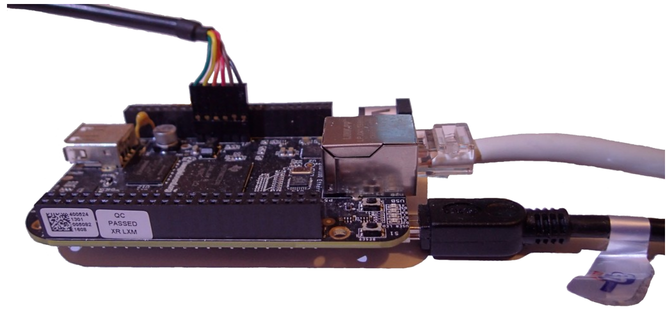
MindRoad

Embedded Linux

Kjell Enblom,
Mindroad.se



2024-02-28

MindRoad Academy MindRoad Embedded MindRoad Application MindRoad Syd MindRoad Sourcing

Who am I ?

- Kjell Enblom
  - Computer Science, Linköping university
  - Computer consultant
  - I have used Unix since 1985.
  - I have been working with Linux since 1995.
    - Workstations
    - Servers
    - Embedded Linux since 2007

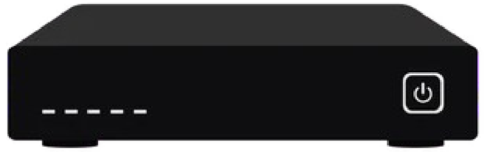
MindRoad Academy

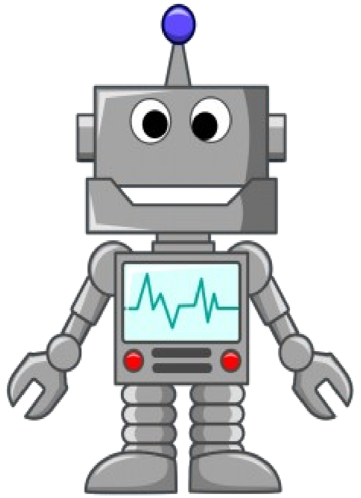
Content

- Where can we find Embedded Linux?
- When to use Linux and not to use Linux.
- The four elements.
- Using standard Linux distribution versus build an embedded Linux distribution.
- How to deploy.
  - Manually
  - Using Buildroot
  - Using Yocto Project

Where can we find Embedded Linux?

- Routers
- Firewalls
- Network encryption.
- Infotainment system
- TV, screens
- Robots
- NAS (network storage)
- Blast furnace
- Set-top-box (TV)
- Measuring equipment
- Washing machines.
- Coffee machines.
- Cameras.





MindRoad Academy

When to use Linux

- We need network support.
- We need to be able to easily run multiple programs.
- We don’t need real time or only need soft real time support.
- The application require more than 1-3 megabytes of memory to run smoothly.
- With large and complex systems the boilerplate code required just to initialise the device becomes very complex.
- We need network connectivity, touch screen, sound, video, embedded web server, encryption.
- Benefits of using embedded Linux
  - its open source nature (free as in price and as in freedom),
  - flexibility and scalability,
  - support for a wide range of hardware architectures,
  - robustness and stability,
  - it has support for process management, support for different file systems, multi-user support, etc
  - large community of developers and users.

When to not to use Linux

- We need hard real time support.
  - RTOSes are designed to handle multiple processes at one time, ensuring that these processes respond to events within a predictable time limit.
- The hardware lacks MMU.
- Resources, like memory, storage and CPU etc. are severely limited.

The four elements

- Toolchain
- Bootloader
- Linux kernel
- Root-filesystem including application for system’s usage.

MindRoad Academy

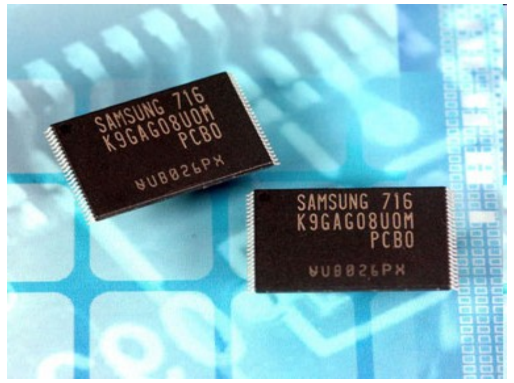
The four elements - Toolchain

- A collection of tools for creating binaries or libraries from code. Contains usually:
  - Compiler or cross compiler
  - Assembler
  - Linker
  - System library, libc, e.g. glibc, uClibc-ng, Dietlibc, Bionic etc.

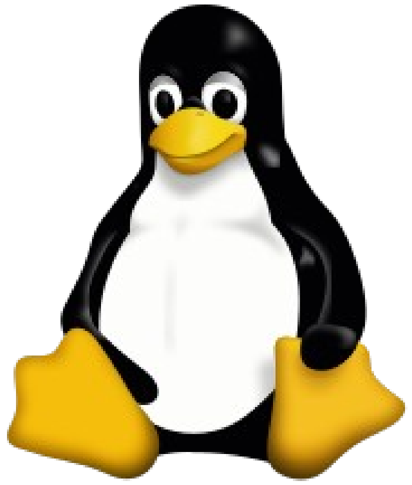
The four elements - Toolchain

- A toolchain based on gnu tools, consists of:
  - GCC (Compiler)
  - Binutils (assembler, linker, profiles, object file tool, etc)
  - Glibc (GNU libc, standard library)

The four elements - Bootloader



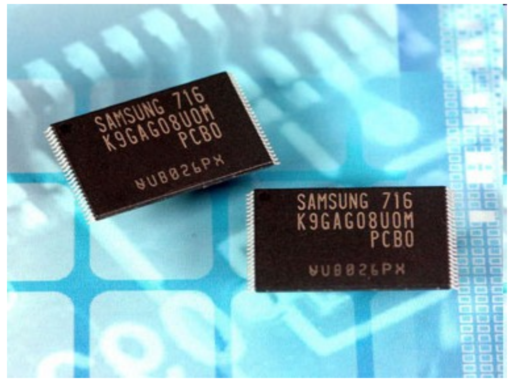
- Hardware specific.
- Loads data from non-volatile memory to RAM
- Launches the loaded program, such as a linux kernel

