

Yocto Project and OpenEmbedded system development training

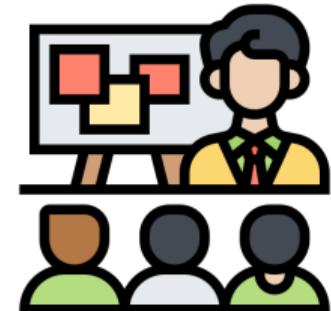
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Latest update: February 24, 2023.

Document updates and training details:
<https://bootlin.com/training/yocto>

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Send them to feedback@bootlin.com



- ▶ These slides are the training materials for Bootlin's *Yocto Project and OpenEmbedded system development* training course.
- ▶ If you are interested in following this course with an experienced Bootlin trainer, we offer:
 - **Public online sessions**, opened to individual registration. Dates announced on our site, registration directly online.
 - **Dedicated online sessions**, organized for a team of engineers from the same company at a date/time chosen by our customer.
 - **Dedicated on-site sessions**, organized for a team of engineers from the same company, we send a Bootlin trainer on-site to deliver the training.
- ▶ Details and registrations:
<https://bootlin.com/training/yocto>
- ▶ Contact: training@bootlin.com



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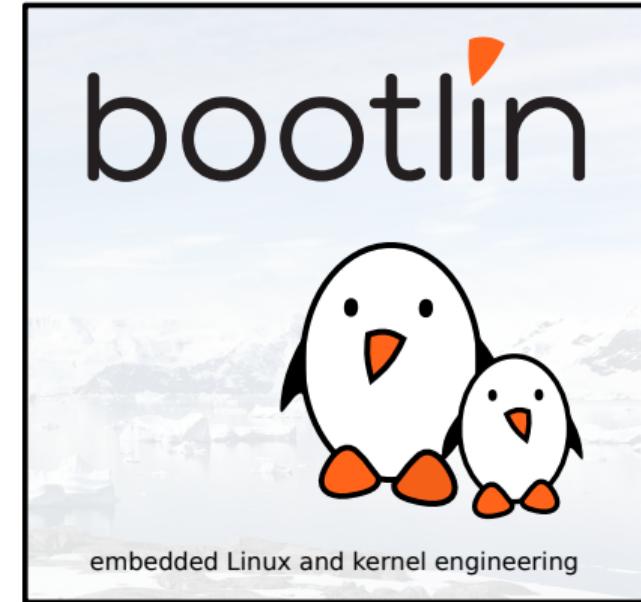


About Bootlin

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Bootlin introduction

- ▶ Engineering company
 - In business since 2004
 - Before 2018: *Free Electrons*
- ▶ Team based in France and Italy
- ▶ Serving **customers worldwide**
- ▶ **Highly focused and recognized expertise**
 - Embedded Linux
 - Linux kernel
 - Embedded Linux build systems
- ▶ **Strong open-source contributor**
- ▶ Activities
 - **Engineering** services
 - **Training** courses
- ▶ <https://bootlin.com>





Bootlin engineering services

Bootloader /
firmware
development

U-Boot, Barebox,
OP-TEE, TF-A, .../

Linux kernel
porting and
driver
development

Linux BSP
development,
maintenance
and upgrade

Embedded Linux
build systems

Yocto, OpenEmbedded,
Buildroot, ...

Embedded Linux
integration

Boot time, real-time,
security, multimedia,
networking

Open-source
upstreaming

Get code integrated
in upstream
Linux, U-Boot, Yocto,
Buildroot, ...



Bootlin training courses

Embedded Linux system development

On-site: 4 or 5 days
Online: 7 * 4 hours

Linux kernel driver development

On-site: 5 days
Online: 7 * 4 hours

Yocto Project system development

On-site: 3 days
Online: 4 * 4 hours

Buildroot system development

On-site: 3 days
Online: 5 * 4 hours

Understanding the Linux graphics stack

On-site: 2 days
Online: 4 * 4 hours

Embedded Linux boot time optimization

On-site: 3 days
Online: 4 * 4 hours

Real-Time Linux with PREEMPT_RT

On-site: 2 days
Online: 3 * 4 hours

Linux debugging, tracing, profiling and performance analysis

On-site: 3 days
Online: 4 * 4 hours



- ▶ Strong contributor to the **Linux** kernel
 - In the top 30 of companies contributing to Linux worldwide
 - Contributions in most areas related to hardware support
 - Several engineers maintainers of subsystems/platforms
 - 8000 patches contributed
 - <https://bootlin.com/community/contributions/kernel-contributions/>
- ▶ Contributor to **Yocto Project**
 - Maintainer of the official documentation
 - Core participant to the QA effort
- ▶ Contributor to **Buildroot**
 - Co-maintainer
 - 5000 patches contributed
- ▶ Significant contributions to U-Boot, OP-TEE, Barebox, etc.
- ▶ Fully **open-source training materials**



- ▶ Website with a technical blog:
<https://bootlin.com>
- ▶ Engineering services:
<https://bootlin.com/engineering>
- ▶ Training services:
<https://bootlin.com/training>
- ▶ Twitter:
<https://twitter.com/bootlincom>
- ▶ LinkedIn:
<https://www.linkedin.com/company/bootlin>
- ▶ Elixir - browse Linux kernel sources on-line:
<https://elixir.bootlin.com>



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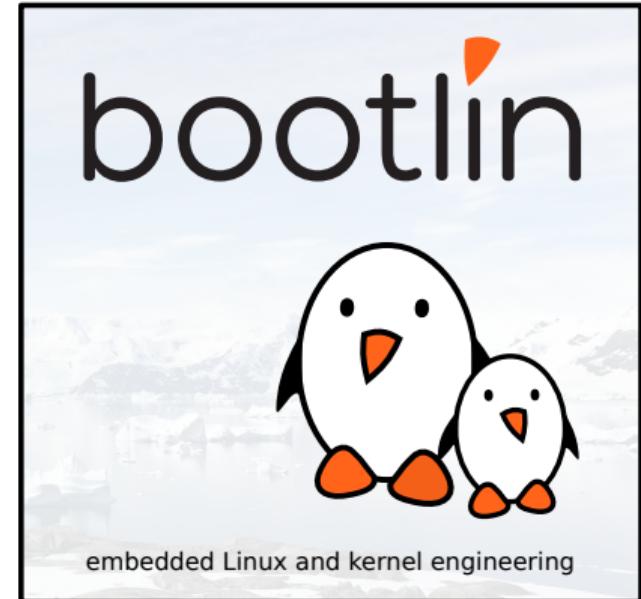


Generic course information

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Two supported hardware platforms

Two variants for this course, each using a different hardware platform.



Beaglebone Black

<https://bootlin.com/doc/training/yocto/>



STM32MP157D-DK1 Discovery

<https://bootlin.com/doc/training/yocto-stm32/>



Shopping list: BeagleBone Black Wireless variant

- ▶ Beaglebone Black or Beaglebone Black Wireless, USB-A to micro B power cable included

<https://www.mouser.fr/ProductDetail/BeagleBoard-by-GHI/BBBWL-SC-562?qs=k%2Fsw%252B3Yi%2FUbELBjXQpiBUQ%3D%3D>



- ▶ USB Serial Cable - 3.3 V - female ends (for serial console)

<https://www.olimex.com/Products/Components/Cables/USB-Serial-Cable/USB-SERIAL-F/>

- ▶ Nintendo Nunchuk with UEXT connector

<https://www.olimex.com/Products/Modules/Sensors/MOD-WII/MOD-Wii-UEXT-NUNCHUCK/>

- ▶ Breadboard jumper wires - Male ends (to connect to Nunchuk) <https://www.olimex.com/Products/Breadboarding/JUMPER-WIRES/JW-110x10/>



- ▶ Micro SD card with 8 GB capacity





Shopping list: STM32MP1 Discovery Kit variant

- ▶ STMicroelectronics STM32MP157D-DK1 Discovery kit

<https://www.st.com/en/evaluation-tools/stm32mp157d-dk1.html#sample-buy>



- ▶ USB-C cable for the power supply
- ▶ USB-A to micro B cable for the serial console
- ▶ RJ45 cable for networking
- ▶ Nintendo Nunchuk with UEXT connector

<https://www.olimex.com/Products/Modules/Sensors/MOD-WII/MOD-Wii-UEXT-NUNCHUCK/>



- ▶ Breadboard jumper wires - Male ends

<https://www.olimex.com/Products/Breadboarding/JUMPER WIRES/JW-110x10/>



- ▶ Micro SD card with 8 GB capacity





Supported hardware

BeagleBone Black or BeagleBone Black Wireless, from [BeagleBoard.org](https://beagleboard.org)

- ▶ Texas Instruments AM335x (ARM Cortex-A8 CPU)
- ▶ SoC with 3D acceleration, additional processors (PRUs) and lots of peripherals.
- ▶ 512 MB of RAM
- ▶ 4 GB of on-board eMMC storage
- ▶ USB host and USB device, microSD, micro HDMI
- ▶ WiFi and Bluetooth (wireless version), otherwise Ethernet
- ▶ 2 x 46 pins headers, with access to many expansion buses (I2C, SPI, UART and more)
- ▶ A huge number of expansion boards, called *capes*. See https://elinux.org/Beagleboard:BeagleBone_Capes.





Supported hardware

Discovery Kits from STMicroelectronics: STM32MP157A-DK1, STM32MP157D-DK1, STM32MP157C-DK2 or STM32MP157F-DK2

- ▶ STM32MP157 (Dual Cortex-A7 + Cortex-M4) CPU from STMicroelectronics
- ▶ 512 MB DDR3L RAM
- ▶ Gigabit Ethernet port
- ▶ 4 USB 2.0 host ports, 1 USB-C OTG port
- ▶ 1 Micro SD slot
- ▶ On-board ST-LINK/V2-1 debugger
- ▶ Misc: buttons, LEDs, audio codec
- ▶ LCD touchscreen (DK2 only)
- ▶ Currently sold at 72 EUR + VAT (DK1) and 113 EUR + VAT (DK2) at Mouser



DK1 Discovery Kit

Board and CPU documentation, design files, software: [A-DK1](#), [D-DK1](#), [C-DK2](#), [F-DK2](#)



Training quiz and certificate

- ▶ You have been given a quiz to test your knowledge on the topics covered by the course. That's not too late to take it if you haven't done it yet!
- ▶ At the end of the course, we will submit this quiz to you again. That time, you will see the correct answers.
- ▶ It allows Bootlin to assess your progress thanks to the course. That's also a kind of challenge, to look for clues throughout the lectures and labs / demos, as all the answers are in the course!
- ▶ Another reason is that we only give training certificates to people who achieve at least a 50% score in the final quiz **and** who attended all the sessions.



Participate!

During the lectures...

- ▶ Don't hesitate to ask questions. Other people in the audience may have similar questions too.
- ▶ Don't hesitate to share your experience too, for example to compare Linux with other operating systems you know.
- ▶ Your point of view is most valuable, because it can be similar to your colleagues' and different from the trainer's.
- ▶ In on-line sessions
 - Please always keep your camera on!
 - Also make sure your name is properly filled.
 - You can also use the "Raise your hand" button when you wish to ask a question but don't want to interrupt.
- ▶ All this helps the trainer to engage with participants, see when something needs clarifying and make the session more interactive, enjoyable and useful for everyone.



Collaborate!

As in the Free Software and Open Source community, collaboration between participants is valuable in this training session:

- ▶ Use the dedicated Matrix channel for this session to add questions.
- ▶ If your session offers practical labs, you can also report issues, share screenshots and command output there.
- ▶ Don't hesitate to share your own answers and to help others especially when the trainer is unavailable.
- ▶ The Matrix channel is also a good place to ask questions outside of training hours, and after the course is over.

The screenshot shows a Matrix channel interface with several messages from users Srinath and michael.o. Srinath asks about the CROSS_COMPILE variable for the Xplained board. Michael.o responds with instructions on setting it correctly. Srinath also mentions asking about labs after the session is over. A message from arnsud.i is visible at the bottom, and a file attachment 'Decrypt Image.png' is shown.

E # embedded-linux-nov2020 Channel for

Srinath

michael.o: What should be CROSS_COMPILE variable set to in case of the Xplained board? I ran into some issues with my USB hub so doing the u-boot again

michael.o: you should look at the name of the cross-compiler in the toolchain's bin/ directory. CROSS_COMPILE should be set to what's before "gcc" in the name, including the trailing "-". Like if the compiler is arm-buildroot-linux-gcc, CROSS_COMPILE should be arm-buildroot-linux-

2 messages deleted.

Srinath

Will ask them here since I am going to do labs after the session is over! Thanks!

michael.o changed their display name to michael.r.

@bootlin-eu@matrix.org

I tried to finalize Kernel - Cross-compiling task, but my system is not able to restart the new kernel. Does anyone know what can be the root cause?

arnsud.i

I had the same because I accidentally removed the .overlays from the kernel

arnsud.i: Send an encrypted message...

Decrypt Image.png (109.2 KB)



Practical lab - Training Setup



Prepare your lab environment

- ▶ Download and extract the lab archive

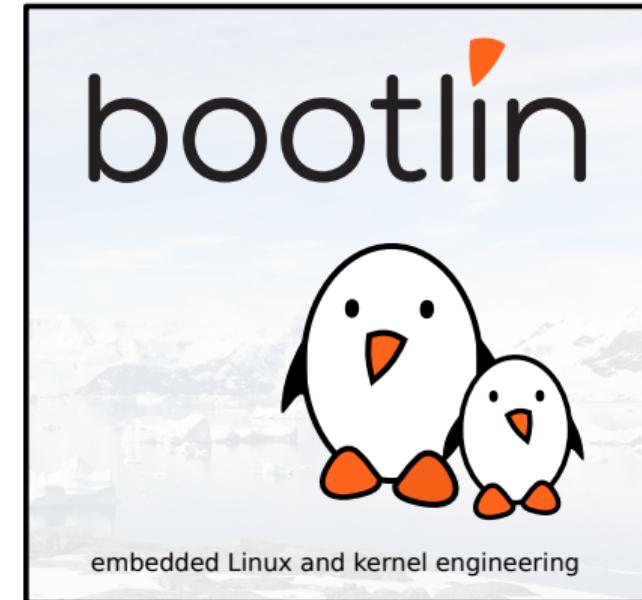


Introduction to Embedded Linux

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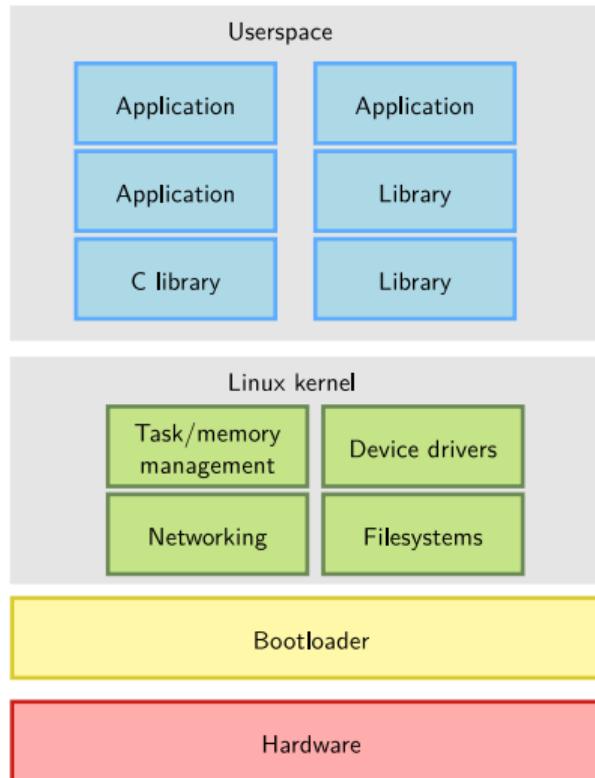
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Corrections, suggestions, contributions and translations are welcome!



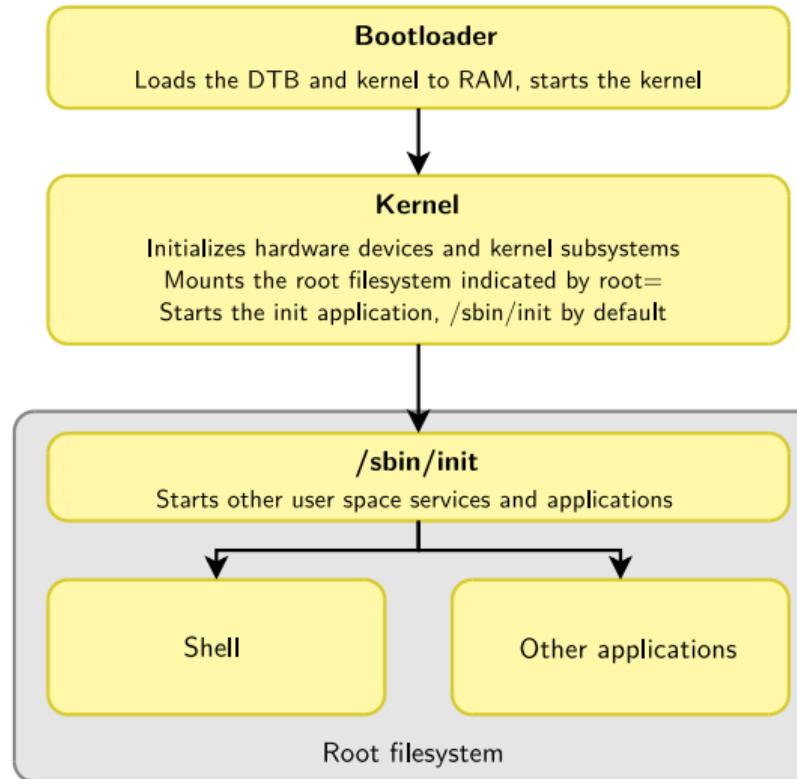


Simplified Linux system architecture





Overall Linux boot sequence

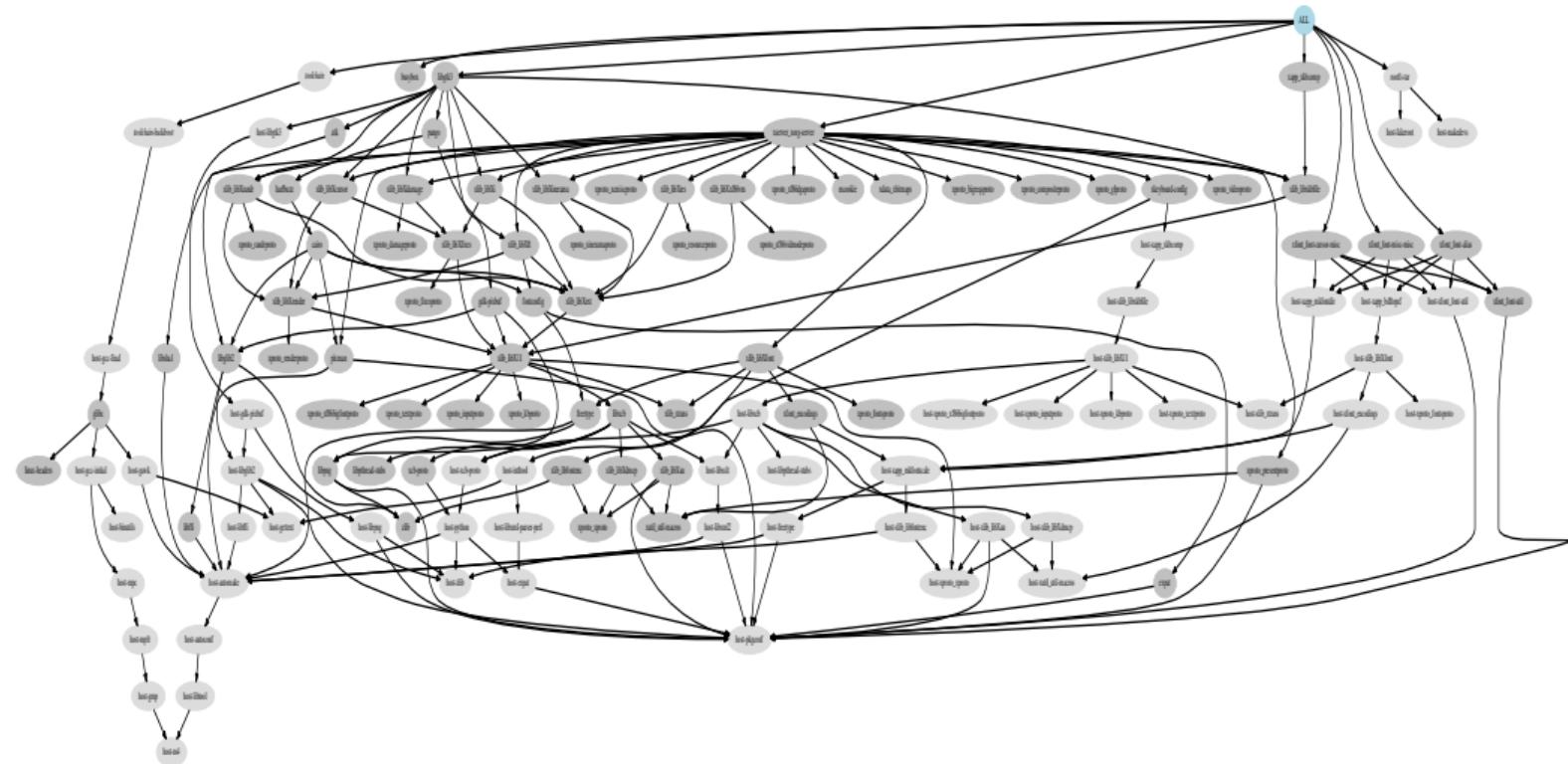




- ▶ **BSP work:** porting the bootloader and Linux kernel, developing Linux device drivers.
- ▶ **system integration work:** assembling all the user space components needed for the system, configure them, develop the upgrade and recovery mechanisms, etc.
- ▶ **application development:** write the company-specific applications and libraries.



