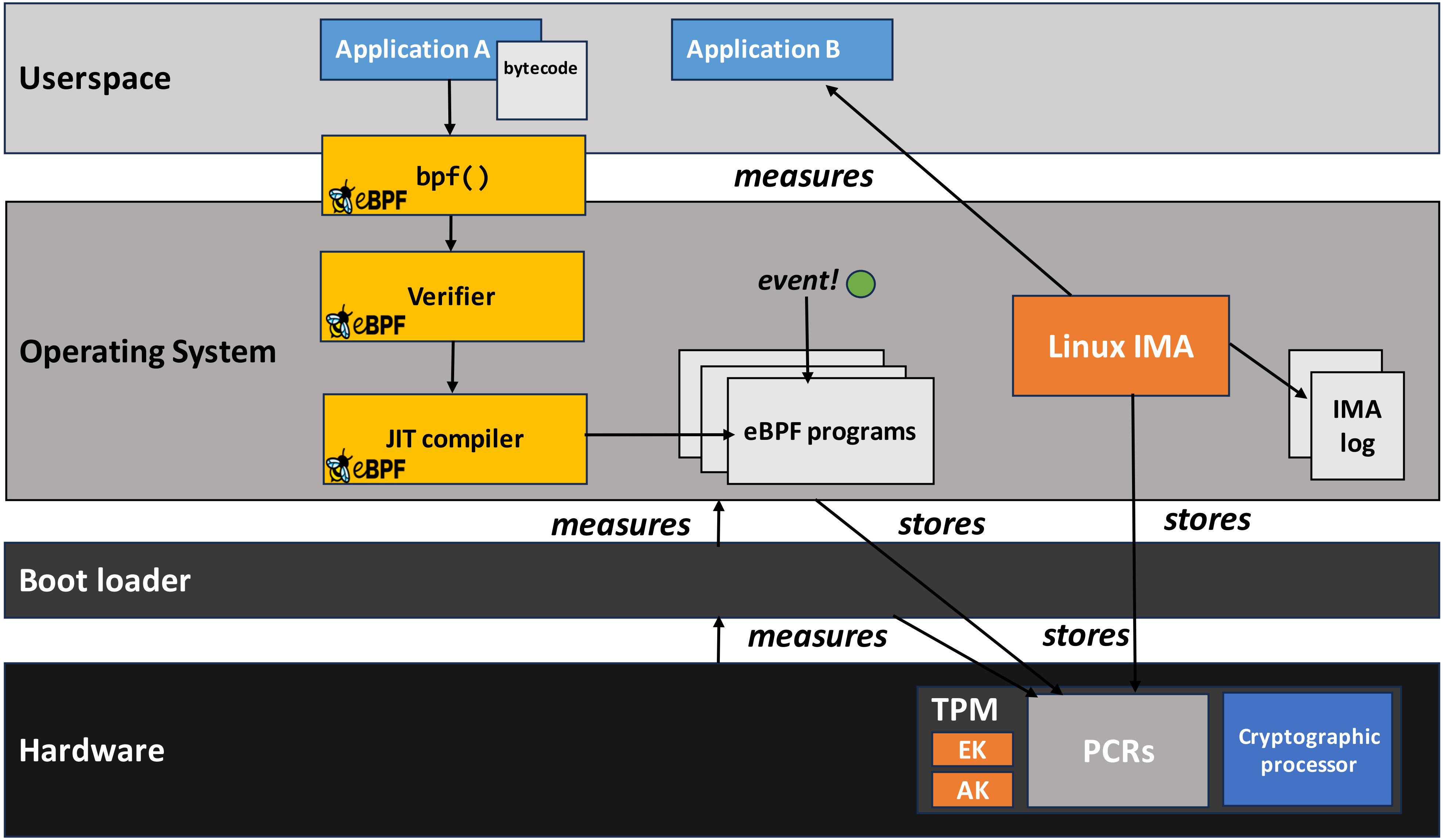
```c
#include "vmlinux.h"
#include <bpf/bpf_tracing.h>
#include <bpf/bpf_core_read.h>
#include <bpf/bpf_helpers.h>
#include <string.h>

#define bpf_target_x86
#define bpf_target_defined
#define PROT_EXEC 0x04

char _license[] SEC("license") = "GPL";

struct ebpf_data {
        struct file *file;
        unsigned int ns;
};

extern int bpf_process_measurement(void *, int) __ksym;

SEC("lsm.s/mmap_file")
int BPF_PROG(mmap_hook, struct file *file, unsigned int reqprot,
                unsigned int prot, int flags)
{
    struct task_struct *task;
    unsigned int ns;
    int ret;

    if (!file)
        return 0;

    if (prot & PROT_EXEC || reqprot & PROT_EXEC) {

        task = (void *) bpf_get_current_task();
        ns = BPF_CORE_READ(task, nsproxy, uts_ns, ns.inum);

        struct ebpf_data data = { .file = file, .ns = ns };

        ret = bpf_process_measurement((void *) &data,
                        sizeof(&data));
    }
    return 0;

}
```

