Securing Yocto Built Systems

ELCE 2025

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Root Commit

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Michael Opdenacker

root commit

Embedded Linux expert and trainer

- https://rootcommit.com/about/michael-opdenacker/
- Former founder of Bootlin
- New founder of Root Commit
- Contributor to the Yocto Project and other Free Software projects
- Never missed a single ELC Europe since 2007!
- Free Software enthusiast and advocate (member of April.org)

April
promouvoir et défendre le logiciel libre

What I Do For a Living — What's Funding This Work

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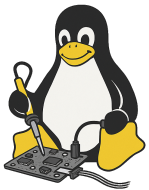
Consulting and engineering work

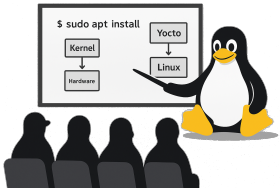
- Yocto Project
  Project reviews, system implementation, new features
- Linux Kernel
  Driver development, board bring-up, debugging
- Embedded Linux
  Boot time, bug fixing, security and other optimizations



Training — https://rootcommit.com/training

- Yocto Project and OpenEmbedded — Free Materials!
- Linux kernel, board support, driver development
  Free Materials after next course!
- Embedded Linux
- Linux Boot Time Reduction

What's special: focus on practical activities, interactivity and learning techniques.



Introduction

Goals of This Presentation?

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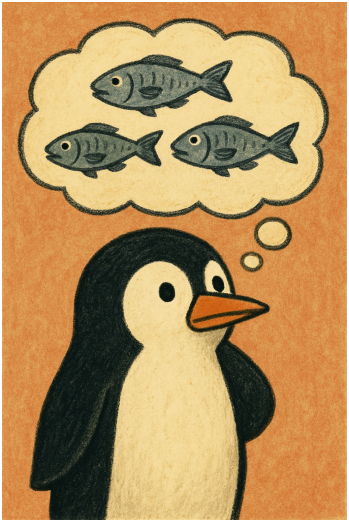
- Yocto's Manual "Making Images More Secure" is too short and highlevel: https://docs.yoctoproject.org/dev-manual/securing-images.html Find opportunities to improve it.
- One of my customer projects has a "Security Audit" task
- Want to share what I'm learning!
- Trying to focus on Yocto specific techniques



Not Covered in This Presentation

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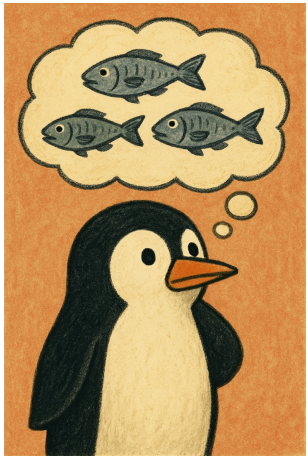
Linux security is a very wide topic.
Some aspects require dedicated presentations and can be SoC specific

- Firewalls
- Block device / filesystem encryption
- Extended file attributes
- Linux Security Modules (SELinux, AppArmor, SMACK, Tomoyo)

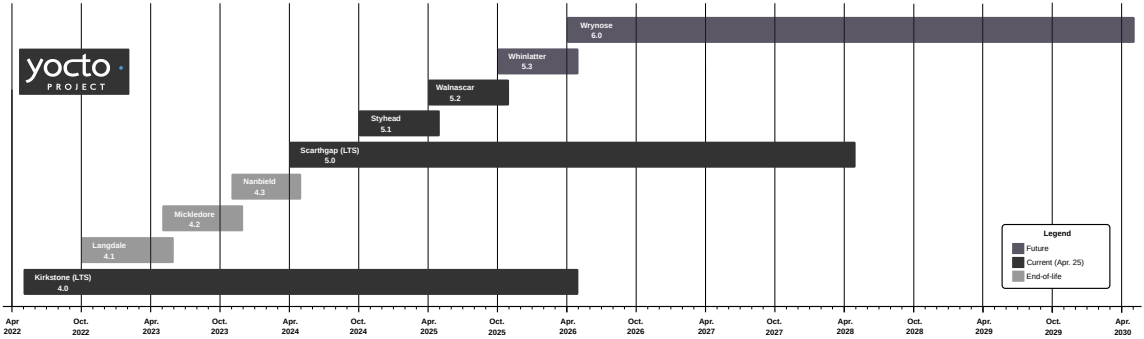
- Software updates
- Secure boot
- Verified boot
- Using TPM devices
- Integrity measurement



Getting Started

Use a Long Term Support Yocto Release

- Critical to get bug fixes and security updates from the project and community
- Also guarantees the availability of third party layers
- Exception: in development phase when the next LTS release is close, could use the latest stable release in the meantime.



Choose your kernel carefully

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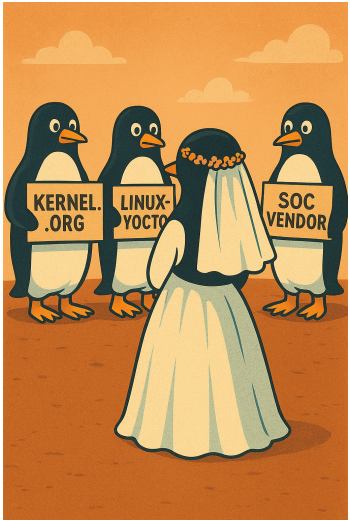
- An **LTS kernel** from kernel.org is the best solution to get kernel updates quickly
- **linux-yocto** is pretty well supported, you can wait a few weeks for updates.
- **Vendor kernels** support your hardware well, but they are not meant to include vulnerability fixes in a timely fashion. They can also be pretty outdated.



