MPLAB® Harmony Help - Understanding MPLAB Harmony

MPLAB Harmony Integrated Software Framework v1.11

Release Notes

This topic provides the release notes for this version of MPLAB Harmony.

Description

MPLAB Harmony Version: v1.11 **Release Date:** April 2017

Software Requirements

Before using MPLAB Harmony, ensure that the following are installed:

- MPLAB X IDE 3.60
- MPLAB XC32 C/C++ Compiler 1.43
- MPLAB Harmony Configurator 1.11.xx

Updating to This Release of MPLAB Harmony

Updating to this release of MPLAB Harmony is relatively simple. For detailed instructions, please refer to Porting and Updating to MPLAB Harmony.

What is New and Known Issues

The following tables list the features that have been changed or added and any known issues that have been identified since the last release of MPLAB Harmony. Any known issues that have yet to be resolved were retained from the previous release.

MPLAB Harmony:

Feature	Additions and Updates	Known Issues
General		MPLAB Harmony has not been tested with C++; therefore, support for this programming language is not supported. The `"-O1"` optimization level is recommended when building any projects that include the MPLAB Harmony prebuilt binary (.a file) peripheral library. This is necessary so that the linker will remove code from unused sections (for peripheral library features that are not used). Alternately, you may select "Remove Unused Sections" in the General options for the `xc32-ld` (linker) properties dialog box. The MPLAB Harmony uninstaller will delete all files installed by the installer, even if they were modified by the user. However, the uninstaller *will not* delete new files added by the user to the MPLAB Harmony installation folder. The MPLAB Harmony Display Manager plug-in provides complete configuration and simulation support to the LCC generated driver, and also provides basic support for all other graphics controller drivers. Full configuration and simulation support for the other graphics controller drivers will be added in a future release of MPLAB Harmony.

Middleware and Libraries:

Feature	Additions and Updates	Known Issues
Bootloader Library		The UDP bootloader does not compile for PIC32MZ devices when microMIPS is selected.
Crypto Library	N/A	Migrating projects that use the hardware Crypto library, and have multiple configurations, may run into a compile issue after regenerating code. MPLAB X IDE will show that the `pic32mz-crypt.h` and `pic32mz-hash.c` files are excluded from the configuration, even though it tried to add them. The compiler will generate errors, saying that certain Crypto functions cannot be referenced. To work around this issue, remove both files (`pic32mz-crypt.h` and `pic32mz-hash.c`) from the project and use the MPLAB Harmony Configurator (MHC) to regenerate all configurations that use these files.

Decoder Libraries		Due to memory requirements and the amount of available SRAM, some decoders cannot operate concurrently with other decoders. However, each decoder will operate individually in the universal_audio_decoders demonstration.
File System	Found and fixed potential null pointer exception in the unmount function.	
Graphics Libraries		JPEG decoding does not support progressive scanned images. Some transparency-incorporated animated GIF images may demonstrate tearing. The generated LCCG driver supports display resolution up to WVGA or equivalent.
TCP/IP Stack		**SMTPC:** • API to abort a message, which is useful when retries are needed is currently not available • Multiple DNS addresses to provide a more reliable mail transmission is currently not available • Support for the optional mail header fields is currently not available
USB Device Library	N/A	The USB Device Stack has been tested in limited capacity with RTOS. While running the USB Device Stack on a PIC32MZ family device, the stack requires three seconds to initialize for PIC32MZ EC devices and three milliseconds for PIC32MZ EF devices.
USB Host Library	Removed MHC support for USB Host Beta software. Support for USB Host Beta APIs will be removed in future releases.	The following USB Host Stack functions are not implemented: • USB_HOST_BusResume • USB_HOST_DeviceSuspend • USB_HOST_DeviceResume The Hub, Audio v1.0, and HID Host Client Drivers have been tested in limited capacity. The USB Host Stack has been tested in limited capacity with RTOS. Polled mode operation has not been tested. Attach/Detach behavior has been tested in a limited capacity. While running the USB Host Stack on a PIC32MZ family device, the stack requires three seconds to initialize for PIC32MZ EC devices and three milliseconds for PIC32MZ EF devices. The USB Host Layer does not perform overcurrent checking. This feature will be available in a future release of MPLAB Harmony. The USB Host Layer does not check for the Hub Tier Level. This feature will be available in a future release of MPLAB Harmony. The USB Host Layer will only enable the first configuration when there are multiple configurations. If there are no interface matches in the first configuration, this causes the device to be become inoperative. Multiple configuration enabling will be activated in a future release of the of MPLAB Harmony. The MSD Host Client Driver has been tested with a limited number of commercially available USB Flash drives. The MSD Host Client Driver and the USB Host Layer have not been tested for read/write throughput. This testing will be done in a future release of MPLAB Harmony. The MSD Host Client Driver and SCSI block driver can only be used with the File system if the file system Auto-Mount feature is enabled. The MSD Host Client Driver has not been tested with Multi-LUN Mass Storage Device and USB Card Readers.