From the eBPF side

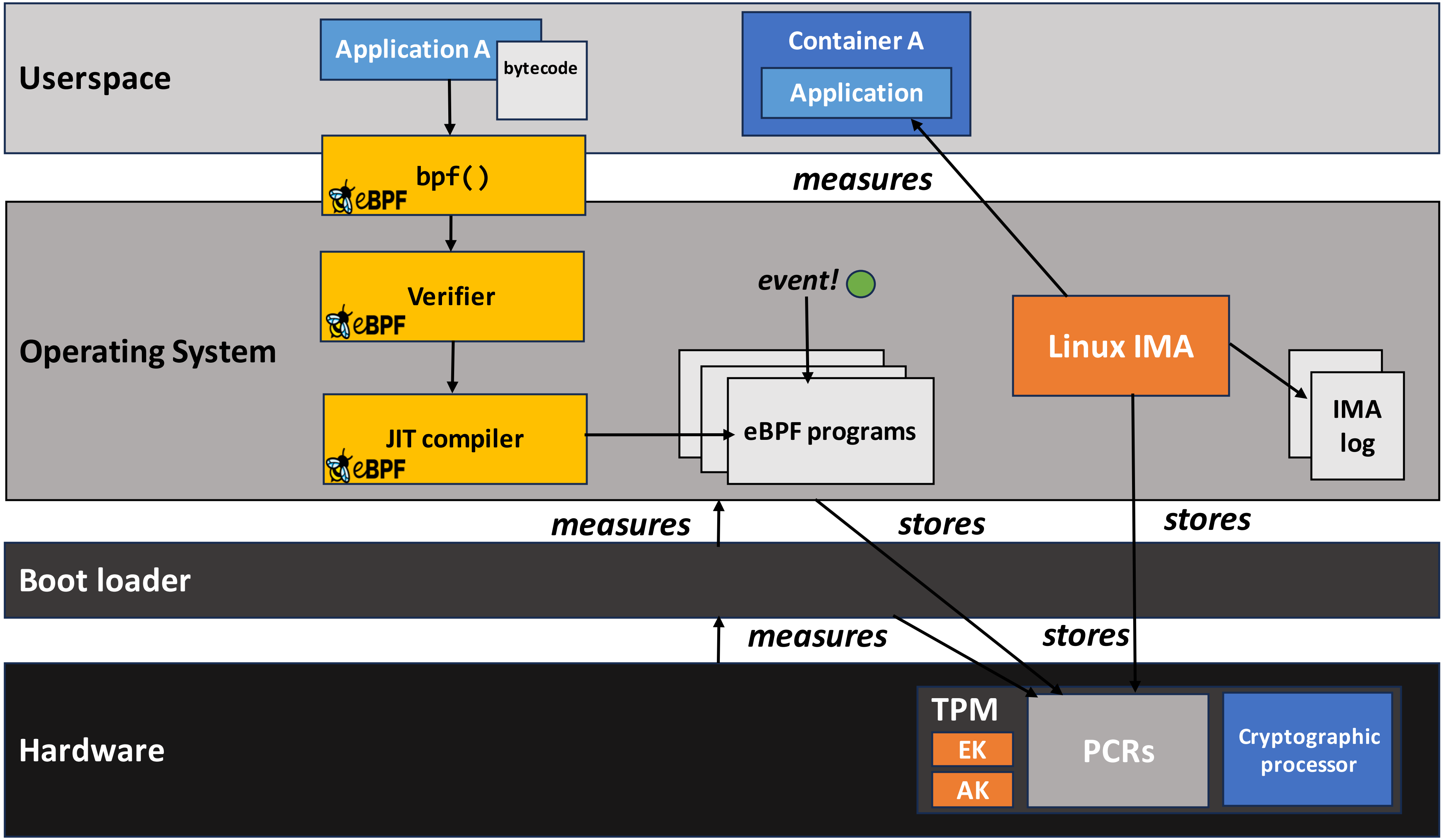
- Available to sleepable eBPF programs
- Programs can provoke the measurement and storage of formatted data and files

```c
#include "vmlinux.h"
#include <bpf/bpf_tracing.h>
#include <bpf/bpf_core_read.h>
#include <bpf/bpf_helpers.h>
#include <string.h>

#define bpf_target_x86
#define bpf_target_defined
#define PROT_EXEC 0x04

char _license[] SEC("license") = "GPL";

struct ebpf_data {
        struct file *file;
        unsigned int ns;
};

extern int bpf_process_measurement(void *, int) __ksym;

SEC("lsm.s/mmap_file")
int BPF_PROG(mmap_hook, struct file *file, unsigned int reqprot,
                unsigned int prot, int flags)
{
    struct task_struct *task;
    unsigned int ns;
    int ret;

    if (!file)
        return 0;

    if (prot & PROT_EXEC || reqprot & PROT_EXEC) {

        task = (void *) bpf_get_current_task();
        ns = BPF_CORE_READ(task, nsproxy, uts_ns, ns.inum);

        struct ebpf_data data = { .file = file, .ns = ns };

        ret = bpf_process_measurement((void *) &data,
                        sizeof(&data));
    }
    return 0;

}
```