Create Your Own Distribution

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Build your own distribution, don't start from Poky

- Poky is made for testing purposes, it has way too many unnecessary features
- Unnecessary features increase the attack surface
- No problem to start from scratch!

conf/distro/distro-prod.conf

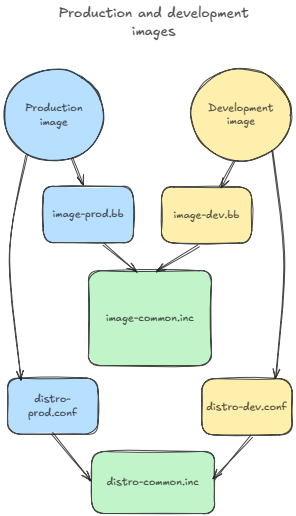
```
DISTRO = "distro-prod"
DISTRO_NAME = "Production Distro"
DISTRO_VERSION = "1.0"

INIT_MANAGER = "systemd"
```

Production and Development Images

Good practise early enough during development

- Maintain a development image alongside the production image
- Development settings isolated from the start from the production one
- Less risk of forgetting debug features in the production image

Note: diagram created with https://excalidraw.io ❤️



A look at the meta-security layer

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Maintained by Scott Murray and Marta Rybczynska (thanks!)

- meta-integrity: support for Linux Integrity Measurement Architecture (IMA)
- meta-parsec: support for PARSEC, common API to hardware security and cryptographic services
- meta-tpm: TPM device support
- recipes-compliance: support for openSCAP (security audits)
- recipes-core: mostly images and package groups
- recipes-ids: support for Intrusion Detection Systems (Samhain, Suricata)
- recipes-mac: support for AppArmor and SMACK
- recipes-scanners: support for multiple scanners (but some are broken)
- recipes-security: support for multiple utilities

Note: the security DISTRO_FEATURE has a very limited scope: it just adds a few configuration fragments to the kernel (SMACK, AppArmor, dm-verity, eCryptfs, LKRG)

My conclusion: mostly useful for the features it supports. Other packages won't be compiled with tighter security features.

System Hardening

System Hardening

Reduce the Attack Surface

Disable Debugging Image Features (1)

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- Walnascar (6.2) removed the `debug-tweaks` image feature.
  There was too much risk to forget it in a configuration file.
- It was corresponding to these image features:
  - `allow-empty-password`
  - `allow-root-login`
  - `empty-root-password`
  - `post-install-logging`

Disable Debugging Image Features (2)

Enable these debugging image features **only** in the development image:

- `allow-empty-password`
- `empty-root-password`
- `tools-debug`: installs debugging tools such as `strace` and `gdb`
- `perf`: installs profiling tools such as `perf`, `systemtap`, and `lttng`
- `tools-sdk`: installs a full SDK that runs on the device.

Review all `IMAGE_FEATURES` on https://docs.yoctoproject.org/ref-manual/features.html#ref-features-image

recipes-core/images/image-dev.bb

```
IMAGE_FEATURES += "allow-empty-password \
                   allow-root-login \
                   empty-root-password \
                   tools-debug \
                   tools-sdk \
                   post-install-logging"
```

Disable Distro Features

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In the production image, it's also good to remove unnecessary DISTRO_FEATURES

```
$ bitbake-getvar DISTRO_FEATURES
DISTRO_FEATURES="acl alsa bluetooth debuginfod ext2 ipv4 ipv6 pcmcia usbgadget usbhost wifi
xattr nfs zeroconf pci 3g nfc x11 vfat seccomp systemd usrmerge pulseaudio gobject-
introspection-data ldconfig"
```

Remove the unnecessary ones:

conf/distro/distro-prod.conf

```
DISTRO_FEATURES:remove = "alsa bluetooth debuginfod pcmcia usbgadget usbhost \
wifi xattr nfs zeroconf pci 3g nfc x11 vfat pulseaudio
```

Result:

```
$ bitbake-getvar DISTRO_FEATURES
DISTRO_FEATURES="acl ext2 ipv4 ipv6 seccomp systemd usrmerge gobject-introspection-
data ldconfig"
```

Remove Unnecessary Packages (1)

root commit

To figure out installed packages

- `bitbake-getvar` doesn't help here, because images are defined by **packagegroups**:

```
$ bitbake-getvar -r core-image-minimal IMAGE_INSTALL
IMAGE_INSTALL="packagegroup-core-boot  u-boot"
```

- The best way is to look at the contents of the image manifest in `tmp/deploy/images/<machine>/<image>-<machine>.rootfs.manifest`

```
base-files genericarm64 3.0.14
base-passwd armv8a 3.6.4
busybox armv8a 1.36.1
busybox-hwclock armv8a 1.36.1
busybox-syslog armv8a 1.36.1
busybox-udhcpc armv8a 1.36.1
eudev armv8a 3.2.14
grub-bootconf genericarm64 1.00
grub-common armv8a 2.12
grub-editenv armv8a 2.12
grub-efi armv8a 2.12
lnlt-ifupdown genericarm64 1.0
init-system-helpers-service armv8a 1.66
initscripts armv8a 1.0
initscripts-functions armv8a 1.0
kbd armv8a 2.6.4
kernel genericarm64 6.13.11
kernel-6.13.11 genericarm64 6.13.11
kernel-image-6.13.11 genericarm64 6.13.11
kernel-image-image-6.13.11 genericarm64 6.13.11
keymaps genericarm64 1.0
kmod armv8a 33
ldconfig armv8a 2.40+git0+626c048f32
libblkid1 armv8a 2.40.2
libc6 armv8a 2.40+git0+626c048f32
libcrypto3 armv8a 3.3.1
libkmod2 armv8a 33
liblzma5 armv8a 5.6.2
libz1 armv8a 1.3.1
modutils-initscripts armv8a 1.0
netbase noarch 6.4
openssl-conf armv8a 3.3.1
openssl-ossl-module-legacy armv8a 3.3.1
packagegroup-core-boot genericarm64 1.0
sysvinit armv8a 3.04
sysvinit-inittab genericarm64 2.88dsf
sysvinit-pidof armv8a 3.04
ttyrun armv8a 2.34.0
u-boot genericarm64 2024.07
u-boot-env genericarm64 2024.07
update-alternatives-opkg armv8a 0.7.0
update-rc.d noarch 0.8+git0+b8f9501050
```

Manifest for `core-image-minimal` + `u-boot` on release Styhead

Remove Unnecessary Packages (2)

root commit

To remove the unwanted packages from the production image:

- For the same reasons, `IMAGE_INSTALL:remove` doesn't always work.
- Instead, use `PACKAGE_EXCLUDE`:

conf/distro/distro-prod.conf

```
# Packages to skip installing
PACKAGE_EXCLUDE += "busybox-udhcpc kbd-keymaps-pine"
```

System Hardening

Harden Password Security

Use Stronger Passwords 😉

https://www.linkedin.com/posts/clayr_genius-takes-many-forms-activity-7211897352754798592-Ir0T/

Device Specific Credentials

Yocto lets you create specific users, groups and passwords using the `extrausers` class.