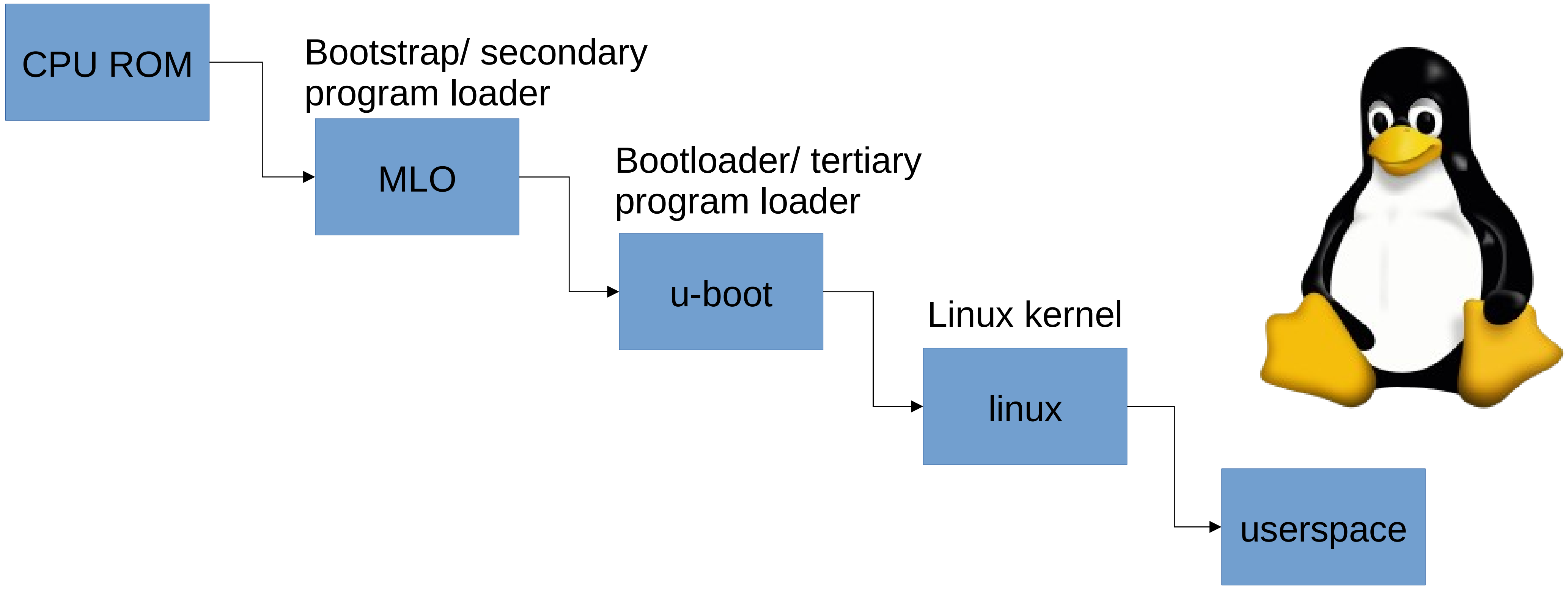


MindRoad Academy

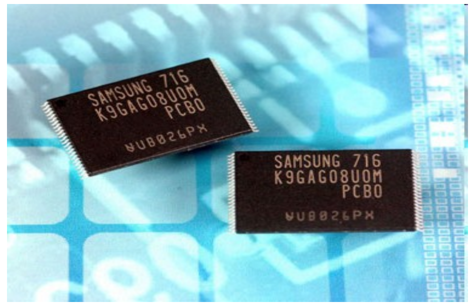
The four elements - Bootloader

- On embedded systems it is common that the bootloader is loaded from a flash memory.
- Really small systems only have a bootstrap.
- Larger systems have a bootstrap and a bootloader.

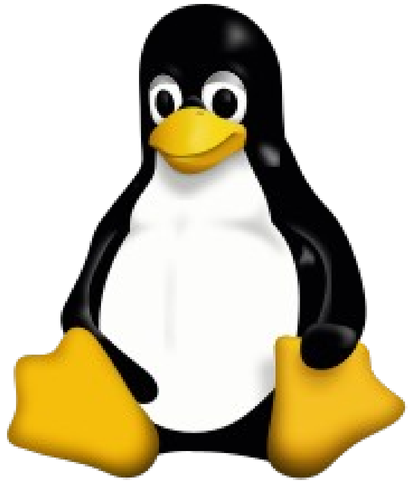




The four elements - Bootloader



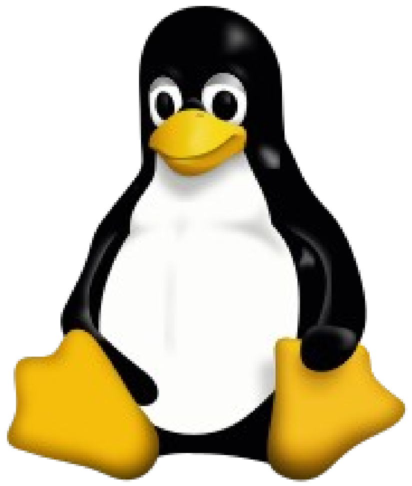
- Some of the most common bootloaders are:
  - LILO (x86 and x86_64 based systems. Used to be standard bootloader)
  - Grub (x86 and x86_64. The standard bootloader in most Linux distributions)
  - U-Boot (System with ARM, AVR32, PPC, Blackfin, x86, Motorola m68k, MIPS, Super-H and more) common in many embedded systems.
  - RedBoot (ARM, x86, m68k, MIPS, PowerPC, Super-H and more)
  - CFE (Broadcom Common Firmware Environment for MIPS, PowerPC and x86)
  - BSSP (proprietary bootloader from STMicroelectronics)



MindRoad Academy

The four elements - Linux Kernel

- An abstraction of hardware.
- A generic platform for applications.
  - Handles hardware, filesystems, network, processes, security (firewall, selinux, apparmor).
- Implementing a standard API against user space.
- In ARM and PowerPC systems we also need a device tree.
  - A device tree is a data structure for describing hardware layout.
  - Device trees are used by U-Boot and by the Linux kernel.
  - With device trees there are no need for hard coded hardware specific values in the device drivers.



MindRoad Academy

The four elements - Root filesystem

- Set of files and application to start the system.
- Contains all necessary applications, libraries, device files, system files for the complete system function.
- Contains everything that is necessary to add extra file systems if needed.