Example Use Case



Extending Linux IMA to Containers

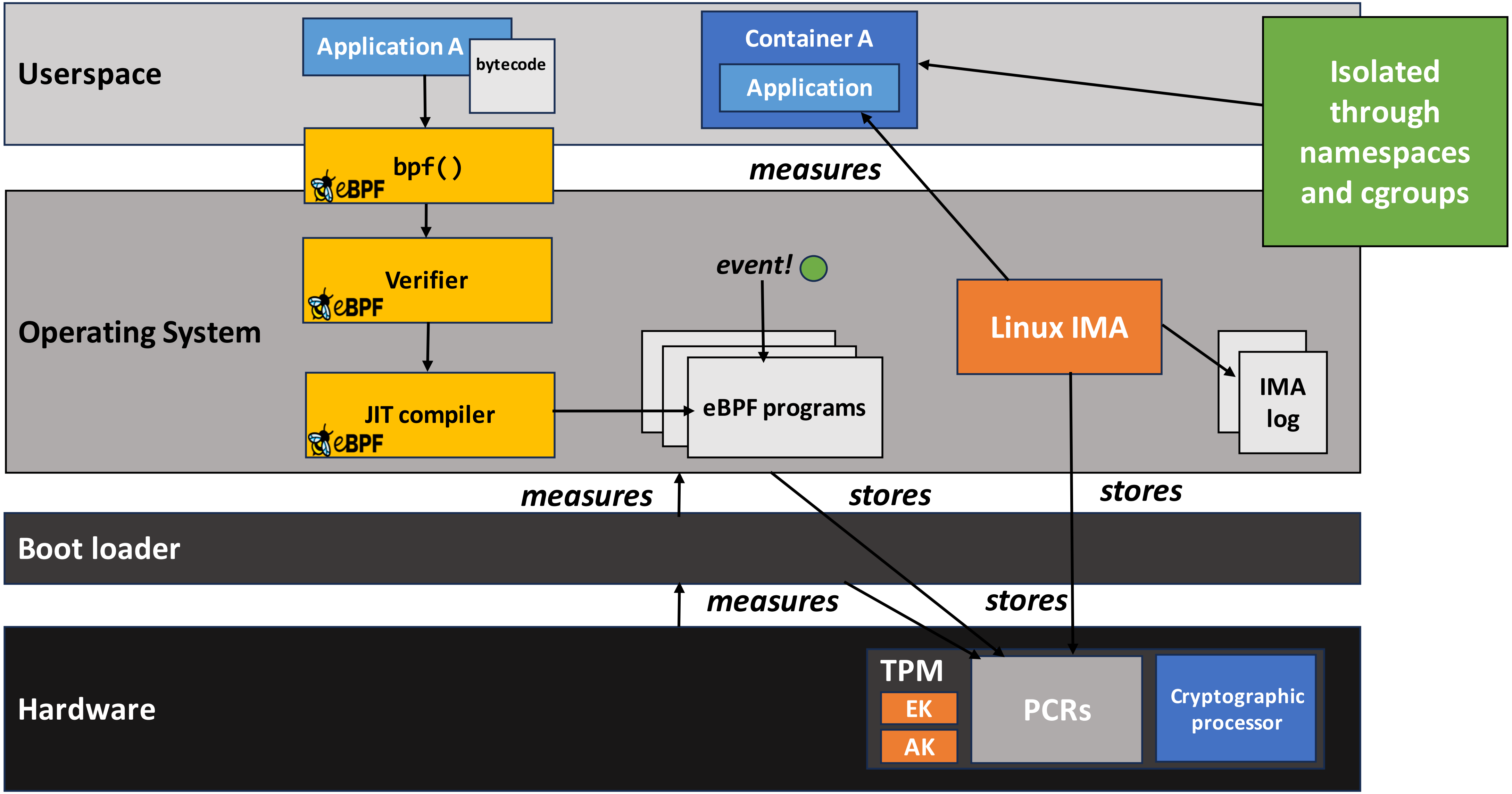


The Need for Namespace Support

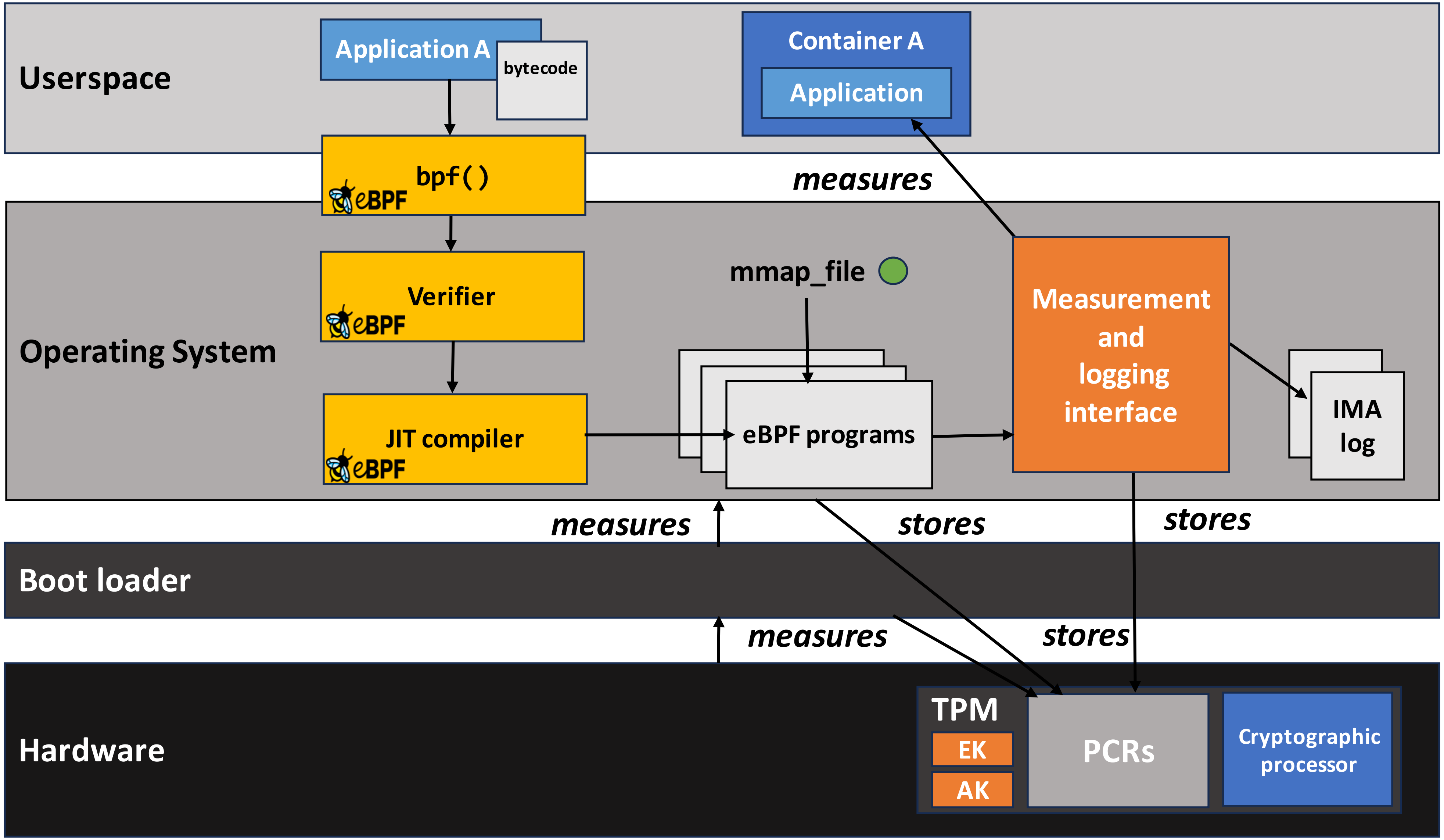
```
[[avery@fedora ~]$ sudo tail -n 20 /sys/kernel/security/integrity/ima/ascii_runtime_measurements
10 240d3f5bb871c7540d5fa91a7a9b0e616ff34b37 ima-ng sha256:06757b36daadb8228df0031496c2e9f3e16b1e2fe9cf5935756b9e4d0a315cff /usr/lib64/security/pam_motd.so
10 2d6ae2a41111b8ef8ac131d03891e1795de64b02 ima-ng sha256:7a935fb9c4735483548f79c218ee0c549a0412beba1079c9d58ab361956f8762 /usr/bin/id
10 526280709ef5c30d1d295d329573d606a5a14508 ima-ng sha256:604c924cd216b077739d5cc7668b4c917c3c784bff30c03454dd5fa4337da6af /usr/bin/hostnamectl
10 4431b8f9ded554c13422329d704d4bc335e3a656 ima-ng sha256:b91c10cb140a1593b37fba2dcab5cddf53c8e2c5104980b2ed7a1b42b7aa7d1b /usr/libexec/grepconf.sh
10 df4fc4579582f97fb2b26501acbaed387be07865 ima-ng sha256:14a956e5ca7f5c6353c1c402e540ee90681139f480730a3ae2cec90979a06426 /usr/bin/dircolors