- However, these apply to all devices
- Shared credentials, if compromized on a device, compromise the security of the whole fleet
- One solution: set credentials at first boot
- Another solution: expire credentials to force users to modify them at the next (actually first) login.
- Drawback: as long as you haven't logged in, the original password remains.

```
$ man passwd
...
   -e, --expire
        Immediately expire an account's password.
        This in effect can force a user to change
        their password at the user's next login.
...
```

```
# passwd -e root
```

```
qemux86-64 login: root
Password:
Your password has expired.  Choose a new password.
Changing password for root
Enter the new password (minimum of 5 characters)
Please use a combination of upper and lower case letters and numbers.
New password:
Re-enter new password:
passwd: password changed.
```

Setting Root Password At First Boot (1)

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If you have `systemd`, you can use `systemd-firstboot` to set the root password, without having to create a shared initial password.

Compile `systemd` with `firstboot` support, typically in your `distro.conf` file:

conf/distro/secure-distro.conf

```
PACKAGECONFIG:append:pn-systemd = " firstboot"
```

Setting Root Password At First Boot (2)

root commit

Create a `firstboot.conf` file to customize the `getty` (login prompt) service

recipes-core/systemd/files/firstboot.conf

```
[Unit]
Description=First Boot Root Password Setup

[Service]
ExecStartPre=/bin/sh -c '[ -f /etc/firstboot.done ] || /usr/bin/sed -i "/^root:/d" /etc/shadow'
ExecStartPre=/bin/sh -c '[ -f /etc/firstboot.done ] || /usr/bin/systemd-firstboot --prompt-root-password'
ExecStartPre=/bin/sh -c '[ -f /etc/firstboot.done ] || /bin/touch /etc/firstboot.done'
TTYReset=yes
TTYVHangup=yes
```

The `-f /etc/firstboot.done` test is repeated, because if you set it as a precondition, the unit fails and `getty` is not even started.

Setting Root Password At First Boot (3)

root commit

Create a recipe to deploy this file

recipes-core/systemd/systemd-firstboot-getty.bb

```
DESCRIPTION = "Systemd service add-on to prompt for a root password at first boot"
LICENSE = "MIT"
LIC_FILES_CHKSUM = "file://${COMMON_LICENSE_DIR}/CC-BY-4.0;md5=9b33bbd06fb58995fb0e299cd38d1838"

SRC_URI += "file://firstboot.conf"

S = "${UNPACKDIR}"

do_install() {
    install -d ${D}${systemd_system_unitdir}/serial-getty@.service.d
    install -m 0644 ${S}/firstboot.conf ${D}${systemd_system_unitdir}/serial-getty@.service.d
}

FILES:${PN} += "${systemd_system_unitdir}/serial-getty@.service.d/firstboot.conf"
```

System Hardening

User-space Hardening

Use Compiler Hardening Features

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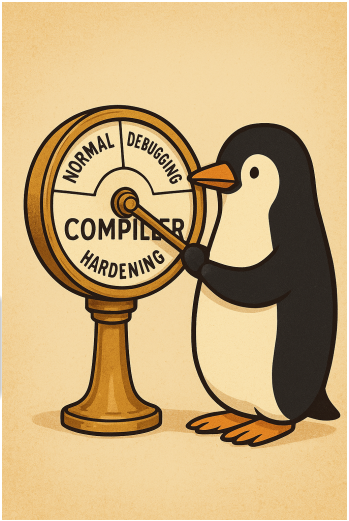
OpenEmbedded Core ships with compiler hardening features:

- meta/conf/distro/include/security_flags.inc
- meta/conf/distro/include/rust_security_flags.inc

conf/distro/distro-prod.conf

```
require conf/distro/include/security_flags.inc
require conf/distro/include/rust_security_flags.inc
```



Need for Production Test Image

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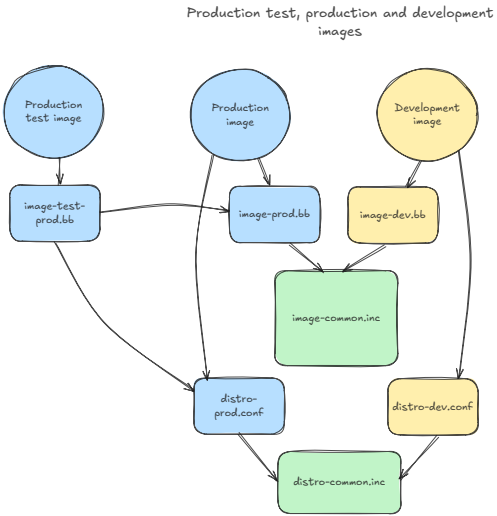
At this stage, need some tools to test the production image

- Don't want to put them in the development image, will get false positives with development tools and features.
- Don't want to leave them in the production image, could be used to reveal weak spots. They may also pull unwanted dependencies.
- Solution: create a third "Production test" image.



Looking for User-space Hardening Checkers

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Looked at tools in `meta-security`

- `buck-security`: security scanner for Debian and Ubuntu Linux.
  Builds but currently broken, and the project has been idle for 10 years.
  Not interested in reviving a Perl based project 😉.
- `checksec`: scan your system for several simple security holes.
  Also broken, the commands given as examples don't work.
  Maintained by Debian but not actively maintained anyway.
- `nikto`: web server scanner
  Still maintained, but broken too (also in Perl)

Does anybody know a good (and modern!) security scanner we could use for userspace hardening?

