Linux for embedded systems

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Why should we use Linux for embedded systems?

- Re-using components
  - Open-source
  - Many components for standard features
  - Wide-spread enough, high chance of having open-source components
  - Quickly design and develop complicated products.
  - Don’t re-develop yet another operating system kernel, TCP/IP stack, USB stack or another graphical toolkit library.
  - Focus on the added value of your product.
- Low cost
  - Free of charge.
  - Can reduce the cost of software licenses to zero.
    - The development tools are free, unless you choose a commercial embedded Linux edition.
  - You still need substantial learning and engineering efforts
  - Allows to have a higher budget for the hardware or to increase the company’s skills and knowledge

Why should we use Linux for embedded systems? (continue)

- Full control
  - Open-source
  - Unlimited modifications, changes, tuning, debugging, optimization, for an unlimited period of time
  - Without lock-in or dependency from a third-party vendor
  - Non open-source components must be avoided when the system is designed and developed
  - Have full control over the software part of your system
- Quality
  - Many open-source components are widely used, on millions of systems
  - Usually higher quality than what an in-house development can produce, or even proprietary vendors
  - Most widely-used open-source components have good quality.
  - Allows to design your system with high-quality components at the foundations

Why should we use Linux for embedded systems? (continue)

- Eases testing of new features
  - Open-source being freely available, it is easy to get a piece of software and evaluate it
  - Allows to easily study several options while making a choice
  - Much easier than purchasing and demonstration procedures needed with most proprietary products
  - Allows to easily explore new possibilities and solutions
- Community support
  - Open-source software components are developed by communities of developers and users
  - This community can provide high-quality support: you can directly contact the main developers of the component you are using. The likelyhood of getting an answer doesn't depend what company you work for.
  - Often better than traditional support, but one needs to understand how the community works to properly use the community support possibilities
  - Allows to speed up the resolution of problems when developing your system

Embedded hardware for Linux systems

Processor and architecture

- x86 and x86-64, as found on PC platforms, but also embedded systems (multimedia, industrial)
- ARM, with hundreds of different SoCs (all sorts of products)
- RiscV, the rising architecture with a free instruction set (from high-end cloud computing to the smallest embedded systems)
- PowerPC (mainly real-time, industrial applications)
- MIPS (mainly networking applications)
- SuperH (mainly set top box and multimedia applications)
- c6x (TI DSP architecture)
- Microblaze (soft-core for Xilinx FPGA)
- Others: ARC, m68k, Xtensa...

RAM and storage

- RAM: a very basic Linux system can work within 8 MB of RAM, but a more realistic system will usually require at least 32 MB of RAM. Depends on the type and size of applications.
- Storage: a very basic Linux system can work within 4 MB of storage, but usually more is needed.
  - Flash storage is supported, both NAND and NOR flash, with specific filesystems
  - Block storage including SD/MMC cards and eMMC is supported
- Not necessarily interesting to be too restrictive on the amount of RAM/storage: having flexibility at this level allows to re-use as many existing components as possible.

Communication

- The Linux kernel has support for many common communication buses
  - I2C
  - SPI
  - CAN
  - 1-wire
  - SDIO
  - USB
- And also extensive networking support
  - Ethernet, Wifi, Bluetooth, CAN, etc.
  - IPv4, IPv6, TCP, UDP, SCTP, DCCP, etc.
  - Firewalling, advanced routing, multicast