USB Host Library (continued)		The USB Host SCSI Block Driver, the CDC Client Driver, and the Audio Host Client Driver only support single-client operation. Multi-client operation will be enabled in a future release of MPLAB Harmony. USB HID Host Client driver has not been tested with multiple usage devices. Sending of output or feature report has not been tested. The USB Audio Host Client driver does not provide implementation for the following functions: • USB_HOST_AUDIO_V1_DeviceObjHandleGet • USB_HOST_AUDIO_V1_FeatureUnitChannelVolumeRangeGet • USB_HOST_AUDIO_V1_FeatureUnitChannelVolumeSubRangeNumbersGet • USB_HOST_AUDIO_V1_StreamSamplingFrequencyGet • USB_HOST_AUDIO_V1_TerminalIDGet

Device Drivers:

Feature	Additions and Updates	Known Issues
LCC	.	The MPLAB Harmony Graphics Composer (MHGC) is not capable of providing a palette table; therefore, users must supply a uint16_t array of 256 16 bpp RGB colors to the LCC Driver using the DRV_GFX_PalletteSet function. The content of this array will serve to map color indices to TFT display colors. The DMA Trigger Source setting in MHC has changed. If your project's setting is on 3, 5, 7 or 9, MHC will flag it as red. Please change to either 2, 4, 6, or 8. All the odd-numbered timers are removed from selection. While these timers are functional at default, only the even-numbered timers (2, 4, 6, 8) will accept changes in prescaler values.
I2C	N/A	**I2C Driver Using the Peripheral and the Bit-banged Implementation:** • Has only been tested in a single master environment • Does not support RTOS; therefore, it is not thread-safe when used in a RTOS environment • Has not been tested in a Polled environment • Operation in power-saving modes has not been tested **I2C Driver Using the Bit-banged Implementation**: • Non-blocking and uses a Timer resource for performing I2C operations. This Timer resource cannot be used for any other Timer needs. • The Timer Interrupt priority should be one of the highest priority interrupts in the application • Testing of this implementation has been done only with a system clock of 200 MHz and a peripheral bus clock of 100 MHz for the Timer • Can be configured to work only in Master mode • Only available in the dynamic driver setting • The baud rate is dependent on CPU utilization. It has been tested to run reliably up to 100 kHz. • Does not support PIC32MX family devices • Only works on the SCL and SDA pins of the corresponding I2C peripheral • Only works in Interrupt mode
MRF24WN Wi-Fi	New `wdrvext_mx.a`, `wdrvext_ec.a`, and `wdrvext_mz.a` library files.	

S1D13517		The S1D13517 Driver does not support the getting of a pixel or array of pixels from the S1D13517 framebuffer and does not support font rendering when Anti-aliasing is enabled.
Secure Digital (SD) Card	N/A	The SD Card Driver has not been tested in a high frequency interrupt environment.
SPI	N/A	The SPI Slave mode with DMA is not operational. This issue will be corrected in a future release of MPLAB Harmony.
SPI Flash		Flash features such as high-speed read, hold, and write-protect are not supported by the driver library. Static implementation of the driver library is not available.
USB		The USB Driver Library has been tested in limited capacity with RTOS. While running the USB Driver Library on a PIC32MZ family device, the stack requires three seconds to initialize for PIC32MZ EC devices and three milliseconds for PIC32MZ EF devices. Some APIs for USB Host Driver Library may change in the next release. USB Host Driver Library Polled mode operation has not been tested. USB Host Driver Library Attach/Detach behavior has been tested in a limited capacity.