10 884bdeca3d357b2d4a1841579acb4dca707a69be ima-ng sha256:a392c3fb23c8f6dc6ea60686e6bea7d7ba02b801feed60d48a15f708e5d45227 /usr/bin/tr
10 4eee461a1cc8acd0de77681f3b40dd61810c6d59 ima-ng sha256:2385b88763aa30afbbb883f9d4986eeae930565f0359136bb9c2db455a5936d7 /usr/bin/locale
10 6e3d31be5ce90f101a51f9c3cd4ff1028b8e2aa9 ima-ng sha256:998d3149a3da2f8b7e25dca9939527344e8cd72a3592d91a5f7565e94205ba9a /usr/bin/basename
10 4fbf9276e099a3595ed92f7f645e84490a20421f ima-ng sha256:a6bcff8384282225 8a65d7f192b5b7614ad84eadb7b8798856242218e32965e4 /usr/bin/sudo
10 f023c1f61dcaa830c9ae16ff76e9820851a3233f ima-ng sha256:52168dda87781f2ae7d141558d6f2bf0d22a9d984dd3e7d7e4d3f10dbc78505b /usr/libexec/sudo/libsudo_util.so.0.0.
10 7be972007b6c71eb9da55f3df38419f8d2866dd6 ima-ng sha256:f5133e9455f155edcec2a715f6bf4eae41937da7ef73536ea0123f4544535924 /usr/libexec/sudo/sudoers.so
10 c462d2c296c96946edc1659ded465c87d09c03c7 ima-ng sha256:96243a67c64c1de805f2a0da43232f1ba9ae44447c0fc84863aaed2d6ef0de0e /usr/lib64/security/pam_fprintd.so
10 dafe26ca42d945a6807199624fe3e12eda7c5266 ima-ng sha256:b98ecafe49699d4eb55789efd4e8f1d9208622da4972af761eb19fad93d90162 /usr/bin/docker