Complexity of user space integration



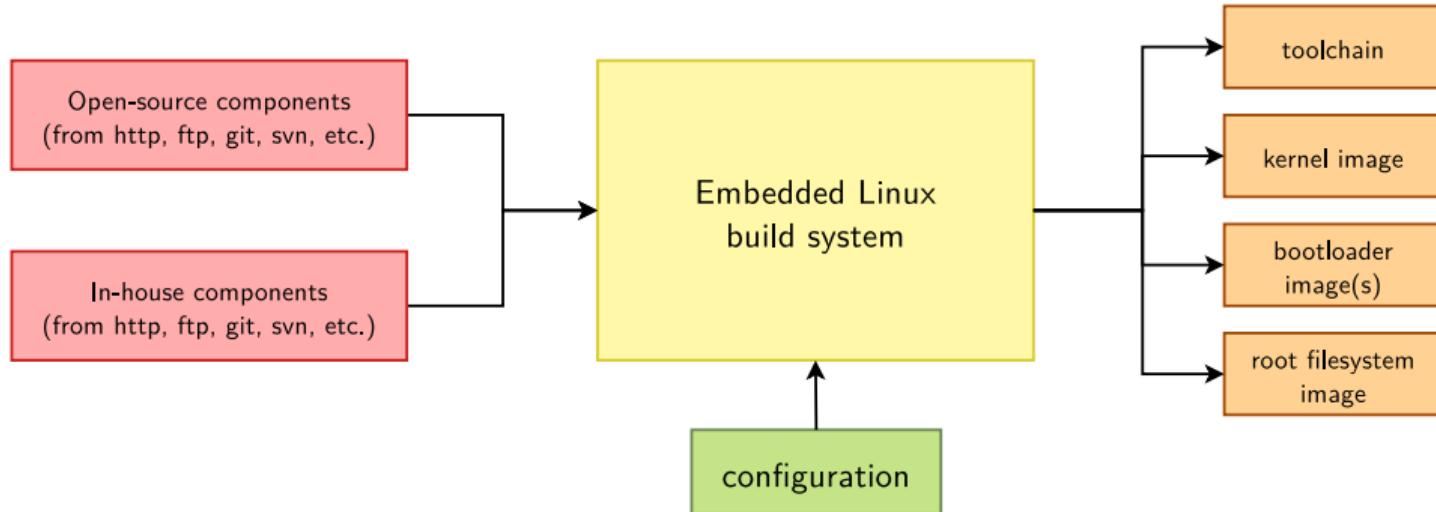


System integration: several possibilities

	Pros	Cons
Building everything manually	Full flexibility Learning experience	Dependency hell Need to understand a lot of details Version compatibility Lack of reproducibility
Binary distribution Debian, Ubuntu, Fedora, etc.	Easy to create and extend	Hard to customize Hard to optimize (boot time, size) Hard to rebuild the full system from source Large system Uses native compilation (slow) No well-defined mechanism to generate an image Lots of mandatory dependencies Not available for all architectures
Build systems Buildroot, Yocto, PTXdist, etc.	Nearly full flexibility Built from source: customization and optimization are easy Fully reproducible Uses cross-compilation Have embedded specific packages not necessarily in desktop distros Make more features optional	Not as easy as a binary distribution Build time



Embedded Linux build system: principle



- ▶ Building from source → lot of flexibility
- ▶ Cross-compilation → leveraging fast build machines
- ▶ Recipes for building components → easy



Embedded Linux build system: tools

- ▶ A wide range of solutions: Yocto/OpenEmbedded, PTXdist, Buildroot, OpenWRT, and more.
- ▶ Today, two solutions are emerging as the most popular ones
 - **Yocto/OpenEmbedded**
Builds a complete Linux distribution with binary packages. Powerful, but somewhat complex, and quite steep learning curve.
 - **Buildroot**
Builds a root filesystem image, no binary packages. Much simpler to use, understand and modify.



Yocto Project and Poky reference system overview

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The Yocto Project overview

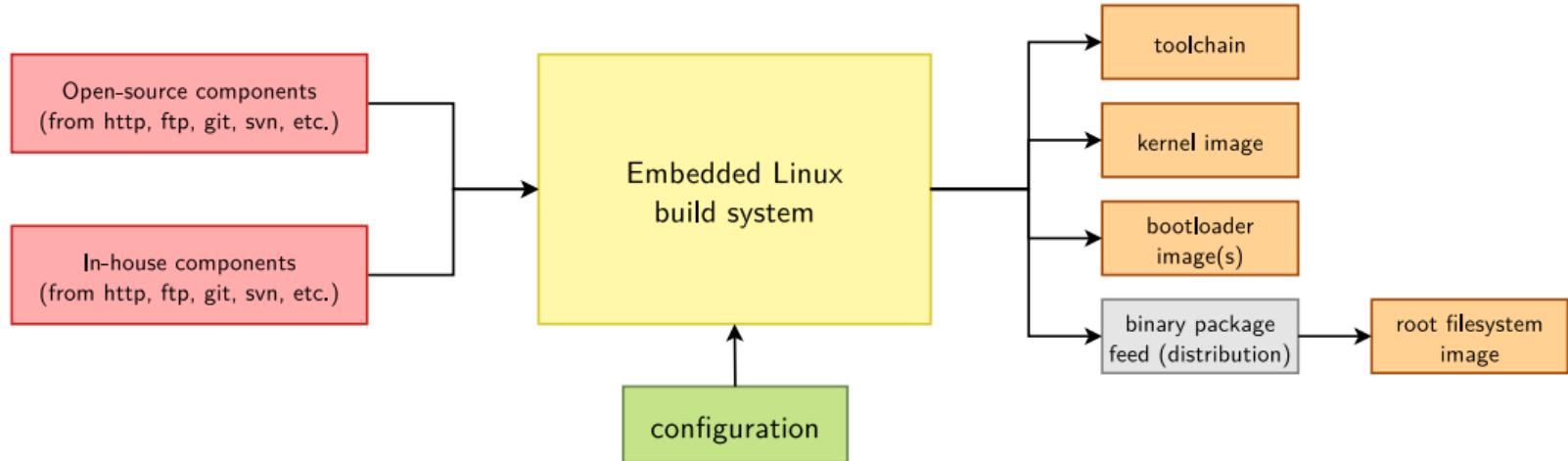


About

- ▶ The Yocto Project is a set of templates, tools and methods that allow to build custom embedded Linux-based systems.
- ▶ It is an open source project initiated by the Linux Foundation in 2010 and is still managed by one of its fellows: Richard Purdie.



Yocto: principle



- ▶ Yocto always builds binary packages (a “distribution”)
- ▶ The final root filesystem is generated from the package feed
- ▶ The **big picture** is way more complex

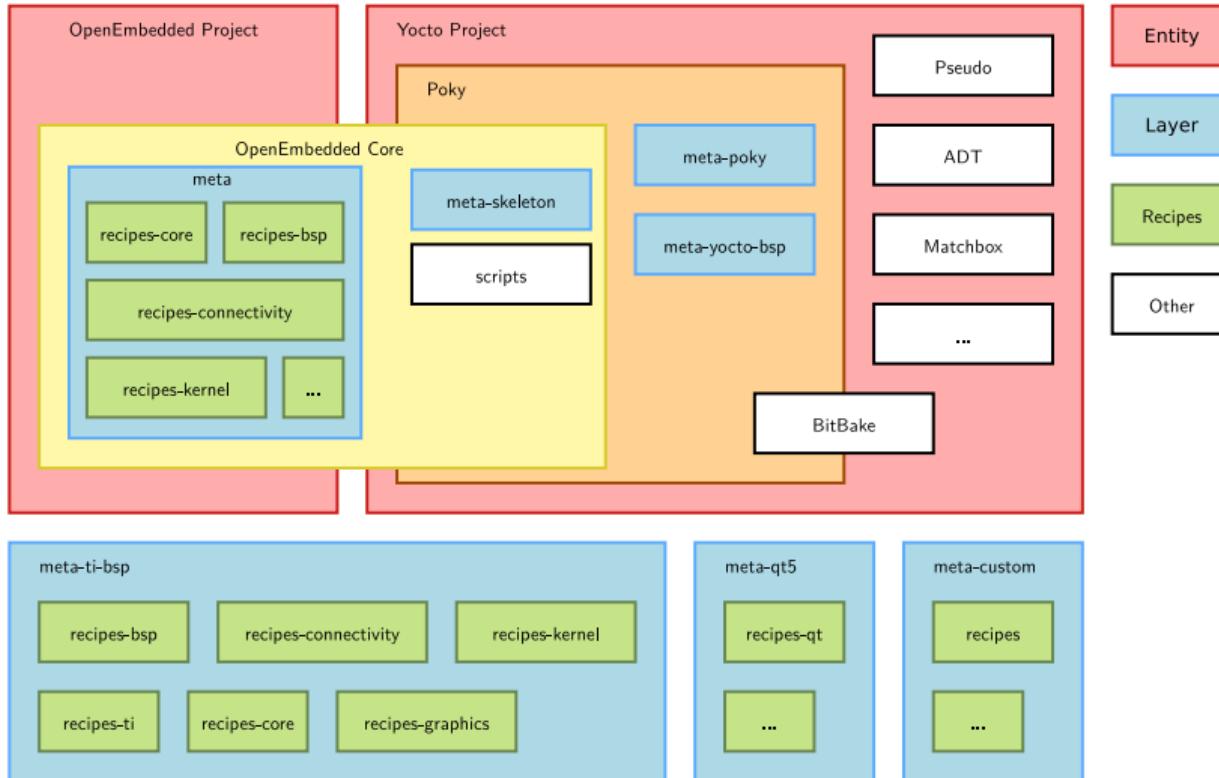


The Yocto Project lexicon

- ▶ The core components of the Yocto Project are:
 - BitBake, the *build engine*. It is a task scheduler, like `make`. It interprets configuration files and recipes (also called *metadata*) to perform a set of tasks, to download, configure and build specified applications and filesystem images.
 - OpenEmbedded-Core, a set of base *layers*. It is a set of recipes, layers and classes which are shared between all OpenEmbedded based systems.
 - Poky, the *reference system*. It is a collection of projects and tools, used to bootstrap a new distribution based on the Yocto Project.



The Yocto Project lexicon





► Organization of OpenEmbedded-Core:

- *Recipes* describe how to fetch, configure, compile and package applications and images. They have a specific syntax.
- *Layers* are sets of recipes, matching a common purpose. For Texas Instruments board support, the *meta-ti-bsp* layer is used.
- Multiple layers are used within a same distribution, depending on the requirements.
- It supports the ARM, MIPS (32 and 64 bits), PowerPC, RISC-V and x86 (32 and 64 bits) architectures.
- It supports QEMU emulated machines for these architectures.



The Yocto Project lexicon

- ▶ The Yocto Project is **not used as** a finite set of layers and tools.
- ▶ Instead, it provides a **common base** of tools and layers on top of which custom and specific layers are added, depending on your target.
- ▶ The main required element is **Poky**, the reference system which includes OpenEmbedded-Core. Other available tools are optional, but may be useful in some cases.



Example of a Yocto Project based BSP

- ▶ To build images for a BeagleBone Black, we need:
 - The Poky reference system, containing all common recipes and tools.
 - The *meta-ti-bsp* layer, a set of Texas Instruments specific recipes.
- ▶ All modifications are made in your own layer. Editing Poky or *meta-ti* is a **no-go!**
- ▶ We will set up this environment in the lab.



The Poky reference system overview

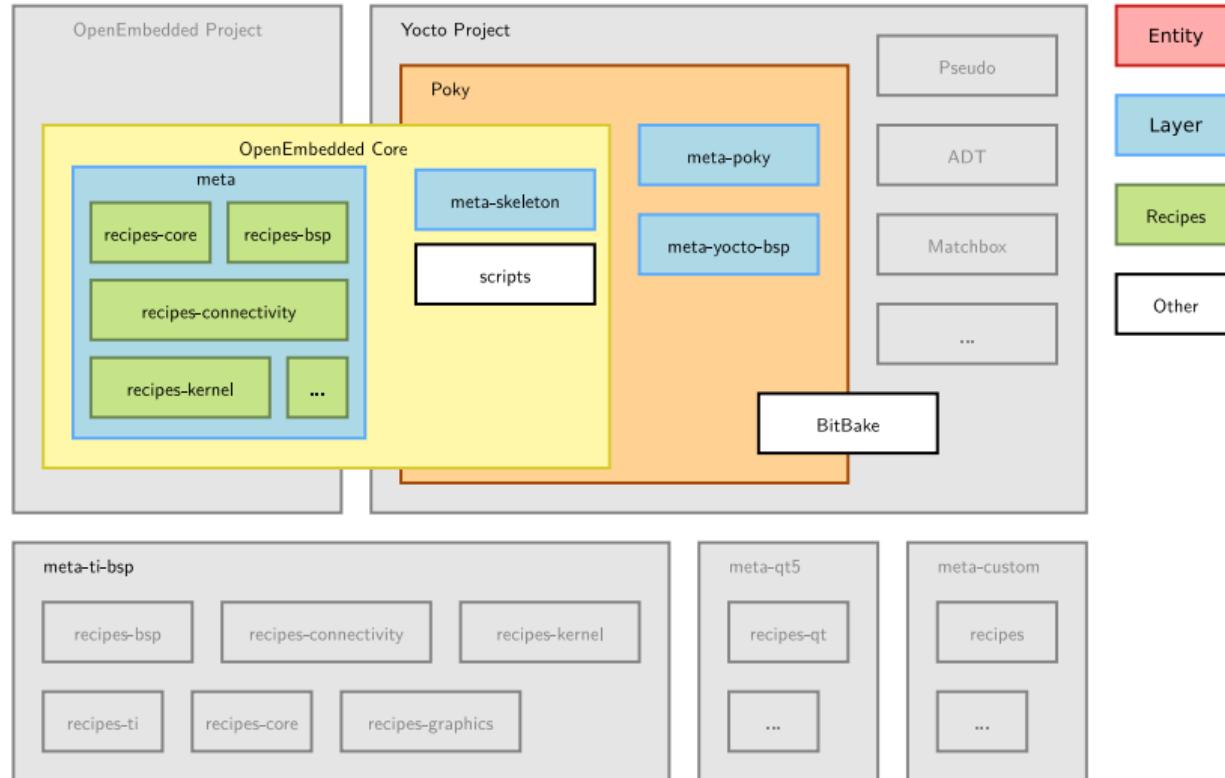


Getting the Poky reference system

- ▶ All official projects part of the Yocto Project are available at
<https://git.yoctoproject.org/>
- ▶ To download the Poky reference system:
`git clone -b kirkstone https://git.yoctoproject.org/git/poky`
- ▶ A new version is released every 6 months, and maintained for 7 months
- ▶ **LTS** versions are maintained for 2 years, and announced before their release.
- ▶ Each release has a codename such as kirkstone or honister, corresponding to a release number.
 - A summary can be found at <https://wiki.yoctoproject.org/wiki Releases>



Poky





`bitbake/` Holds all scripts used by the BitBake command. Usually matches the stable release of the BitBake project.

`documentation/` All documentation sources for the Yocto Project documentation. Can be used to generate nice PDFs.

`meta/` Contains the OpenEmbedded-Core metadata.

`meta-skeleton/` Contains template recipes for BSP and kernel development.



`meta-poky/` Holds the configuration for the Poky reference distribution.

`meta-yocto-bsp/` Configuration for the Yocto Project reference hardware board support package.

`LICENSE` The license under which Poky is distributed (a mix of GPLv2 and MIT).

`oe-init-build-env` Script to set up the OpenEmbedded build environment. It will create the build directory.

`scripts/` Contains scripts used to set up the environment, development tools, and tools to flash the generated images on the target.



- ▶ Documentation for the current sources, compiled as a "mega manual", is available at: <https://docs.yoctoproject.org/singleindex.html>
- ▶ Variables in particular are described in the variable glossary:
<https://docs.yoctoproject.org/genindex.html>

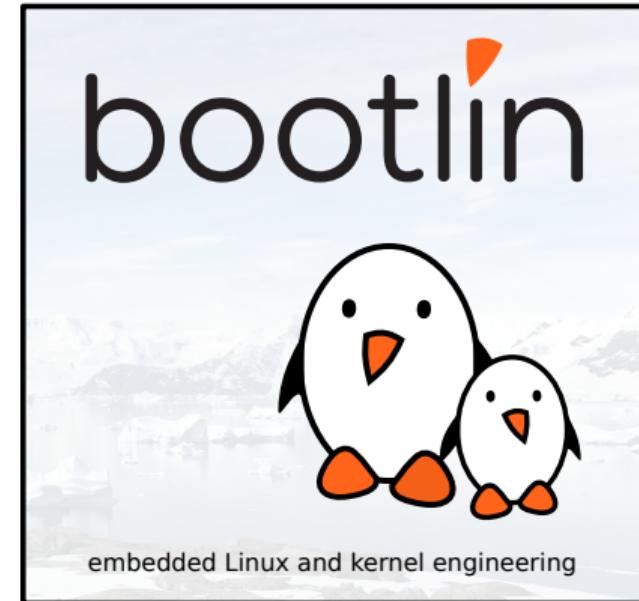


Using Yocto Project - basics

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Corrections, suggestions, contributions and translations are welcome!





Environment setup



- ▶ All Poky files are left unchanged when building a custom image.
- ▶ Specific configuration files and build repositories are stored in a separate build directory.
- ▶ A script, `oe-init-build-env`, is provided to set up the build directory and the environment variables (needed to be able to use the `bitbake` command for example).



- ▶ Modifies the environment: has to be sourced!
- ▶ Adds environment variables, used by the build engine.
- ▶ Allows you to use commands provided in Poky.
- ▶ `source ./oe-init-build-env [builddir]`
- ▶ Sets up a basic build directory, named `builddir` if it is not found. If not provided, the default name is `build`.



- ▶ Common targets are listed when sourcing the script:

`core-image-minimal` A small image to boot a device and have access to core command line commands and services.

`core-image-sato` Image with Sato support. Sato is a GNOME mobile-based user interface.

`meta-toolchain` Generates the cross-toolchain in an installable format.

`meta-ide-support` Generates the cross-toolchain and additional tools (gdb, qemu, ...) for IDE integration.



Exported environment variables

BUILDDIR Absolute path of the build directory.

PATH Contains the directories where executable programs are located.
Absolute paths to scripts/ and bitbake/bin/ are prepended.



Available commands

- bitbake** The main build engine command. Used to perform tasks on available recipes (download, configure, compile...).
- bitbake-*** Various specific commands related to the BitBake build engine.



The build/ directory 1/2

- `conf/` Configuration files. Image specific and layer configuration.
- `downloads/` Downloaded upstream tarballs of the recipes used in the builds.
- `sstate-cache/` Shared state cache. Used by all builds.
- `tmp/` Holds all the build system outputs.



The build/ directory 2/2

- tmp/work/** Set of specific work directories, split by architecture. They are used to unpack, configure and build the packages. Contains the patched sources, generated objects and logs.
- tmp/sysroots/** Shared libraries and headers used to compile applications for the target but also for the host.
- tmp/deploy/** Final output of the build.
- tmp/deploy/images/** Contains the complete images built by the OpenEmbedded build system. These images are used to flash the target.
- tmp/buildstats/** Build statistics for all packages built (CPU usage, elapsed time, host, timestamps...).



Configuring the build system



The build/conf/ directory

- ▶ The conf/ directory in the build one holds build specific configuration.
 - `bblayers.conf` Explicitly list the layers to use.
 - `local.conf` Set up the configuration variables relative to the current user for the build. Configuration variables can be overridden there.



Configuring the build

- ▶ The `conf/local.conf` configuration file holds local user configuration variables:
 - `BB_NUMBER_THREADS` How many tasks BitBake should perform in parallel.
Defaults to the number of CPU threads on the system.
 - `PARALLEL_MAKE` How many processes should be used when compiling.
Defaults to the number of CPU threads on the system.
 - `MACHINE` The machine the target is built for, e.g. `beaglebone`.



Building an image



- ▶ The compilation is handled by the BitBake *build engine*.
- ▶ Usage: `bitbake [options] [recipename/target ...]`
- ▶ To build a target: `bitbake [target]`
- ▶ Building a minimal image: `bitbake core-image-minimal`
 - This will run a full build for the selected target.



