Component-based Software Development for Cortex-M Microcontrollers

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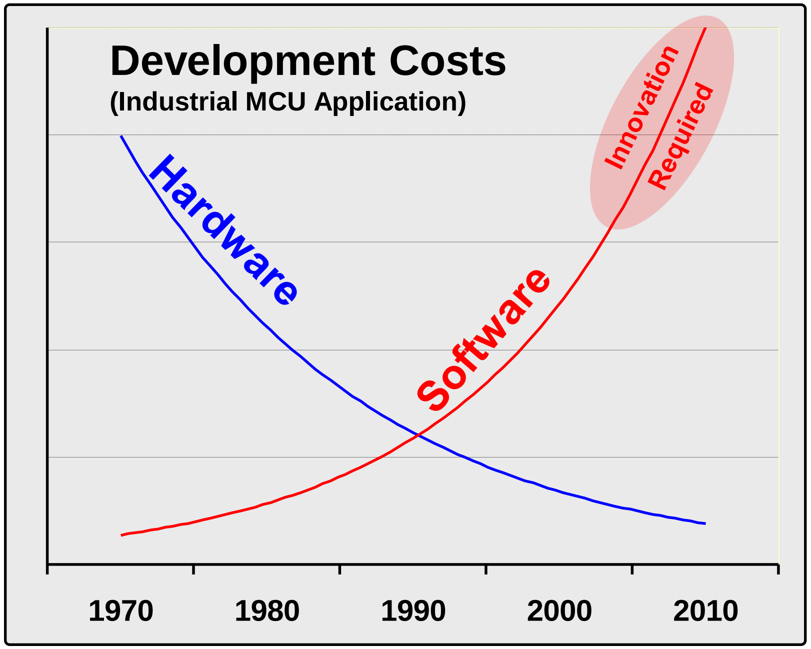
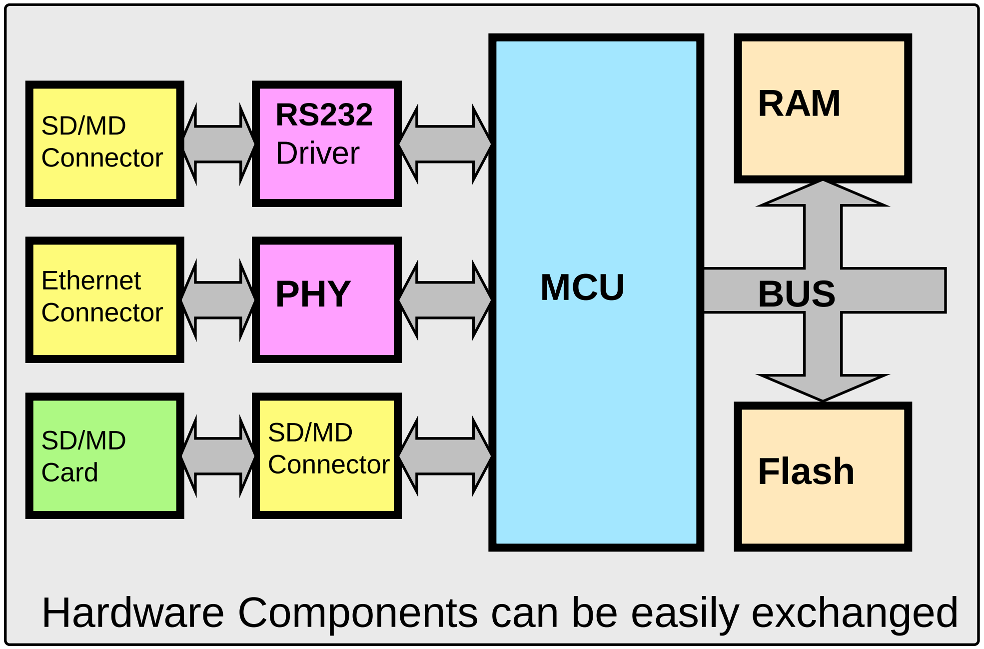
Software Complexity – The Challenge



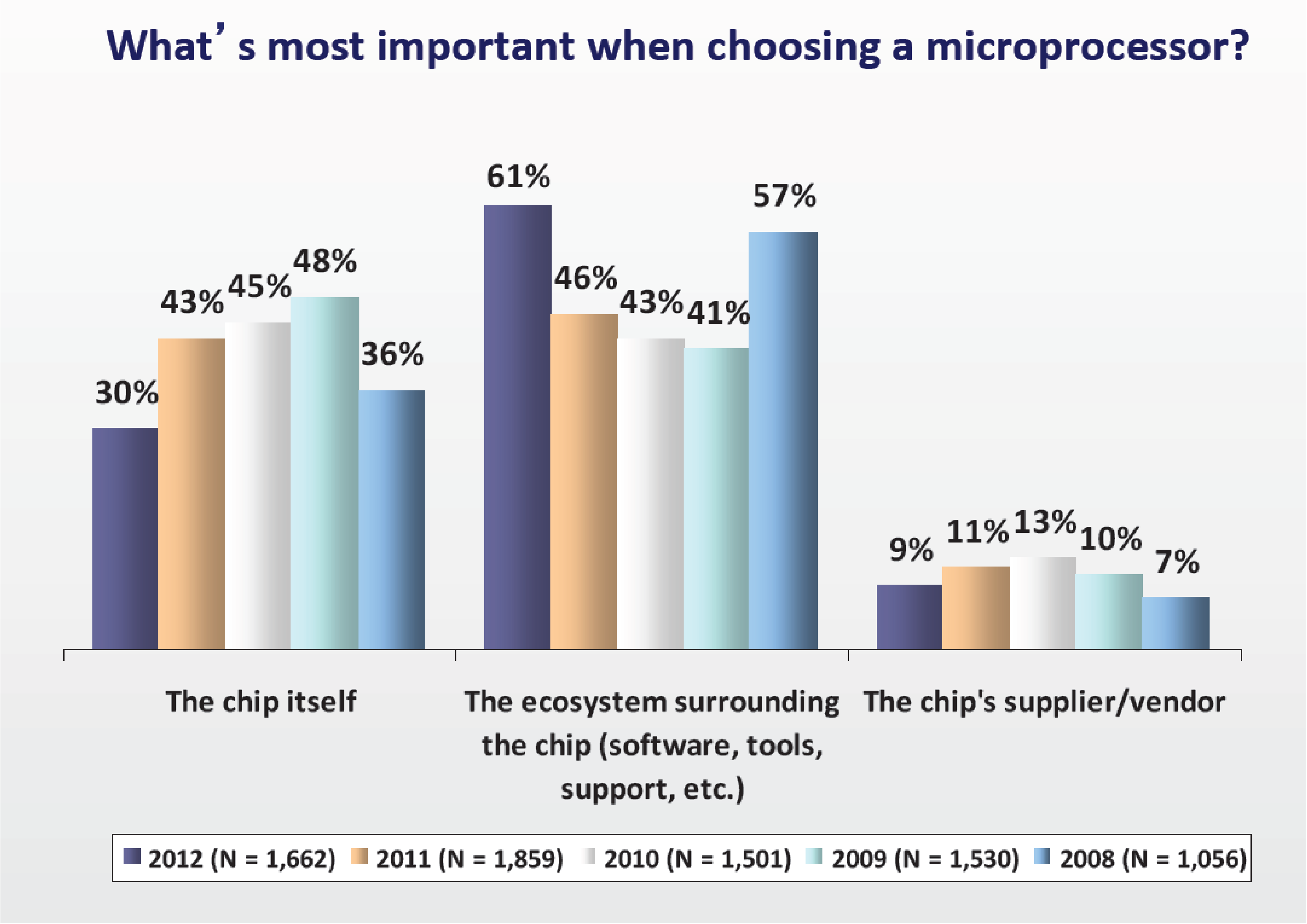


- Well-known issues that drive software development costs
  - Increasing product requirements that are implemented by software
  - Hardware problems tend to become compensated by software