Types of hardware platforms

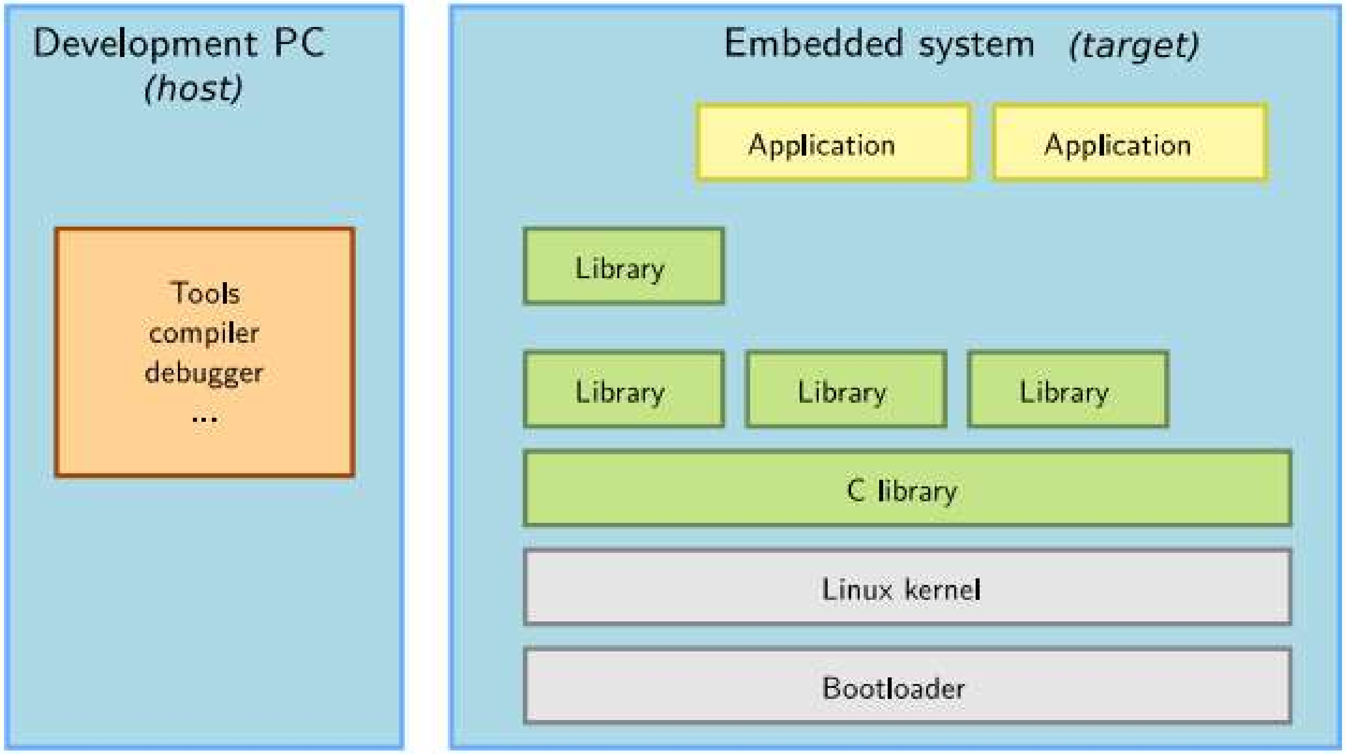
- Evaluation platforms from the SoC vendor. Usually expensive, but many peripherals are built-in. Generally unsuitable for real products.
- Component on Module, a small board with only CPU/RAM/flash and a few other core components, with connectors to access all other peripherals. Can be used to build end products for small to medium quantities.
- Community development platforms, to make a particular SoC popular and easily available. These are ready-to-use and low cost, but usually have less peripherals than evaluation platforms. To some extent, can also be used for real products.
- Custom platform. Schematics for evaluation boards or development platforms are more and more commonly freely available, making it easier to develop custom platforms.

Criteria for choosing the hardware

- Make sure the hardware you plan to use is already supported by the Linux kernel, and has an open-source ***bootloader***, especially the SoC you're targeting.
- Having support in the official versions of the projects (kernel, bootloader) is a lot better: quality is better, and new versions are available.
- Some SoC vendors and/or board vendors do not contribute their changes back to the mainline Linux kernel. Ask them to do so, or use another product if you can. A good measurement is to see the delta between their kernel and the official one.
- Between properly supported hardware in the official Linux kernel and poorly-supported hardware, there will be huge differences in development time and cost.

Embedded Linux system architecture

Host and target



Software components

- Cross-compilation toolchain
  - Compiler that runs on the development machine, but generates code for the target
- Bootloader
  - Started by the hardware, responsible for basic initialization, loading and executing the kernel
- Linux Kernel
  - Contains the process and memory management, network stack, device drivers and provides services to user space applications
- C library
  - The interface between the kernel and the user space applications
- Libraries and applications
  - Third-party or in-house