System Services:

Feature	Additions and Updates	Known Issues
DMA		

Peripheral Libraries:

Feature	Additions and Updates	Known Issues
ADCHS	N/A	FIFO is not supported in this version of the peripheral library.
SQI	N/A	A SQI clock divider value higher than CLK_DIV_16 will not work. To achieve optimal SQI clock speeds, use a SQI clock divider value lower than CLK_DIV_16. **Note:** This issue is applicable to any applications that use the SQI module.

Applications:

Feature	Additions and Updates	Known Issues
Audio Demonstrations	Changed in Universal_audio_decoders to limit directory depth in the file system. This will prevent an exception if that otherwise would occur beyond 6 sub-directory levels.	usb_headset, usb_microphone, and usb_speaker Demonstrations: • When switching between these applications, the Windows driver may become confused by the type of device that is connected. For example, audio streaming is prevented by the driver. If a condition like this occurs, do the following to remedy the issue: 1. While the device is connected, uninstall the driver. 2. A restart of the Windows operating system may also be required. universal_audio_decoder Demonstration: • The 270f512lpim_bt_audio_dk and pic32mz_da_sk_meb2 configurations do not support the display. The display may appear to be ON but is blank because the backlight is illuminated. • The 270f512lpim_bt_audio_dk configuration does not support the WMA and AAC decoders. • Volume control is only available on the bt_audio_dk and 270f512lpim_bt_audio_dk configurations • Minor audio glitches are present for 96 kHz WAVE audio files by default buffer size. As a workaround, eliminating glitches by using a larger buffer size. • Audio glitches may appear when playing high sampling rate AAC files. The higher the sampling rate, the more severe the glitch. • Some USB Flash drives may not work with this demonstration • Due to memory limitations, the Speex Decoder and the WMA Decoder cannot operate concurrently with other decoders audio_tone Demonstration: • The display is static • Switch debounce is not implemented usb_speaker Demonstration: • The left and right output channels are swapped for the pic32mz_ef_sk_meb2 configuration at the output connector. **Note:** This is an issue with the MEB II hardware and not the application software. • The mute feature (as controlled from the PC) does not function usb_headset: The mute feature (as controlled from the PC) does not function. mac_audio_hi_res Demonstration: Muting the audio at the PC only works properly the first time
Bluetooth Demonstrations	Fixed issues found in WVGA display on a2dp_avrcp demo. This is a premium demonstration.	Graphics have been temporarily turned off/removed in all PIC32MZ DA configurations and will be made available in a future release
File System Demonstrations		LED_3, which is used to indicate demonstration success does not illuminate, which affects the following demonstrations: • sdcard_fat_single_disk (pic32mz_da_sk_adma configuration) • sdcard_msd_fat_multi_disk (pic32mz_da_sk_meb2 configuration) As a work around, the user can place a breakpoint in the application code to see the status of the demonstrations.