- Hardware uses defined interfaces that simplify re-use
  - Software components are hard to integrate

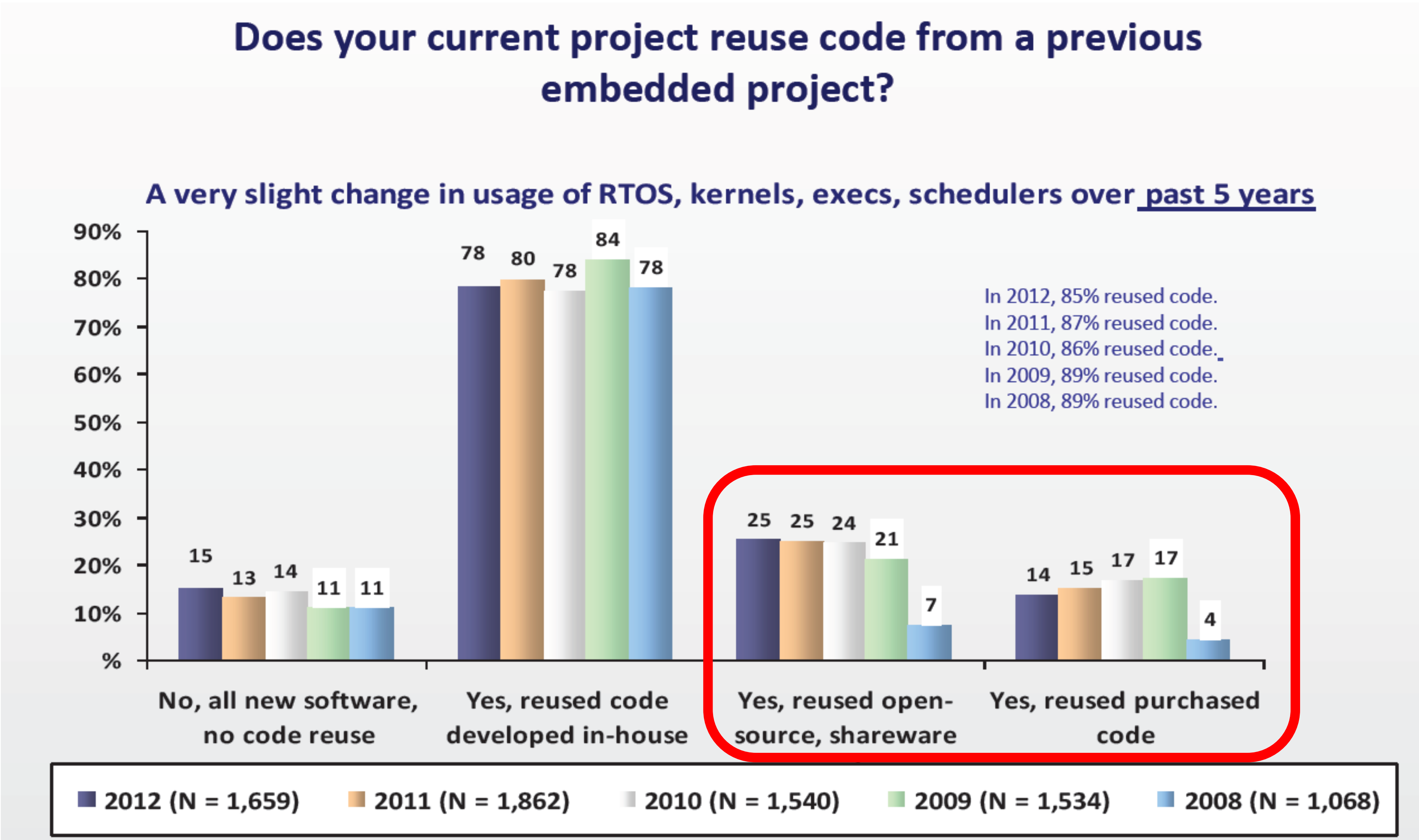
Software Standards and Software Components are key for productivity!

An Ecosystem is considered helpful…



Source: UBM Electronics – 2012 Embedded Market Study

…but Software Reuse is Limited



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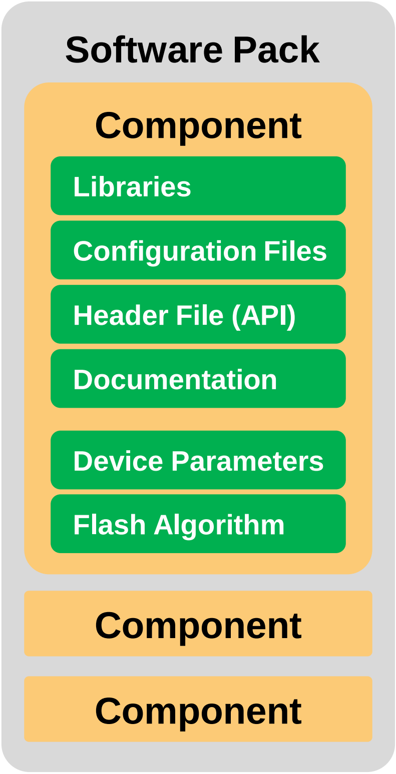
Questions when using external source code

- Usage of files (source code, header, library) is unclear
  - Will my Compiler and Tool Environment work?
  - Where is the documentation to the software component?
  - What other requirements (i.e. libraries or RTOS) does this software have?
  - Will the source code run on my target hardware?
  - Does the source code need adaptations or configuration?

- Project Maintenance after files are integrated
  - Where did I get the source code from; who to contact for support?
  - What is the version of that source code?
  - What do I need to change when I update the files?

- What are the License conditions of the code
  - Can I use this files in my project?