Practical lab - First Yocto build



- ▶ Download the sources
- ▶ Set up the environment
- ▶ Configure the build
- ▶ Build an image

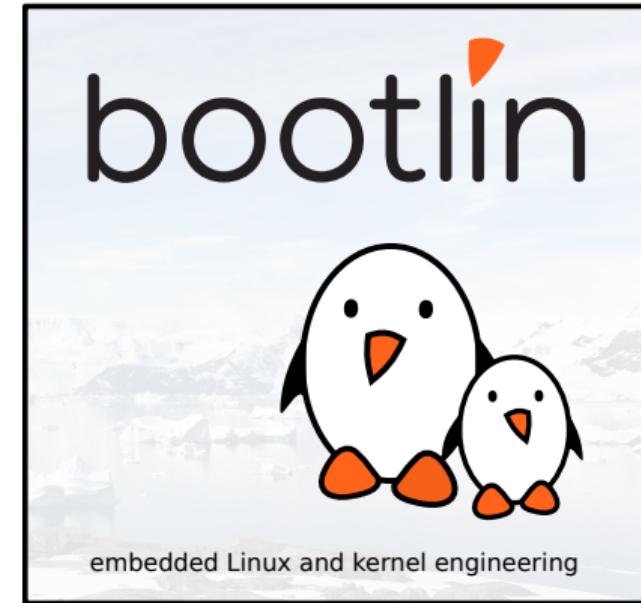


Using Yocto Project - advanced usage

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- ▶ Variable operators and overrides.
- ▶ Select package variants.
- ▶ Manually add packages to the generated image.
- ▶ Run specific tasks with BitBake.



A little reminder

- ▶ *Recipes* describe how to fetch, configure, compile and install applications.
- ▶ These tasks can be run independently (if their dependencies are met).
- ▶ All available packages in Poky are not selected by default in the images.
- ▶ Some packages may provide the same functionality, e.g. OpenSSH and Dropbear.



Variables



- ▶ The OpenEmbedded build system uses configuration *variables* to hold information.
- ▶ Variable *names* are in upper-case by convention, e.g. CONF_VERSION
- ▶ Variable *values* are strings
- ▶ To make configuration easier, it is possible to prepend, append or define these variables in a conditional way.
- ▶ Variables defined in **Configuration Files** have a **global** scope
 - Files ending in .conf
- ▶ Variables defined in **Recipes** have a **local** scope
 - Files ending in .bb, .bbappend and .bbclass
- ▶ Recipes can also access the global scope
- ▶ All variables can be overridden or modified in \$BUILDDIR/conf/local.conf



- ▶ Various operators can be used to assign values to configuration variables:
 - = expand the value when using the variable
 - := immediately expand the value
 - += append (with space)
 - =+ prepend (with space)
 - .= append (without space)
 - =. prepend (without space)
 - ?= assign if no other value was previously assigned
 - ??= same as previous, with a lower precedence



Operators caveats

- ▶ The operators apply their effect during parsing
- ▶ Example:

```
VAR ?= "a"  
VAR += "b"
```

Result: VAR = "a b"

```
VAR += "b"  
VAR ?= "a"
```

Result: VAR = "b"

- ▶ The parsing order of files is difficult to predict, no assumption should be made about it.
- ▶ To avoid the problem, avoid using +=, =+, .= and =. in
\$BUILDDIR/conf/local.conf. Always use overrides (see following slides).



- ▶ Bitbake **overrides** allow appending, prepending or modifying a variable at expansion time, when the variable's value is read
- ▶ Overrides are written as `<VARIABLE>:<override> = "some_value"`
- ▶ A different syntax was used before **Honister**, with no retrocompatibility:
`<VARIABLE>_<override> = "some_value"`



Overrides to modify variable values

- ▶ The append override adds **at the end** of the variable (without space).
 - `IMAGE_INSTALL:append = " dropbear"` adds dropbear to the packages installed on the image.
- ▶ The prepend override adds **at the beginning** of the variable (without space).
 - `FILESEXTRAPATHS:prepend := "${THISDIR}/${PN}:"` adds the folder to the set of paths where files are located (in a recipe).
- ▶ The remove override removes all occurrences of a value within a variable.
 - `IMAGE_INSTALL:remove = "i2c-tools"`



Overrides for conditional assignment

- ▶ Append the machine name to only define a configuration variable for a given machine.
- ▶ It tries to match with values from `OVERRIDES` which includes `MACHINE`, `SOC_FAMILY`, and more.
- ▶ If the override is in `OVERRIDES`, the assignment is applied, otherwise it is ignored.

```
OVERRIDES="arm:armv7a:ti-soc:ti33x:beaglebone:poky"
```

```
KERNEL_DEVICETREE:beaglebone = "am335x-bone.dtb" # This is applied  
KERNEL_DEVICETREE:dra7xx-evm = "dra7-evm.dtb"      # This is ignored
```



Combining overrides 1/2

- ▶ The previous methods can be combined.
- ▶ If we define:
 - IMAGE_INSTALL = "busybox mtd-utils"
 - IMAGE_INSTALL:append = " dropbear"
 - IMAGE_INSTALL:append:beaglebone = " i2c-tools"
- ▶ The resulting configuration variable will be:
 - IMAGE_INSTALL = "busybox mtd-utils dropbear i2c-tools" if the machine being built is beaglebone.
 - IMAGE_INSTALL = "busybox mtd-utils dropbear" otherwise.



Combining overrides 2/2

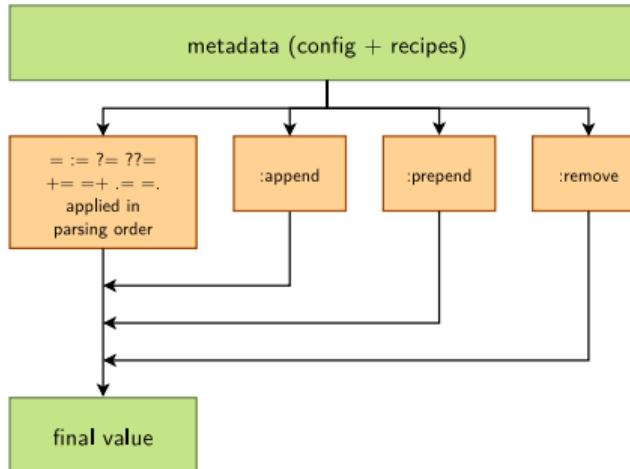
- ▶ The most specific variable takes precedence.
- ▶ Example:

```
IMAGE_INSTALL:beaglebone = "busybox mtd-utils i2c-tools"  
IMAGE_INSTALL = "busybox mtd-utils"
```

- ▶ If the machine is beaglebone:
 - IMAGE_INSTALL = "busybox mtd-utils i2c-tools"
- ▶ Otherwise:
 - IMAGE_INSTALL = "busybox mtd-utils"



Order of variable assignment



1. All the operators are applied, in parsing order
2. :append overrides are applied
3. :prepend overrides are applied
4. :remove overrides are applied



Packages variants



Introduction to package variants

- ▶ Some packages have the same purpose, and only one can be used at a time.
- ▶ The build system uses **virtual packages** to reflect this. A virtual package describes functionalities and several packages may provide it.
- ▶ Only one of the packages that provide the functionality will be compiled and integrated into the resulting image.



- ▶ The virtual packages are often in the form `virtual/<name>`
- ▶ Example of available virtual packages with some of their variants:
 - `virtual/bootloader`: `u-boot`, `u-boot-ti-staging...`
 - `virtual/kernel`: `linux-yocto`, `linux-yocto-tiny`, `linux-yocto-rt`, `linux-ti-staging...`
 - `virtual/libc`: `glibc`, `musl`, `newlib`
 - `virtual/xserver`: `xserver-xorg`



- ▶ Variants are selected thanks to the `PREFERRED_PROVIDER` configuration variable.
- ▶ The package names **have to** suffix this variable.
- ▶ Examples:
 - `PREFERRED_PROVIDER_virtual/kernel ?= "linux-ti-staging"`
 - `PREFERRED_PROVIDER_virtual/libgl = "mesa"`



Version selection

- ▶ By default, Bitbake will try to build the provider with the highest version number, from the highest priority layer, unless the recipe defines
`DEFAULT_PREFERENCE = "-1"`
- ▶ When multiple package versions are available, it is also possible to explicitly pick a given version with `PREFERRED_VERSION`.
- ▶ The package names **have to** suffix this variable.
- ▶ **%** can be used as a wildcard.
- ▶ Example:
 - `PREFERRED_VERSION_nginx = "1.20.1"`
 - `PREFERRED_VERSION_linux-yocto = "5.14%"`



Packages



- ▶ The set of packages installed into the image is defined by the target you choose (e.g. `core-image-minimal`).
- ▶ It is possible to have a custom set by defining our own target, and we will see this later.
- ▶ When developing or debugging, adding packages can be useful, without modifying the recipes.
- ▶ Packages are controlled by the `IMAGE_INSTALL` configuration variable.



- ▶ The list of packages to install is also filtered using the PACKAGE_EXCLUDE variable.
- ▶ If you choose to not install a package using this variable and some other package is dependent on it (i.e. listed in a recipe's RDEPENDS variable), the OpenEmbedded build system generates a fatal installation error.
- ▶ This only works with RPM and IPK packages.



The power of BitBake



Common BitBake options

- ▶ BitBake can be used to run a full build for a given target with `bitbake [target]`
 - target is a recipe name, possibly with modifiers, e.g. `-native`
 - `bitbake ncurses`
 - `bitbake ncurses-native`
- ▶ But it can be more precise, with optional options:
 - `-c <task>` execute the given task
 - `-s` list all locally available recipes and their versions
 - `-f` force the given task to be run by removing its stamp file
 - `world` keyword for all recipes
 - `-b <recipe>` execute tasks from the given recipe (without resolving dependencies).



BitBake examples

- ▶ `bitbake -c listtasks virtual/kernel`
 - Gives a list of the available tasks for the recipe providing the package `virtual/kernel`. Tasks are prefixed with `do_`.
- ▶ `bitbake -c menuconfig virtual/kernel`
 - Execute the task `menuconfig` on the recipe providing the `virtual/kernel` package.
- ▶ `bitbake -f dropbear`
 - Force the `dropbear` recipe to run all tasks.
- ▶ `bitbake --runall=fetch core-image-minimal`
 - Download all recipe sources and their dependencies.
- ▶ For a full description: `bitbake --help`



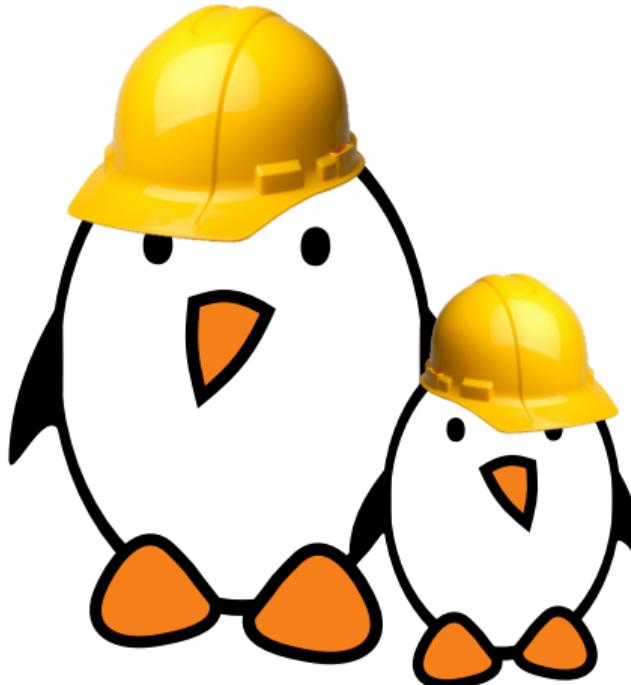
shared state cache

- ▶ BitBake stores the output of each task in a directory, the shared state cache. Its location is controlled by the `SSTATE_DIR` variable.
- ▶ This cache is used to speed up compilation.
- ▶ Over time, as you compile more recipes, it can grow quite big. It is possible to clean old data with:

```
$ ./poky/scripts/sstate-cache-management.sh -y -d \
--cache-dir=sstate-cache/
```



Practical lab - Advanced Yocto configuration



- ▶ Modify the build configuration
- ▶ Customize the package selection
- ▶ Experiment with BitBake
- ▶ Mount the root file system over NFS



Writing recipes - basics

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Corrections, suggestions, contributions and translations are welcome!

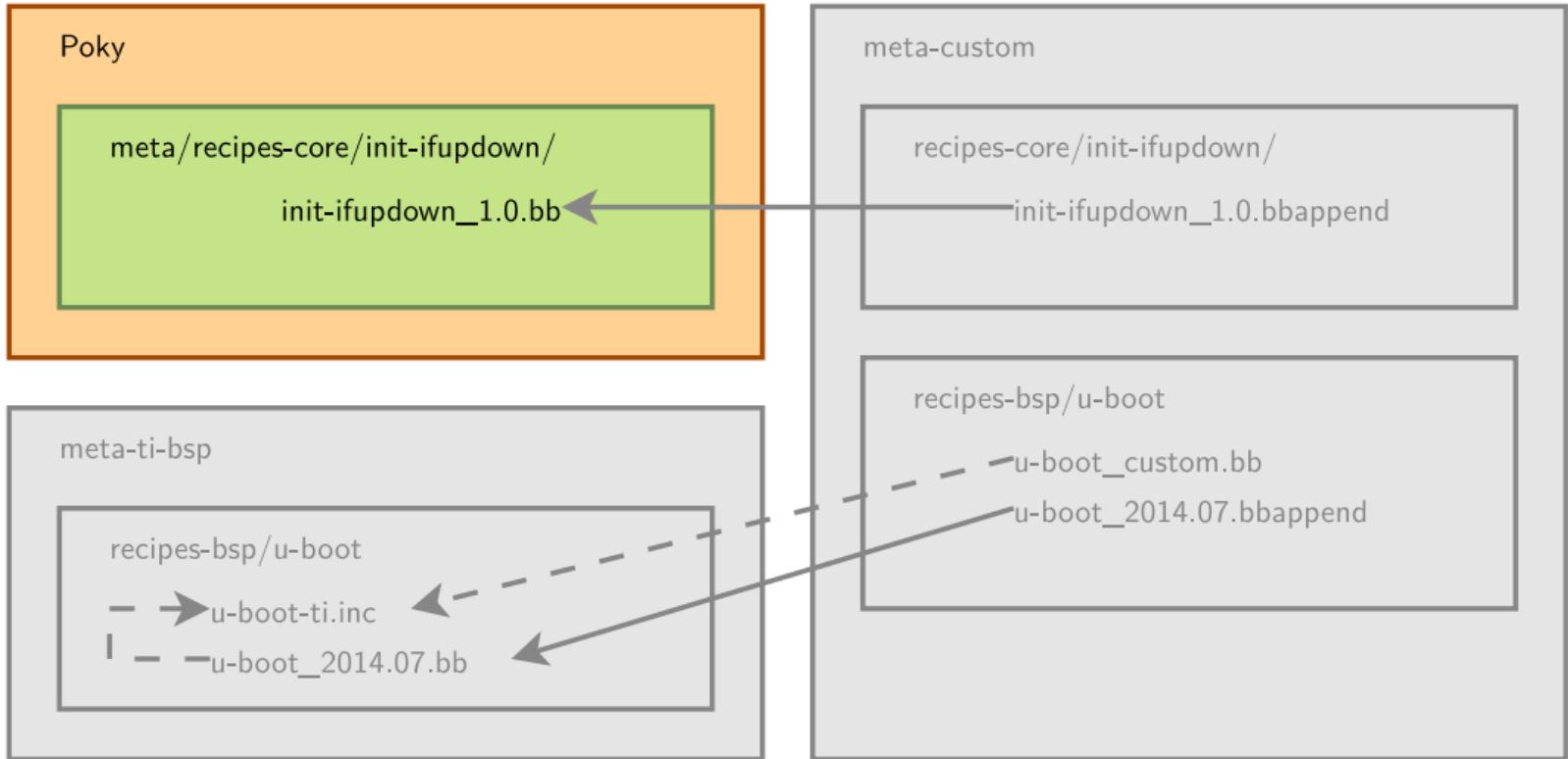




Recipes: overview



Recipes





- ▶ Recipes describe how to handle a given application.
- ▶ A recipe is a set of instructions to describe how to retrieve, patch, compile, install and generate binary packages for a given application.
- ▶ It also defines what build or runtime dependencies are required.
- ▶ The recipes are parsed by the BitBake build engine.
- ▶ The format of a recipe file name is <application-name>_<version>.bb



Content of a recipe

- ▶ A recipe contains configuration variables: name, license, dependencies, path to retrieve the source code...
- ▶ It also contains functions that can be run (fetch, configure, compile...) which are called **tasks**.
- ▶ Tasks provide a set of actions to perform.
- ▶ Remember the `bitbake -c <task> <target>` command?



Common variables

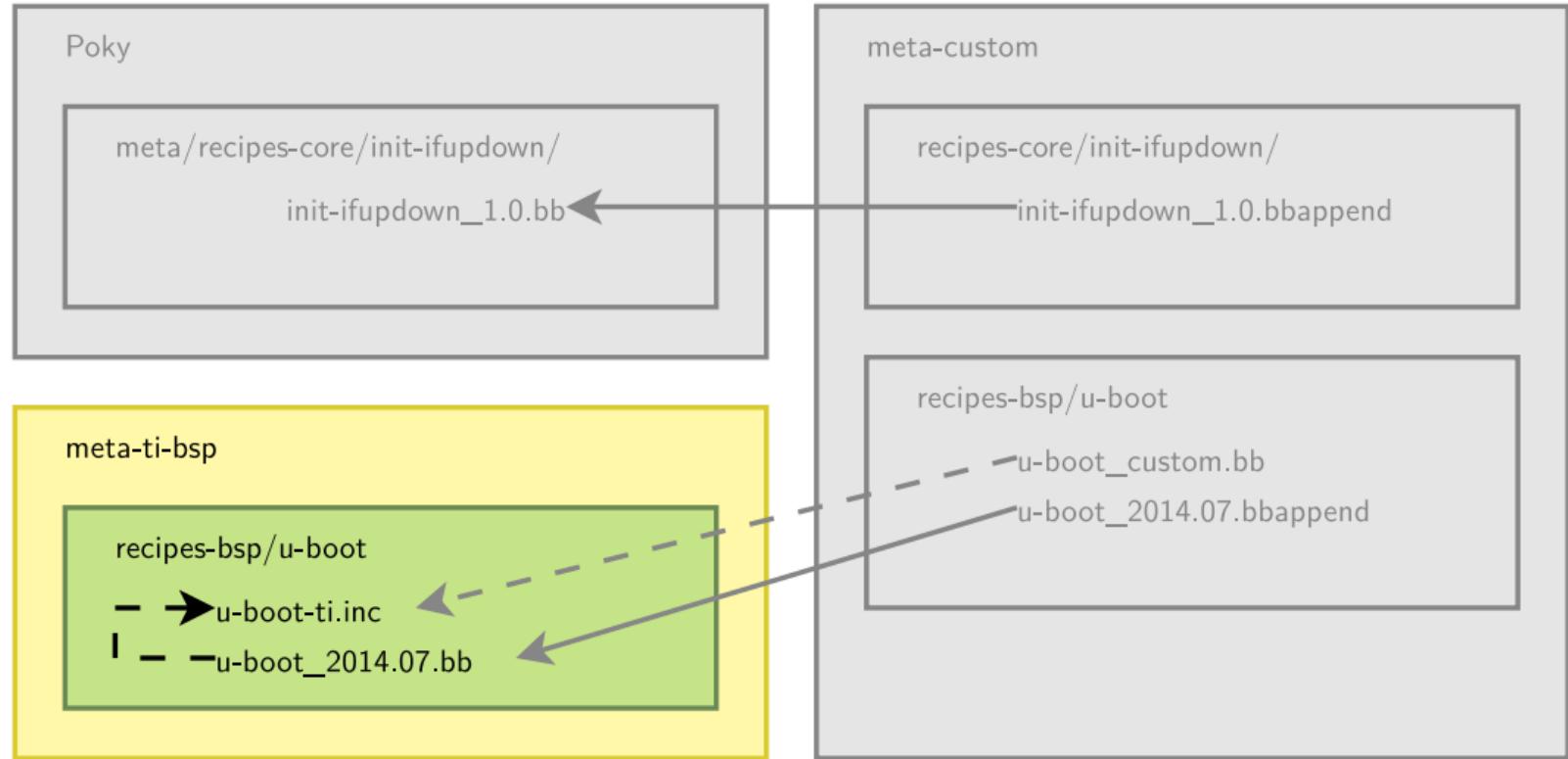
- ▶ To make it easier to write a recipe, some variables are automatically available:
 - PN** package name, as specified in the recipe file name
 - BPN** PN with prefixes and suffixes removed such as nativesdk-, or -native
 - PV** package version, as specified in the recipe file name
 - PR** package revision, defaults to r0
 - BP** defined as \${BPN}-\${PV}
- ▶ The recipe name and version usually match the upstream ones.
- ▶ When using the recipe `bash_5.1.bb`:
 - \${PN} = "bash"
 - \${PV} = "5.1"



Organization of a recipe



Organization of a recipe





Organization of a recipe

- ▶ Many applications have more than one recipe, to support different versions. In that case the common metadata is included in each version specific recipe and is in a .inc file:
 - <application>.inc: version agnostic metadata.
 - <application>_<version>.bb: require <application>.inc and version specific metadata.
- ▶ We can divide a recipe into three main parts:
 - The header: what/who
 - The sources: where
 - The tasks: how



- ▶ Configuration variables to describe the application:
 - DESCRIPTION** describes what the software is about
 - HOMEPAGE** URL to the project's homepage
 - PRIORITY** defaults to optional
 - SECTION** package category (e.g. console/utils)
 - LICENSE** the application's license, using SPDX identifiers
(<https://spdx.org/licenses/>)



The source locations: overview

- ▶ We need to retrieve both the raw sources from an official location and the resources needed to configure, patch or install the application.
- ▶ SRC_URI defines where and how to retrieve the needed elements. It is a set of URI schemes pointing to the resource locations (local or remote).
- ▶ URI scheme syntax: scheme://url;param1;param2
- ▶ scheme can describe a local file using file:// or remote locations with https://, git://, svn://, hg://, ftp://...
- ▶ By default, sources are fetched in \$BUILDDIR/downloads. Change it with the DL_DIR variable in conf/local.conf



The source locations: remote files 1/2

► The git scheme:

- `git://<url>;protocol=<protocol>;branch=<branch>`
- When using git, it is necessary to also define SRCREV. It has to be a commit hash and not a tag to be able to do offline builds. The branch parameter is mandatory unless nobranch=1 is used.