Graphics Demonstrations		Starter kit PKOB programming and debugging may produce the following error: *The programmer could not be started: Failed to program the target device*. If this message occur, repower the device and the application will start. If debugging is required, the suggested work around is to install the appropriate header onto the starter kit using MPLAB REAL ICE. The following issues apply to the external_resources demonstration: • Currently, JPEG decode support has been enabled for internal storage only • During the demonstration, latency is observed in fetching the images from external off-chip memory, which causes slow population of the display while rendering the images on screen memory. • A similar latency to the previous issue is also seen while displaying JPEG images on-screen due to the delay caused by JPEG run-time decoding
MEB II Demonstrations		The segger_emwin demonstration application does not yet include touch input.
RTOS Demonstrations		The SEGGER embOS Library with FPU support is required for PIC32MZ EF configuration and the user needs to explicitly include this. By default, the library without FPU support is included.
System Service Library Examples	N/A	The command_appio demonstration does not function using MPLAB X IDE v3.06, but is operational with v3.00.
TCP/IP Wi-Fi Demonstrations	N/A	The tcpip_tcp_client demonstration using the ENC24xJ600 or the ENC28J60 configurations does not work properly if the SPI Driver enables DMA. Please disable the SPI DMA option for these configurations. This will be corrected in a future release of MPLAB Harmony.
Test Applications	N/A	The FreeRTOS configurations for use with the PIC32MZ EF Starter Kit have the floating-point library disabled in the project options.
USB Demonstrations		The msd_basic Device demonstration application when built using PIC32MZ devices, requires that the SCSI Enquiry response data structure to be placed in RAM. Placing this data structure in program Flash memory causes the enquiry response to become corrupted. This issue will be corrected in a future release. The hid_basic_keyboard Host demonstration captures keystrokes from A-Z, a-z, 0-9, Shift and CAPS LOCK key *only*. The keyboard LED glow functionality and support for other key combinations will be updated in a future release. In the audio_speaker Host demonstration, Plug and Play may not work for the pic32mz_ef_sk_int_dyn and pic32mx_usb_sk2_int_dyn configurations. This issue will be corrected in a future release. In the hub_msd Host demonstration application, Hub plug and play detection may occasionally fail. However, if the hub is plugged in before the PIC32MZ device is released from reset, the demonstration application operates as expected. This issue is under investigation and a correction will be available in a future release of MPLAB Harmony. It is recommended to use a self-powered hub while attempting to use the available hub demonstration applications. The VBUS supply regulator on the starter kit may not be able to meet the current requirements of a bus-powered hub, which would then cause unpredictable demonstration application behavior.

Build Framework:

Feature	Additions and Updates	Known Issues
Bluetooth Stack Library		N/A
Math Libraries		DSP Fixed-Point Math Library: • Optimized only for PIC32MZ devices with microAptiv™ core features, which utilize DSP ASE • Will not function with the `_Fract` data type LibQ Fixed-Point Math Library: • Optimized for PIC32MZ devices with microAptiv core features • The `_fast` functions have reduced precision

Utilities:

Feature	Additions and Updates	Known Issues
MPLAB Harmony Configurator (MHC)	N/A	• The MHC does not support changing the relative path from the project to the source files within the MPLAB Harmony installation, once the project has been created • When viewing the MPLAB Harmony Help in the MHC, the Index is accessible, but is not functional. This is due to a limitation in the browser that is utilized by MHC. As a work around, the Index is accessible and functional when the HTML Help is opened in an external Web browser. • A tab character after `"---endhelp---"` in a `.hconfig` file may cause the next configuration symbol to be skipped

Third-Party Software:

Feature	Additions and Updates	Known Issues
SEGGER emWin Graphics Library	N/A	Only the LCC display controller is supported. Support for other display controllers is not available in this release. An API to retrieve the Dialog widget handle is not available in this release.