Packing Software is a Solution



- All software components are delivered in one Software Pack that is easy to install (like an IC)
- A package description file (PDSC) contains:
  - Supplier information
    - Download URL
    - License
    - Release version
  - Usage of source code and libraries files for:
    - Specific processors
    - Specific microcontroller families and devices
    - Tool Chains
  - Other components that are required or related

Pack Description File Example

```
<package schemaVersion="1.0" xmlns:xs="..." xs:noNamespaceSchemaLocation="PACK.xsd">
  <vendor>Keil</vendor>
  <name>CMSIS_RTX</name>
  <description>RTX is a CMSIS-RTOS compliant RTOS for Cortex-M based devices</description>
  <license>License.txt</license>
  <url>http://www.keil.com/demo/eval/rtx.htm</url>

  <releases>
    <release version="4.70.0">
      Updates:
      - osTimerCreate can be called prior to osKernelStart (but after osKernelInitialize)
      - initialization of external timer corrected for Cortex-M0/M0+/M1
      - Message/Mail Queue behaviour corrected when timeout expires
    </release>
  </releases>
```

Supplier and release information

```
  <conditions>
    <condition id= "CMSIS_Core">
      <description>This component requires the CMSIS CORE component</d...
      <require Cclass ="CMSIS" Cgroup="CORE"/>
    </condition>
```

Dependency on other component

```
    <!-- ARMCC -->
    <condition id="CM0_LE_ARMCC">
      <description>Cortex-M0 or Cortex-M0+ or SC000 processor based device in little endian mode for the ARM
    Compiler</description>
      <accept Dcore="Cortex-M0"/>
      <accept Dcore="Cortex-M0+"/>
      <accept Dcore="SC000"/>
      <require Dendian="Little-endian"/>
      <require Tcompiler="ARMCC"/>
    </condition>
```

Dependency on core, endianness and toolchain

Pack Description File Example

```
  <components>
    <component Cclass="CMSIS" Cgroup="RTOS" Csub="Keil RTX" condition="CMSIS_Core">
      <description>RTX is a CMSIS RTOS implementation for Cortex-M, processor based devices.</description>
      <files>
        <!-- CPU and Compiler independent -->
        <file category="doc" name="Doc\index.html"/>
        <file category="header" name="INC\cmsis_os.h"/>
        <file category="source" name="Templates\RTX_Conf_CM.c" copy="true"/>
        <!-- CPU and Compiler dependent -->
        <!-- ARMCC -->
        <file category="library" condition="CM0_LE_ARMCC" name="Lib\ARM\RTX_CM0.lib"/>
        <file category="library" condition="CM0_BE_ARMCC" name="Lib\ARM\RTX_CM0_B.lib"/>
        <file category="library" condition="CM3_LE_ARMCC" name="Lib\ARM\RTX_CM3.lib"/>
        <file category="library" condition="CM3_BE_ARMCC" name="Lib\ARM\RTX_CM3_B.lib"/>
        <file category="library" condition="CM4F_LE_ARMCC" name="Lib\ARM\RTX_CM4.lib"/>
        <file category="library" condition="CM4F_BE_ARMCC" name="Lib\ARM\RTX_CM4_B.lib"/>
        <!-- GCC -->
        <file category="library" condition="CM0_LE_GCC" name=
        <file category="library" condition="CM0_BE_GCC" name="Lib\GCC\
            :
        <!-- IAR -->
            :
        <file category="library" condition="CM4F_LE_IAR" name="Lib\IAR\RTX_CM4.a"/>
        <file category="library" condition="CM4F_BE_IAR" name="Lib\IAR\RTX_CM4_B.a"/>
      </files>
    </component>
  </components>
</package>
```