10 5fb55ea1517fb800aea13744cf6f8b9b366ebf0d ima-ng sha256:0efb18f93ab7c680ba28ba9bc50c3fabed9fa49d22e18a76b381039cfd01d4cf /usr/bin/containerd-shim-runc-v2
10 5c4f7bddfc3988228ca9d50629d524b4dacb1454 ima-ng sha256:d3f7d10e296e5c626ea78539cb38cd8dffd043bea3627da35ce3b20c0ac68014 /hello
10 1844bd922c570347569afc8ca2551b0c26302661 ima-ng sha256:8a56e729fd7764215090c1a02781c465ddf534a50b602f76b3cc33c19e013bbd /usr/bin/tail
10 bfc24c544fc3f85107c65e69856f43cc54ef72b4 ima-ng sha256:415a5f6f063d6b6c0183947708651e5424b3c38d68357fd23103ad7c56a2a3cf /usr/lib64/ld-linux-x86-64.so.2
10 7393b51a9384e4254a9c8df419309a41fac0d5f5 ima-ng sha256:9f2e4d479a9a7d7e27e639701da4ffbcfb8ff40512b5c676ac42801058847c28 /usr/lib64/libc.so.6
10 60776682416701d59dc629e089d78c6e5b09c9a5 ima-ng sha256:9f4a5f1f38860c5479da080378a632636d818675b3f19849a4c43fe5242beadc /usr/bin/locale
10 39e08422189f153283aafba2fa32240fb2149177 ima-ng sha256:d91502c3a044c776ae0c9b799b59df4fb1901aa84dcb4c26c4dcbe55cf5951be /usr/bin/sha256sum
[avery@fedora ~]$
```