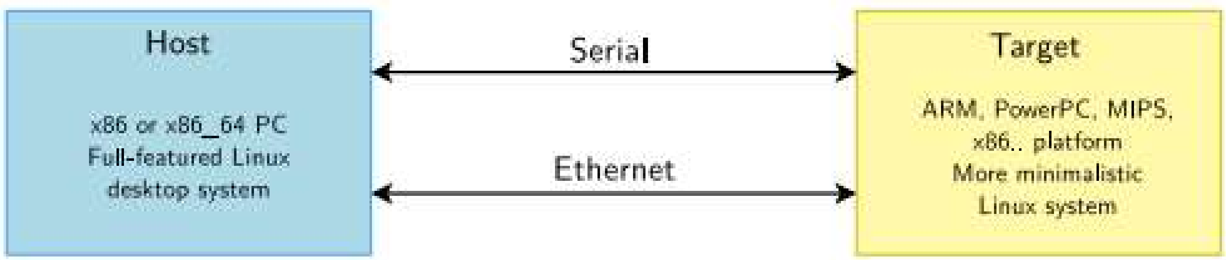
Embedded Linux development environment

Embedded Linux solutions

- Two ways to switch to embedded Linux
  - Use solutions provided and supported by vendors like MontaVista, Wind River or TimeSys. These solutions come with their own development tools and environment. They use a mix of open-source components and proprietary tools.
- Use community solutions. They are completely open, supported by the community.
- OS for Linux development
  - Recommend to use Linux as the desktop operating system to embedded Linux developers, for multiple reasons
- Any good and sufficiently recent Linux desktop distribution can be used for the development workstation
  - Ubuntu, Debian, Fedora, openSUSE, Red Hat, etc

Host vs target

- When doing embedded development, there is always a split between
  - The host, the development workstation, which is typically a powerful PC
  - The target, which is the embedded system under development
- They are connected by various means: almost always a serial line for debugging purposes, frequently an Ethernet connection, sometimes a JTAG interface for low-level debugging



Need to install necessary packages/software/programs

Principle of software management

Software components	Manage sofware	How to manage
• Executable files • Libraries • Configuration files • Temporary files	• Install • Remove • Reconfigure • Get information	• Independent • Script for each software • Software database • Tools

Install software from source codes

Install source code

Compile source code
- Install dependent packages if needed

Install the software
- Installation scripting

Configure software
- Configuration scripting

Remove software
- Removal scripting

Scripts for all above operations

Makefile, Automake, make, other developing tools

Install software from management program

Program to install/remove/configure

Check the conflict with other software

Use tools/programs to manage software

- Software are packed as packages
- Software database
- Detect software conflict (redundance, missing, different versions)

Tools to manage software

	Redhat	Debian
Manage packages	rpm	dpkg
Package Management System	yum, urpm*, dnf	apt-*
Interactive interface	dselect, taskshell	aptitude
GUI	krpm, yumex	synaptic
Package repositories		/etc/apt/sources.list

apt-*

Same as yum but for Debian distributions

Some operations

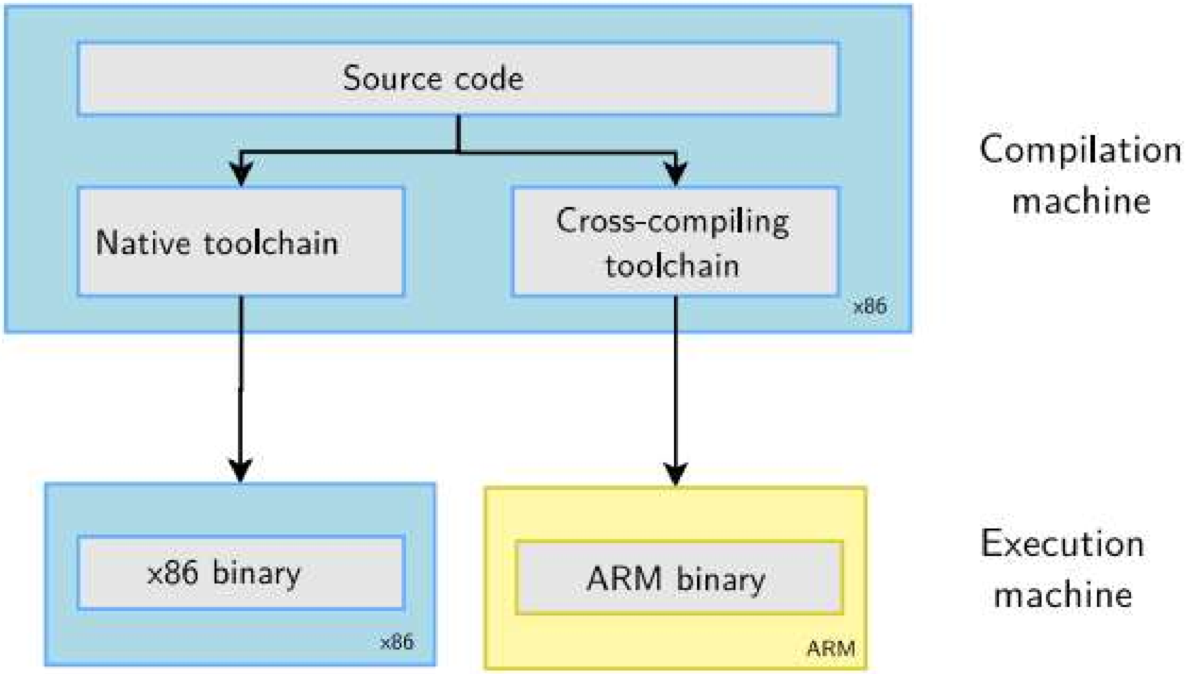
- apt-get install/ download/ remove/ source application
- apt-get clean
- apt-get update/ upgrade
- Note: New Debian OS: apt is a subset of apt-get or apt-cache