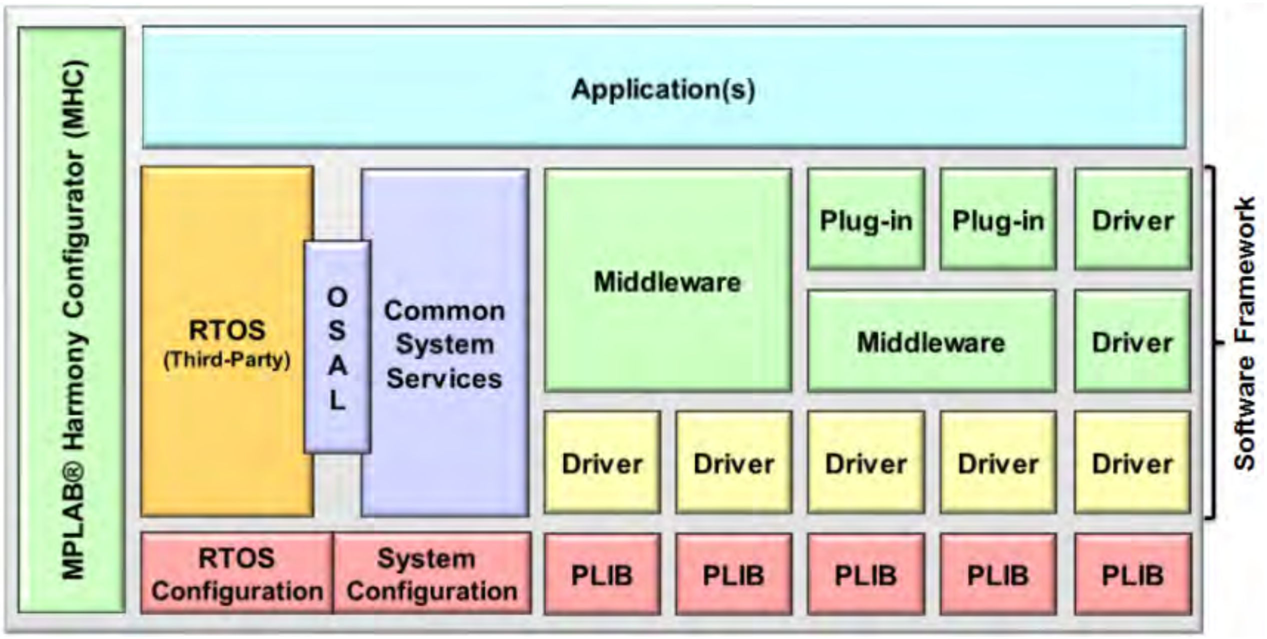
What is MPLAB Harmony?

This topic provides an overview of MPLAB Harmony.

Description

Microchip MPLAB® Harmony is the result of a holistic, aggregate approach to creating firmware solutions for embedded systems using Microchip PIC32 microcontrollers. As shown in the following diagram, MPLAB Harmony consists of portable, modular and compatible libraries provided by Microchip and third-party ecosystem partners. MPLAB Harmony also includes easy-to-use development utilities like the MPLAB Harmony Configurator (MHC) plug-in for the MPLAB X IDE, which accelerate development of highly capable and reusable PIC32 embedded firmware applications.

MPLAB® Harmony Block Diagram



Designed almost completely in the C language (see **Note**), MPLAB Harmony takes key elements of modular and object-oriented design, adds in the flexibility to use a Real-Time Operating System (RTOS) or work without one if you prefer, and provides a framework of software modules that are easy to use, configurable for your specific needs, and that work together in complete harmony.

Note: MPLAB Harmony has not been tested with C++; therefore, support for this programming language is not supported.

Portability

Portability is a concern that is often overlooked when a silicon manufacturer provides software. However, breadth of solutions is a hallmark strength of Microchip, and MPLAB Harmony provides simple libraries to abstract away part-specific details and make a Microchip device easy to use, regardless of which device you choose. Any time you design a new product or update an existing one, cost must be balanced with capabilities; however, cost is more than just the bill of materials – it's also the Non-Refundable Engineering (NRE) cost to design and develop your solution. MPLAB Harmony provides peripheral libraries, device drivers, and other libraries that use clear and consistent interfaces, requiring little or no change in your application code and minimizing the engineering time and effort for each new design.

Device Drivers

The primary purpose of a MPLAB Harmony device driver (or "driver") is to provide a simple and highly abstracted interface to a peripheral, allowing your application (or any other module in the system) to interact with a peripheral through a consistent set of functions. A driver is responsible for managing access to a peripheral, so that requests from different modules do not conflict with each other, and for managing the state of that peripheral so that it always operates correctly.