MindRoad Academy

Using a standard Linux distribution

- You don’t need to build the OS.
- Vast number of packages, ready to install.
- You can use the distros package manager to install packages.
- Little setup time.
- When rebuilding a package you need to do than on the board or cross compile on your development station.

Using a standard Linux distribution

- Minuses:
  - Requires hardware support
    - Only works out-of-the-box on commodity hardware such as PC or Raspberry Pi.
    - Standard distros don’t have support for most embedded hardware.
  - Native development means compiling on the machine.
    - Ok for PC, but not scalable for Raspberry Pi.
  - Too big
    - e.g. Ubuntu Core is 500 MB, but we might have only 256 MB storage.
  - Software update via package manager is not robust.
    - We need atomic update, e.g. the entire root filesystem image or root filesystem tree.

Build and use an embedded Linux distribution

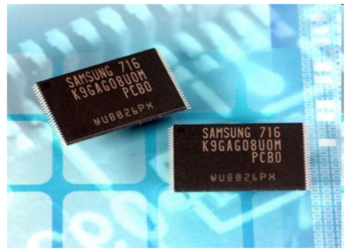
- With a BSP, Board Support Package, you can have support for your hardware.
  - There is plenty of support for many hardware boards.
- It is possible to build a small custom embedded distribution.
- There is good support for cross-compilation development for embedded Linux distributions.
  - You can do the development and cross compilation on your workstation.
- Atomic updates are supported.
  - The system could be in orbit around Jupiter or in a cave deep under the sea.
  - You must not brick the system.

Deploy - manually

- To deploy you need the four elements; cross compiler toolchain, boot loader source code, Linux kernel source code and root filesystem applications and root filesystem files.
- Toolchains come in several different variants; proprietary, ready-made open source, and the ones that you build yourself.
- The easiest way is to use one of the ready-made ones. Example:
  - Linaro, https://www.linaro.org/downloads
  - https://toolchains.bootlin.com/
- You get the most flexibility and customization with those you build yourself.
  - You can for example use crosstool-ng to build your own toolchain.

Deploy - manually

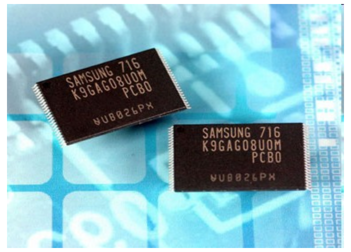
- Next step is to cross compile the bootloader.
- We need to decide which bootloader to use.
- Then we need the source code for the bootloader and configure it for our target system and for the functions we need and then cross compile it.



- A very common open source bootloader used in many embedded systems is u-boot from DENX Software Engineering.

Deploy - manually

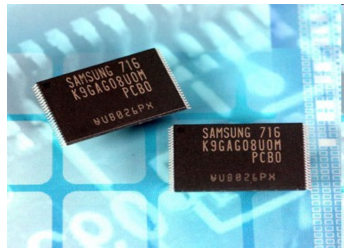
- Example for u-boot for Beaglebone black:
  - Download the source code and extract it and go to the source code directory.



    - export ARCH=arm
    - export CROSS_COMPILE=arm-cortex_a8-linux-gnueabi- # Prefix part of toolchain name
    - make am335x_boneblack_defconfig # Select the beaglebone black configuration.
    - make menuconfig # Do some more configuration
    - make all # Compile U-Boot and U-Boot tools
    - We will get the files MLO and u-boot.img. We need to install them on the target.

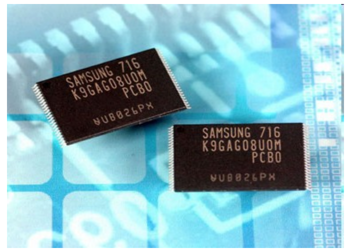
Deploy - manually

- Next step is to compile the Linux kernel.
  - Download the Linux kernel and extract the source code.
    - You can get it from https://www.kernel.org/
  - Example for Beaglebone black:
    - make ARCH=arm CROSS_COMPILE=arm-cortex_a8-linux-gnueabi- multi_v7_defconfig # Select Beaglebone black configuration
    - make menuconfig # Do some more configuration
    - Make # Compile the Linux Kernel
    - We will get a kernel image and a device tree to install to the target.



Deploy - manually

- Then we need to create the root filesystem.
- For that we need to create som directories and some files and cross compile the applicatoins we need.

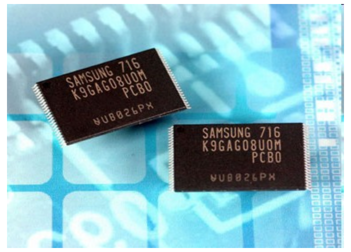


- Use the toolchain to do that.
- For all the standard Linux commands we can use busybox.
- Download the source code and configure it and cross compile it.
  - export ARCH=arm
  - export CROSS_COMPILE=arm-cortex_a8-linux-gnueabi- # Prefix part of toolchain name
  - make menuconfig # Do some configuration
  - make && make install # Install busybox in a directory tree on your development machine.

MindRoad Academy

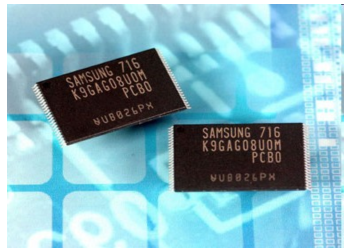
Deploy - manually

- Finally, we need to deploy everything to the target system.
- How the system is installed on the target varies between different systems.
  - Install the entire system on an SD card.
  - Copy the files to a bootable media and boot with this on the target to install.
  - Flash the files to a flash memory on the target.



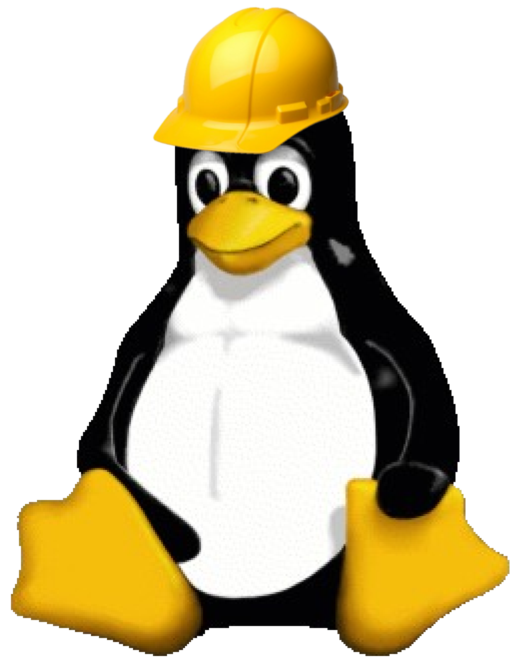
Deploy - manually

- For the Beaglebone black, we can e.g. install the whole system on an SD card and boot from this SD card.
- We create two partitions:
  - A partition that contains the bootloader files, the Linux kernel and a device tree file.
  - One partition containing the root filesystem.