Component Description

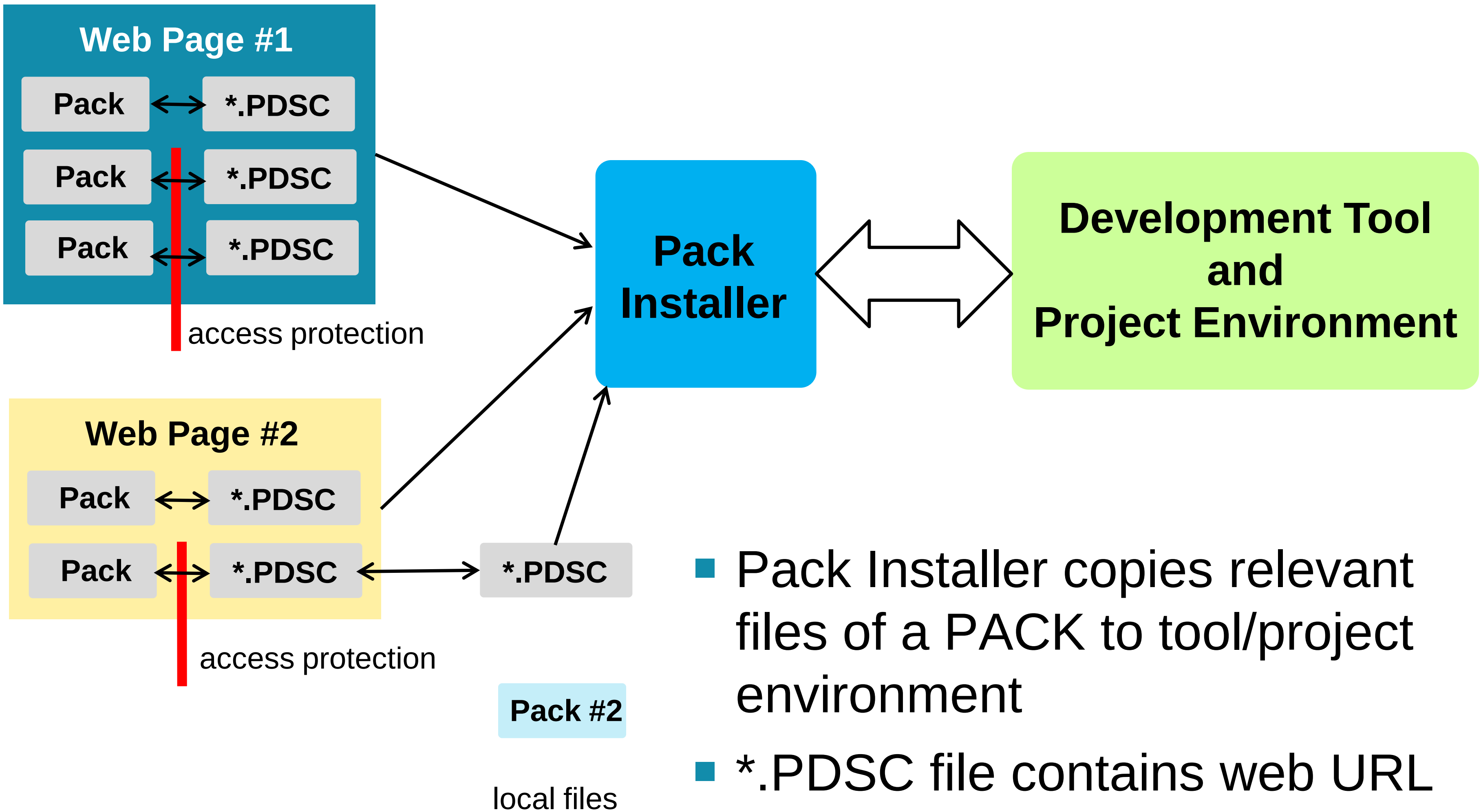
Common files

Files with processor dependencies for ARM Compiler

Files with processor dependencies for GCC Compiler

Files with processor dependencies for IAR Compiler

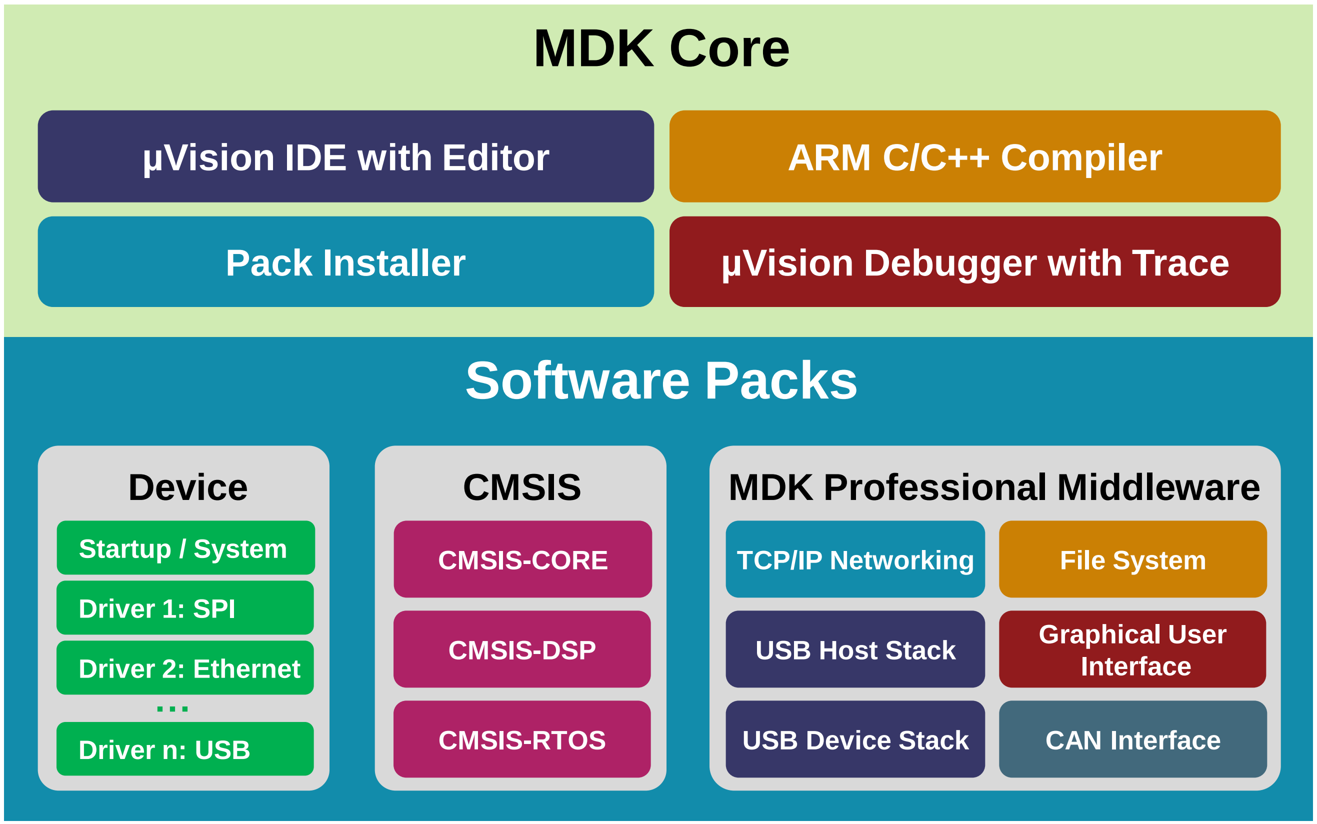
Pack Installation and Updates



- Pack Installer copies relevant files of a PACK to tool/project environment
- *.PDSC file contains web URL for initial download & update