Peripheral Libraries

A Peripheral Library (PLIB) is a simple access library that provides a consistent (but very low level) interface to a peripheral that is "on board" the MCU. PLIBs hide register details, making it easier to write drivers that support multiple microcontroller families, but they are not normally used by applications directly to interact with peripherals, as they provide little abstraction, and because they require the caller to manage the detailed operation of a peripheral (including preventing conflicting requests from other modules). Because of the lack of conflict protection in a PLIB, only one module in a system should directly access the PLIB for a peripheral. Therefore, PLIBs are primarily used to implement device drivers (and some system services) to make them portable.

Modularity

MPLAB Harmony libraries are modular software "building blocks" that allow you to divide-and-conquer your firmware design. The interface to each library consists of a highly cohesive set of functions (not globally accessible variables or shared registers), so that each module can manage its own resources. If one module needs to use the resources of another module, it calls that module's interface functions to do so. Interfaces between modules are kept simple with minimal inter-dependencies so that modules are loosely coupled to each other. This approach helps to eliminate conflicts between modules and allows them to be more easily used together like building blocks to create the solutions you need.

Middleware Libraries

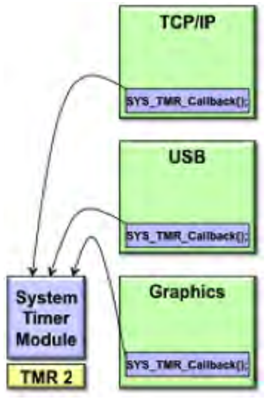
The normal usage models of some of the more complex peripherals, (i.e., USB or network interfaces) require interpreting complex protocols or may require substantial additional processing to produce useable results, such as drawing graphical images on an LCD screen with an LCD controller peripheral. Therefore, while a device driver may be completely sufficient for a simple peripheral like a UART, some peripherals require what is frequently called "middleware" (aptly named because it sits between your application and the hardware abstraction layer or "driver" layer). MPLAB Harmony provides several middleware library "stacks" to manage these more complex peripherals and provide the functionality you need and expect.

MPLAB Harmony middleware "stacks" are usually built upon device drivers and system services so that they can be supported on any Microchip microcontroller for which the required driver or service is supported. However, special purpose implementations may be available that integrate the driver, certain services, and various modules within the "stack" for efficiency.

System Services

MPLAB Harmony system services are responsible for managing shared resources so that other modules, such as drivers, middleware, and applications, do not conflict on shared resources. For example, if the TCP/IP, USB, and Graphics stacks attempted to concurrently use the Timer2 peripheral to perform some periodic task, they would very likely interfere with each other. However, if instead they used a timer system service (as the following image illustrates), it is the responsibility of the system service to keep the separate requests from interfering with each other. The timer service can be configured as desired for a specific system (for example, you may decide to use Timer3 instead of Timer2) isolating the necessary changes to the configuration of a single module and preventing potential conflicts.

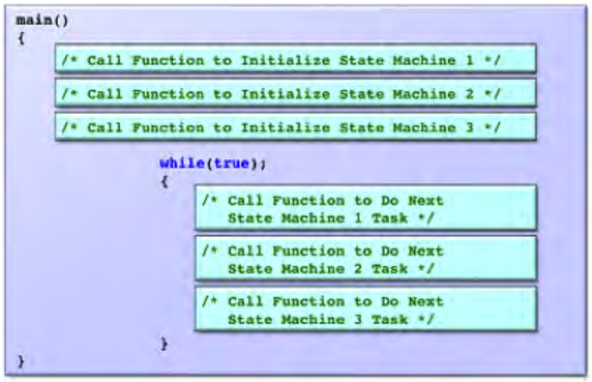
The use of a system service is very similar the use of a device driver, except that a driver normally requires the caller to "open" it to create a unique client-to-driver association. A system service does not normally require the caller to open the service before using it because system services are frequently shared by many clients within the system.