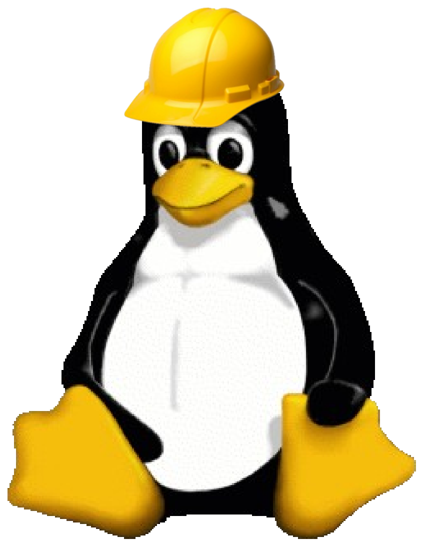
Deploy - Buildroot

- Putting everything together manually is quite cumbersome and time-consuming.
- It's easier with a ready-made building system.
- Buildroot and Yocto Project are two such systems.
- They are both open source.
- We will first take a look at buildroot.
  - https://buildroot.org/



Deploy - Buildroot

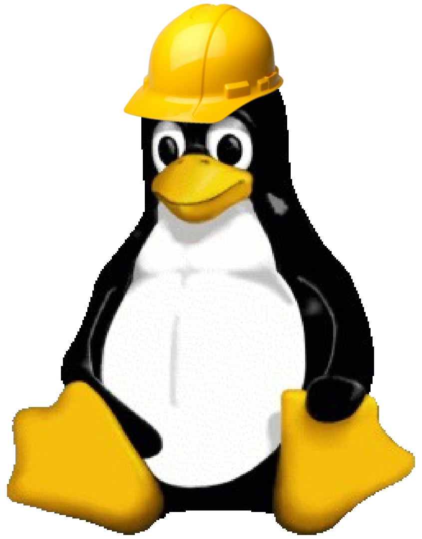
- Buildroot is built around make files and the program make.
- Buildroot can build the toolchain, it builds bootloader, Linux kernel and root filesystem including the programs you develop.
  - It is possible to use an external toolchain with buildroot.



- To build a distribution download the buildroot build system and extract the archive file.
- Run make menuconfig and do all the necessary configuration.
- Then run make to build.
  - Buildroot will download all source code and build it.

Deploy - Buildroot

- For own applictions we need to create a subdirectory under package and populate it with a configuration file and a makefile.
  - Config.in
  - mypackage.mk



- Then add a line in the file package/Config.in
- For this to work, you need basic knowledge of make and make files.
- With buildroot you can build archive files, complete images for different filesystems to deploy to the target.

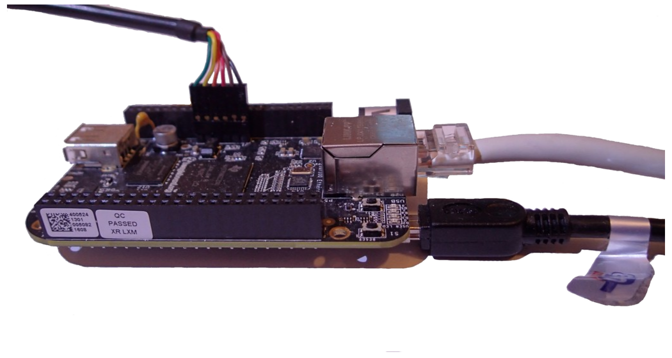
MindRoad Academy

Deploy - Buildroot

- Buildroot is relatively easy to learn.
- It is easier to learn Buildroot than to learn Yocto Project.
- If you only have one system, it works well to use buildroot.
- If you have several different systems, buildroot is not as good.
- There is more vendor support for Yocto Project than for Buildroot.
- There is more out-of-the-box BSP support for Yocto Project than for Buildroot.
- With buildroot, however, it is relatively easy to create your own BSP.

MindRoad

Deploy - yocto PROJECT



Yocto Project is a system to build an embedded Linux distribution.

https://www.yoctoproject.org/

MindRoad Academy MindRoad Embedded MindRoad Application MindRoad Syd MindRoad Sourcing