Cross-compiling toolchains

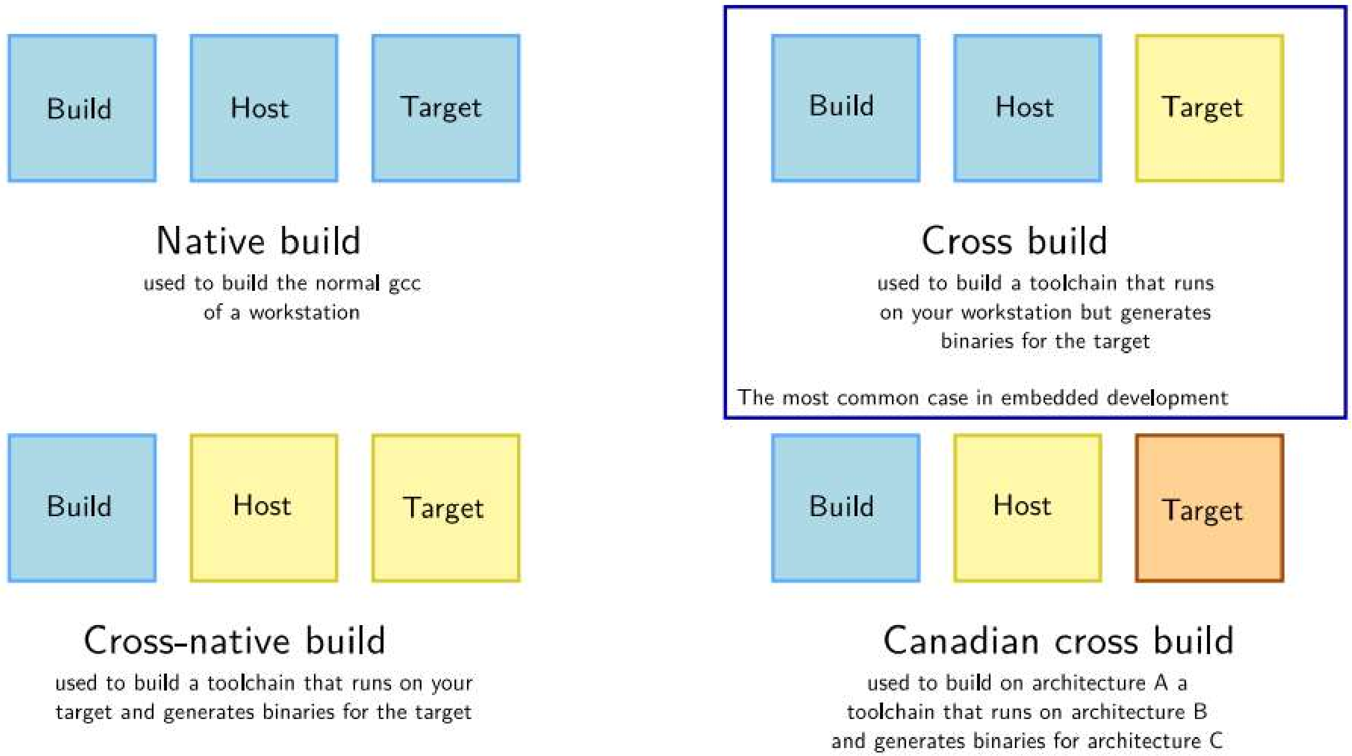
Toolchain

- The usual development tools available on a GNU/Linux workstation is a native toolchain
- This toolchain runs on your workstation and generates code for your workstation, usually x86
- For embedded system development, it is usually impossible or not interesting to use a native toolchain
  - The target is too restricted in terms of storage and/or memory
  - The target is very slow compared to your workstation
  - You may not want to install all development tools on your target.
- Therefore, cross-compiling toolchains are generally used. They run on your workstation but generate code for your target.