► The http, https and ftp schemes:

- `https://example.com/application-1.0.tar.bz2`
- A few variables are available to help pointing to remote locations:
 `${SOURCEFORGE_MIRROR}, ${GNU_MIRROR}, ${KERNELORG_MIRROR}...`
- Example: `${SOURCEFORGE_MIRROR}/<project-name>/${BPN}-${PV}.tar.gz`
- See `meta/conf/bitbake.conf`



The source locations: remote files 2/2

- ▶ An md5 or an sha256 sum must be provided when the protocol used to retrieve the file(s) does not guarantee their integrity. This is the case for https, http or ftp.

```
SRC_URI[md5sum] = "97b2c3fb082241ab5c56ab728522622b"
```

```
SRC_URI[sha256sum] = "..."
```

- ▶ It's possible to use checksums for more than one file, using the name parameter:

```
SRC_URI = "http://example.com/src.tar.bz2;name=tarball \
           http://example.com/fixes.patch;name=patch"
```

```
SRC_URI[tarball.md5sum] = "97b2c3fb082241ab5c56..."
```

```
SRC_URI[patch.md5sum] = "b184acf9eb39df794ffd..."
```



The source locations: local files

- ▶ All local files found in SRC_URI are copied into the recipe's working directory, in \$BUILDDIR/tmp/work/.
- ▶ The searched paths are defined in the FILESPATH variable.

```
FILESPATH = "${@base_set_filespath(["${FILE_DIRNAME}/${BP}",  
"${FILE_DIRNAME}/${BPN}", "${FILE_DIRNAME}/files"], d)}
```

```
FILESOVERRIDES = "${TRANSLATED_TARGET_ARCH}:  
${MACHINEOVERRIDES}:${DISTROOVERRIDES}"
```

- ▶ The base_set_filespath(path) function uses its path parameter, FILESEXTRAPATHS and FILESOVERRIDES to fill the FILESPATH variable.
- ▶ Custom paths and files can be added using FILESEXTRAPATHS and FILESOVERRIDES.
- ▶ Prepend the paths, as the order matters.



The source locations: tarballs

- ▶ When extracting a tarball, BitBake expects to find the extracted files in a directory named <application>-<version>. This is controlled by the S variable. If the directory has another name, you must explicitly define S.
- ▶ If the scheme is git, S must be set to \${WORKDIR}/git



The source locations: license files

- ▶ License files must have their own checksum.
- ▶ LIC_FILES_CHKSUM defines the URI pointing to the license file in the source code as well as its checksum.

```
LIC_FILES_CHKSUM = "file://gpl.txt;md5=393a5ca..."  
LIC_FILES_CHKSUM = \  
    "file://main.c;beginline=3;endline=21;md5=58e..."  
LIC_FILES_CHKSUM = \  
    "file://${COMMON_LICENSE_DIR}/MIT;md5=083..."
```

- ▶ This allows to track any license update: if the license changes, the build will trigger a failure as the checksum won't be valid anymore.



- ▶ A recipe can have dependencies during the build or at runtime. To reflect these requirements in the recipe, two variables are used:

DEPENDS List of the recipe build-time dependencies.

RDEPENDS List of the package runtime dependencies. Must be package specific (e.g. with :\${PN}).

- ▶ DEPENDS = "recipe-b": the local `do_prepare_recipe_sysroot` task depends on the `do_populate_sysroot` task of recipe-b.
- ▶ RDEPENDS:\${PN} = "package-b": the local `do_build` task depends on the `do_package_write_<archive-format>` task of recipe b.



Dependencies 2/2

- ▶ Sometimes a recipe have dependencies on specific versions of another recipe.
- ▶ BitBake allows to reflect this by using:
 - DEPENDS = "recipe-b (>= 1.2)"
 - RDEPENDS:\${PN} = "recipe-b (>= 1.2)"
- ▶ The following operators are supported: =, >, <, >= and <=.
- ▶ A graphical tool can be used to explore dependencies or reverse dependencies:
 - `bitbake -g -u taskexp core-image-minimal`



Default tasks already exists, they are defined in classes:

- ▶ do_fetch
- ▶ do_unpack
- ▶ do_patch
- ▶ do_configure
- ▶ do_compile
- ▶ do_install
- ▶ do_package
- ▶ do_rootfs

You can get a list of existing tasks for a recipe with:

```
bitbake <recipe> -c listtasks
```



Writing tasks 1/2

- ▶ Functions use the sh shell syntax, with available OpenEmbedded variables and internal functions available.

WORKDIR the recipe's working directory

- S The directory where the source code is extracted
- B The directory where bitbake places the objects generated during the build
- D The destination directory (root directory of where the files are installed, before creating the image).

- ▶ Syntax of a task:

```
do_task() {  
    action0  
    action1  
    ...  
}
```



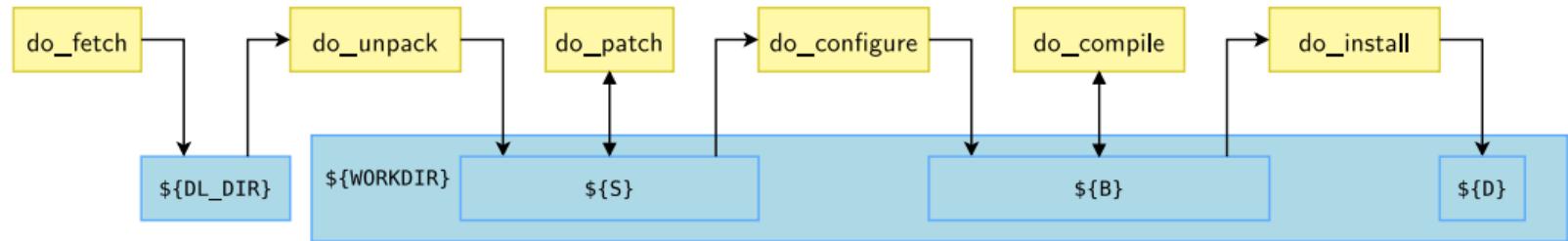
Writing tasks 2/2

► Example:

```
do_compile() {  
    oe_runmake  
}  
  
do_install() {  
    install -d ${D}${bindir}  
    install -m 0755 hello ${D}${bindir}  
}
```



The main tasks





Modifying existing tasks

Tasks can be extended with :prepend or :append

```
do_install:append() {
    install -d ${D}${sysconfdir}
    install -m 0644 hello.conf ${D}${sysconfdir}
}
```



Adding new tasks

Tasks can be added with addtask

```
do_mkimage () {  
    uboot-mkimage ...  
}
```

```
addtask do_mkimage after do_compile before do_install
```



Applying patches



Patches can be applied to resolve build-system problematics:

- ▶ To support old versions of a software: bug and security fixes.
- ▶ To fix cross-compilation issues.
 - In certain simple cases the `-e` option of `make` can be used.
 - The `-e` option gives variables taken from the environment precedence over variables from Makefiles.
 - Helps when an upstream Makefile uses hardcoded `CC` and/or `CFLAGS`.
- ▶ To apply patches before they get their way into the upstream version.



The source locations: patches

- ▶ Files ending in .patch, .diff or having the apply=yes parameter will be applied after the sources are retrieved and extracted, during the do_patch task.

```
SRC_URI += "file://joystick-support.patch \
            file://smp-fixes.diff \
            "
```

- ▶ Patches are applied in the order they are listed in SRC_URI.
- ▶ It is possible to select which tool will be used to apply the patches listed in SRC_URI variable with PATCHTOOL.
- ▶ By default, PATCHTOOL = 'quilt' in Poky.
- ▶ Possible values: git, patch and quilt.



- ▶ The PATCHRESOLVE variable defines how to handle conflicts when applying patches.
- ▶ It has two valid values:
 - noop: the build fails if a patch cannot be successfully applied.
 - user: a shell is launched to resolve manually the conflicts.
- ▶ By default, PATCHRESOLVE = "noop" in meta-poky.



Example of a recipe



Hello world recipe

```
DESCRIPTION = "Hello world program"
HOMEPAGE = "http://example.net/hello/"
PRIORITY = "optional"
SECTION = "examples"
LICENSE = "GPL-2.0-or-later"

SRC_URI = "git://git.example.com/hello;protocol=https;branch=master"
SRCREV = "2d47b4eb66e705458a17622c2e09367300a7b118"
S = "${WORKDIR}/git"
LIC_FILES_CHKSUM = "file://hello.c;beginline=3;endline=21;md5=58e..."

do_compile() {
    oe_runmake
}
do_install() {
    install -d ${D}${bindir}
    install -m 0755 hello ${D}${bindir}
}
```



Example of a recipe with a version agnostic part



```
SUMMARY = "GNU file archiving program"
HOMEPAGE = "https://www.gnu.org/software/tar/"
SECTION = "base"

SRC_URI = "${GNU_MIRROR}/tar/tar-${PV}.tar.bz2"

do_configure() { ... }

do_compile() { ... }

do_install() { ... }
```



```
require tar.inc

LICENSE = "GPL-2.0-only"
LIC_FILES_CHKSUM = \
    "file://COPYING;md5=59530bdf33659b29e73d4adb9f9f6552"

SRC_URI += "file://avoid_heap_overflow.patch"

SRC_URI[md5sum] = "c6c4f1c075dbf0f75c29737faa58f290"
```



tar_1.26.bb

```
require tar.inc

LICENSE = "GPL-3.0-only"
LIC_FILES_CHKSUM = \
    "file://COPYING;md5=d32239bcb673463ab874e80d47fae504"

SRC_URI[md5sum] = "2cee42a2ff4f1cd4f9298eeeb2264519"
```



Practical lab - Add a custom application



- ▶ Write a recipe for a custom application
- ▶ Integrate it in the image

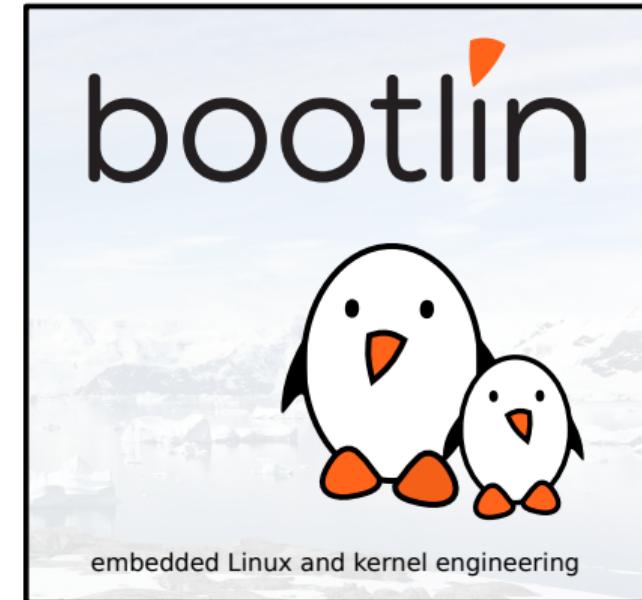


Writing recipes - advanced

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Extending a recipe



Introduction to recipe extensions

- ▶ It is a good practice **not** to modify recipes available in Poky.
- ▶ But it is sometimes useful to modify an existing recipe, to apply a custom patch for example.
- ▶ The BitBake *build engine* allows to modify a recipe by extending it.
- ▶ Multiple extensions can be applied to a recipe.

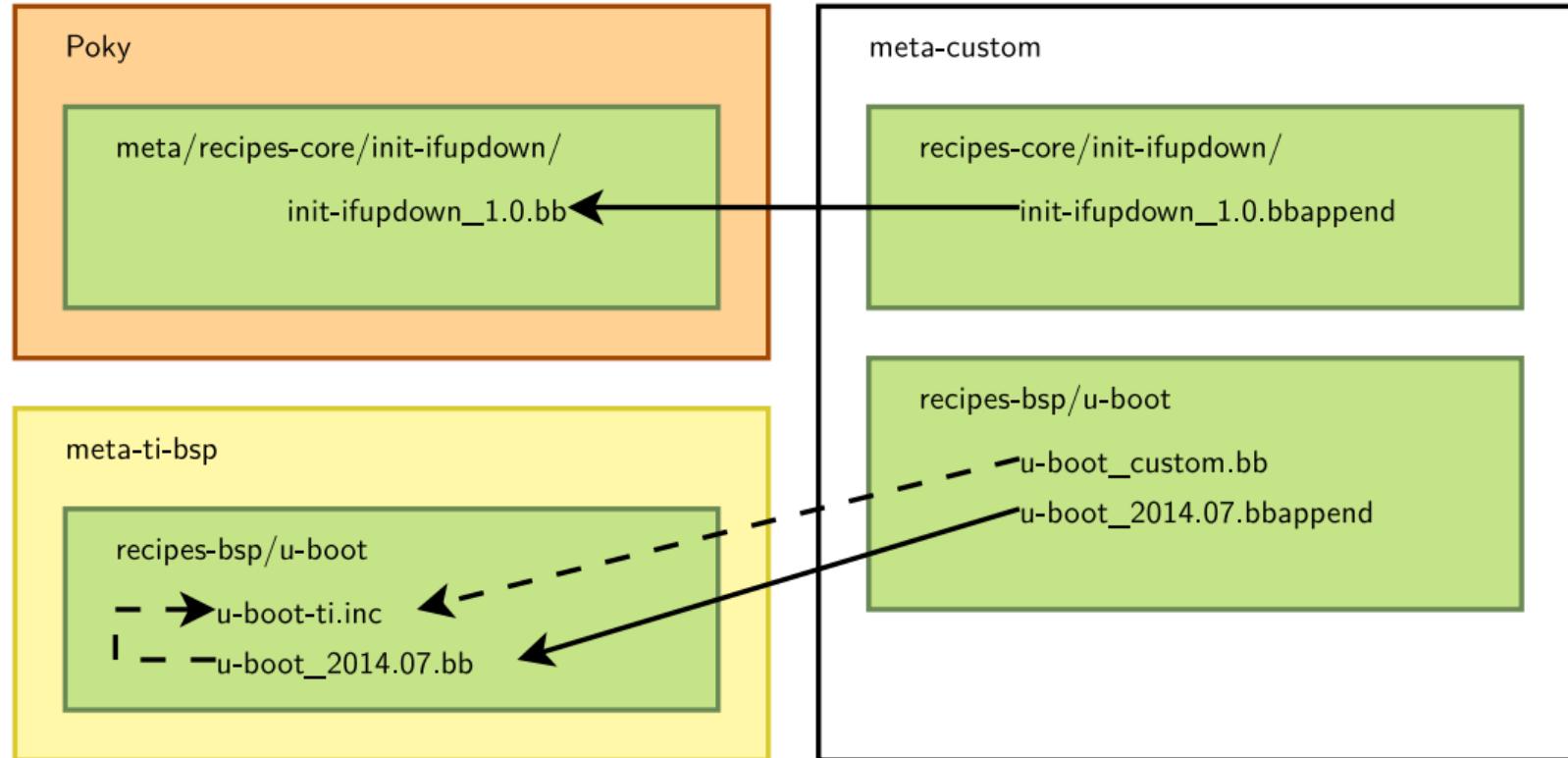


Introduction to recipe extensions

- ▶ Metadata can be changed, added or appended.
- ▶ Tasks can be added or appended.
- ▶ Operators are used extensively, to add, append, prepend or assign values.



Extend a recipe





Extend a recipe

- ▶ The recipe extensions end in `.bbappend`
- ▶ Append files must have the same root name as the recipe they extend, but can also use wildcards.
 - `example_0.1.bbappend` applies to `example_0.1.bb`
 - `example_0.%.bbappend` applies to `example_0.1.bb` and `example_0.2.bb` but not `example_1.0.bb`
- ▶ Append files are **version specific**. If the recipe is updated to a newer version, the append files must also be updated.
- ▶ If adding new files, the path to their directory must be prepended to the `FILESEXTRAPATHS` variable.
 - Files are looked up in paths referenced in `FILESEXTRAPATHS`, from left to right.
 - Prepending a path makes sure it has priority over the recipe's one. This allows to override recipes' files.



Append file example



Hello world append file

```
FILESEXTRAPATHS:prepend := "${THISDIR}/files:  
  
SRC_URI += "file://custom-modification-0.patch \  
           file://custom-modification-1.patch \  
           "
```



Advanced recipe configuration



- ▶ In the real world, more complex configurations are often needed because recipes may:
 - Provide virtual packages
 - Inherit generic functions from classes



Providing virtual packages

- ▶ BitBake allows to use virtual names instead of the actual package name. We saw a use case with *package variants*.
- ▶ The virtual name is specified through the `PROVIDES` variable.
- ▶ Several recipes can provide the same virtual name. Only one will be built and installed into the generated image.
- ▶ `PROVIDES = "virtual/kernel"`



Classes



Introduction to classes

- ▶ Classes provide an abstraction to common code, which can be re-used in multiple recipes.
- ▶ Common tasks do not have to be re-developed!
- ▶ Any metadata and task which can be put in a recipe can be used in a class.
- ▶ Classes extension is .bbclass
- ▶ Classes are located in the classes folder of a layer.
- ▶ Recipes can use this common code by inheriting a class:
 - inherit <class>



Common classes

► Common classes can be found in `meta/classes/`

- `base.bbclass`
- `kernel.bbclass`
- `autotools.bbclass`
- `autotools-brokensep.bbclass`
- `cmake.bbclass`
- `native.bbclass`
- `systemd.bbclass`
- `update-rc.d.bbclass`
- `useradd.bbclass`
- ...



The base class

- ▶ Every recipe inherits the base class automatically.
- ▶ Defines basic common tasks with a default implementation:
 - fetch, unpack, patch
 - configure, compile, install
 - Utility tasks such as: clean, listtasks
- ▶ Automatically applies patch files listed in SRC_URI
- ▶ Defines mirrors: SOURCEFORGE_MIRROR DEBIAN_MIRROR, GNU_MIRROR, KERNELORG_MIRROR...
- ▶ Defines oe_runmake, using EXTRA_OEMAKE to use custom arguments.



The kernel class

- ▶ Used to build Linux kernels.
- ▶ Defines tasks to configure, compile and install a kernel and its modules.
- ▶ The kernel is divided into several packages: kernel, kernel-base, kernel-dev, kernel-modules...
- ▶ Automatically provides the virtual package `virtual/kernel`.
- ▶ Configuration variables are available:
 - `KERNEL_IMAGETYPE`, defaults to `zImage`
 - `KERNEL_EXTRA_ARGS`
 - `INITRAMFS_IMAGE`



The autotools class

- ▶ Defines tasks and metadata to handle applications using the autotools build system (autoconf, automake and libtool):
 - `do_configure`: generates the configure script using `autoreconf` and loads it with standard arguments or cross-compilation.
 - `do_compile`: runs `make`
 - `do_install`: runs `make install`
- ▶ Extra configuration parameters can be passed with `EXTRA_OECONF`.
- ▶ Compilation flags can be added thanks to the `EXTRA_OEMAKE` variable.



Example: use the autotools class

```
DESCRIPTION = "Print a friendly, customizable greeting"
HOMEPAGE = "https://www.gnu.org/software/hello/"
PRIORITY = "optional"
SECTION = "examples"
LICENSE = "GPL-3.0-or-later"

SRC_URI = "${GNU_MIRROR}/hello/hello-${PV}.tar.gz"
SRC_URI[md5sum] = "67607d2616a0faaf5bc94c59dca7c3cb"
SRC_URI[sha256sum] = "ecbb7a2214196c57ff9340aa71458e1559abd38f6d8d169666846935df191ea7"
LIC_FILES_CHKSUM = "file://COPYING;md5=d32239bcb673463ab874e80d47fae504"

inherit autotools
```



The useradd class

- ▶ This class helps to add users to the resulting image.
- ▶ Adding custom users is required by many services to avoid running them as root.
- ▶ `USERADD_PACKAGES` must be defined when the `useradd` class is inherited. Defines the list of packages which needs the user.
- ▶ Users and groups will be created before the packages using it perform their `do_install`.
- ▶ At least one of the two following variables must be set:
 - `USERADD_PARAM`: parameters to pass to `useradd`.
 - `GROUPADD_PARAM`: parameters to pass to `groupadd`.