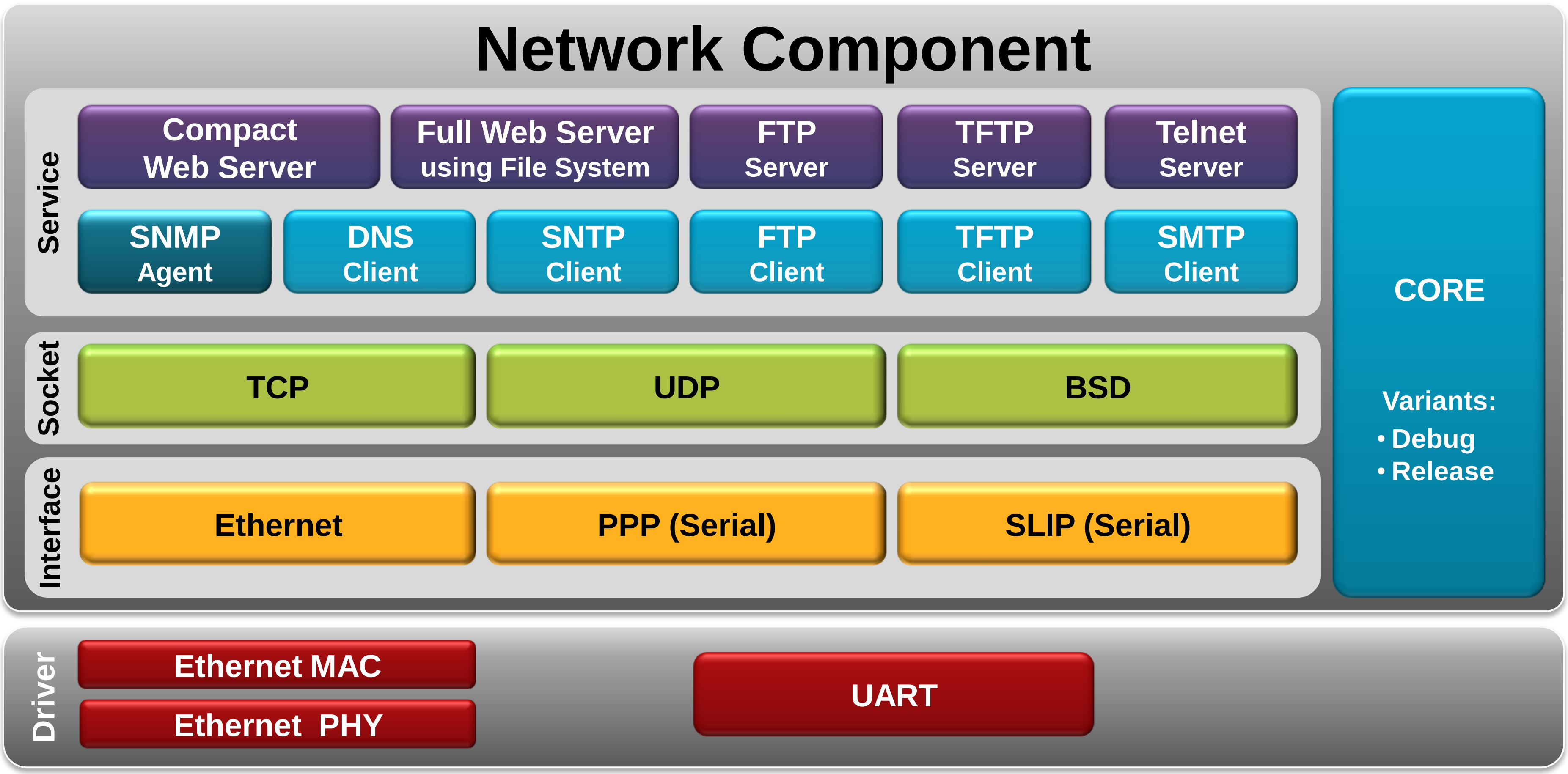
MDK-ARM Version 5 – Overview

- MDK-ARM Core: contains development tools



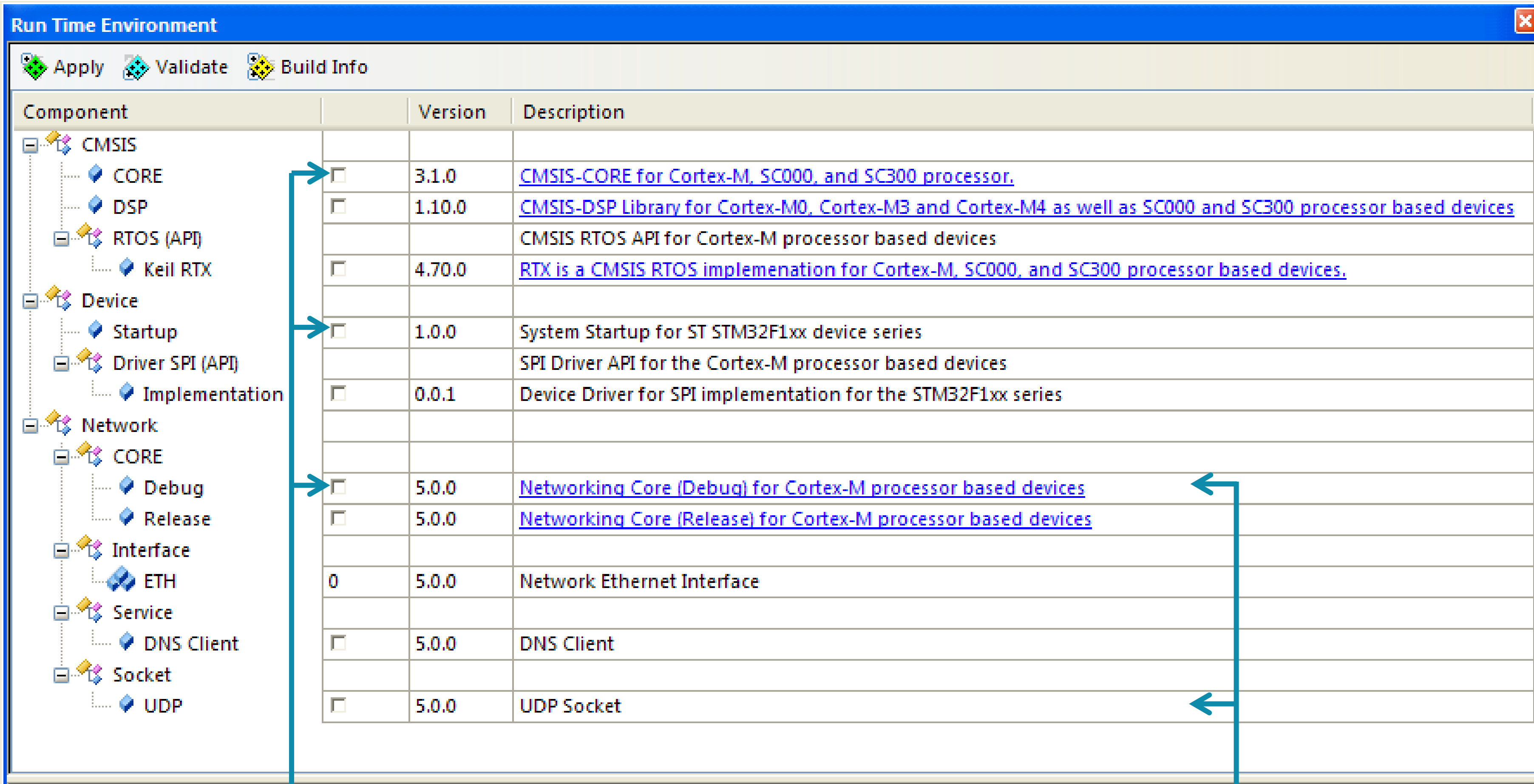
- Software Packs: contain device support & middleware
  - Installed & updated on demand using the Pack Installer

Component Example: TCP/IP Networking



- TCP/IP Networking Components
  - Easy customization of application requirements

Component View in MDK-ARM

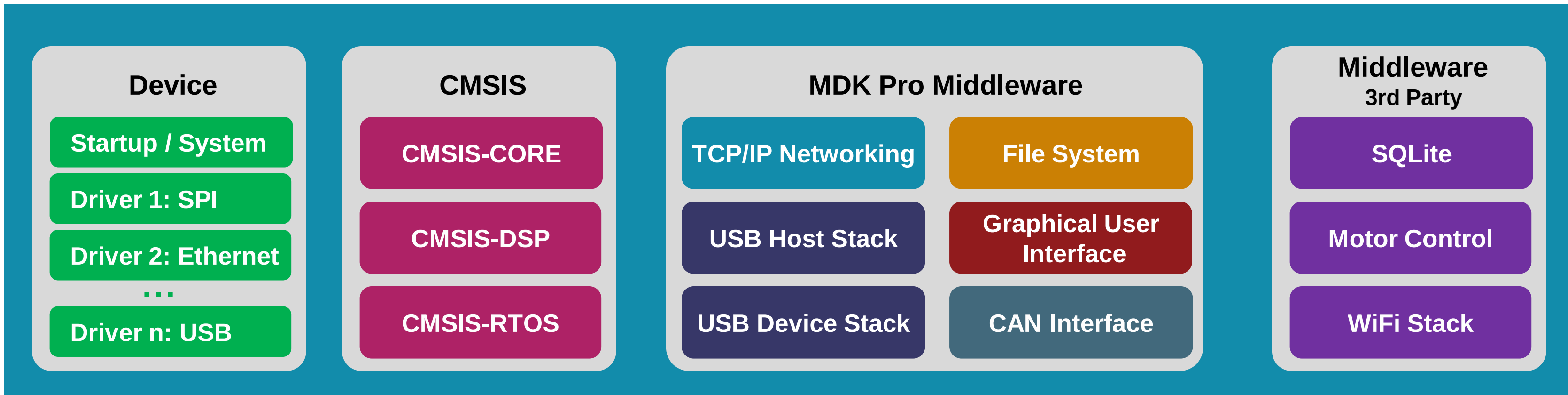


The Run-Time Environment is created by selecting available software components

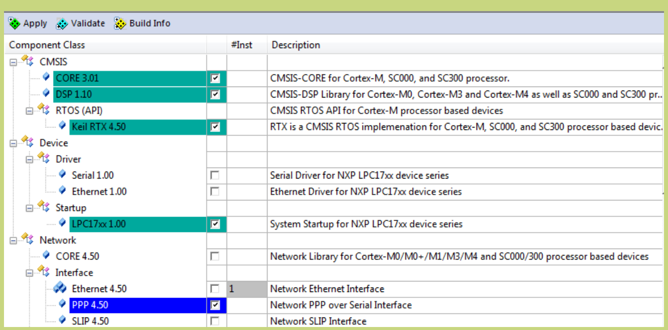
Dependencies and conflicts between components can be automatically resolved