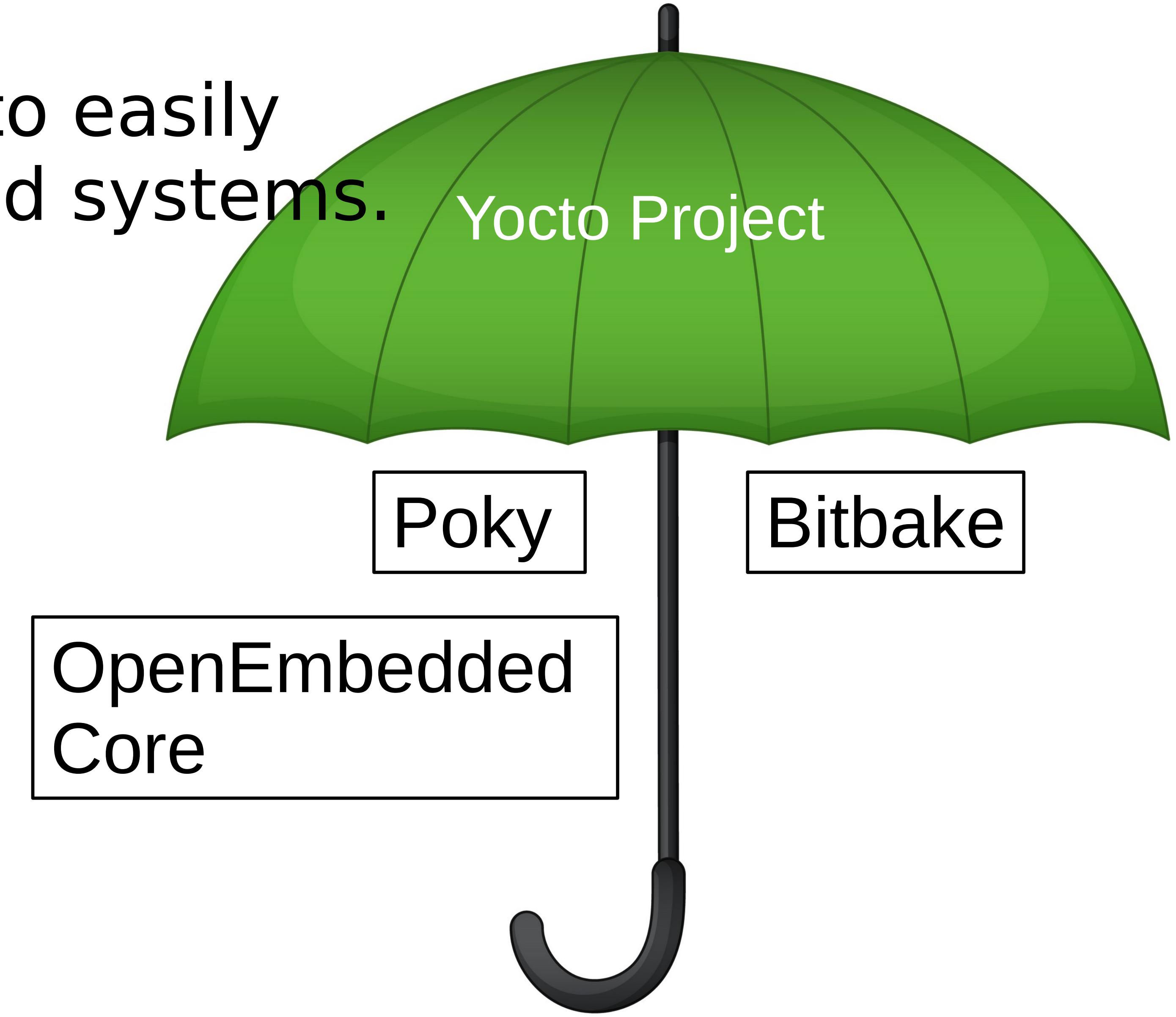
Deploy – Yocto Project

- Yocto project was created in 2010 when several companies wanted a unified system to build Linux distributions for embedded systems.
- The first version of Yocto was released in early 2011.
- The project is run by the Linux Foundation.
- Embedded linux world was sparse and difficult to get into.
- It needed something uniform, an industry standard.
- Huge support from both hardware and software companies and organizations:

    Texas Instruments, Intel, Enea, Huawei, OpenEmbedded, etc.

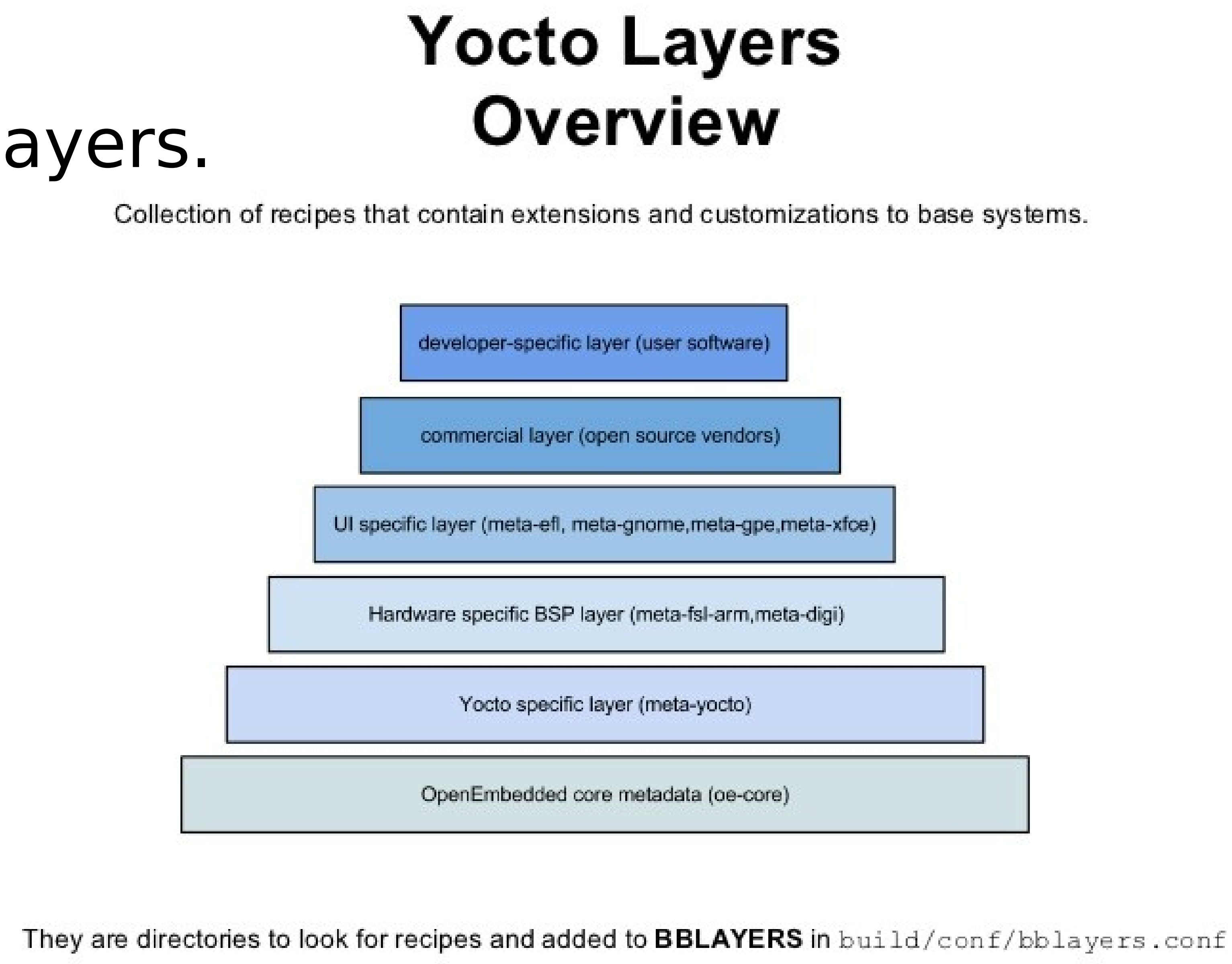
Deploy – Yocto Project

- What is Yocto?
  - Large collection of recipes and tools to easily build Linux distributions for embedded systems.
  - Configurable to meet your needs.
- Yocto is an umbrella for some projects
  - Poky
  - OpenEmbedded Core
  - Bitbake