Answers from the audience:

- Lynis (https://cisofy.com/lynis/)
- OpenSCAP (https://www.open-scap.org/)

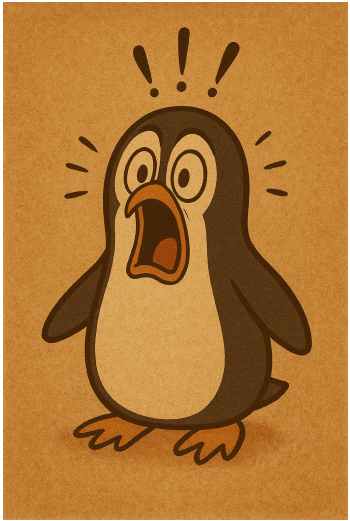
Both are supported by `meta-security`)

System Hardening

Run Public Services With Limited Resources

The `lighttpd` case

- Surprised to see that `lighttpd` in OE-core is run as `root`
- If the web server is compromised, the whole system is!
- Important to run public services with restricted privileges and resources.



Easy To Fix With Systemd!

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Let's modify `lighttpd.service` provided by the `lighttpd` sources:

- Make the service run with user `lighttpd` and group `daemon`:

```
User=lighttpd
Group=daemon
```

- We can also restrict privileges to the bare minimum:

```
# If not starting lighttpd as root,
# minimal capability to bind to ports < 1024:
CapabilityBoundingSet=CAP_NET_BIND_SERVICE
```

- Another issue: `lighttpd` won't be able to write its log to `/var/log` (owned by root by default). As `/var/log` is volatile (`tmpfs`), a solution is to change its permissions before starting the service:

```
# "+" means running the command as root
ExecStartPre=+/bin/chgrp daemon /var/log
ExecStartPre=+/bin/chmod 775 /var/log
```

- Then the server runs as intended:

```
root@qemux86-64:~# ps | grep light
  249 lighttpd  9312 S    /usr/sbin/lighttpd -D -f ...
  258 root      4056 S    grep light
```

Practical Implementation

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Changes to my custom layer:

```
recipes-extended/lighttpd
|-- files
|   `-- lighttpd.service
`-- lighttpd_%.bbappend

2 directories, 2 files
```

recipes-extended/lighttpd/lighttpd_%.bbappend

```
FILESEXTRAPATHS:prepend := "${THISDIR}/files:"

# Create lighttpd user, group daemon
inherit useradd
USERADD_PACKAGES = "${PN}"
USERADD_PARAM:${PN} = "--system --no-create-home --gid daemon \
                       --shell /usr/sbin/nologin lighttpd"

# Customize lighttpd.service
SRC_URI += "file://lighttpd.service"

do_install:append() {
    install -d ${D}${systemd_system_unitdir}
    install -m 0644 ${UNPACKDIR}/lighttpd.service ${D}${systemd_system_unitdir}
}
```

Systemd Security Benefits

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- Makes it easy to run services and applications with just the necessary privileges
- Also possible to limit resources to reduce Denial of Service possibilities:
  - Access to filesystems and namespaces
  - RAM
  - CPU
  - I/O
  - Access to network
- It would be costly to implement this infrastructure by yourself 😉.

See https://www.man7.org/linux/man-pages/man5/systemd.resource-control.5.html

System Hardening

Kernel and Bootloader Hardening

Kernel Hardening

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Came across `kernel-hardening-checker` from Alexander Popov

- https://github.com/a13xp0p0v/kernel-hardening-checker
- Introduced only in Walnascar (`meta-oe`)
- Reports all the kernel configuration and command line settings which could be changed to harden the running kernel.
- My contributions:
  - Updated `meta-oe` to support the latest version: 0.6.10.2 (many recent changes), supporting a `-a` option and the RISC-V architecture (link)
  - Submitted a backport to Scarthgap too (link)

recipes-core/images/image-prod-test.bb

```
IMAGE_INSTALL += "kernel-hardening-checker"
```