Example: use the useradd class

```
DESCRIPTION = "useradd class usage example"
PRIORITY = "optional"
SECTION = "examples"
LICENSE = "MIT"

SRC_URI = "file://file0"
LIC_FILES_CHKSUM = "file://${COREBASE}/meta/files/common-licenses/MIT;md5=0835ade698e0bc..."

inherit useradd

USERADD_PACKAGES = "${PN}"
USERADD_PARAM = "-u 1000 -d /home/user0 -s /bin/bash user0"

do_install() {
    install -m 644 file0 ${D}/home/user0/
    chown user0:user0 ${D}/home/user0/file0
}
```



Binary packages



Specifics for binary packages

- ▶ In some cases you only need to install pre-built files into the generated root filesystem
 - E.g.: firmware blobs
- ▶ `bin_package.bbclass` simplifies this
 - Disables `do_configure` and `do_compile`
 - Provides a default `do_install` that copies whatever is in `S` (useful e.g. when extracting a pre-built RPM/DPKG)
- ▶ Additionally you probably need:
 - Remember to set the `LICENSE` to `CLOSED` if applicable
 - You probably should also inherit `allarch`



BitBake file inclusions



Locate files in the build system

- ▶ Metadata can be shared using included files.
- ▶ BitBake uses the BBPATH to find the files to be included. It also looks into the current directory.
- ▶ Three keywords can be used to include files from recipes, classes or other configuration files:
 - inherit
 - include
 - require



The inherit keyword

- ▶ `inherit` can be used in recipes or classes, to inherit the functionalities of a class.
- ▶ To inherit the functionalities of the `kernel` class, use: `inherit kernel`
- ▶ `inherit` looks for files ending in `.bbclass`, in `classes` directories found in `BBPATH`.
- ▶ It is possible to include a class conditionally using a variable: `inherit ${FOO}`



The include and require keywords

- ▶ `include` and `require` can be used in all files, to insert the content of another file at that location.
- ▶ If the path specified on the `include` (or `require`) path is relative, BitBake will insert the first file found in `BBPATH`.
- ▶ `include` does not produce an error when a file cannot be found, whereas `require` raises a parsing error.
- ▶ To include a local file: `require ninvaders.inc`
- ▶ To include a file from another location (which could be in another layer):
`require path/to/file.inc`



Debugging recipes



Debugging recipes

- ▶ For each task, logs are available in the temp directory in the work folder of a recipe. This includes both the actual tasks code that ran and the output of the task.
- ▶ bitbake can dump the whole environment, including the variable values and how they were set:

```
$ bitbake -e ninvaders
# $DEPENDS [4 operations]
#   set /yocto-labs/poky/meta/conf/bitbake.conf:268
#     ""
#   set /yocto-labs/poky/meta/conf/documentation.conf:130
#     [doc] "Lists a recipe's build-time dependencies (i.e. other recipe files)."
#   :prepend /yocto-training/yocto-labs/poky/meta/classes/base.bbclass:74
#     "${BASEDEPENDS} "
#   set /yocto-labs/meta-bootlinlabs/recipes-games/ninvaders/ninvaders.inc:11
#     "ncurses"
# pre-expansion value:
#   "${BASEDEPENDS} ncurses"
DEPENDS="virtual/arm-poky-linux-gnueabi-gcc virtual/arm-poky-linux-gnueabi-compilerlibs virtual/libc ncurses"
```



Debugging recipes

- ▶ A development shell, exporting the full environment can be used to debug build failures:

```
$ bitbake -c devshell <recipe>
```

- ▶ To understand what a change in a recipe implies, you can activate build history in local.conf:

```
INHERIT += "buildhistory"  
BUILDHISTORY_COMMIT = "1"
```

Then use the buildhistory-diff tool to examine differences between two builds.

- buildhistory-diff



Network usage



Source fetching

- ▶ BitBake will look for files to retrieve at the following locations, in order:
 1. `DL_DIR` (the local download directory).
 2. The `PREMIRRORS` locations.
 3. The upstream source, as defined in `SRC_URI`.
 4. The `MIRRORS` locations.
- ▶ If all the mirrors fail, the build will fail.



Mirror configuration in OpenEmbedded-Core

meta/classes/mirrors.bbclass

```
PREMIRRORS += "git://sourceware.org/git/glibc.git      https://downloads.yoctoproject.org/mirror/sources/ \
               git://sourceware.org/git/binutils-gdb.git https://downloads.yoctoproject.org/mirror/sources/"

MIRRORS += "\\\n
svn://.*.*   http://sources.openembedded.org/ \
git://.*.*   http://sources.openembedded.org/ \
https?://.*.* http://sources.openembedded.org/ \
ftp://.*.*   http://sources.openembedded.org/ \
...
"
```



Configuring the premirrors

- ▶ It is easy to add a custom mirror to the PREMIRRORS by using the own-mirrors class (only one URL supported):

```
INHERIT += "own-mirrors"  
SOURCE_MIRROR_URL = "http://example.com/my-mirror"
```

- ▶ For a more complex setup, prepend custom mirrors to the PREMIRRORS variable:

```
PREMIRRORS:prepend = "\\\n    git://.*.* http://example.com/my-mirror-for-git/ \\\n    svn://.*.* http://example.com/my-mirror-for-svn/ \\\n    http://.*.* http://www.yoctoproject.org/sources/ \\\n    https://.*.* http://www.yoctoproject.org/sources/ "
```



Forbidding network access

- ▶ You can use `BB_GENERATE_MIRROR_TARBALLS = "1"` to generate tarballs of the git repositories in `DL_DIR`
- ▶ You can also completely disable network access using `BB_NO_NETWORK = "1"`
 - To download all the sources before disabling network access use
`bitbake --runall=fetch core-image-minimal`
- ▶ Or restrict BitBake to only download files from the PREMIRRORS, using
`BB_FETCH_PREMIRRORONLY = "1"`



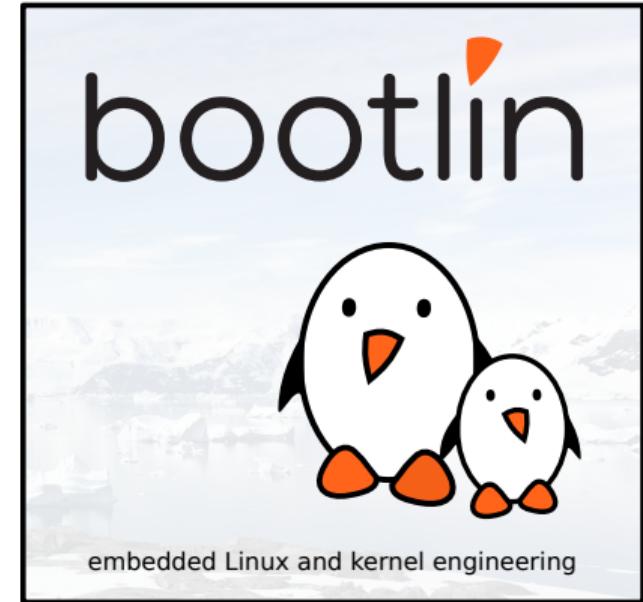
Layers

Layers

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Introduction to layers

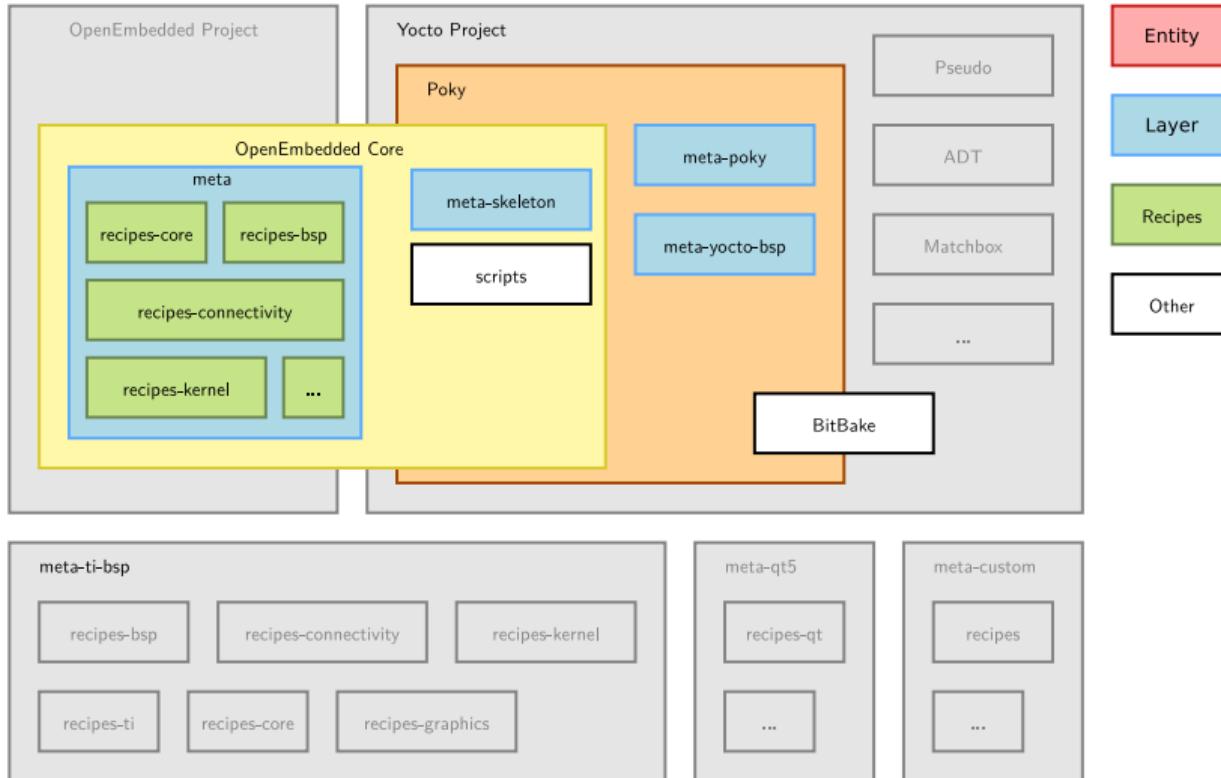


Layers' principles

- ▶ The OpenEmbedded *build system* manipulates *metadata*.
- ▶ Layers allow to isolate and organize the metadata.
 - A layer is a collection of recipes.
- ▶ It is a good practice to begin a layer name with the prefix `meta-`.



Layers in Poky

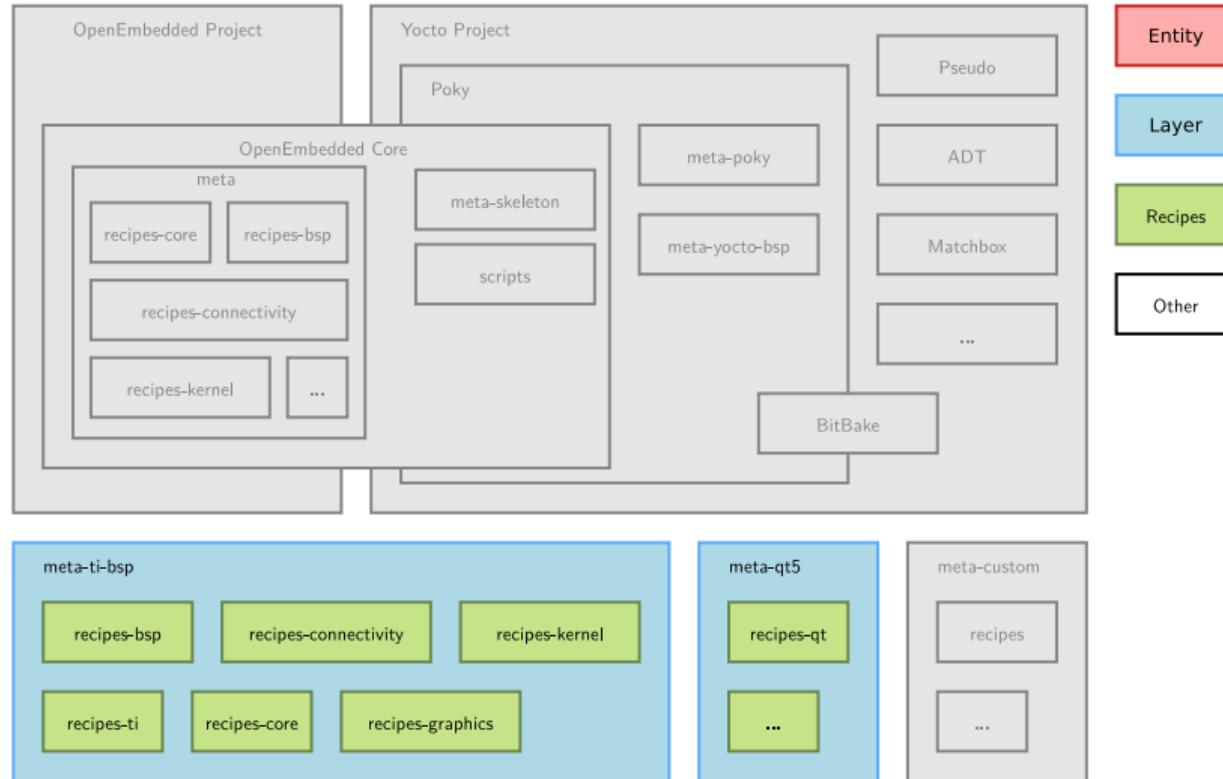




- ▶ The Poky *reference system* is a set of basic common layers:
 - meta
 - meta-skeleton
 - meta-poky
 - meta-yocto-bsp
- ▶ Poky is not a final set of layers. It is the common base.
- ▶ Layers are added when needed.
- ▶ When making modifications to the existing recipes or when adding new ones, it is a good practice not to modify Poky. Instead you can create your own layers!



Third party layers





Integrate and use a layer 1/3

- ▶ A list of existing and maintained layers can be found at
<https://layers.openembedded.org>
- ▶ Instead of redeveloping layers, always check the work hasn't been done by others.
- ▶ It takes less time to download a layer providing a package you need and to add an append file if some modifications are needed than to do it from scratch.



Integrate and use a layer 2/3

- ▶ The location where a layer is saved on the disk doesn't matter.
 - But a good practice is to save it where all others layers are stored.
- ▶ The only requirement is to let BitBake know about the new layer:
 - The list of layers BitBake uses is defined in `$BUILDDIR/conf/bblayers.conf`
 - To include a new layer, add its absolute path to the `BBLAYERS` variable.
 - BitBake parses each layer specified in `BBLAYERS` and adds the recipes, configurations files and classes it contains.



Integrate and use a layer 3/3

- ▶ The bitbake-layers tool is provided alongside bitbake.
- ▶ It can be used to inspect the layers and to manage
\$BUILDDIR/conf/bblayers.conf:
 - bitbake-layers show-layers
 - bitbake-layers add-layer meta-custom
 - bitbake-layers remove-layer meta-qt5



Some useful layers

- ▶ Many SoC specific layers are available, providing support for the boards using these SoCs. Some examples: `meta-ti`, `meta-freescale` and `meta-raspberrypi`.
- ▶ Other layers offer to support applications not available in the Poky reference system:
 - `meta-browser`: web browsers (Chromium, Firefox).
 - `meta-filesystems`: support for additional filesystems.
 - `meta-gstreamer10`: support for GStreamer 1.0.
 - `meta-java` and `meta-oracle-java`: Java support.
 - `meta-linaro-toolchain`: Linaro toolchain recipes.
 - `meta-qt5`: QT5 modules.
 - `meta-realtime`: real time tools and test programs.
 - `meta-telephony` and many more...

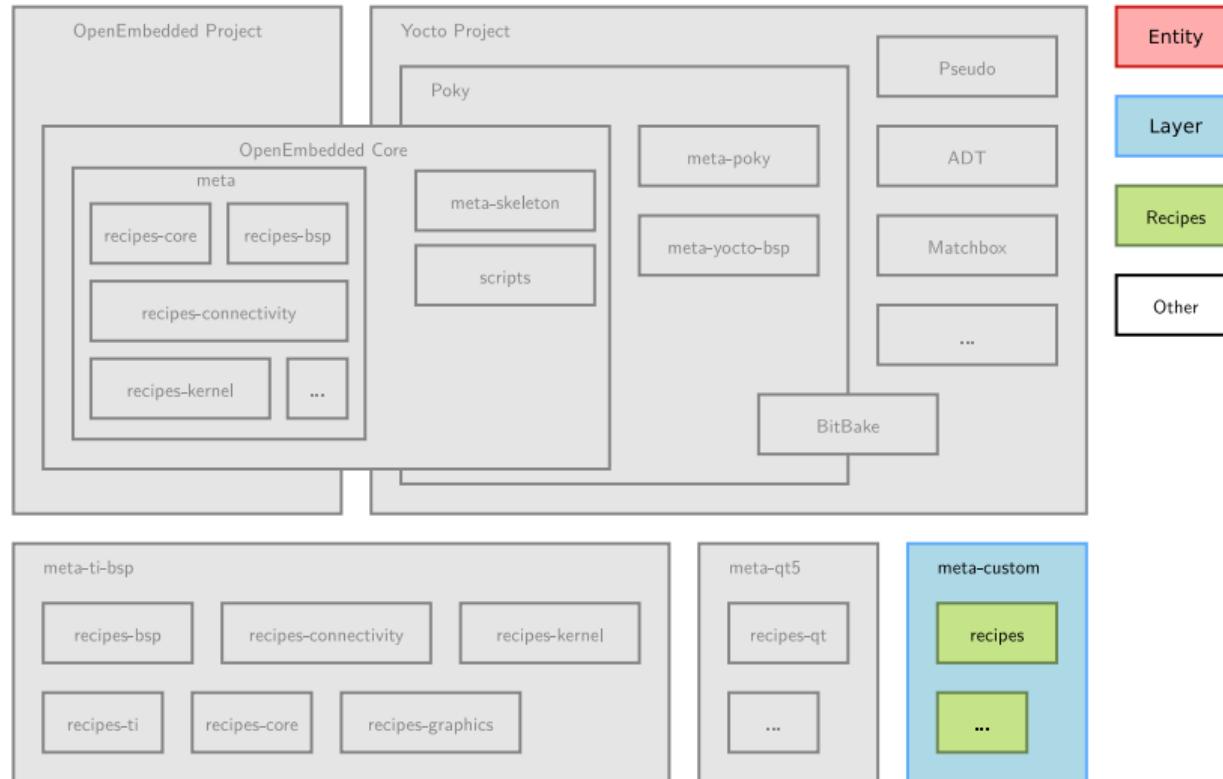
Notice that some of these layers do not come with all the Yocto branches. The `meta-browser` did not have a `krogoth` branch, for example.



Creating a layer



Custom layer





Create a custom layer 1/2

- ▶ A layer is a set of files and directories and can be created by hand.
- ▶ However, the `bitbake-layers create-layer` command helps us create new layers and ensures this is done right.
- ▶ `bitbake-layers create-layer -p <PRIORITY> <layer>`
- ▶ The **priority** is used to select which recipe to use when multiple layers contains the same recipe
- ▶ The recipe priority takes precedence over the version number ordering



Create a custom layer 2/2

- ▶ The layer created will be pre-filled with the following files:
 - `conf/layer.conf` The layer's configuration. Holds its priority and generic information. No need to modify it in many cases.
 - `COPYING.MIT` The license under which a layer is released. By default MIT.
 - `README` A basic description of the layer. Contains a contact e-mail to update.
- ▶ By default, all metadata matching `./recipes-*/*/*.bb` will be parsed by the BitBake *build engine*.

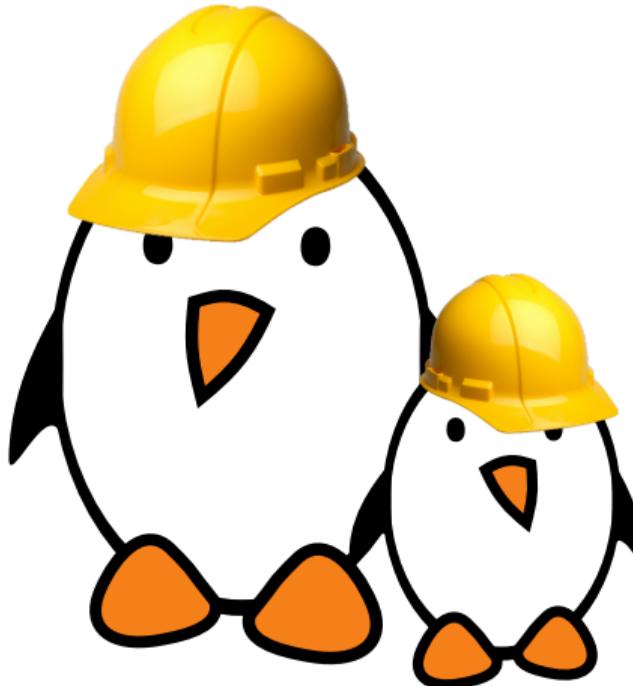


Use a layer: best practices

- ▶ Do not copy and modify existing recipes from other layers. Instead use append files.
- ▶ Avoid duplicating files. Use append files or explicitly use a path relative to other layers.
- ▶ Save the layer alongside other layers.
- ▶ Use LAYERDEPENDS to explicitly define layer dependencies.
- ▶ Use LAYERSERIES_COMPAT to define the Yocto version(s) with which the layer is compatible.