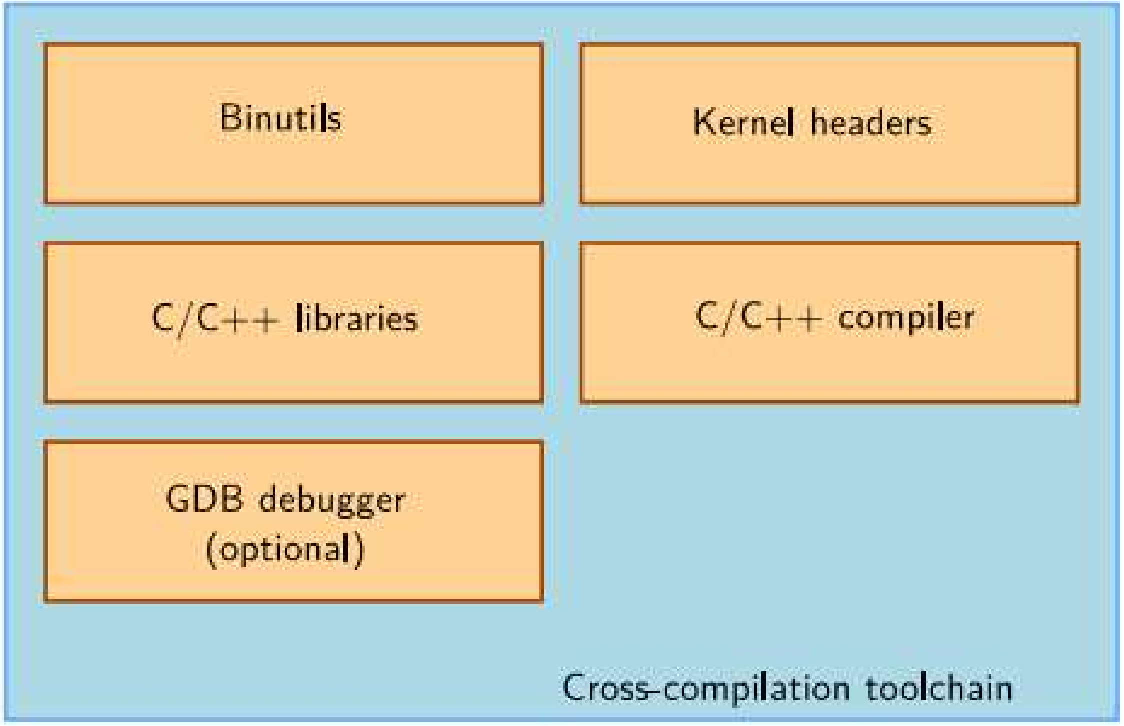
Toolchain


Source code
Native toolchain
Cross-compiling toolchain
x86
x86 binary
x86
ARM binary
ARM
Compilation machine
Execution machine

Different toolchain build procedures



Components


Binutils
Kernel headers
C/C++ libraries
C/C++ compiler
GDB debugger
(optional)
Cross-compilation toolchain

Building or obtaining a toolchain

Obtaining a toolchain

- Build a toolchain manually
  - Flexible
  - A difficult and painful task
- Get a pre-compiled toolchain
  - Advantage: simplest and most convenient solution
  - Disadvantage: you cannot fine tune the toolchains to your needs
  - Make sure the toolchain you find meets your requirements: CPU, endianesss, C library, component version, etc.
- Possible choice:
  - Toolchains packaged by your distribution
  - Sourcery CodeBench toolchains, now only supporting MIPS, NIOS-II, AMD64, Hexagon. Old versions with ARM support still available through build systems

Toolchain building utilities

- Another solution is to use utilities that automate the process of building the toolchain
  - Same advantage as the pre-compiled toolchains: you don’t need to mess up with all the details of the build process
  - But also offers more flexibility in terms of toolchain configuration, component version selection, etc.
  - They also usually contain several patches that fix known issues with the different components on some architectures
  - Multiple tools with identical principle: shell scripts or Makefile that automatically fetch, extract, configure, compile and install the different components
- Some solutions
  - Crosstool-ng
  - Buildroot
  - PTXdist
  - OpenEmbedded/ Yocto Project