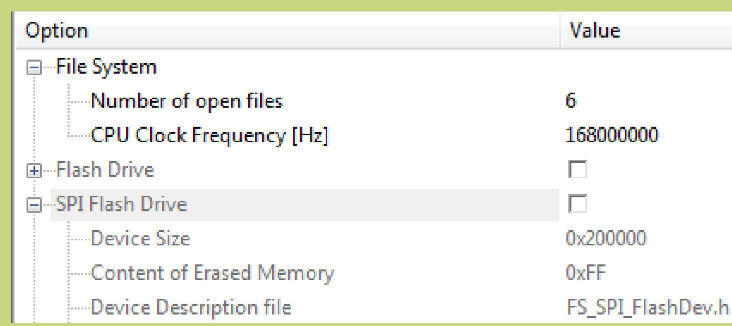
Design with Software Components

1. Explore available Software Components from the installed Software Packs



2. Choose components and create a configurable Run-Time Environment (RTE)





3. Develop application in C/C++ using the APIs of RTE components

Using external source code needs Standards

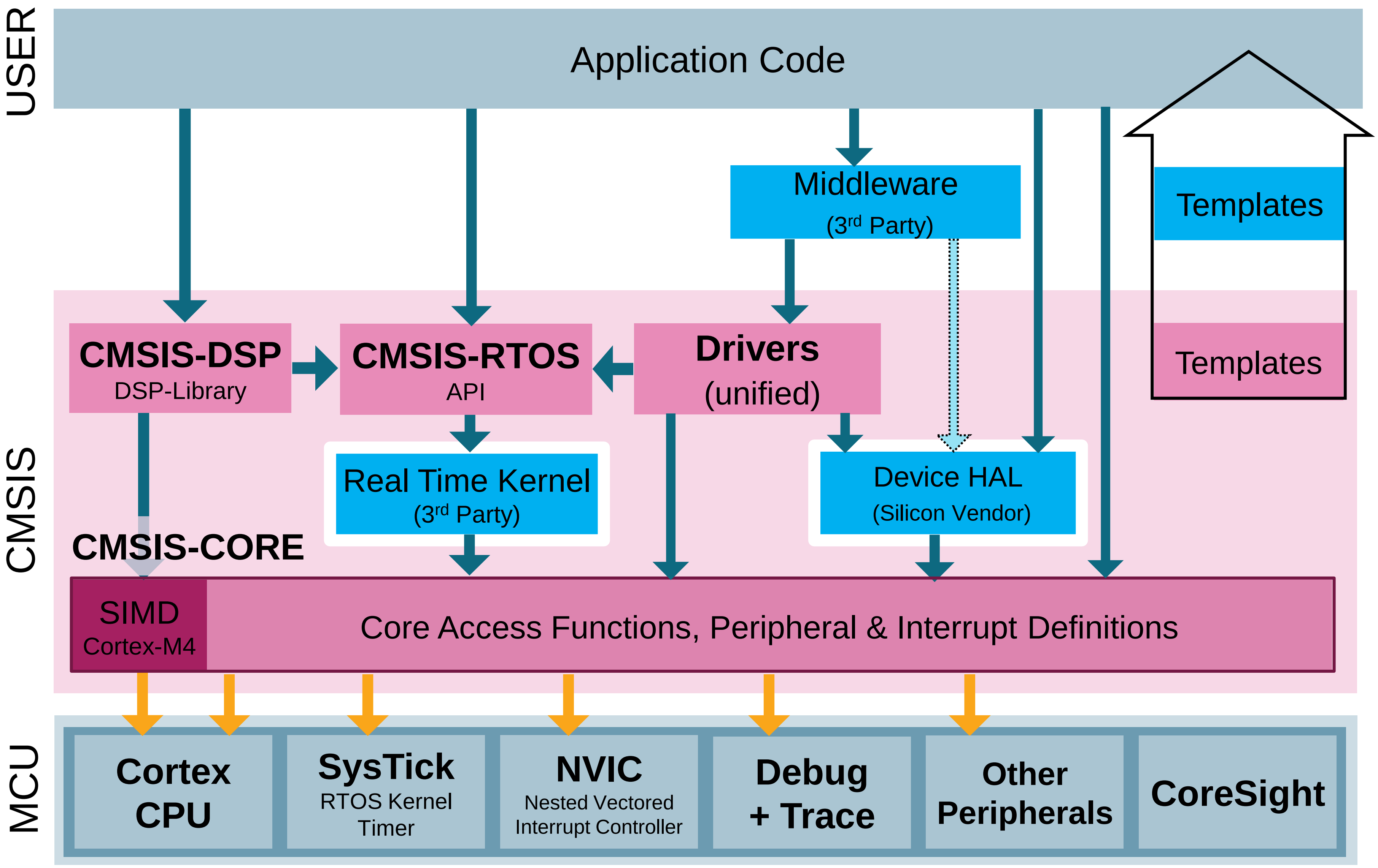
What is required to use standard Software Components on Microcontrollers?

- Standard Processor Architecture
  - ARM Cortex™-M series ensure a compatible target processor and provide common core peripherals (i.e. NVIC interrupt system, SysTick timer)

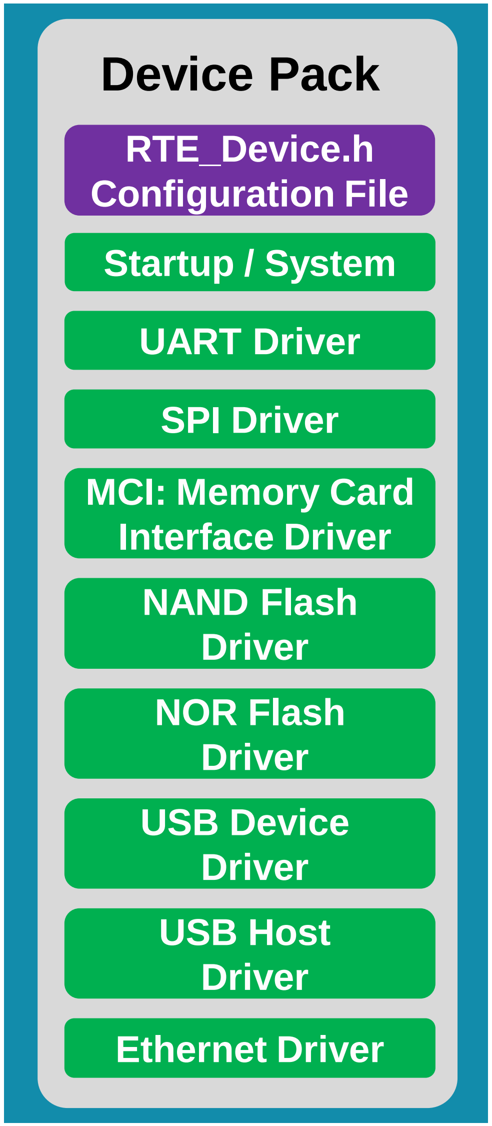
- Programming Standards on ARM Cortex-M series already provide
  - Consistent Code Generation and Parameter Passing (ARM EABI)
  - ABI for Special Processor Instructions and Core Peripherals (CMSIS-CORE)
  - Guidelines for definition of Peripheral-Registers & Interrupts (CMSIS-CORE)
  - A rich set of optimized DSP Functions (CMSIS-DSP Library)
  - A standardized RTOS Kernel API (CMSIS-RTOS API)