kernel-hardening-checker example output

```
root@beaglebone-yocto:~# kernel-hardening-checker -a
[+] Going to autodetect and check the security hardening options of the running kernel
[+] Detected version of the running kernel: (6, 12, 41)
[+] Detected kconfig file of the running kernel: /proc/config.gz
[+] Detected cmdline parameters of the running kernel: /proc/cmdline
ICMPv6: process `sysctl' is using deprecated sysctl (syscall) net.ipv6.neigh.default.base_reachable_time - use net.ipv6.neigh.default.base_reachable_
[!] WARNING: sysctl command returned 1
[+] Saved sysctls to a temporary file /tmp/sysctl-58k0_iyd
[+] Detected architecture: ARM
[+] Detected compiler: GCC 150200
[!] WARNING: can't check CONFIG_ARCH_MMAP_RND_COMPAT_BITS without CONFIG_ARCH_MMAP_RND_COMPAT_BITS_MAX
[!] WARNING: can't check vm.mmap_rnd_compat_bits without CONFIG_ARCH_MMAP_RND_COMPAT_BITS_MAX
=========================================================================================================================
              option_name               | type |       reason       | decision |desired_val | check_result
=========================================================================================================================
CONFIG_BUG                              |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_SLUB_DEBUG                       |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_THREAD_INFO_IN_TASK              |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_IOMMU_DEFAULT_PASSTHROUGH        |kconfig| self_protection   |defconfig | is not set | OK: is not found
CONFIG_IOMMU_SUPPORT                    |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_STACKPROTECTOR                   |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_STACKPROTECTOR_STRONG            |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_STRICT_KERNEL_RWX                |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_STRICT_MODULE_RWX                |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_REFCOUNT_FULL                    |kconfig| self_protection   |defconfig |      y     | OK: version >= (5, 4, 208)
CONFIG_INIT_STACK_ALL_ZERO              |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_CPU_MITIGATIONS                  |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_VMAP_STACK                       |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_IOMMU_DEFAULT_DMA_STRICT         |kconfig| self_protection   |defconfig |      y     | FAIL: is not found
CONFIG_STACKPROTECTOR_PER_TASK          |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_HW_RANDOM_TPM                    |kconfig| self_protection   |defconfig |      y     | FAIL: is not found
CONFIG_CPU_SW_DOMAIN_PAN                |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_HARDEN_BRANCH_PREDICTOR          |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_HARDEN_BRANCH_HISTORY            |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_DEBUG_ALIGN_RODATA               |kconfig| self_protection   |defconfig |      y     | OK
CONFIG_RANDOM_KMALLOC_CACHES            |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SLAB_MERGE_DEFAULT               |kconfig| self_protection   |   kspp   | is not set | FAIL: "y"
CONFIG_BUG_ON_DATA_CORRUPTION           |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SLAB_FREELIST_HARDENED           |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SLAB_FREELIST_RANDOM             |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SHUFFLE_PAGE_ALLOCATOR           |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_FORTIFY_SOURCE                   |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_DEBUG_VIRTUAL                    |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_INIT_ON_ALLOC_DEFAULT_ON         |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_STATIC_USERMODEHELPER            |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SECURITY_LOCKDOWN_LSM            |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_LSM                              |kconfig| self_protection   |   kspp   | *lockdown* | OK: in "landlock,lockdown,yama,loadpin,safesetid,ipe,bpf"
CONFIG_SECURITY_LOCKDOWN_LSM_EARLY      |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_LOCK_DOWN_KERNEL_FORCE_CONFIDENTIALITY|kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_DEBUG_CREDENTIALS                |kconfig| self_protection   |   kspp   |      y     | OK: version >= (6, 6, 8)
CONFIG_DEBUG_NOTIFIERS                  |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_KFENCE                           |kconfig| self_protection   |   kspp   |      y     | OK
CONFIG_KFENCE_SAMPLE_INTERVAL           |kconfig| self_protection   |   kspp   |     100    | OK
CONFIG_RANDSTRUCT_FULL                  |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_HARDENED_USERCOPY                |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_HARDENED_USERCOPY_FALLBACK       |kconfig| self_protection   |   kspp   | is not set | FAIL: CONFIG_HARDENED_USERCOPY is not "y"
CONFIG_HARDENED_USERCOPY_PAGESPAN       |kconfig| self_protection   |   kspp   | is not set | FAIL: CONFIG_HARDENED_USERCOPY is not "y"
CONFIG_GCC_PLUGIN_LATENT_ENTROPY        |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_MODULE_SIG                       |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_MODULE_SIG_ALL                   |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_MODULE_SIG_SHA512                |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_MODULE_SIG_FORCE                 |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_INIT_ON_FREE_DEFAULT_ON          |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_EFI_DISABLE_PCI_DMA              |kconfig| self_protection   |   kspp   |      y     | OK: CONFIG_EFI is "is not set"
CONFIG_RESET_ATTACK_MITIGATION          |kconfig| self_protection   |   kspp   |      y     | OK: CONFIG_EFI is "is not set"
CONFIG_UBSAN_BOUNDS                     |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_UBSAN_LOCAL_BOUNDS               |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_UBSAN_TRAP                       |kconfig| self_protection   |   kspp   |      y     | FAIL: CONFIG_UBSAN_BOUNDS is not "y"
CONFIG_UBSAN_SANITIZE_ALL               |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_SCHED_CORE                       |kconfig| self_protection   |   kspp   |      y     | FAIL: is not found
CONFIG_DEBUG_SG                         |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_LIST_HARDENED                    |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_SCHED_STACK_END_CHECK            |kconfig| self_protection   |   kspp   |      y     | OK: CONFIG_VMAP_STACK is "y"
CONFIG_SYN_COOKIES                      |kconfig| self_protection   |   kspp   |      y     | OK
CONFIG_WERROR                           |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_DEFAULT_MMAP_MIN_ADDR            |kconfig| self_protection   |   kspp   |    32768   | FAIL: "4096"
CONFIG_ARM_DEBUG_WX                     |kconfig| self_protection   |   kspp   |      y     | FAIL: "is not set"
CONFIG_ARM_SMMU                         |kconfig| self_protection   |a13xp0p0v |      y     | FAIL: "is not set"
CONFIG_ARM_SMMU_DISABLE_BYPASS_BY_DEFAULT|kconfig| self_protection   |a13xp0p0v |      y     | FAIL: is not found
```