Deploy – Yocto Project

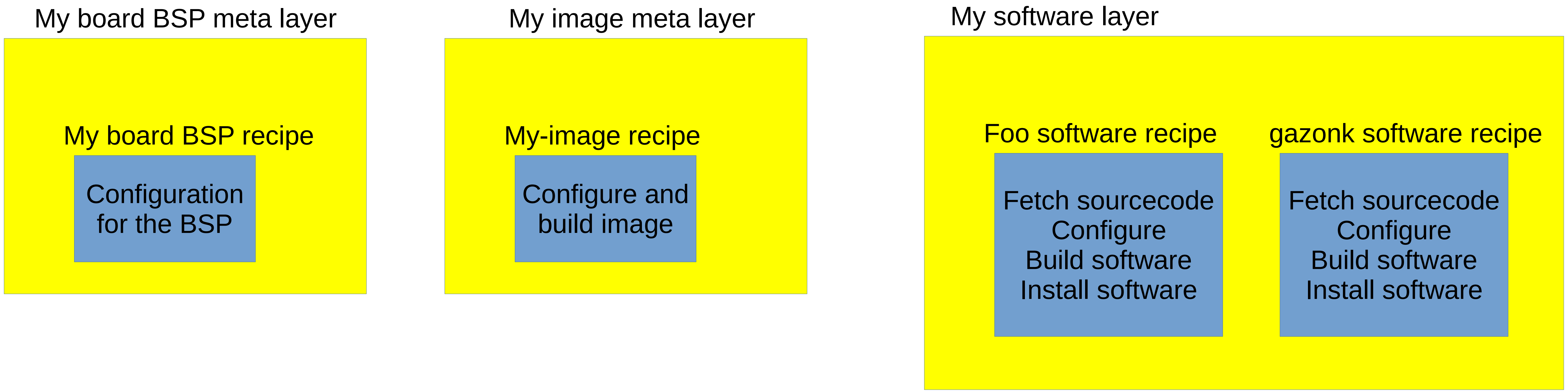
- Yocto is made of layers.
- Recipes are collected in the meta-layers.
- The recipes in a meta-layer contains instructions for how to build, e.g.:
  - An application
  - A BSP
  - An image



MindRoad Academy

Deploy – Yocto Project

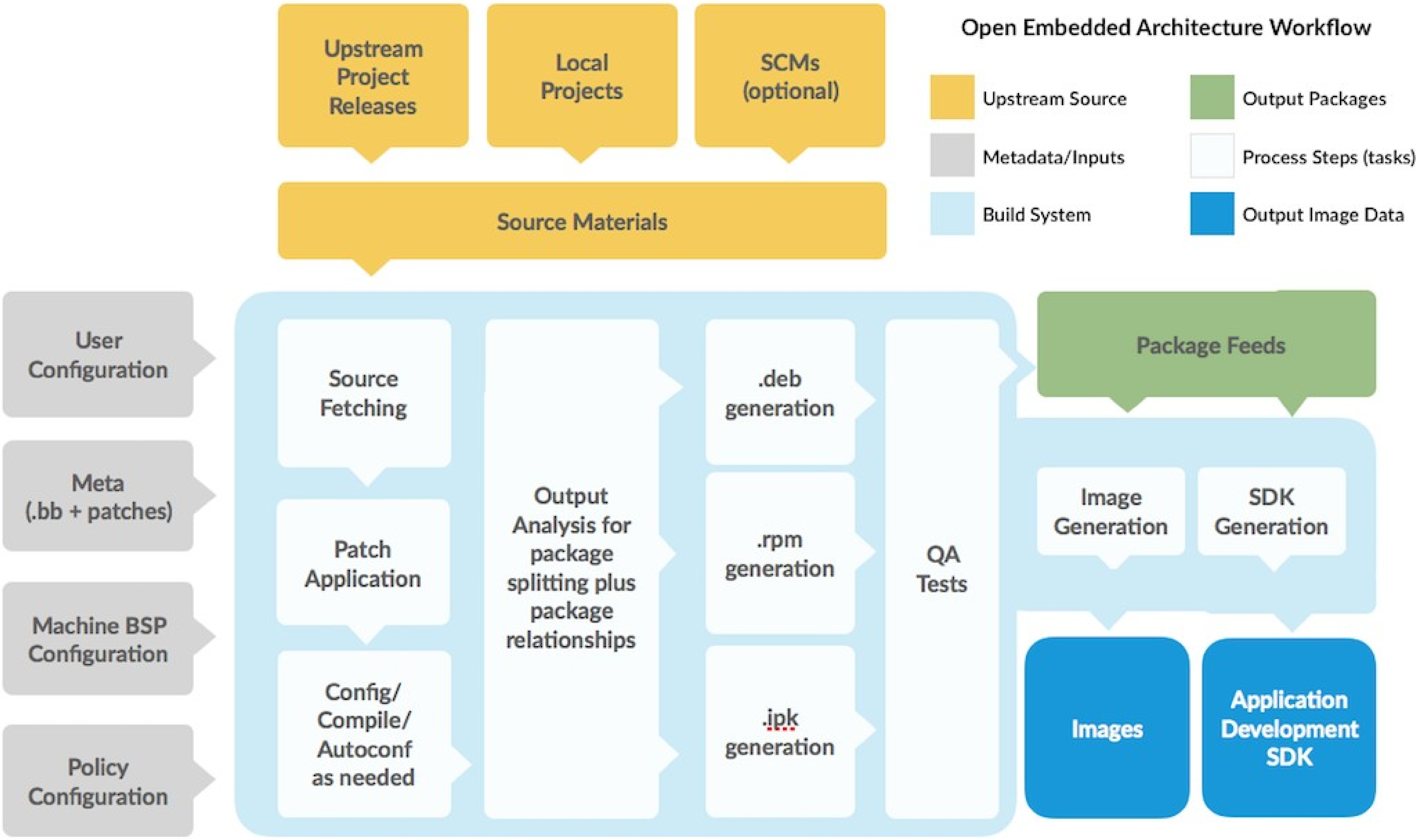
- A meta-layer consists of a collection of recipes.