- APIs and Drivers for Peripherals are provided by Silicon vendors
  - But have problems: RTOS interface, DMA, Interrupt, Low-power modes ...
  - Inconsistent APIs across silicon vendors

CMSIS-Drivers: Structure with Drivers



Consistent Driver APIs for Peripherals



- Each driver module provides one or more drivers for a specific peripheral type
  - Devices may offer several peripherals of same type
  - Driver is configurable to use interrupt and/or DMA
  - Driver uses CMSIS-RTOS functionality to synchronise interrupt and DMA events
- Each driver is accessed by a control structure containing control and data functions
  - Each driver provides the functions: Initialize, Uninitialize, and PowerControl
  - Other functions are specific to the peripheral type
- The RTE_Device.h file centralizes the configuration for all drivers
  - RTE_Device.h could be controlled by a configuration utility.

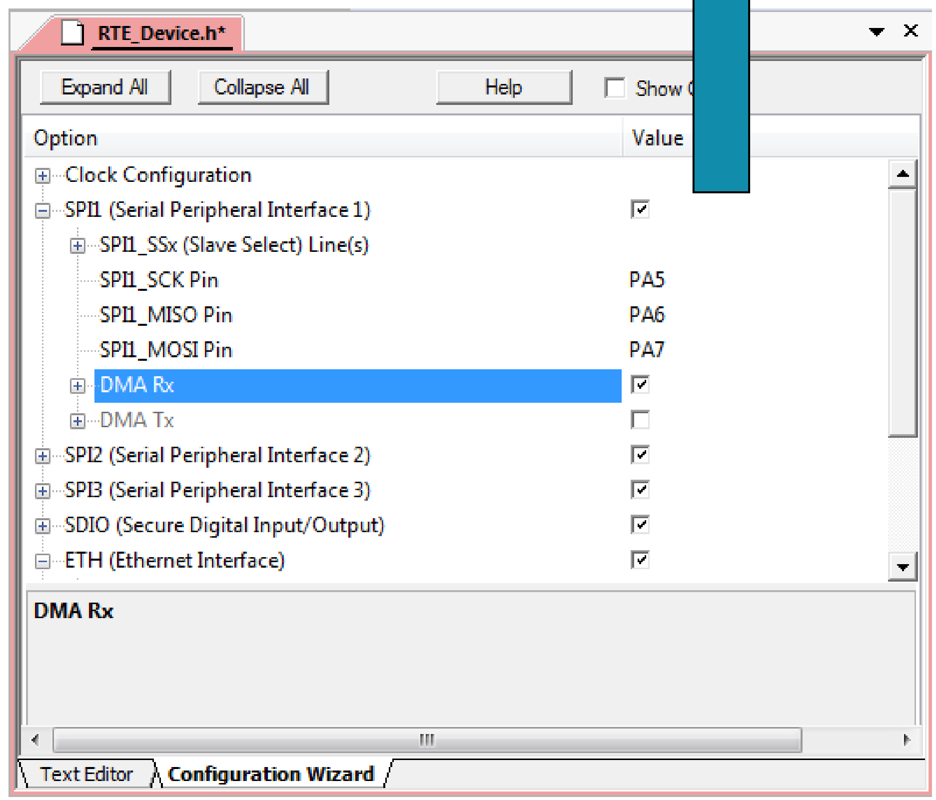
Drivers: Potential Design Flow

Device Pack

- **RTE_Device.h Configuration File**
- **Startup / System**
- **UART Driver**
- **SPI Driver**
- **Ethernet Driver**
- **MCI: Memory Card Interface Driver**
- **NAND Flash Driver**
- **NOR Flash Driver**
- **USB Device Driver**
- **USB Host Driver**