Which of these measurements are from a container?

Extending Linux IMA to Containers



Adding Namespace Support to IMA



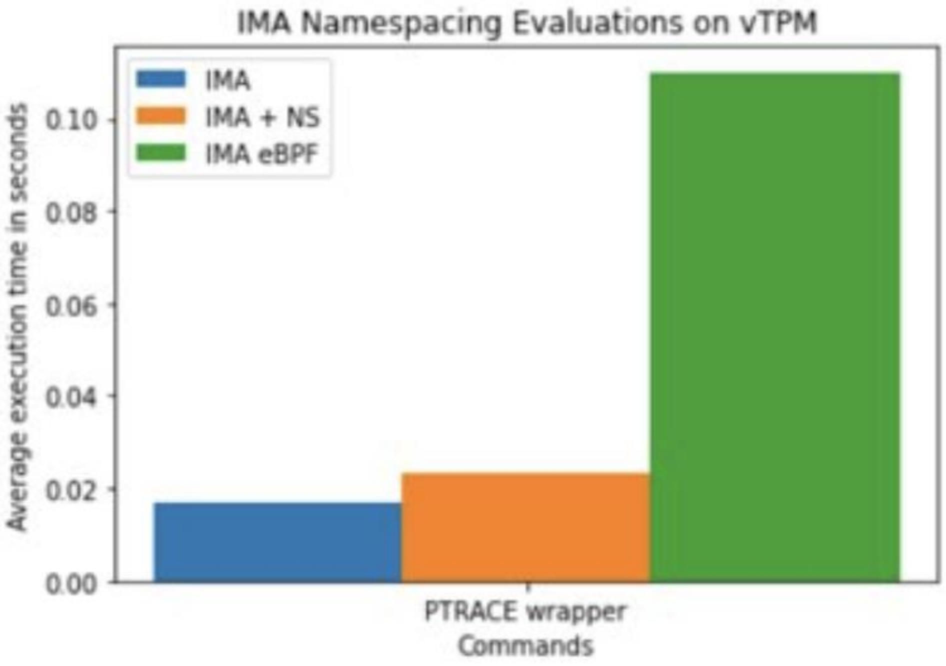
Resulting IMA Log

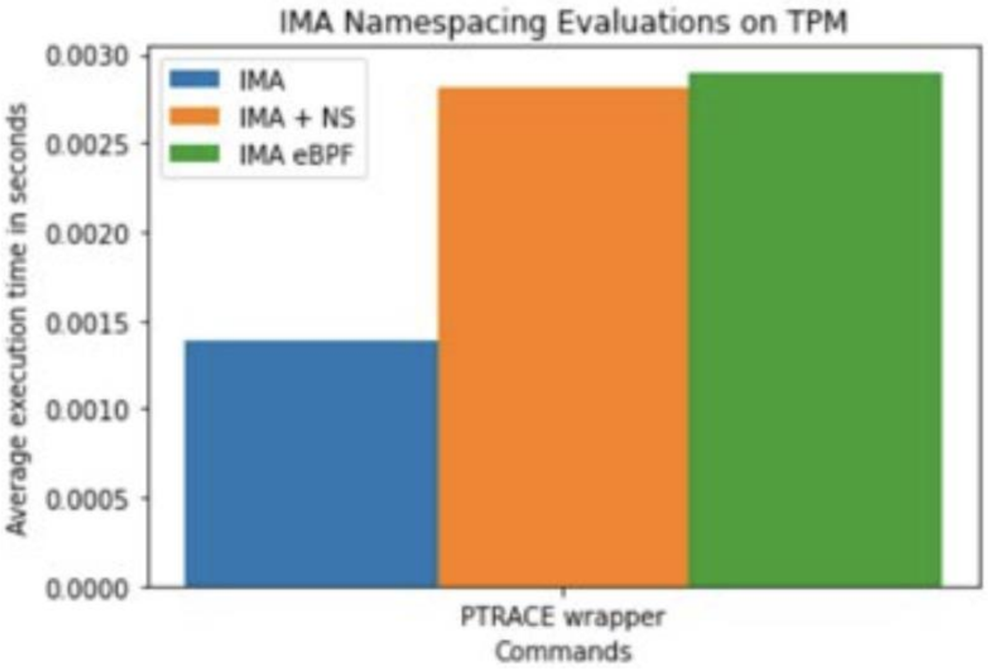
```
[avery@fedora container-ima]$ sudo tail -n 25 /sys/kernel/security/ima/ascii_runtime_measurements
11 56c23fc8baf7155d5e50797c55b0a0436eb4f1e0 ima-ng sha256:5353978a6cc92dad314d0ef0bfbdec1f84241b77aa12b06aba221893fee8c728 4026532423:/usr/lib64/libpcre2-8.so.0.11.2
11 cf5f9b53ad9292dd5759fcccc49a643442deb583 ima-ng sha256:0b50ab927bd942ef6a7434e16f8819caedcdbfc5445176a7eba6990d2cb2e233 4026532423:/usr/lib64/libcap-ng.so.0.0.0
10 5fb55ea1517fb800aea13744cf6f8b9b366ebf0d ima-ng sha256:0efb18f93ab7c680ba28ba9bc50c3fabed9fa49d22e18a76b381039cfd01d4cf /usr/bin/containerd-shim-runc-v2
10 5c4f7bddfc3988228ca9d50629d524b4dacb1454 ima-ng sha256:d3f7d10e296e5c626ea78539cb38cd8dffd043bea3627da35ce3b20c0ac68014 /hello
11 eec36e004d3dd397484f9302bfc209b5e98a91b7 ima-ng sha256:aa15dcbe503ee00f9f72924e8bea3b0c9bd42ca5205c40e70dde9d7c963e56e0 4026532981:/hello
11 f6422a7bd7c8cdab8de4130492ecc3b88918447a ima-ng sha256:0458c4bf9471e7b2083b4fc1d3f8b7632b2b2fe1f54fbaa2b43d8b37b1e53690 4026532896:/usr/bin/bash
11 bf122367ae1321e9d50a35a9578fd9c78f6af526 ima-ng sha256:21d54feee92cd42390a9fa151f8950813ecd5eaf8607b3e353aa4742a3cff08d 4026532896:/usr/lib64/ld-linux-x86-64.so.2
10 bfc24c544fc3f85107c65e69856f43cc54ef72b4 ima-ng sha256:415a5f6f063d6b6c0183947708651e5424b3c38d68357fd23103ad7c56a2a3cf /usr/lib64/ld-linux-x86-64.so.2
11 828866f89825ac2b847c97b5189a74ba38151729 ima-ng sha256:8046a139aa8590f8004da1319b64c09194596dd5a0abf59020a8568e9b6d61f1 4026532896:/usr/lib64/libtinfo.so.6.4
11 c79143cc2fc5bf4780b9a35a02acaad81e9a28f7 ima-ng sha256:be13ff2194f060dff73c96f317d16e3a2c380ba3beedc1b485af866b3b7e4729 4026532896:/usr/lib64/libc.so.6
10 7393b51a9384e4254a9c8df419309a41fac0d5f5 ima-ng sha256:9f2e4d479a9a7d7e27e639701da4ffbcfb8ff40512b5c676ac42801058847c28 /usr/lib64/libc.so.6
11 3f81e07160ed9c5a0306d04070f222e73e25f405 ima-ng sha256:e5fef662f3f426b94c10d288a7ce06caa14bea7b2452976232b8d20b99d3c61e 4026532896:/usr/bin/grep