- To build the software for different boards we swith the BSP layer.

MindRoad Academy

Deploy – Yocto Project



MindRoad Academy

Deploy – Yocto Project

- Yocto downloads all source code for all open source parts and compiles them when you build with Yocto.
- It will build toolchain, bootloader, Linux kernel and the root filesystem.
- To speed up later builds, it saves information from earlier builds in a state cache.
- Developers can share a sstate cache to speed up builds.
- As a result you will get; packages (rpm, deb, ipk), images for different filesystems, archive files (tar, zip).
  - Which of these are created depends on your configuration.

MindRoad Academy

Deploy – Yocto Project

- Yocto project is well supported and developed by many companies.
- Yocto project is an industry standard.
- Yocto project is flexible.
- Yocto has a learning curve to learn the basics.
  - Learning Yocto is well worth it.
- For small projects it can be easier to use buildroot.
- More and more companies are using Yocto to build Linux for their embedded systems.

Deploy – Yocto Project

- Example: a virtual machine

```
git clone  -b Kirkstone git://git.yoctoproject.org/poky.git          # check out poky (Yocto 4.0.x)

cd poky
source oe-init-build-env                                              # set up the environment

# edit the MACHINE variable in the file conf/local.conf to for example
MACHINE ?= "qemuarm"

bitbake core-image-minimal                                            # build the image core-image-minimal
# take a long coffe break

# Test run the system in the qemu virtual machine
runqemu core-image-minimal
```

MindRoad Academy

Deploy – Yocto Project

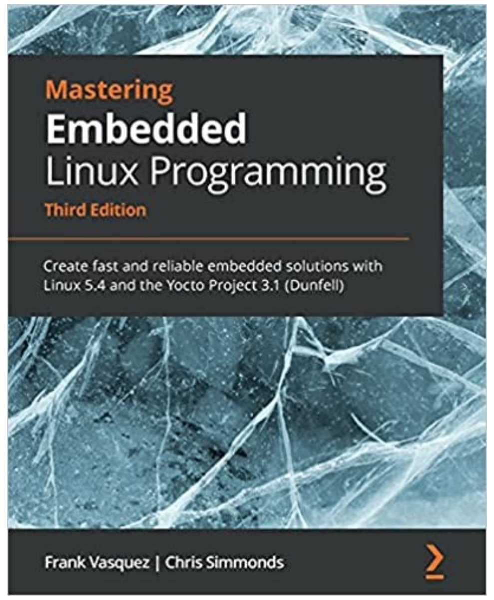
- Example: Beaglebone black

```
git clone  -b Kirkstone git://git.yoctoproject.org/poky.git          # check out poky (Yocto 4.0.x)

cd poky
source oe-init-build-env    build-bbb                               # set up the environment

# edit the MACHINE variable in the file conf/local.conf to for example
MACHINE ?= "beaglebone-yocto"

bitbake core-image-minimal                                          # build the image core-image-minimal
# take a long coffe break

# Install the bootloader, kernel and root filesystem image to a SD card and boot the Beaglebone black.
```

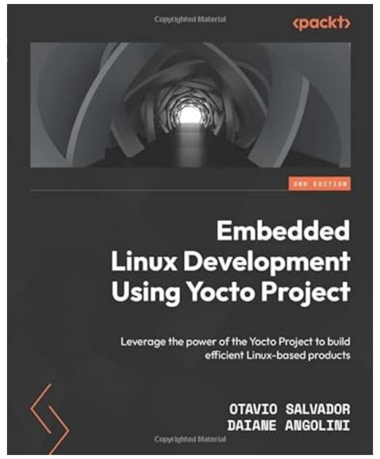
MindRoad Academy

Links and books

- Links:
  - https://www.yoctoproject.org/ Yocto Project
  - https://buildroot.org/ Buildroot
  - https://www.linuxfoundation.org/ Linux Foundation
  - https://www.embeddedlinuxconference.com/ Previous Linux Foundation Embedded Linux Conferences
  - https://kernel.org/ The Linux kernel
  - https://github.com/u-boot/u-boot U-Boot
  - https://www.lysator.liu.se/~kjell-e/tekla/linux My pages about Linux and embedded Linux.



- Books:
  - Mastering embedded Linux programming Third Edition, 2021
    By Chris Simmonds & Frank Vasquez
  - Embedded Linux Development Using Yocto Project, 3rd ed.
    By Otavio Salvador, Daiane Angolini