UART1
SPI2
SPI3
RMII
NAND
USBH1
USBD2

1. Define Peripheral Pin Assignment and Configure Peripherals



Configuration creates control structures

Drivers: Potential Design Flow

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- RTE_Device.h Configuration File
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- UART Driver
- SPI Driver
- Ethernet Driver
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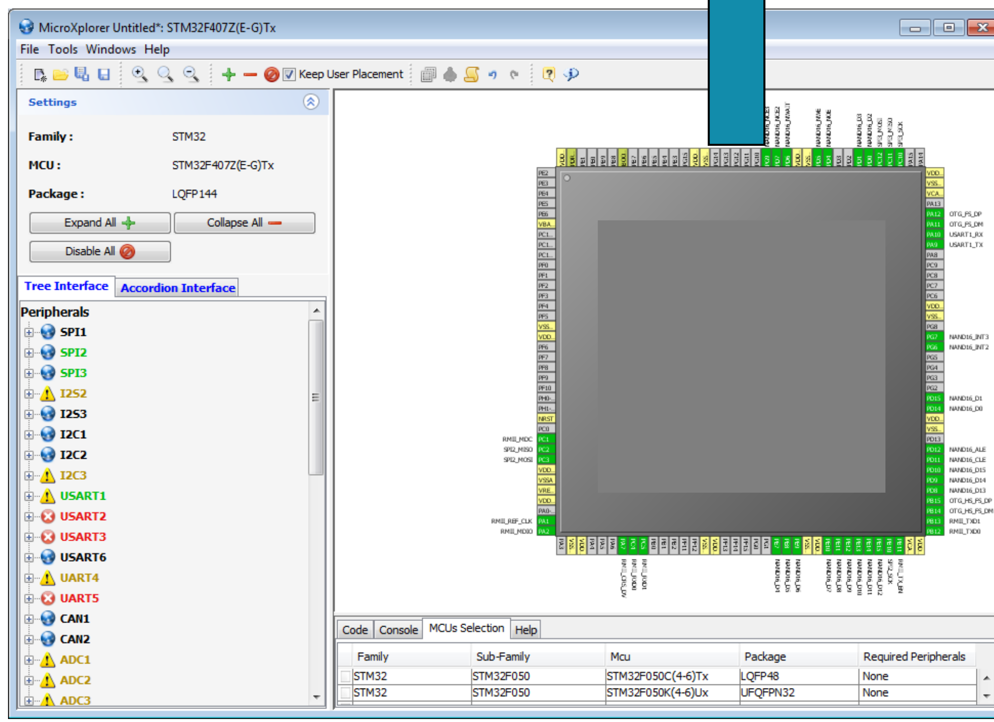
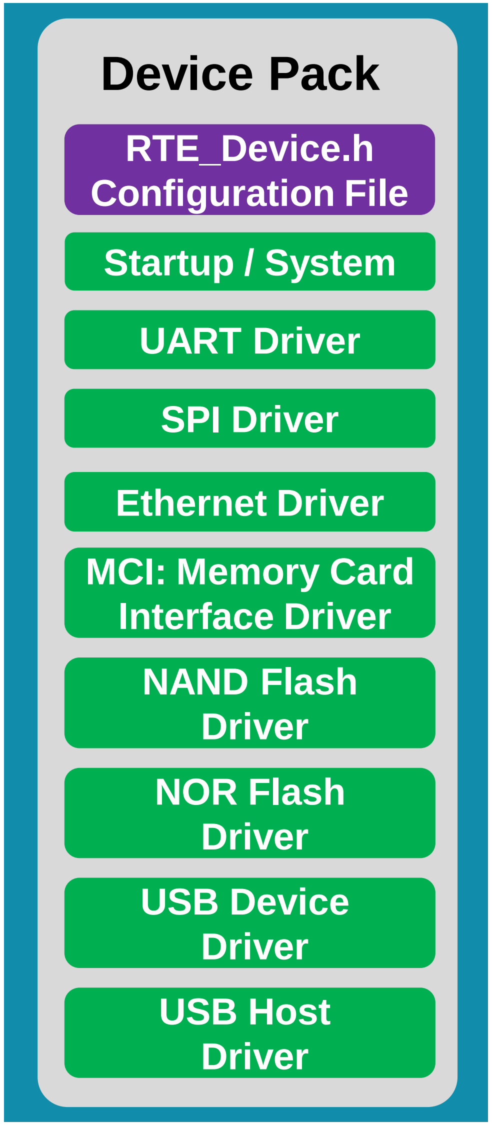
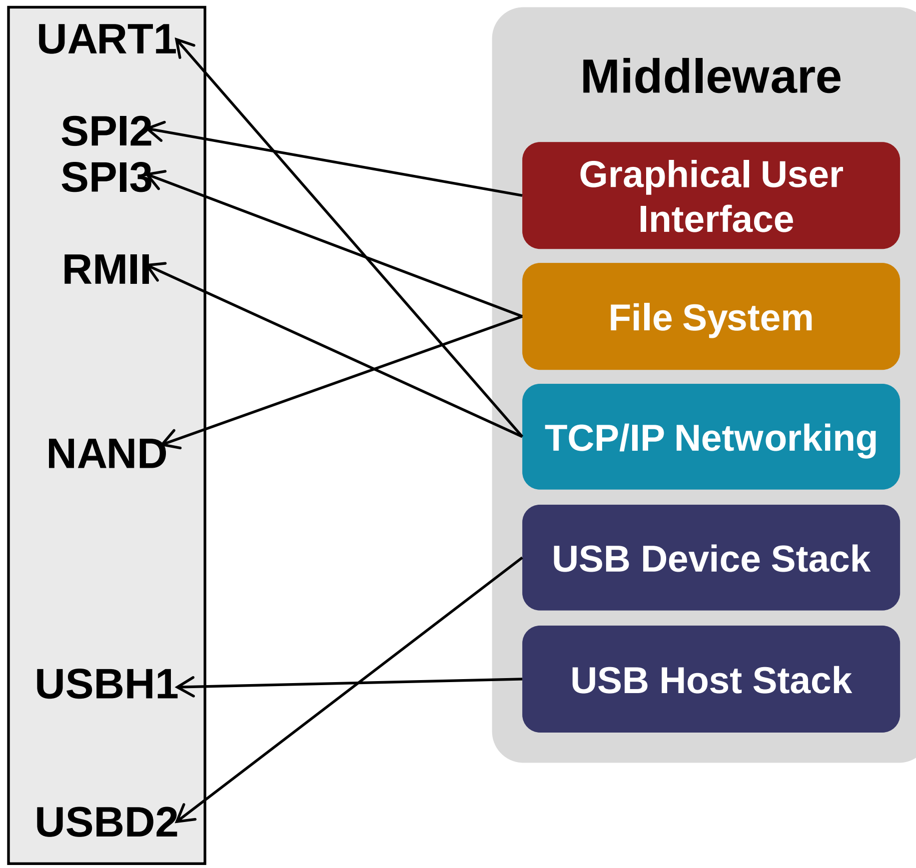


Possible vendor Config Tool integration

Drivers: Potential Design Flow



2. Assign Middleware to Peripherals by selecting the right control structure



Drivers: Implementation & Optimization

- Driver functions are accessed via a struct
  - Pre-configured drivers (or middleware) may reside in on-chip ROM

```
typedef struct DRIVER_SPI {
  DRV_VERSION (*GetVersion)      (void);
  SPI_CAPABILITIES (*GetCapabilities)(void);
  SPI_STATUS   (*Initialize)     (SPI_SignalEvent_t cb_event);
  SPI_STATUS   (*Uninitialize)   (uint32_t slave);
  SPI_STATUS   (*PowerControl)   (POWER_STATE state);
  SPI_STATUS   (*Configure)      (uint32_t slave, SPI_FRAME_FORMAT frame_format,
                                  SPI_BIT_ORDER bit_order);
  uint32_t     (*BusSpeed)       (uint32_t slave, uint32_t bps);
  SPI_STATUS   (*SlaveSelect)    (uint32_t slave, SPI_SS_SIGNAL ss);
  uint8_t      (*TransferByte)   (uint8_t out);
  SPI_STATUS   (*SendData)       (const uint8_t *buf, uint32_t len);
  SPI_STATUS   (*ReceiveData)    (      uint8_t *buf, uint32_t len, uint8_t  out);
  SPI_STATUS   (*AbortTransfer)  (void);
} const DRIVER_SPI;
```

- Driver implementation uses CMSIS-RTOS
  - Synchronisation via Semaphore or Mail/Message passing
- Optimal implementations use interrupts and DMA
  - Configuration options are stored in RTE_Drivers.h

Drivers: Function Call Sequence

- Drivers provide common functions, even for power control
  - After initialization, drivers are in power-off mode (minimal power consumption)
  - Before using “transfer” functions, power-on mode must be activated
  - “transfer” functions may cause thread switches

Function Call Sequence

- **GetVersion** (optional): middleware may use this to insure a certain driver
- **GetCapabilities** (optional): implemented capabilities may differ; middleware can adjust to implemented functionality
- **Initialize:** allocate memory, reserve RTOS & peripheral resources, register (optional) call back events
- **PowerControl**: put the peripheral into low-power (to detect events) or power-up (to transfer data) mode
- **Transfer**: receive or transmit information; buffers are available after the call to hold new data
- **PowerControl**: put the peripheral into low-power (to detect events) or power-off (to stop operation) mode
- **Uninitialize**: release resources consumed by driver

User Benefits: Component-based Approach

- Faster development of complex projects
  - Software components are selected with a mouse click from a library
  - Clean overview of available software components relevant to a device
  - RTE Manager identifies component requirements and connects to device drivers
- Components are separate and give a clean view to application code
  - Libraries: not copied to the project folder; separate of the project
  - Configuration files: accessed as part of a component; stored separate from application code
  - Version control: Select a specific version of a component
- Help System integrated provides painless reading of user manuals
  - Easy access to the API documentation of a component
- Easy adaption to new project requirements
  - Software components can be added or removed any time; project is kept up-to-date
  - Devices can be changed quickly; RTE Manager selects device-relevant software components

Thank you!