...

```
CONFIG_MMIOTRACE_TEST                   |kconfig|cut_attack_surface| lockdown | is not set | OK: is not found
CONFIG_KPROBES                          |kconfig|cut_attack_surface| lockdown | is not set | FAIL: "y"
CONFIG_BPF_SYSCALL                      |kconfig|cut_attack_surface| lockdown | is not set | FAIL: "y"
CONFIG_MMIOTRACE                        |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_LIVEPATCH                        |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_IP_DCCP                          |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_FTRACE                           |kconfig|cut_attack_surface|a13xp0p0v | is not set | FAIL: "y"
CONFIG_VIDEO_VIVID                      |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_INPUT_EVBUG                      |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_CORESIGHT                        |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_XFS_SUPPORT_V4                   |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_BLK_DEV_WRITE_MOUNTED            |kconfig|cut_attack_surface|a13xp0p0v | is not set | FAIL: "y"
CONFIG_FAULT_INJECTION                  |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_ARM_PTDUMP_DEBUGFS               |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_ARM_PTDUMP                       |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK: is not found
CONFIG_SECCOMP_CACHE_DEBUG              |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_LKDTM                            |kconfig|cut_attack_surface|a13xp0p0v | is not set | OK
CONFIG_TRIM_UNUSED_KSYMS                |kconfig|cut_attack_surface|a13xp0p0v |      y     | FAIL: "is not set"
CONFIG_VMSPLIT_3G                       |kconfig| harden_userspace |defconfig |      y     | OK
CONFIG_COREDUMP                         |kconfig| harden_userspace |  clipos  | is not set | FAIL: "y"
CONFIG_ARCH_MMAP_RND_BITS               |kconfig| harden_userspace |a13xp0p0v |     16     | FAIL: "8"
nosmep                                  |cmdline| self_protection  |defconfig | is not set | OK: is not found
nosmap                                  |cmdline| self_protection  |defconfig | is not set | OK: is not found
nokaslr                                 |cmdline| self_protection  |defconfig | is not set | OK: is not found
nopti                                   |cmdline| self_protection  |defconfig | is not set | OK: is not found
no_hash_pointers                        |cmdline| self_protection  |defconfig | is not set | OK: is not found
nospectre_v1                            |cmdline| self_protection  |defconfig | is not set | OK: is not found
nospectre_v2                            |cmdline| self_protection  |defconfig | is not set | OK: is not found
nospectre_bhb                           |cmdline| self_protection  |defconfig | is not set | OK: is not found
nospec_store_bypass_disable             |cmdline| self_protection  |defconfig | is not set | OK: is not found
dis_ucode_ldr                           |cmdline| self_protection  |defconfig | is not set | OK: is not found
arm64.nobti                             |cmdline| self_protection  |defconfig | is not set | OK: is not found
arm64.nopauth                           |cmdline| self_protection  |defconfig | is not set | OK: is not found
arm64.nomte                             |cmdline| self_protection  |defconfig | is not set | OK: is not found
iommu.passthrough                       |cmdline| self_protection  |defconfig |      0     | OK: CONFIG_IOMMU_DEFAULT_PASSTHROUGH is not found
rodata                                  |cmdline| self_protection  |defconfig |     on     | OK: rodata is not found
iommu.strict                            |cmdline| self_protection  |defconfig |      1     | FAIL: is not found
mitigations                             |cmdline| self_protection  |defconfig |    auto    | OK: mitigations is not found
slab_merge                              |cmdline| self_protection  |   kspp   | is not set | OK: is not found
slub_merge                              |cmdline| self_protection  |   kspp   | is not set | OK: is not found
page_alloc.shuffle                      |cmdline| self_protection  |   kspp   |      1     | FAIL: is not found
slab_nomerge                            |cmdline| self_protection  |   kspp   | is present | FAIL: is not present
init_on_alloc                           |cmdline| self_protection  |   kspp   |      1     | FAIL: is not found
init_on_free                            |cmdline| self_protection  |   kspp   |      1     | FAIL: is not found
hardened_usercopy                       |cmdline| self_protection  |   kspp   |      1     | FAIL: is not found
slab_common.usercopy_fallback           |cmdline| self_protection  |   kspp   | is not set | OK: is not found
kfence.sample_interval                  |cmdline| self_protection  |   kspp   |     100    | OK: CONFIG_KFENCE_SAMPLE_INTERVAL is "100"
nosmt                                   |cmdline|cut_attack_surface|   kspp   | is present | FAIL: is not present
debugfs                                 |cmdline|cut_attack_surface|  grsec   |     off    | FAIL: is not found
sysrq_always_enabled                    |cmdline|cut_attack_surface|grapheneos| is not set | OK: is not found
bdev_allow_write_mounted                |cmdline|cut_attack_surface|a13xp0p0v |      0     | FAIL: is not found
norandmaps                              |cmdline| harden_userspace |defconfig | is not set | OK: is not found
net.core.bpf_jit_harden                 |sysctl | self_protection  |   kspp   |      2     | FAIL: "0"
kernel.oops_limit                       |sysctl | self_protection  |a13xp0p0v |     100    | FAIL: "10000"
kernel.warn_limit                       |sysctl | self_protection  |a13xp0p0v |     100    | FAIL: "0"
vm.mmap_min_addr                        |sysctl | self_protection  |   kspp   |    32768   | FAIL: "4096"
kernel.dmesg_restrict                   |sysctl |cut_attack_surface|   kspp   |      1     | FAIL: "0"
kernel.perf_event_paranoid              |sysctl |cut_attack_surface|   kspp   |      3     | FAIL: "2"
dev.tty.ldisc_autoload                  |sysctl |cut_attack_surface|   kspp   |      0     | FAIL: "1"
kernel.kptr_restrict                    |sysctl |cut_attack_surface|   kspp   |      2     | FAIL: "0"
dev.tty.legacy_tiocsti                  |sysctl |cut_attack_surface|   kspp   |      0     | FAIL: "1"
user.max_user_namespaces                |sysctl |cut_attack_surface|   kspp   |      0     | FAIL: "3740"
kernel.kexec_load_disabled              |sysctl |cut_attack_surface|   kspp   |      1     | OK: CONFIG_KEXEC_CORE is not found
kernel.unprivileged_bpf_disabled        |sysctl |cut_attack_surface|   kspp   |      1     | FAIL: "2"
vm.unprivileged_userfaultfd             |sysctl |cut_attack_surface|   kspp   |      0     | OK: CONFIG_USERFAULTFD is "is not set"
kernel.modules_disabled                 |sysctl |cut_attack_surface|   kspp   |      1     | FAIL: "0"
kernel.io_uring_disabled                |sysctl |cut_attack_surface|  grsec   |      2     | FAIL: "0"
kernel.sysrq                            |sysctl |cut_attack_surface|a13xp0p0v |      0     | FAIL: "16"
fs.protected_symlinks                   |sysctl | harden_userspace |   kspp   |      1     | OK
fs.protected_hardlinks                  |sysctl | harden_userspace |   kspp   |      1     | OK
fs.protected_fifos                      |sysctl | harden_userspace |   kspp   |      2     | FAIL: "1"
fs.protected_regular                    |sysctl | harden_userspace |   kspp   |      2     | FAIL: "1"
fs.suid_dumpable                        |sysctl | harden_userspace |   kspp   |      0     | OK
kernel.randomize_va_space               |sysctl | harden_userspace |   kspp   |      2     | FAIL: "1"
kernel.yama.ptrace_scope                |sysctl | harden_userspace |   kspp   |      3     | FAIL: is not found
vm.mmap_rnd_bits                        |sysctl | harden_userspace |a13xp0p0v |     16     | FAIL: "8"

[+] Config check is finished: 'OK' - 145 / 'FAIL' - 109
root@beaglebone-yocto:~#
```

Kernel Hardening Notes

- Kernel configuration: remove unnecessary features
  - This reduces the attack surface, and boot time too!
  - Yocto stores kernel modules in separate packages. This helps to identify unnecessary ones!
- See `security/self-protection` (kernel documentation) for details about kernel protection techniques.

Bootloader Hardening

root commit

A wide topic too!