11 35d240dbf1f63cef20c3a374c2f02055da7477e0 ima-ng sha256:5353978a6cc92dad314d0ef0bfbdec1f84241b77aa12b06aba221893fee8c728 4026532896:/usr/lib64/libpcre2-8.so.0.11.2
11 509eed1e60450cacb7a50135b0b5bad68bfdbea4 ima-ng sha256:696e58e522641b5e1392f8927f1ec6da7dc2227ff224f9341bf795108603f9d2 4026532896:/usr/bin/dircolors
10 60776682416701d59dc629e089d78c6e5b09c9a5 ima-ng sha256:9f4a5f1f38860c5479da080378a632636d818675b3f19849a4c43fe5242beadc /usr/bin/locale
11 a8644b70da2f5c21375daf0282b54ba14a664475 ima-ng sha256:e9d92cd921a0aff13e408f1a2584d1d1bf6d6e385e4587ed315750de2e3a4afd 4026532896:/usr/bin/locale
11 244db78d5a27491ff64dd2e4151504d87f5dab8e ima-ng sha256:f67b8429b6c88aed90d42f0ae5c10cbd0db870999f07f9ab64b81920557cf243 4026532896:/usr/bin/sed
11 9b1628bd57965c0e533792d7387d7aed7f325c7b ima-ng sha256:2bc581d5f250e8cc107293dc20146c5ca4c284542fe2a710ddd7a86d18922689 4026532896:/usr/lib64/libacl.so.1.1.2301
11 4f95cb7d1f8eeea324de0daf4f991ae7f4d8d5e9 ima-ng sha256:f60ce3ddcc706168ed8af61c585782e841e242d3053132bfd60e01f9980b776a 4026532896:/usr/lib64/libselinux.so.1
11 930798123fa89441440093cd8f9f1226a07a6e63 ima-ng sha256:29bd22f15758028d3a11ed853b9fb93156cc19915fdb844b73e3075d3ce6510b 4026532896:/usr/lib64/libattr.so.1.1.2501
10 39e08422189f153283aafba2fa32240fb2149177 ima-ng sha256:d91502c3a044c776ae0c9b799b59df4fb1901aa84dcb4c26c4dcbe55cf5951be /usr/bin/sha256sum
11 07d6e54b15a424d098754beb53826dc4302e47cb ima-ng sha256:45c8aa2c7fbac7881cc7edd30d12e4584ce83ad4733d03d80eaf1a53a3b555e5 4026532896:/usr/bin/sha256sum
11 e55e3e1e1b707e9b0a7833dae9ef518f9cdf5d86 ima-ng sha256:a034c7cb9eaa990a1e71ff0b72b689b5a311de8117a1bdf8191cce5f6157fce7 4026532896:/usr/lib64/libcrypto.so.3.0.9
11 c4c94f9689565e866c0fd79e53da7ca46f3deb7b ima-ng sha256:d6c93839cc0e7c29fab74d08bfda639ce776c594ac77a4704160bd5069b9a7e8 4026532896:/usr/lib64/libz.so.1.2.13
10 1844bd922c570347569afc8ca2551b0c26302661 ima-ng sha256:8a56e729fd7764215090c1a02781c465ddf534a50b602f76b3cc33c19e013bbd /usr/bin/tail
[avery@fedora container-ima]$
```