Practical lab - Create a custom layer



- ▶ Create a layer from scratch
- ▶ Add recipes to the new layer
- ▶ Integrate it to the build



Practical lab - Extend a recipe



- ▶ Apply patches to an existing recipe
- ▶ Use a custom configuration file for an existing recipe
- ▶ Extend a recipe to fit your needs

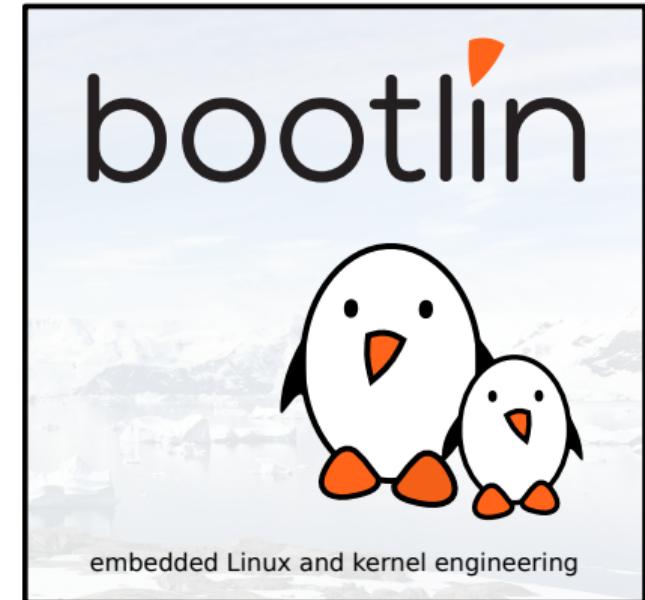


BSP Layers

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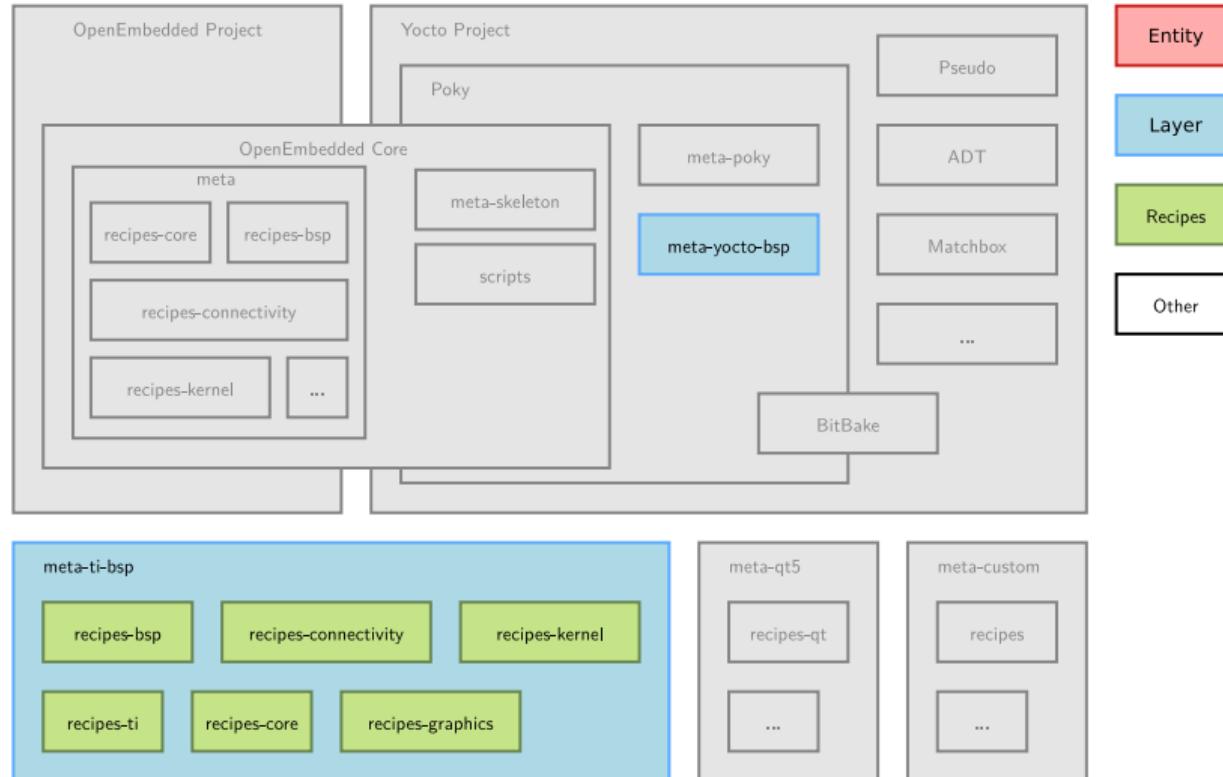




Introduction to BSP layers in the Yocto Project



BSP layers





- ▶ BSP layers are a subset of the layers.
- ▶ They hold metadata with the purpose of supporting a specific class of hardware devices.
- ▶ They usually provide:
 - Hardware configuration files (`machines`)
 - Custom kernel and bootloader recipes and configurations
 - Modules and drivers to enable specific hardware features (e.g. multimedia accelerators)
 - Pre-built user binaries and firmwares
- ▶ A good practice is to name it `meta-<bsp_name>`.



Hardware configuration files



- ▶ A layer provides one machine file (hardware configuration file) per machine it supports.
- ▶ These configuration files are stored under
meta-<bsp_name>/conf/machine/*.conf
- ▶ The file names correspond to the values set in the MACHINE configuration variable.
 - meta-ti/meta-ti-bsp/conf/machine/beaglebone.conf
 - MACHINE = "beaglebone"
- ▶ Each machine should be described in the README file of the BSP.



- ▶ The hardware configuration file contains configuration variables related to the architecture and to the machine features.
- ▶ Some other variables help customize the kernel image or the filesystems used.



Machine configuration

TARGET_ARCH The architecture of the device being built.

PREFERRED_PROVIDER_virtual/kernel The default kernel.

MACHINE_FEATURES List of hardware features provided by the machine, e.g.
usbgadget usbhost screen wifi

SERIAL_CONSOLES Speed and device for the serial console to attach. Used to
configure getty, e.g. 115200;ttyS0

KERNEL_IMAGETYPE The type of kernel image to build, e.g. zImage



- ▶ Lists the hardware features provided by the machine.
- ▶ These features are used by package recipes to enable or disable functionalities.
- ▶ Some packages are automatically added to the resulting root filesystem depending on the feature list.
- ▶ The feature `bluetooth`:
 - Asks the `bluez` daemon to be built and added to the image.
 - Enables bluetooth support in ConnMan.



```
# Common definitions for cfa-10036 boards
include conf/machine/include/imx-base.inc
include conf/machine/include/tune-arm926ejs.inc

SOC_FAMILY = "mxs:mx28:cfa10036"

PREFERRED_PROVIDER_virtual/kernel ?= "linux-cfa"
PREFERRED_PROVIDER_virtual/bootloader ?= "barebox"
IMAGE_BOOTLOADER = "barebox"
BAREBOX_BINARY = "barebox"
IMAGE_FSTYPES:mxs = "tar.bz2 barebox.mxsboot-sdcard sdcard.gz"
IMXBOOTLETS_MACHINE = "cfa10036"

KERNEL_IMAGETYPE = "zImage"
KERNEL_DEVICETREE = "imx28-cfa10036.dtb"
# we need the kernel to be installed in the final image
IMAGE_INSTALL:append = " kernel-image kernel-devicetree"
SDCARD_ROOTFS ?= "${DEPLOY_DIR_IMAGE}/${IMAGE_NAME}.rootfs.ext3"
SERIAL_CONSOLE = "115200 ttyAMA0"
MACHINE_FEATURES = "usbgadget usbhost vfat"
```



```
#@TYPE: Machine
#@NAME: Crystalfontz CFA-10057
#@SOC: i.MX28
#@DESCRIPTION: Machine configuration for CFA-10057, also called CFA-920
#@MAINTAINER: Alexandre Belloni <alexandre.belloni@bootlin.com>

include conf/machine/include/cfa10036.inc

KERNEL_DEVICETREE += "imx28-cfa10057.dtb"

MACHINE_FEATURES += "touchscreen"
```



Bootloader



Default bootloader 1/2

- ▶ By default the bootloader used is the mainline version of U-Boot, with a fixed version (per Poky release).
- ▶ All the magic is done in `meta/recipes-bsp/u-boot/u-boot.inc`
- ▶ Some configuration variables used by the U-Boot recipe can be customized, in the machine file.



SPL_BINARY If an SPL is built, describes the name of the output binary. Defaults to an empty string.

UBOOT_SUFFIX bin (default) or img.

UBOOT_MACHINE The target used to build the configuration.

UBOOT_ENTRYPOINT The bootloader entry point.

UBOOT_LOADADDRESS The bootloader load address.

UBOOT_MAKE_TARGET Make target when building the bootloader. Defaults to all.



Customize the bootloader

- ▶ It is possible to support a custom U-Boot by creating an extended recipe and to append extra metadata to the original one.
- ▶ This works well when using a mainline version of U-Boot.
- ▶ Otherwise it is possible to create a custom recipe.
 - Try to still use `meta/recipes-bsp/u-boot/u-boot.inc`



Kernel



- ▶ There are mainly two ways of compiling a kernel:
 - By creating a custom kernel recipe, inheriting `kernel.bbclass`
 - By using the `linux-yocto` packages, provided in Poky, for very complex needs
- ▶ The kernel used is selected in the machine file thanks to:
`PREFERRED_PROVIDER_virtual/kernel`
- ▶ Its version is defined with: `PREFERRED_VERSION_<kernel_provider>`



- ▶ linux-yocto is a set of recipes with advanced features to build a mainline kernel
- ▶ PREFERRED_PROVIDER_virtual/kernel = "linux-yocto"
- ▶ PREFERRED_VERSION_linux-yocto = "5.14%"



- ▶ Automatically applies a defconfig listed in SRC_URI
- ▶ Automatically applies configuration fragments listed in SRC_URI with a .cfg extension

```
SRC_URI += "file://defconfig      \
            file://nand-support.cfg \
            file://ethernet-support.cfg"
```



- ▶ Another way of configuring linux-yocto is by using *Advanced Metadata*.
- ▶ It is a powerful way of splitting the configuration and the patches into several pieces.
- ▶ It is designed to provide a very configurable kernel, at the cost of higher complexity.
- ▶ The full documentation can be found at
<https://docs.yoctoproject.org/kernel-dev/advanced.html#working-with-advanced-metadata-yocto-kernel-cache>



- ▶ Kernel Metadata is a way to organize and to split the kernel configuration and patches in little pieces each providing support for one feature.
- ▶ Two main configuration variables help taking advantage of this:
LINUX_KERNEL_TYPE standard (default), tiny or preempt-rt
 - standard: generic Linux kernel policy.
 - tiny: bare minimum configuration, for small kernels.
 - preempt-rt: applies the PREEMPT_RT patch.

KERNEL_FEATURES List of features to enable. Features are sets of patches and configuration fragments.



- ▶ Kernel Metadata description files have their own syntax to describe an optional kernel feature
- ▶ A basic feature is defined as a patch to apply and a configuration fragment to add
- ▶ Simple example, features/nunchuk.scc

```
define KFEATURE_DESCRIPTION "Enable Nunchuk driver"
```

```
kconf hardware enable-nunchuk-driver.cfg  
patch Add-nunchuk-driver.patch
```

- ▶ To integrate the feature into the kernel image:
`KERNEL_FEATURES += "features/nunchuk.scc"`



Practical lab - Create a custom machine configuration



- ▶ Write a machine configuration
- ▶ Understand how the target architecture is chosen

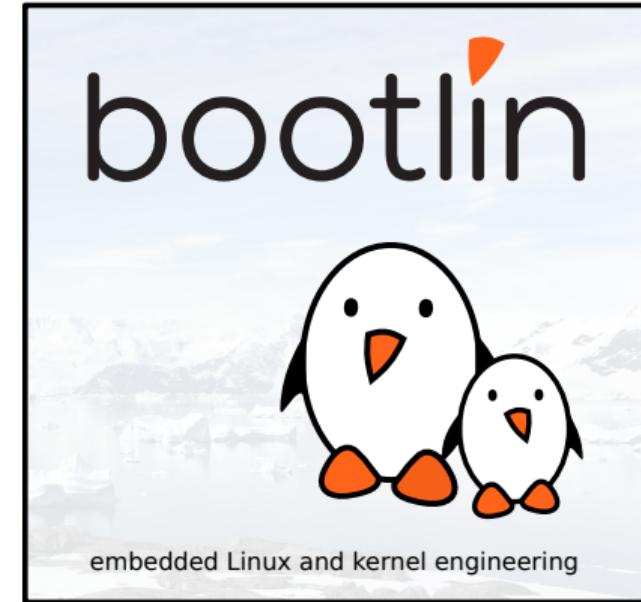


Distro Layers

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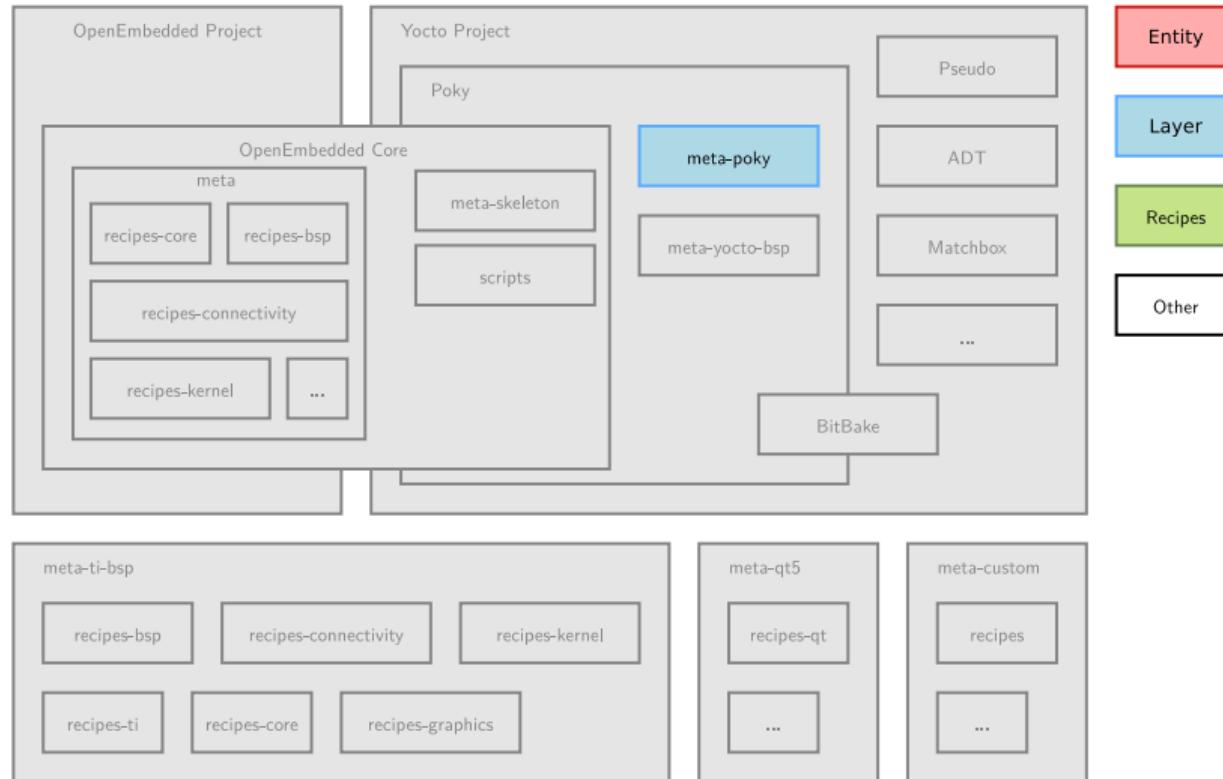




Distro Layers



Distro layers





Distro layers

- ▶ You can create a new distribution by using a Distro layer.
- ▶ This allows to change the defaults that are used by Poky.
- ▶ It is useful to distribute changes that have been made in local.conf



- ▶ A distro layer is used to provide policy configurations for a custom distribution.
- ▶ It is a best practice to separate the distro layer from the custom layers you may create and use.
- ▶ It often contains:
 - Configuration files.
 - Specific classes.
 - Distribution specific recipes: initialization scripts, splash screen...



Creating a Distro layer

- ▶ The configuration file for the distro layer is `conf/distro/<distro>.conf`
- ▶ This file must define the `DISTRO` variable.
- ▶ It is possible to inherit configuration from an existing distro layer.
- ▶ You can also use all the `DISTRO_*` variables.
- ▶ Use `DISTRO = "<distro>"` in `local.conf` to use your distro configuration.

```
require conf/distro/poky.conf

DISTRO = "distro"
DISTRO_NAME = "distro description"
DISTRO_VERSION = "1.0"

MAINTAINER = "..."
```



- ▶ Lists the features the distribution will provide.
- ▶ As for MACHINE_FEATURES, this is used by package recipes to enable or disable functionalities.
- ▶ COMBINED_FEATURES provides the list of features that are enabled in both MACHINE_FEATURES and DISTRO_FEATURES.



Toolchain selection

- ▶ The toolchain selection is controlled by the TCMODE variable.
- ▶ It defaults to "default".
- ▶ The conf/distro/include/tcmode- $\$\{TCMODE\}$.inc file is included.
 - This configures the toolchain to use by defining preferred providers and versions for recipes such as gcc, binutils, *libc...
- ▶ The providers' recipes define how to compile or/and install the toolchain.
- ▶ Toolchains can be built by the build system or external.



- ▶ A distro layer often contains sample files, used as templates to build key configurations files.
- ▶ Example of sample files:
 - `bblayers.conf.sample`
 - `local.conf.sample`
- ▶ In Poky, they are in `meta-poky/conf/`.
- ▶ The `TEMPLATECONF` variable controls where to find the samples.
- ▶ It is set in `${OEROOT}/.templateconf`.
 - `OEROOT` is the directory that contains the `oe-init-build-env` script.



Release management



There are multiple tasks that OE/bitbake based projects let you do on your own to ensure build reproducibility:

- ▶ Code distribution and project setup.
- ▶ Release tagging

A separate tool is needed for that, usual solutions are:

- ▶ combo-layer, as done by Poky:
<https://wiki.yoctoproject.org/wiki/Combo-layer>
- ▶ git submodules + setup script. Great example in YOE:
<https://github.com/YoeDistro/yoe-distro>
- ▶ repo and templateconf or setup script
- ▶ kas



Distribute the distribution

- ▶ A good way to distribute a distribution (Poky, custom layers, BSP, .templateconf...) is to use Google's repo.
- ▶ Repo is used in Android to distribute its source code, which is split into many git repositories. It's a wrapper to handle several git repositories at once.
- ▶ The only requirement is to use git.
- ▶ The repo configuration is stored in manifest file, usually available in its own git repository.
- ▶ It could also be in a specific branch of your custom layer.
- ▶ It only handles fetching code, handling local.conf and bblayers.conf is done separately



Manifest example

```
<?xml version="1.0" encoding="UTF-8"?>
<manifest>
    <remote name="yocto-project" fetch="git.yoctoproject.org" />
    <remote name="private" fetch="git.example.net" />

    <default revision="kirkstone" remote="private" />

    <project name="poky" remote="yocto-project" />
    <project name="meta-ti" remote="yocto-project" />
    <project name="meta-custom" />
    <project name="meta-custom-bsp" />
    <project path="meta-custom-distro" name="distro">
        <copyfile src="templateconf" dest="poky/.templateconf" />
    </project>
</manifest>
```



Retrieve the project using repo

```
$ mkdir my-project; cd my-project  
$ repo init -u https://git.example.net/manifest.git  
$ repo sync -j4
```

- ▶ `repo init` uses the `default.xml` manifest in the repository, unless specified otherwise.
- ▶ You can see the full repo documentation at <https://source.android.com/source/using-repo.html>.



To tag a release, a few steps have to be taken:

- ▶ Optionally tag the custom layers
- ▶ For each project entry in the manifest, set the revision parameter to either a tag or a commit hash.
- ▶ Commit and tag this version of the manifest.