- Make sure your bootloader is well maintained. Use mainline U-Boot if possible.
- Implement secure boot or verified boot if possible.
- No documentation available in in U-Boot to increase security.
- Lock down your serial console. Pretty easy to attack or brick a device if you have U-Boot shell access.
  - Completely disable the interactive shell: `CONFIG_BOOTDELAY=-2`
  - Or require a specific string to unlock it: `CONFIG_AUTOBOOT_ENCRYPTION=y`
- Disable all unnecessary features (network, filesystems, usb-serial...) and devices (USB, SD card...)

System Hardening

Other Hardening Techniques

Read-Only Filesystem

root commit

Very easy to implement with Yocto, whatever the init manager

- Add this image feature:

recipes-core/images/image-prod.bb

```
IMAGE_FEATURES += "read-only-rootfs"
```

- Just make sure that the mount point(s) for your read-write partition(s) are created at root filesystem creation time. The mounts points are created on demand by `systemd` when you have a read-write root filesystem.

recipes-core/images/image-common.bb

```
# Create mount point for data partition
do_rootfs[postfuncs] += "image_create_data_dir"

image_create_data_dir() {
    install -d ${IMAGE_ROOTFS}/data
}
```

Don't write, this is read-only!

overlayfs.bbclass and overlayfs-etc.bbclass

root commit

- Had to use the `overlayfs-etc` to allow to modify `/etc/shadow` and `/etc/passwd` for setting the root password at first boot.
- Except for this special need, `systemd` started the system without a single issue when the whole root filesystem is read-only 👏.
  This works as important "dynamic" files (such as `/etc/resolv.conf` are links to volatile mount points.
- Had no need for the `overlayfs` class (for the whole root filesystem), but this may be needed to allow applications to make local changes to the root filesystem, while the base system remains read-only.

recipes-core/images/image-prod.bb

```
IMAGE_FEATURES += "overlayfs-etc"
OVERLAYFS_ETC_MOUNT_POINT = "/data"
OVERLAYFS_ETC_DEVICE = "/dev/mmcblk0p3"
OVERLAYFS_ETC_FSTYPE ?= "ext4"
```

recipes-kernel/linux/linux-yocto_%.bbappend

```
FILESEXTRAPATHS:prepend := "${THISDIR}/files:"
SRC_URI += "file://overlayfs.cfg"
```

recipes-kernel/linux/files/overlayfs.cfg

```
CONFIG_OVERLAY_FS=y
```

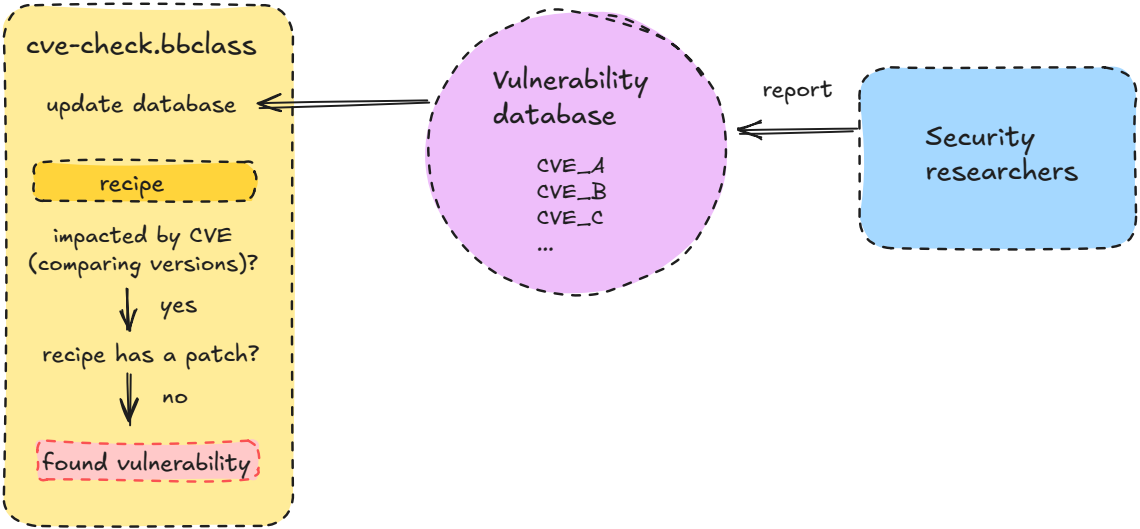
Maintaining your system

Maintaining your system

Addressing Vulnerabilities

How vulnerability checking works

root commit



Enable vulnerability checking

root commit

- Add this to `conf/local.conf`:
  ```
  INHERIT += "cve-check"
  ```
- This will add a CVE task to the recipes you're building
- You may also want to ignore CVEs that are irrelevant to Poky and OE-core:
  ```
  include conf/distro/include/cve-extra-exclusions.inc
  ```
- To speed up NVD database dowloads, request a unique key (`NVDCVE_API_KEY`)
  ```
  NVDCVE_API_KEY = "xxxxxxx-xxxx-xxxx-xxxx-xxxxxxxxxxx"
  ```
- Then, `bitbake` your regular image,
  and the checks will be run (without running the other tasks if not necessary)
- You can also run checks on specific recipes:
  ```
  $ bitbake -c cve_check linux-yocto
  ```

Exploiting vulnerability report

root commit

- Simple command:

```
$ grep Unpatched build/tmp/log/cve/cve-summary.json | wc -l
39
```

- VulnScout (https://github.com/savoirfairelinux/vulnscout) is a new tool to process the vulnerability report and the project SPDX.
  - At last, a tool to consume Yocto SPDX output and generate a vulnerability assessment for it!
  - Supports SPDX 2.3, SPDX 3.0, CycloneDX, Yocto JSON vulnerability output
  - All you need to deliver to the customer is Yocto's initial vulnerability report and the SPDX description of the system.
  - The customer then doesn't need Yocto to scout for new vulnerabilities and make her/his own assessment at any time.
  - Contributed to it through bug reports and small documentation patches. Even had a private demo from the developers.