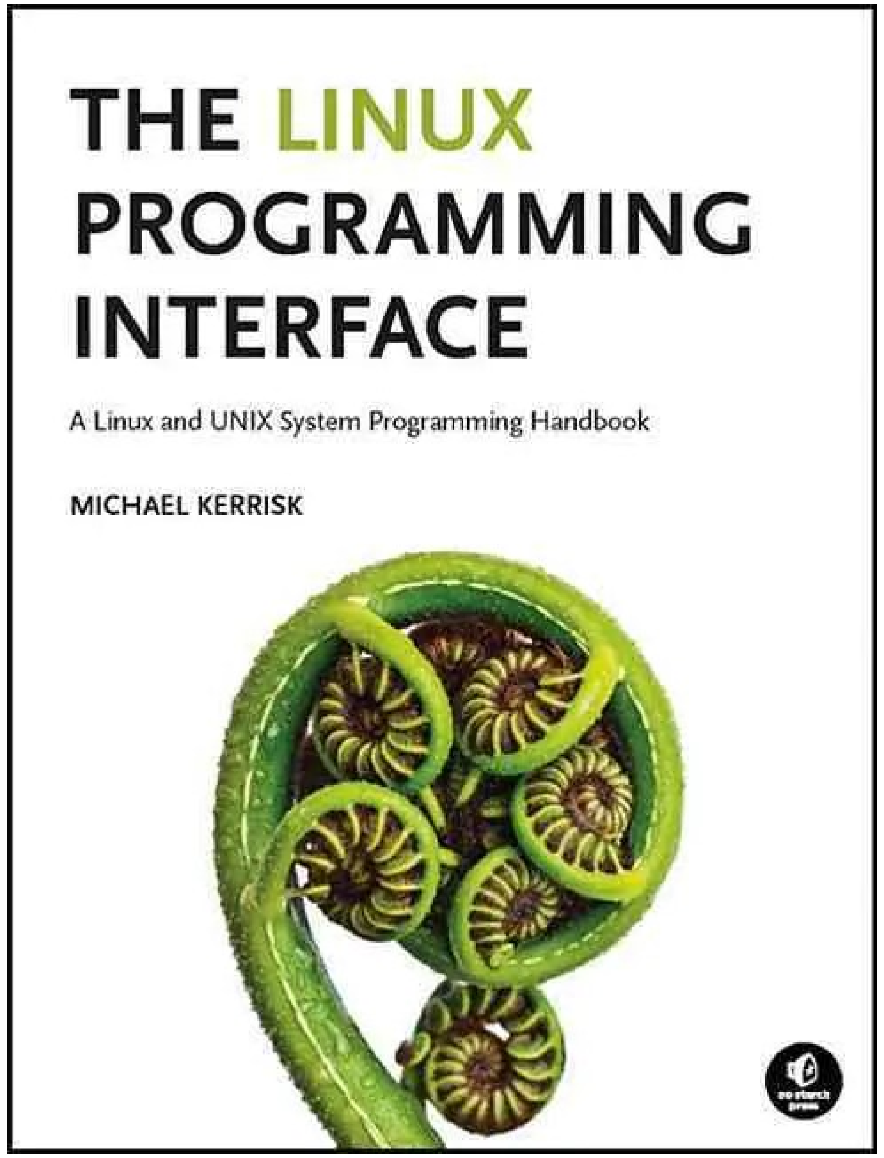


MindRoad Academy

Links and books

- Books:
  - The Linux programming interface
    - By: Michael Kerrisk

    - If you are going to program in Linux,
      this is a book you should consider buying.



Questions?

?

MindRoad Academy

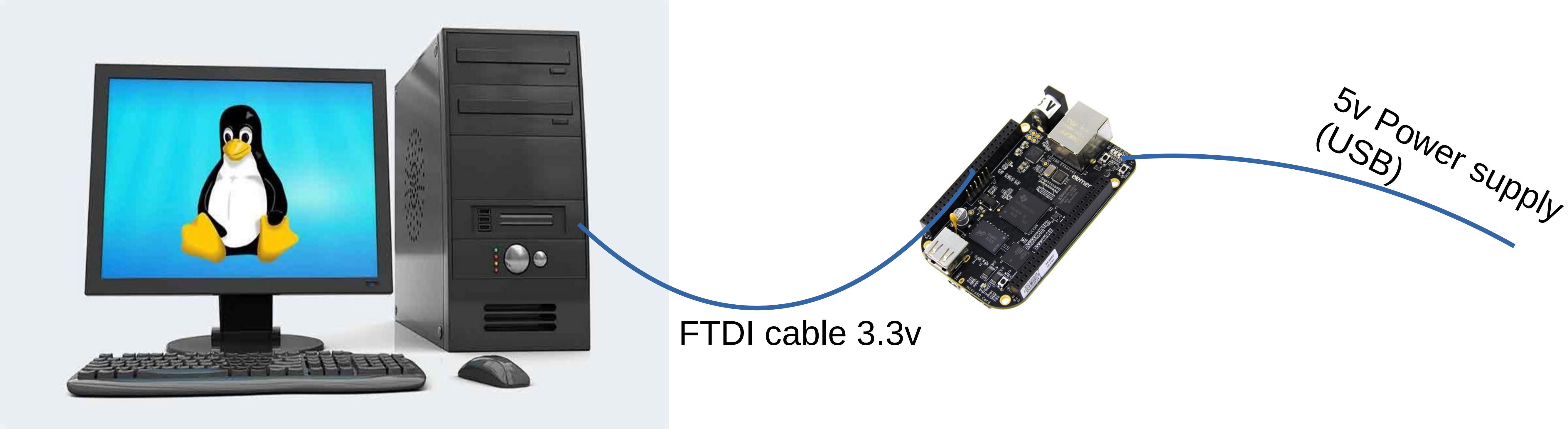
MindRoad

Thank you!

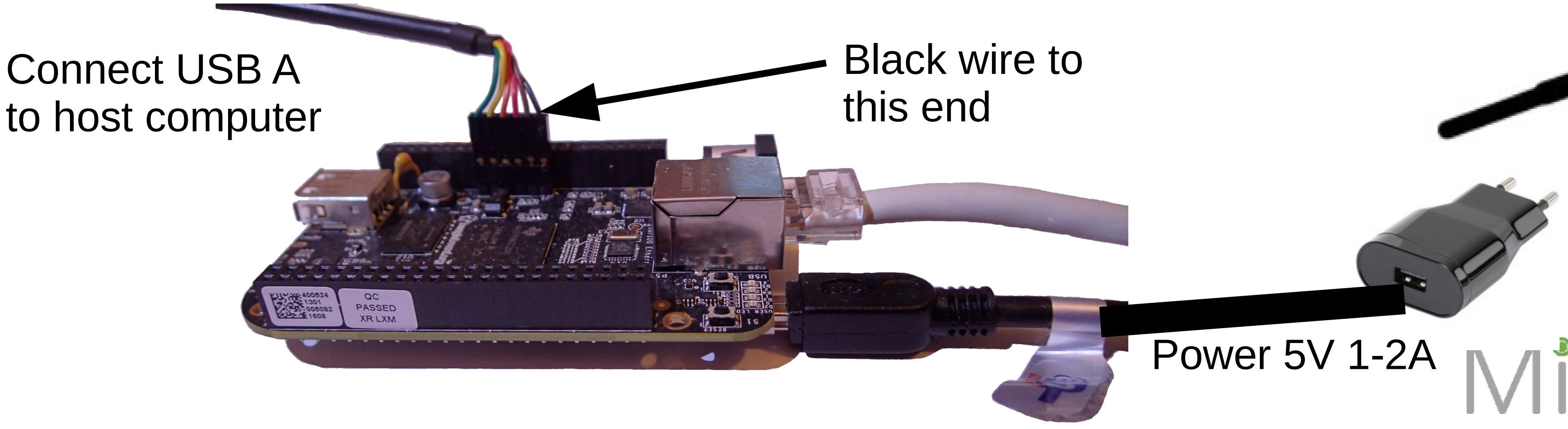
Kjell Enblom

MindRoad Academy

Beaglebone black




```
picocom  -b 115200   /dev/tty/USB0
```



FTDI cable 3.3v