- ▶ Specific tool developed by Siemens for OpenEmbedded:
<https://github.com/siemens/kas>
- ▶ Will fetch layers and build the image in a single command
- ▶ Uses a single JSON or YAML configuration file part of the custom layer
- ▶ Can generate and run inside a Docker container
- ▶ Can setup local.conf and bblayers.conf



kas configuration

```
header:  
    version: 8  
machine: mymachine  
distro: mydistro  
target:  
    - myimage  
  
repos:  
    meta-custom:  
  
    bitbake:  
        url: "https://git.openembedded.org/bitbake"  
        refspec: "2.0"  
        layers:  
            .: excluded  
  
    openembedded-core:  
        url: "https://git.openembedded.org/openembedded-core"  
        refspec: kirkstone  
        layers:  
            meta:
```



kas configuration

```
meta-freescale:  
    url: "https://github.com/Freescale/meta-freescale"  
    refspec: kirkstone  
  
meta-openembedded:  
    url: https://git.openembedded.org/meta-openembedded  
    refspec: kirkstone  
    layers:  
        meta-oe:  
        meta-python:  
        meta-networking:
```

- ▶ Then a single command will build all the listed target for the machine:

```
$ kas build meta-custom/mymachine.yaml
```

- ▶ Or, alternatively, invoke bitbake commands:

```
$ kas shell /path/to/kas-project.yml -c 'bitbake dosfsutils-native'
```



Images

Images

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Corrections, suggestions, contributions and translations are welcome!





Introduction to images



- ▶ An `image` is the top level recipe and is used alongside the `machine` definition.
- ▶ Whereas the `machine` describes the hardware used and its capabilities, the `image` is architecture agnostic and defines how the root filesystem is built, with what packages.
- ▶ By default, several images are provided in Poky:
 - `meta*/recipes*/images/*.bb`



- ▶ Common images are:

`core-image-base` Console-only image, with full support of the hardware.

`core-image-minimal` Small image, capable of booting a device.

`core-image-minimal-dev` Small image with extra tools, suitable for development.

`core-image-x11` Image with basic X11 support.

`core-image-rt` `core-image-minimal` with real time tools and test suite.



- ▶ An `image` is no more than a recipe.
- ▶ It has a description, a license and inherits the `core-image` class.



Organization of an image recipe

- ▶ Some special configuration variables are used to describe an image:

IMAGE_BASENAME The name of the output image files. Defaults to \${PN}.

IMAGE_INSTALL List of packages and package groups to install in the generated image.

IMAGE_ROOTFS_SIZE The final root filesystem size.

IMAGE_FEATURES List of features to enable in the image.

IMAGE_FSTYPES List of formats the OpenEmbedded build system will use to create images.

IMAGE_LINGUAS List of the locales to be supported in the image.

IMAGE_PKGTYPE Package type used by the build system. One of deb, rpm, ipk and tar.

IMAGE_POSTPROCESS_COMMAND Shell commands to run at post process.

EXTRA_IMAGEDEPENDS Recipes to be built with the image, but which do not install anything in the root filesystem (e.g. the bootloader).



Example of an image

```
require recipes-core/images/core-image-minimal.bb

DESCRIPTION = "Example image"

IMAGE_INSTALL += "ninvaders"

LICENSE = "MIT"
```



Image types



- ▶ Configures the resulting root filesystem image format.
- ▶ If more than one format is specified, one image per format will be generated.
- ▶ Image formats instructions are delivered in Poky, thanks to
`meta/classes/image_types.bbclass`
- ▶ Common image formats are: ext2, ext3, ext4, squashfs, squashfs-xz, cpio, jffs2, ubifs, tar.bz2, tar.gz...



Creating an image type

- ▶ If you have a particular layout on your storage (for example bootloader location on an SD card), you may want to create your own image type.
- ▶ This is done through a class that inherits from `image_types`.
- ▶ It has to define a function named `IMAGE_CMD:<type>`.
- ▶ Append it to `IMAGE_TYPES`



Creating an image conversion type

- ▶ Common conversion types are: gz, bz2, sha256sum, bmap...
- ▶ This is done through a class that inherits from `image_types`.
- ▶ It has to define a function named `CONVERSION_CMD:<type>`.
- ▶ Append it to `CONVERSIONTYPES`
- ▶ Append valid combinations to `IMAGE_TYPES`



- ▶ wic is a tool that can create a flashable image from the compiled packages and artifacts.
- ▶ It can create partitions.
- ▶ It can select which files are located in which partition through the use of plugins.
- ▶ The final image layout is described in a .wks or .wks.in file.
- ▶ It can be extended in any layer.
- ▶ Usage example:

```
WKS_FILE = "imx-uboot-custom.wks.in"
IMAGE_FSTYPES = "wic.bmap wic"
```



```
part u-boot --source rawcopy --sourceparams="file=imx-boot" --no-table --align ${IMX_BOOT_SEEK}
part /boot --source bootimg-partition --use-uuid --fstype=vfat --label boot --active --align 8192 --size 64
part / --source rootfs --use-uuid --fstype=ext4 --label root --exclude-path=home/ --exclude-path=opt/ --align 8192
part /home --source rootfs --rootfs-dir=${IMAGE_ROOTFS}/home --use-uuid --fstype=ext4 --label home --align 8192
part /opt --source rootfs --rootfs-dir=${IMAGE_ROOTFS}/opt --use-uuid --fstype=ext4 --label opt --align 8192

bootloader --ptable msdos
```

- ▶ Copies imx-boot from \$DEPLOY_DIR in the image, aligned on (and so at that offset) \${IMX_BOOT_SEEK}.
- ▶ Creates a first partition, formatted in FAT32, with the files listed in the IMAGE_BOOT_FILES variable.
- ▶ Creates an ext4 partition with the contents on the root filesystem, excluding the content of /home and /opt
- ▶ Creates two ext4 partitions, one with the content of /home, the other one with the content of /opt, from the image root filesystem.



Package groups



Overview

- ▶ Package groups are a way to group packages by functionality or common purpose.
- ▶ Package groups are used in image recipes to help building the list of packages to install.
- ▶ They can be found under `meta*/recipes-core/packagegroups/`
- ▶ A package group is yet another recipe.
- ▶ The prefix `packagegroup-` is always used.
- ▶ Be careful about the `PACKAGE_ARCH` value:
 - Set to the value `all` by default,
 - Must be explicitly set to `$(MACHINE_ARCH)` when there is a machine dependency.



Common package groups

- ▶ packagegroup-core-boot
- ▶ packagegroup-core-buildessential
- ▶ packagegroup-core-nfs-client
- ▶ packagegroup-core-nfs-server
- ▶ packagegroup-core-tools-debug
- ▶ packagegroup-core-tools-profile



Example

```
./meta/recipes-core/packagegroups/packagegroup-core-tools-debug.bb:
```

```
SUMMARY = "Debugging tools"
```

```
LICENSE = "MIT"
```

```
inherit packagegroup
```

```
RDEPENDS:${PN} = "\\"
```

```
gdb \
```

```
gdbserver \
```

```
strace"
```



Practical lab - Create a custom image



- ▶ Write an image recipe
- ▶ Choose the packages to install

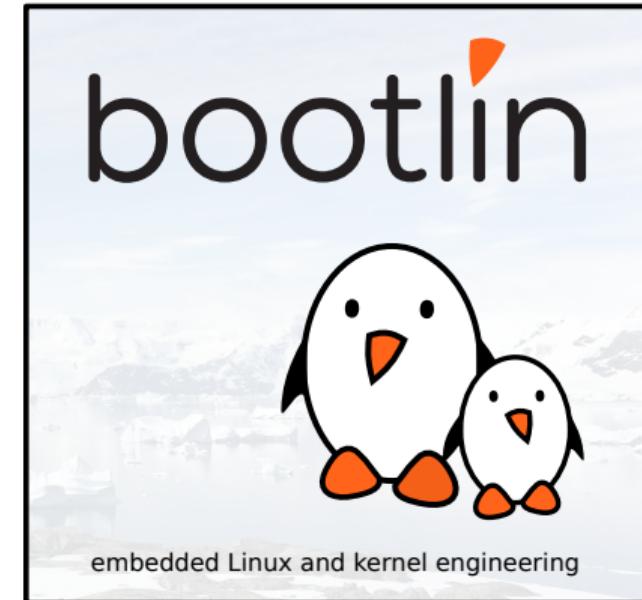


Writing recipes - going further

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Using Python code in metadata



Tasks in Python

- ▶ Tasks can be written in Python when using the `python` keyword.
- ▶ Two modules are automatically imported:
 - `bb`: to access BitBake's internal functions.
 - `os`: Python's operating system interfaces.
- ▶ You can import other modules using the `import` keyword.
- ▶ Anonymous Python functions are executed during parsing.
- ▶ Short Python code snippets can be written inline with the `#{@<python code>}` syntax.



Accessing the datastore with Python

- ▶ The `d` variable is accessible within Python tasks.
- ▶ `d` represents the BitBake datastore (where variables are stored).

`dgetVar("X", expand=False)` Returns the value of X.

`d.setVar("X", "value")` Set X.

`d.appendVar("X", "value")` Append value to X.

`d.prependVar("X", "value")` Prepend value to X.

`d.expand(expression)` Expand variables in expression.



Python code examples

```
# Anonymous function
python __anonymous() {
    if d.getVar("FOO", True) == "example":
        d.setVar("BAR", "Hello, World.")
}

# Task
python do_settime() {
    import time
    d.setVar("TIME", time.strftime('%Y%m%d', time.gmtime()))
}

# Inline
do_install() {
    echo "Build OS: ${@os.uname()[0].lower()}"
}
```



Variable flags



Variable flags

- ▶ *Variable flags* are used to store extra information on tasks and variables.
SRC_URI[md5sum] = "97b2c3fb082241ab5c56ab728522622b"
- ▶ They are used to control task functionalities.
- ▶ A number of these flags are already used by BitBake:
 - dirs: directories that should be created before the task runs. The last one becomes the work directory for the task.
 - noexec: disable the execution of the task.
 - nostamp: do not create a *stamp* file when running the task. The task will always be executed.
 - doc: task documentation displayed by *listtasks*.

```
do_menuconfig[nostamp] = "1"
```

```
do_settime[noexec] = "1"
```

```
do_settime[doc] = "Set the current time in ${TIME}"
```



Packages features



Benefits

- ▶ Features can be built depending on the needs.
- ▶ This allows to avoid compiling all features in a software component when only a few are required.
- ▶ A good example is ConnMan: Bluetooth support is built only if there is Bluetooth on the target.
- ▶ The PACKAGECONFIG variable is used to configure the build on a per feature granularity, for packages.



- ▶ PACKAGECONFIG takes the list of features to enable.
- ▶ PACKAGECONFIG[feature] takes up to six arguments, separated by commas:
 1. Argument used by the configuration task if the feature is enabled (EXTRA_OECONF).
 2. Argument added to EXTRA_OECONF if the feature is disabled.
 3. Additional build dependency (DEPENDS), if enabled.
 4. Additional runtime dependency (RDEPENDS), if enabled.
 5. Additional runtime recommendations (RRECOMMENDS), if enabled.
 6. Any conflicting PACKAGECONFIG settings for this feature.
- ▶ Unused arguments can be omitted or left blank.



Example: from ConnMan

```
PACKAGECONFIG ??= "wifi openvpn"
```

```
PACKAGECONFIG[wifi] = "--enable-wifi,  
                      --disable-wifi,  
                      wpa-supplicant,  
                      wpa-supplicant"
```

```
PACKAGECONFIG[bluez] = "--enable-bluetooth,  
                       --disable-bluetooth,  
                       bluez5,  
                       bluez5"
```

```
PACKAGECONFIG[openvpn] = "--enable-openvpn,  
                         --disable-openvpn,  
                         ,  
                         openvpn"
```



Enabling PACKAGECONFIG features

- ▶ In a .bbappend of the recipe, just append to PACKAGECONFIG

```
PACKAGECONFIG:append = " <feature>"  
PACKAGECONFIG:append = " tui"
```

- ▶ In a config file (e.g. distro conf)

```
PACKAGECONFIG:append:pn-<recipename> = " <feature>"  
PACKAGECONFIG:append:pn-gdb = " tui"
```



Inspecting available PACKAGECONFIG flags

- `${POKY_DIR}/scripts/contrib/list-packageconfig-flags.py` shows the PACKAGECONFIG varflags available for each recipe:

```
$ ./poky/scripts/contrib/list-packageconfig-flags.py
RECIPE NAME      PACKAGECONFIG FLAGS
=====
alsa-plugins    aaf jack libav maemo-plugin maemo-resource-manager pulseaudio samplerate speexdsp
connman         3g bluez client iptables l2tp nfc nftables openvpn pptp systemd tist vpnc wifi ...
gdb             babeltrace debuginfod python readline tui xz
...
```

- The `-a` flag shows all the details:

```
$ ./poky/scripts/contrib/list-packageconfig-flags.py -a
connman-1.41
/home/murray/w/yocto-stm32-labs/poky/meta/recipes-connectivity/connman/connman_1.41.bb
PACKAGECONFIG wispr iptables client          3g wifi          bluez
PACKAGECONFIG[wifi] --enable-wifi, --disable-wifi, wpa-supplicant, wpa-supplicant
PACKAGECONFIG[bluez] --enable-bluetooth, --disable-bluetooth, bluez5, bluez5
PACKAGECONFIG[openvpn] --enable-openvpn --with-openvpn=${sbmdir}/openvpn,--disable-openvpn, ,openvpn
...
```



Conditional features



Conditional features

- ▶ Some values can be set dynamically, thanks to a set of functions:
- ▶ `bb.utils.contains(variable, checkval, trueval, falseval, d)`: if `checkval` is found in `variable`, `trueval` is returned; otherwise `falseval` is used.
- ▶ `bb.utils.filter(variable, checkvalues, d)`: returns all the words in the `variable` that are present in the `checkvalues`.
- ▶ Example:

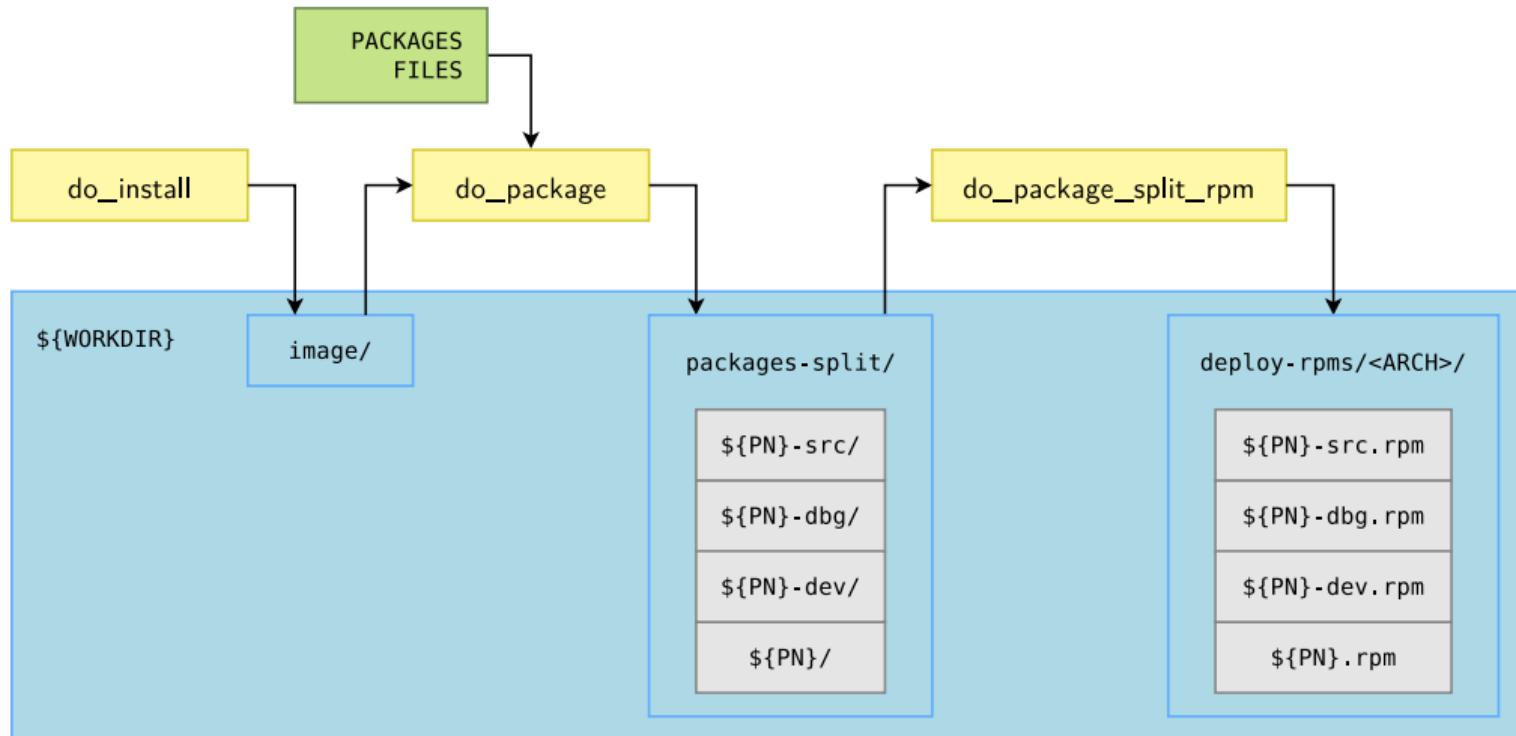
```
PACKAGECONFIG ??= "wispr iptables client\
    ${@bb.utils.filter('DISTRO_FEATURES', '3g systemd wifi', d)} \
    ${@bb.utils.contains('DISTRO_FEATURES', 'bluetooth', 'bluez', '', d)} \
"
```



Package splitting



Package splitting





Package splitting

- ▶ `do_install` copies *all* files in the `D` directory (`${WORKDIR} /image`) .
- ▶ `do_package` splits files in several packages in
 `${WORKDIR} /packages-split`
 - based on the `PACKAGES` and `FILES` variables.
- ▶ `do_package_rpm` generates RPM packages



PACKAGES

- ▶ PACKAGES lists the packages to be built:

```
PACKAGES = "${PN}-src ${PN}-dbg ${PN}-staticdev ${PN}-dev \
${PN}-doc ${PN}-locale ${PACKAGE_BEFORE_PN} ${PN}"
```

- ▶ More packages can be added to the default list
 - Useful when a single remote repository provides multiple binaries or libraries.
 - The order matters. PACKAGE_BEFORE_PN allows to pick files normally included in the default package in another.
- ▶ PACKAGES_DYNAMIC allows to check dependencies with optional packages are satisfied.
- ▶ ALLOW_EMPTY allows to produce a package even if it is empty.
- ▶ To prevent configuration files from being overwritten during the Package Management System update process, use CONFFILES.



FILES

- ▶ For each package a FILES variable lists the files to include.
- ▶ It must be package specific (e.g. with :\${PN}, :\${PN}-dev, dots).
- ▶ Defaults from meta/conf/bitbake.conf:

```
FILES:${PN}-dev = \  
    "${includedir} ${FILESSOLIBSDEV} ${libdir}/*.la \  
    ${libdir}/*.o ${libdir}/pkgconfig ${datadir}/pkgconfig \  
    ${datadir}/aclocal ${base_libdir}/*.o \  
    ${libdir}/${BPN}/*.la ${base_libdir}/*.la \  
    ${libdir}/cmake ${datadir}/cmake"  
  
FILES:${PN}-dbg = \  
    "/usr/lib/debug /usr/lib/debug-static \  
    /usr/src/debug"
```



FILES: the main package

- ▶ The package named just \${PN} is the one that gets installed in the root filesystem.
- ▶ In Poky, defaults to:

```
FILES:${PN} = \
"${bindir}/* ${sbindir}/* ${libexecdir}/* ${libdir}/lib*${SOLIBS} \
${sysconfdir} ${sharedstatedir} ${localstatedir} \
${base_bindir}/* ${base_sbindir}/* \
${base_libdir}/*${SOLIBS} \
${base_prefix}/lib/udev/rules.d ${prefix}/lib/udev/rules.d \
${datadir}/${BPN} ${libdir}/${BPN}/* \
${datadir}/pixmaps ${datadir}/applications \
${datadir}/idl ${datadir}/omf ${datadir}/sounds \
${libdir}/bonobo/servers"
```



Example

- The kexec tools provides kexec and kdump:

```
require kexec-tools.inc
export LDFLAGS = "-L${STAGING_LIBDIR}"
EXTRA_OECONF = " --with-zlib=yes"

SRC_URI[md5sum] = \
    "b9f2a3ba0ba9c78625ee7a50532500d8"
SRC_URI[sha256sum] = "..."

PACKAGES += "kexec kdump"

FILES:kexec = "${sbindir}/kexec"
FILES:kdump = "${sbindir}/kdump"
```



Inspecting packages

oe-pkgdata-util is a tool that can help inspecting packages:

- ▶ Which package is shipping a file:

```
$ oe-pkgdata-util find-path /bin/busybox  
busybox: /bin/busybox
```

- ▶ Which files are shipped by a package:

```
$ oe-pkgdata-util list-pkg-files busybox  
busybox:  
  /bin/busybox  
  /bin/busybox.nosuid  
  /bin/busybox.suid  
  /bin/sh
```

- ▶ Which recipe is creating a package:

```
$ oe-pkgdata-util lookup-recipe kdump  
kexec-tools  
$ oe-pkgdata-util lookup-recipe libtinfo5  
ncurses
```



Root filesystem creation



Root filesystem generation

- ▶ Image generation overview:
 1. An empty directory is created for the root filesystem.
 2. Packages from `IMAGE_INSTALL` are installed into it using the package manager.
 3. One or more images files are created, depending on the `IMAGE_FSTYPES` value.
- ▶ The rootfs creation is specific to the `IMAGE_PKGTYPE` value. It should be defined in the image recipe, otherwise the first valid package type defined in `PACKAGE_CLASSES` is used.
- ▶ All the magic is done in `meta/classes/rootfs_${IMAGE_PKGTYPE}.bbclass`



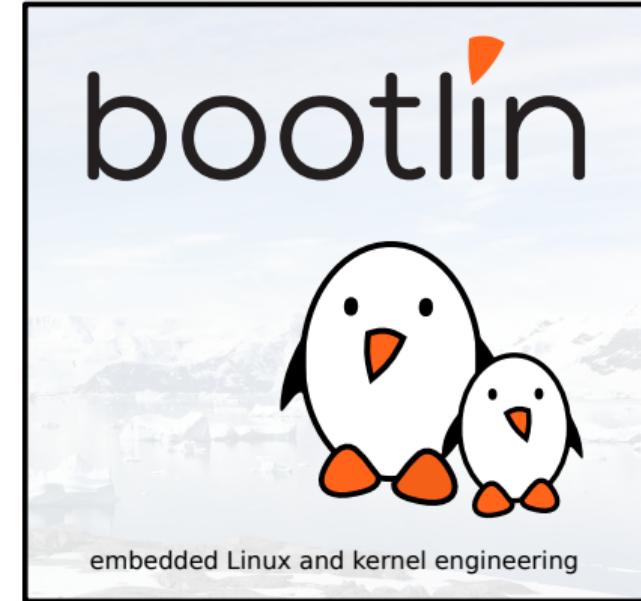
Licensing

Licensing

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Managing licenses



Tracking license changes

- ▶ The license of an external project may change at some point.
- ▶ The LIC_FILES_CHKSUM tracks changes in the license files.
- ▶ If the license's checksum changes, the build will fail.
 - The recipe needs to be updated.

```
LIC_FILES_CHKSUM = "  
    file://COPYING;md5=...  
    file://src/file.c;beginline=3;endline=21;md5=..."
```

- ▶ LIC_FILES_CHKSUM is mandatory in every recipe, unless LICENSE is set to CLOSED.