VulnScout — How to Use

- VulnScout can directly be used on Yocto's SPDX and `cve-check` outputs, but you have to create a YAML configuration file.
- However, it's easier to use with the `meta-vulnscout` layer
  - https://github.com/savoirfairelinux/meta-vulnscout
  - Supports: Yocto 5.0 (Scarthgap), 5.2 (Walnascar) and 5.3 (Whinlatter)
  - Just inherit the `vulnscout` class in an image:

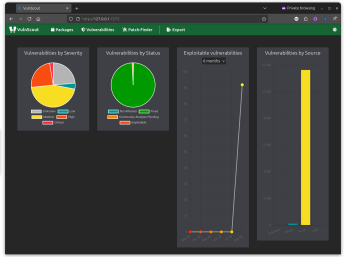
recipes-core/images/image-prod.bb

```
inherit vulnscout
```

  - Building the image generates the YAML file for Vulnscout and a command line to start the tool:

```
$ docker rm -f vulnscout
$ docker-compose -f ".vulnscout/image-prod-test-beaglebone-
yocto/docker-compose.yml" up
```

- You can keep the `.vulnscout` directory for future use outside of Yocto.



VulnScout's web interface

Addressing vulnerabilities in your products

root commit

If a fix is found (typically upstream), add the patch to your recipe

- Include the CVE identifier in the patch file name (recommended)
- Add a `CVE:<id>` line to the patch
- Also set an `Upstream-Status:` field. https://docs.yoctoproject.org/contributor-guide/recipe-style-guide.html#patch-upstream-status
- Share your patch with the Yocto community!

Of course, another option is to upgrade to a newer version of upstream (if available).

meta/recipes-bsp/grub/files/CVE-2025-0622-01.patch

```
From 2123c5bca7e21fbeb0263df4597ddd7054700726 Mon Sep 17 00:00:00 2001
From: B Horn <b@horn.uk>
Date: Fri, 1 Nov 2024 19:24:29 +0000
Subject: [PATCH 1/3] commands/pgp: Unregister the "check_signatures" hooks on
 module unload

If the hooks are not removed they can be called after the module has
been unloaded leading to an use-after-free.

Fixes: CVE-2025-0622

Reported-by: B Horn <b@horn.uk>
Signed-off-by: B Horn <b@horn.uk>
Reviewed-by: Daniel Kiper <daniel.kiper@oracle.com>

CVE: CVE-2025-0622
Upstream-Status: Backport [https://git.savannah.gnu.org/cgit/grub.git/commit/?id=2123c5bca7e21fbeb...]
Signed-off-by: Peter Marko <peter.marko@siemens.com>
---
 grub-core/commands/pgp.c | 2 ++
 1 file changed, 2 insertions(+)

diff --git a/grub-core/commands/pgp.c b/grub-core/commands/pgp.c
index c6766f044..5fadc33c4 100644
--- a/grub-core/commands/pgp.c
+++ b/grub-core/commands/pgp.c
@@ -1010,6 +1010,8 @@ GRUB_MOD_INIT(pgp)

 GRUB_MOD_FINI(pgp)
 {
+  grub_register_variable_hook ("check_signatures", NULL, NULL);
+  grub_env_unset ("check_signatures");
   grub_verifier_unregister (&grub_pubkey_verifier);
   grub_unregister_extcmd (cmd);
   grub_unregister_extcmd (cmd_trust);
```

Ignoring vulnerabilities in your products

root commit

You can also modify the recipe to mark some vulnerabilities as irrelevant:

meta/recipes-devtools/rust/rust-source.inc

```
CVE_STATUS[CVE-2024-24576] = "not-applicable-platform: Issue only applies on Windows"
```

You can also group vulnerabilities that can be ignored in the same way:

meta/recipes-extended/logrotate/logrotate_3.22.0.bb

```
CVE_STATUS_GROUPS = "CVE_STATUS_RECIPE"
CVE_STATUS_RECIPE = "CVE-2011-1548 CVE-2011-1549 CVE-2011-1550"
CVE_STATUS_RECIPE[status] = "not-applicable-platform: CVE is debian, gentoo or SUSE specific on the way logrotate was installed/used"
```

See "Checking for Vulnerabilities" in the Yocto Manual:
https://docs.yoctoproject.org/dev-manual/vulnerabilities.html

Closing

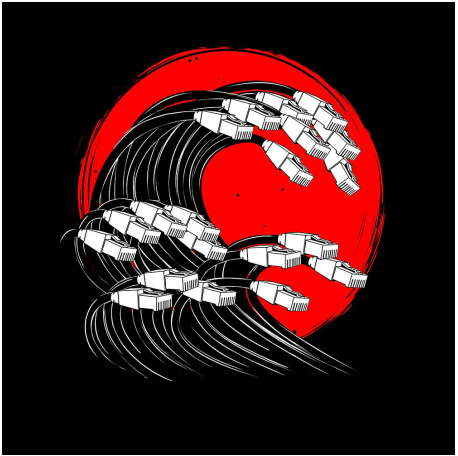
Key Takeaways

- Use LTS versions of Yocto and kernel
- Need 3 images: `dev`, `prod` and `prod-test`
- Remove unnessary packages and features
- No shared passwords between devices
- Read-only root filesystems are easy
- Use `systemd` to restrict priviledges and resources of applications and services.

- `kernel-hardening-checker`: great tool for kernel hardening
- Looking for tools for checking userspace hardening
- More hardening needed: secure / verified boot, TPM, firewall, encryption, extended file attributes, Linux Security Modules...
- VulnScout: new tool to run vulnerability assessments from Yocto SPDX output
- You are going to be busy 😉

Useful Resources

- My `meta-security-demo` layer containing the code shown here (supports QEMU x86-64 and BeagleBone):
  https://gitlab.com/rootcommit/meta-security-demo
- Esa Jääskelä — Yocto Hardening
  Series of blog posts about many aspects of the topic
  Fun and exhaustive!
  https://ejaaskel.dev/yocto-hardening/
- Esa Jääskelä — Sulka Secure Yocto Distribution
  A good example!
  https://codeberg.org/altidSec/meta-sulka-distro
- Darknet Diaries
  My favorite English speaking podcast about IT (in)security
  https://darknetdiaries.com/



https://shop.darknetdiaries.com

Thank you

root commit

Questions? Comments?

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- Slides available under the CC-By-SA 4.0 license
  https://rootcommit.com/pub/conferences/2025/elce/yocto-security/
- Sources (LaTeX):
  https://gitlab.com/rootcommit/yocto-security/