Resulting IMA Log

```
[avery@fedora container-ima]$ sudo tail -n 25 /sys/kernel/security/ima/ascii_runtime_measurements
11 56c23fc8baf7155d5e50797c55b0a0436eb4f1e0 ima-ng sha256:5353978a6cc92dad314d0ef0bfbdec1f84241b77aa12b06aba221893fee8c728 4026532423:/usr/lib64/libpcre2-8.so.0.11.2
11 cf5f9b53ad9292dd5759fcccc49a643442deb583 ima-ng sha256:0b50ab927bd942ef6a7434e16f8819caedcdbfc5445176a7eba6990d2cb2e233 4026532423:/usr/lib64/libcap-ng.so.0.0.0
[illegible]
10 5c4f7bddfc3988228ca9d50629d524b4dacb1454 ima-ng sha256:d3f7d10e296e5c626ea78539cb38cd8dffd043bea3627da35ce3b20c0ac68014 /hello
11 eec36e004d3dd397484f9302bfc209b5e98a91b7 ima-ng sha256:aa15dcbe503ee00f9f72924e8bea3b0c9bd42ca5205c40e70dde9d7c963e56e0 4026532981:/hello
11 f6422a7bd7c8cdab8de4130492ecc3b88918447a ima-ng sha256:0458c4bf9471e7b2083b4fc1d3f8b7632b2b2fe1f54fbaa2b43d8b37b1e53690 4026532896:/usr/bin/bash
11 bf122367ae1321e9d50a35a9578fd9c78f6af526 ima-ng sha256:21d54feee92cd42390a9fa151f8950813ecd5eaf8607b3e353aa4742a3cff08d 4026532896:/usr/lib64/ld-linux-x86-64.so.2
10 bfc24c544fc3f85107c65e69856f43cc54ef72b4 ima-ng sha256:415a5f6f063d6b6c0183947708651e5424b3c38d68357fd23103ad7c56a2a3cf /usr/lib64/ld-linux-x86-64.so.2
11 828866f89825ac2b847c97b5189a74ba38151729 ima-ng sha256:8046a139aa8590f8004da1319b64c09194596dd5a0abf59020a8568e9b6d61f1 4026532896:/usr/lib64/libtinfo.so.6.4
11 c79143cc2fc5bf4780b9a35a02acaad81e9a28f7 ima-ng sha256:be13ff2194f060dff73c96f317d16e3a2c380ba3beedc1b485af866b3b7e4729 4026532896:/usr/lib64/libc.so.6
10 7393b51a9384e4254a9c8df419309a41fac0d5f5 ima-ng sha256:9f2e4d479a9a7d7e27e639701da4ffbcfb8ff40512b5c676ac42801058847c28 /usr/lib64/libc.so.6
11 3f81e07160ed9c5a0306d04070f222e73e25f405 ima-ng sha256:e5fef662f3f426b94c10d288a7ce06caa14bea7b2452976232b8d20b99d3c61e 4026532896:/usr/bin/grep
11 35d240dbf1f63cef20c3a374c2f02055da7477e0 ima-ng sha256:5353978a6cc92dad314d0ef0bfbdec1f84241b77aa12b06aba221893fee8c728 4026532896:/usr/lib64/libpcre2-8.so.0.11.2
11 509eed1e60450cacb7a50135b0b5bad68bfdbea4 ima-ng sha256:696e58e522641b5e1392f8927f1ec6da7dc2227ff224f9341bf795108603f9d2 4026532896:/usr/bin/dircolors
10 60776682416701d59dc629e089d78c6e5b09c9a5 ima-ng sha256:9f4a5f1f38860c5479da080378a632636d818675b3f19849a4c43fe5242beadc /usr/bin/locale
11 a8644b70da2f5c21375daf0282b54ba14a664475 ima-ng sha256:e9d92cd921a0aff13e408f1a2584d1d1bf6d6e385e4587ed315750de2e3a4afd 4026532896:/usr/bin/locale
11 244db78d5a27491ff64dd2e4151504d87f5dab8e ima-ng sha256:f67b8429b6c88aed90d42f0ae5c10cbd0db870999f07f9ab64b81920557cf243 4026532896:/usr/bin/sed
11 9b1628bd57965c0e533792d7387d7aed7f325c7b ima-ng sha256:2bc581d5f250e8cc107293dc20146c5ca4c284542fe2a710ddd7a86d18922689 4026532896:/usr/lib64/libacl.so.1.1.2301
11 4f95cb7d1f8eeea324de0daf4f991ae7f4d8d5e9 ima-ng sha256:f60ce3ddcc706168ed8af61c585782e841e242d3053132bfd60e01f9980b776a 4026532896:/usr/lib64/libselinux.so.1
11 930798123fa8941440093cd8f9f1226a07a6e63 ima-ng sha256:29bd22f15758028d3a11ed853b9fb93156cc19915fdb844b73e3075d3ce6510b 4026532896:/usr/lib64/libattr.so.1.1.2501
10 39e08422189f153283aafba2fa32240fb2149177 ima-ng sha256:d91502c3a044c776ae0c9b799b59df4fb1901aa84dcb4c26c4dcbe55cf5951be /usr/bin/sha256sum
11 07d6e54b15a424d098754beb53826dc4302e47cb ima-ng sha256:45c8aa2c7fbac7881cc7edd30d12e4584ce83ad4733d03d80eaf1a53a3b555e5 4026532896:/usr/bin/sha256sum
11 e55e3e1e1b707e9b0a7833dae9ef518f9cdf5d86 ima-ng sha256:a034c7cb9eaa990a1e71ff0b72b689b5a311de8117a1bdf8191cce5f6157fce7 4026532896:/usr/lib64/libcrypto.so.3.0.9
11 c4c94f9689565e866c0fd79e53da7ca46f3deb7b ima-ng sha256:d6c93839cc0e7c29fab74d08bfda639ce776c594ac77a4704160bd5069b9a7e8 4026532896:/usr/lib64/libz.so.1.2.13
10 1844bd922c570347569afc8ca2551b0c26302661 ima-ng sha256:8a56e729fd7764215090c1a02781c465ddf534a50b602f76b3cc33c19e013bbd /usr/bin/tail
[avery@fedora container-ima]$
```

Evalution





The PTRACE wrapper executed a file, stopping after the first instruction to isolate the measurement and TPM extension.

Enabling non-repudiable logging of workload/platform specific system properties using eBPF.

avery.blanchard@duke.edu

https://github.com/avery-blanchard/container-ima

Duke UNIVERSITY

IBM