- ▶ We may not want some packages due to their licenses.
- ▶ To exclude a specific license, use INCOMPATIBLE_LICENSE
- ▶ To exclude all GPLv3 packages:

```
INCOMPATIBLE_LICENSE = "GPL-3.0* LGPL-3.0* AGPL-3.0*"
```

- ▶ License names are the ones used in the LICENSE variable.



Commercial licenses

- ▶ By default the build system does not include commercial components.
- ▶ Packages with a commercial component define:

```
LICENSE_FLAGS = "commercial"
```

- ▶ To build a package with a commercial component, the package must be in the LICENSE_FLAGS_ACCEPTED variable.
- ▶ Example, gst-plugins-ugly:

```
LICENSE_FLAGS_ACCEPTED = "commercial_gst-plugins-ugly"
```



Listing licenses

OpenEmbedded will generate a manifest of all the licenses of the software present on the target image in \$BUILDDIR/tmp/deploy/licenses/<image>/license.manifest

```
PACKAGE NAME: busybox
PACKAGE VERSION: 1.31.1
RECIPE NAME: busybox
LICENSE: GPL-2.0-only & bzip2-1.0.4
```

```
PACKAGE NAME: dropbear
PACKAGE VERSION: 2019.78
RECIPE NAME: dropbear
LICENSE: MIT & BSD-3-Clause & BSD-2-Clause & PD
```



Providing license text

To include the license text in the root filesystem either:

- ▶ Use `COPY_LIC_DIRS = "1"` and `COPY_LIC_MANIFEST = "1"`
- ▶ or use `LICENSE_CREATE_PACKAGE = "1"` to generate packages including the license and install the required license packages.



Providing sources

OpenEmbedded provides the archiver class to generate tarballs of the source code:

- ▶ Use INHERIT += "archiver"
- ▶ Set the ARCHIVER_MODE variable, the default is to provide patched sources. To provide configured sources:

```
ARCHIVER_MODE[src] = "configured"
```

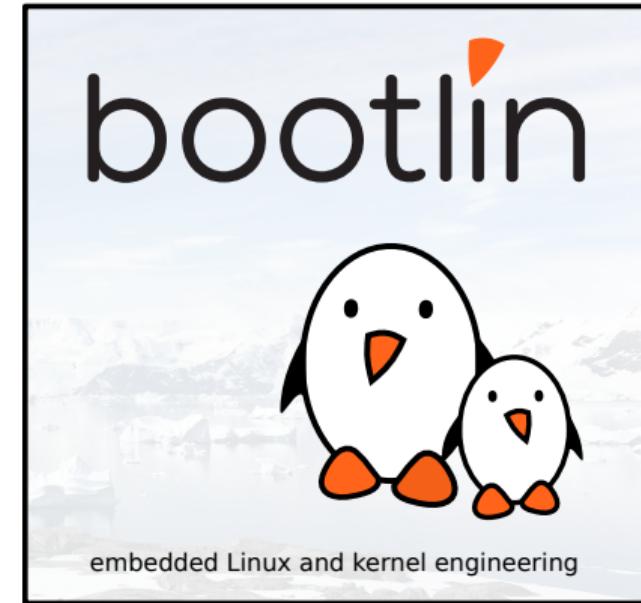


Application development workflow

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Recommended workflows

- ▶ Different development workflows are possible given the needs:
 - Low-level application development (bootloader, kernel).
 - Application development.
 - Temporary modifications on an external project (bug fixes, security fixes).
- ▶ Three workflows exists for theses needs: the SDK, devtool and quilt.



The Yocto Project SDK



- ▶ An SDK (Software Development Kit) is a set of tools allowing the development of applications for a given target (operating system, platform, environment...).
- ▶ It generally provides a set of tools including:
 - Compilers or cross-compilers.
 - Linkers.
 - Library headers.
 - Debuggers.
 - Custom utilities.



The Yocto Project SDK

- ▶ The Poky reference system is used to generate images, by building many applications and doing a lot of configuration work.
 - When developing an application, we only care about the application itself.
 - We want to be able to develop, test and debug easily.
- ▶ The Yocto Project SDK is an application development SDK, which can be generated to provide a full environment compatible with the target.
- ▶ It includes a toolchain, libraries headers and all the needed tools.
- ▶ This SDK can be installed on any computer and is self-contained. The presence of Poky is not required for the SDK to fully work.



Available SDKs

- ▶ Two different SDKs can be generated:
 - A generic SDK, including:
 - A toolchain.
 - Common tools.
 - A collection of basic libraries.
 - An image-based SDK, including:
 - The generic SDK.
 - The sysroot matching the target root filesystem.
 - Its toolchain is self-contained (linked to an SDK embedded libc).
- ▶ The SDKs generated with Poky are distributed in the form of a shell script.
- ▶ Executing this script extracts the tools and sets up the environment.



The generic SDK

- ▶ Mainly used for low-level development, where only the toolchain is needed:
 - Bootloader development.
 - Kernel development.
- ▶ The recipe `meta-toolchain` generates this SDK:
 - `bitbake meta-toolchain`
- ▶ The generated script, containing all the tools for this SDK, is in:
 - `$BUILDDIR/tmp/deploy/sdk`
 - Example:
`poky-glibc-x86_64-meta-toolchain-cortexa8hf-neon-toolchain-2.5.sh`
- ▶ The SDK will be configured to be compatible with the specified MACHINE.



The image-based SDK

- ▶ Used to develop applications running on the target.
- ▶ One task is dedicated to the process. The task behavior can vary between the images.
 - populate_sdk
- ▶ To generate an SDK for core-image-minimal:
 - bitbake -c populate_sdk core-image-minimal
- ▶ The generated script, containing all the tools for this SDK, is in:
 - \$BUILDDIR/tmp/deploy/sdk
 - Example:
poky-glibc-x86_64-core-image-minimal-cortexa8hf-neon-toolchain-2.5.sh
- ▶ The SDK will be configured to be compatible with the specified MACHINE.



Adding packages to the SDK

- ▶ Two variables control what will be installed in the SDK

`TOOLCHAIN_TARGET_TASK` List of target packages to be included in the SDK

`TOOLCHAIN_HOST_TASK` List of host packages to be included in the SDK

- ▶ Both can be appended to install more tools or libraries useful for development.
- ▶ Example: to have native curl on the SDK:

```
TOOLCHAIN_HOST_TASK:append = "nativesdk-curl"
```



- ▶ Both SDKs are distributed as bash scripts.
- ▶ These scripts self extract themselves to install the toolchains and the files they provide.
- ▶ To install an SDK, retrieve the generated script and execute it.
 - The script asks where to install the SDK. Defaults to /opt/poky/<version>
 - Example: /opt/poky/2.5

```
$ ./poky-glibc-x86_64-meta-toolchain-cortexa8hf-neon-toolchain-2.5.sh
Poky (Yocto Project Reference Distro) SDK installer version 2.5
=====
Enter target directory for SDK (default: /opt/poky/2.5):
You are about to install the SDK to "/opt/poky/2.5". Proceed[Y/n]?
Extracting SDK.....done
Setting it up...done
SDK has been successfully set up and is ready to be used.
Each time you wish to use the SDK in a new shell session, you need to source
the environment setup script e.g.
$ . /opt/poky/2.5/environment-setup-cortexa8hf-neon-poky-linux-gnueabi
```



- ▶ To use the SDK, a script is available to set up the environment:

```
$ cd /opt/poky/2.5  
$ source ./environment-setup-cortexa8hf-neon-poky-linux-gnueabi
```

- ▶ The PATH is updated to take into account the binaries installed alongside the SDK.
- ▶ Environment variables are exported to help using the tools.



`environment-setup-cortexa8hf-neon-poky-linux-gnueabi` Exports environment variables.

`site-config-cortexa8hf-neon-poky-linux-gnueabi` Variables used during the toolchain creation

`sysroots` SDK binaries, headers and libraries. Contains one directory for the host and one for the target.

`version-cortexa8hf-neon-poky-linux-gnueabi` Version information.



SDK environment variables

CC Full path to the C compiler binary.

CFLAGS C flags, used by the C compiler.

CXX C++ compiler.

CXXFLAGS C++ flags, used by CPP

LD Linker.

LDFLAGS Link flags, used by the linker.

ARCH For kernel compilation.

CROSS_COMPILE For kernel compilation.

GDB SDK GNU Debugger.

OBJDUMP SDK objdump.

- ▶ To see the full list, open the environment script.



Examples

- ▶ To build an application for the target:

```
$ $CC -o example example.c
```

- ▶ The LDFLAGS variable is set to be used with the C compiler (gcc).
 - When building the Linux kernel, unset this variable.

```
$ unset LDFLAGS  
$ make menuconfig  
$ make
```



Devtool



- ▶ Devtool is a set of utilities to ease the integration and the development of OpenEmbedded recipes.
- ▶ It can be used to:
 - Generate a recipe for a given upstream application.
 - Modify an existing recipe and its associated sources.
 - Upgrade an existing recipe to use a newer upstream application.
- ▶ Devtool adds a new layer, automatically managed, in \$BUILDDIR/workspace/.
- ▶ It then adds or appends recipes to this layer so that the recipes point to a local path for their sources. In \$BUILDDIR/workspace/sources/.
 - Local sources are managed by git.
 - All modifications made locally should be committed.



There are three ways of creating a new devtool project:

- ▶ To create a new recipe: `devtool add <recipe> <fetchuri>`
 - Where `recipe` is the recipe's name.
 - `fetchuri` can be a local path or a remote *uri*.
- ▶ To modify the source for an existing recipe: `devtool modify <recipe>`
- ▶ To upgrade a given recipe: `devtool upgrade -V <version> <recipe>`
 - Where `version` is the new version of the upstream application.



Once a devtool project is started, commands can be issued:

- ▶ `devtool edit-recipe <recipe>`: edit recipe in a text editor (as defined by the `EDITOR` environment variable).
- ▶ `devtool build <recipe>`: build the given recipe.
- ▶ `devtool build-image <image>`: build image with the additional devtool recipes' packages.



- ▶ `devtool deploy-target <recipe> <target>`: upload the recipe's packages on target, which is a live running target with an SSH server running (`user@address`).
- ▶ `devtool update-recipe <recipe>`: generate patches from git commits made locally.
- ▶ `devtool reset <recipe>`: remove recipe from the control of devtool. Standard layers and remote sources are used again as usual.



Quilt



Overview

- ▶ Quilt is a utility to manage patches which can be used without having a clean source tree.
- ▶ It can be used to create patches for recipes already available in the build system.
- ▶ Be careful when using this workflow: the modifications won't persist across builds!



Using Quilt

1. Find the recipe working directory in `$BUILDDIR/tmp/work/`.
2. Create a new Quilt patch: `$ quilt new topic.patch`
3. Add files to this patch: `$ quilt add file0.c file1.c`
4. Make the modifications by editing the files.
5. Test the modifications: `$ bitbake -c compile -f recipe`
6. Generate the patch file: `$ quilt refresh`
7. Move the generated patch into the recipe's directory.



Practical lab - Create and use a Poky SDK



- ▶ Generate an SDK
- ▶ Compile an application for the target in the SDK

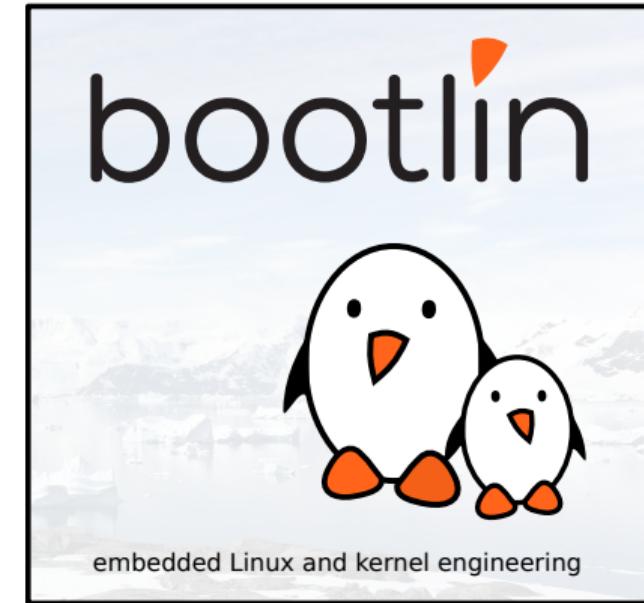


Runtime Package Management

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Introduction

- ▶ BitBake always builds packages selected in `IMAGE_INSTALL`.
- ▶ The packages are used to generate the root filesystem.
- ▶ It is also possible to update the system at runtime using these packages, for many use cases:
 - In-field security updates.
 - System updates over the wire.
 - System, packages or configuration customization at runtime.
 - Remote debugging.
- ▶ Using the Runtime Package Management is an optional feature.
- ▶ We'll use the IPK package format as an example in the following slides.



- ▶ First of all, you need a server to serve the packages to a private subnet or over the Internet. Packages are typically served over https or http.
- ▶ Specific tools are also required on the target, and must be shipped on the product. They should be included into the images generated by the build system.
- ▶ These tools will be specific to the package type used.
 - This is similar to Linux distributions: Debian is using .deb related tools (dpkg, apt...) while Fedora uses .rpm related ones (rpm, dnf).



Build configuration



Build configuration 1/2

- ▶ The PACKAGE_CLASSES variable controls which package format to use. More than one can be used.
- ▶ Valid values are package_rpm, package_deb, package_ipk.
- ▶ By default Poky uses the RPM format, while OpenEmbedded-Core uses the IPK one.
- ▶ Example:
 - PACKAGE_CLASSES = "package_ipk"
 - PACKAGE_CLASSES = "package_rpm package_deb"



To install the required tools on the target, there are two possible solutions:

- ▶ By adding package-management to the images features.
 - The required tool will be installed on the target.
 - The package database corresponding to the build will be installed as well.
- ▶ Or by manually adding the required tools in IMAGE_INSTALL. For example, to use the IPK format we need opkg.



Build considerations

- ▶ The Runtime Package Management uses package databases to store information about available packages and their version.
- ▶ Whenever a build generates a new package or modifies an existing one, the package database must be updated.
- ▶ `$ bitbake package-index`
- ▶ Be careful: BitBake does not properly schedule the package-index target. You must use this target alone to have a consistent package database.
 - `$ bitbake ninvaders package-index` won't necessarily generate an updated package database.



Package server configuration



Apache2 example setup

Apache2 HTTP setup for IPK packages. This should go in
/etc/apache2/sites-enabled/package-server.conf.

```
<VirtualHost *:80>
    ServerName packages.example.net

    DocumentRoot /path/to/build/tmp/deploy/ipk
    <Directory /path/to/build/tmp/deploy/ipk>
        Options +Indexes
        Options Indexes FollowSymLinks
        Order allow,deny
        allow from all
        AllowOverride None
        Require all granted
    </Directory>
</VirtualHost>
```



Target configuration



The IPK runtime management software

- ▶ The IPK runtime management software is opkg.
- ▶ It can be configured using configurations files ending in .conf in /etc/opkg/.
- ▶ This configuration helps opkg to find the package databases you want to use.
- ▶ For example, with our previously configured package server:

```
src/gz all http://packages.example.net/all
src/gz armv7a http://packages.example.net/armv7a
src/gz beaglebone http://packages.example.net/beaglebone
```

- ▶ This can be automatically generated by defining the PACKAGE_FEED_URIS, PACKAGE_FEED_BASE_PATHS and PACKAGE_FEED_ARCHS variables



- ▶ opkg update: fetch and update the package databases, from the remote package servers.
- ▶ opkg list: list available packages.
- ▶ opkg upgrade: upgrade all installed packages.
- ▶ opkg upgrade <package>: upgrade one package explicitly.
- ▶ opkg install <package>: install a specific package.



opkg upgrade over an unstable network

- ▶ To avoid upgrade issues when downloading packages from a remote package server using an unstable connection, you can first download the packages and then proceed with the upgrade.
- ▶ To do this we must use a cache, which can be defined in the opkg configuration with: option cache /tmp/opkg-cache.

```
# opkg update  
# opkg --download-only upgrade  
# opkg upgrade
```



Yocto Project Resources

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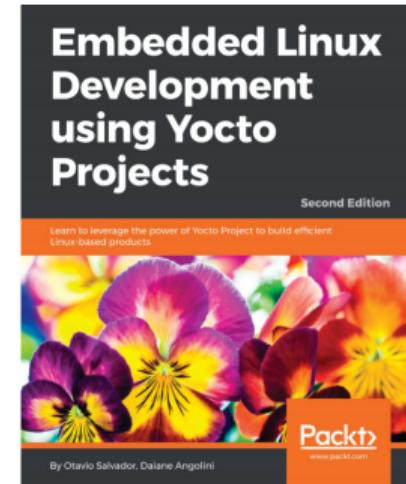
- ▶ <https://docs.yoctoproject.org/>
- ▶ Wiki: https://wiki.yoctoproject.org/wiki/Main_Page
- ▶ <https://layers.openembedded.org/>



Useful Reading (1)

Embedded Linux Development with Yocto Project - Second Edition, Nov 2017

- ▶ <https://www.packtpub.com/virtualization-and-cloud/embedded-linux-development-using-yocto-projects-second-edition>
- ▶ By Otavio Salvador and Daiane Angolini
- ▶ From basic to advanced usage, helps writing better, more flexible recipes. A good reference to jumpstart your Yocto Project development.





Useful Reading (2)

Embedded Linux Projects Using Yocto Project Cookbook - Second Edition, January 2018

- ▶ <https://www.packtpub.com/virtualization-and-cloud/embedded-linux-development-using-yocto-project-cookbook-second-edition>
- ▶ By Alex González
- ▶ A set of recipes that you can refer to and solve your immediate problems instead of reading it from cover to cover.

See our review: <https://bit.ly/1GgVmCB>



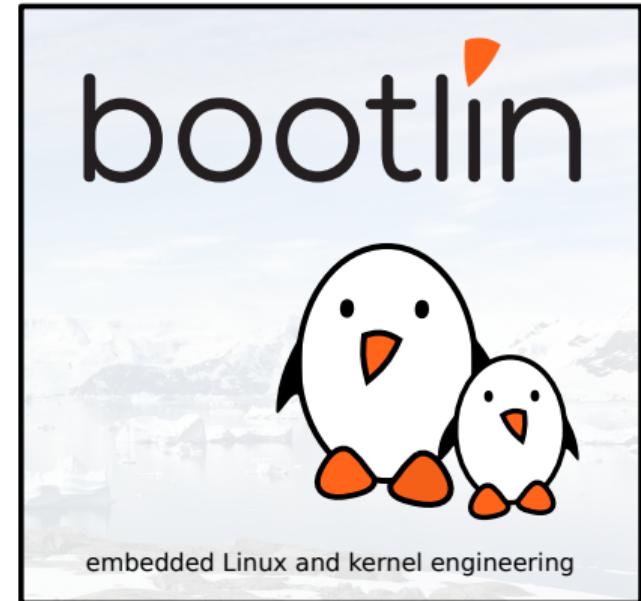


Last slides

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