Compatibility

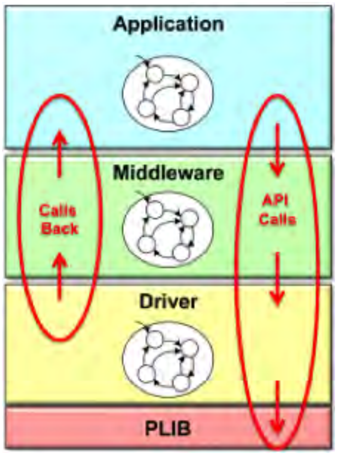
MPLAB Harmony modules (drivers, system services, and middleware – excluding PLIBs) are "active". This means when an application calls a module's interface function, the call will usually return immediately (unless a RTOS is in use) and the module will continue working on its own to complete the operation. Most modules will then provide a notification mechanism so the caller (i.e., client) can determine when the operation has finished.

Most MPLAB Harmony modules are implemented as cooperative state machines. The following image shows the basic idea of how this works. Each module has an "Initialize" function and each module has one (or more) "Tasks" function(s) to maintain its state machine(s). The state machines of all modules are initialized, shortly after the system comes out of reset in "main". After that (in a polled configuration, with no OS), the system drops into a "super loop" where each module's state machine function is repeatedly called, one after the other, to allow it to do the next "task" necessary to keep its state machine running. This allows the system to keep all modules running using a cooperative or shared "multi-tasking" technique. Modules (under control of your application) interact with each other by calling the interface functions of other modules (as illustrated in the following figure) and the system-wide "super loop" keeps all modules in the system running so they stay "active" and do their jobs.



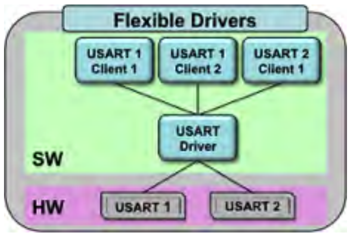
```
main()
{
    /* Call Function to Initialize State Machine 1 */
    /* Call Function to Initialize State Machine 2 */
    /* Call Function to Initialize State Machine 3 */

                while(true);
                {
                    /* Call Function to Do Next
                       State Machine 1 Task */
                    /* Call Function to Do Next
                       State Machine 2 Task */
                    /* Call Function to Do Next
                       State Machine 3 Task */
                }
}
```

This method is not suitable for all needs; therefore, other configurations are possible. However, a polled configuration is the simplest to understand and it best illustrates the basic concept of how MPLAB Harmony allows independent modules to operate cooperatively within an embedded system. To interact with each other, otherwise independent library and application modules make calls to each other's Application Program Interface (API) functions, as shown in the following diagram. Calls *into* a library are made through well-defined API functions and calls back to the client may be made through *callback* functions, statically linked (at build time) or dynamically registered at run-time and called using a function pointer.



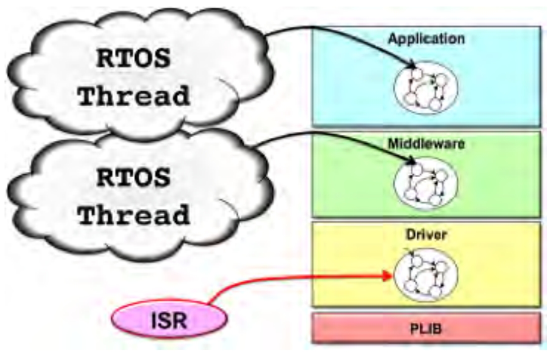
Flexibility

The basic MPLAB Harmony model of cooperating state machine driven modules, when combined with a little configurability, becomes flexible enough to meet the needs of almost any embedded system. For example, if you are using multiple identical peripherals, MPLAB Harmony has "dynamic" driver implementations that can manage all instances of a peripheral with a single instance of the driver code. You might also have a need for multiple "client" modules to use the same instance of a peripheral at the same time (such as the timer example, described previously). To manage this need, MPLAB Harmony has driver implementations that are intelligent enough to manage requests from multiple clients. On the other hand, your needs may be simpler than that. So, static and single client implementations are also available for key libraries to help reduce the amount of code and data storage needed for your system.



Or, your system may need to combine several middleware stacks and multiple, potentially independent, applications. If that is the case, the simple polling operation, using the "super loop" method frequently seen in simple embedded systems may not be sufficient. Wwhen you start adding more modules, it becomes more and more difficult to meet the timing requirements of all peripherals using a simple polled super loop.

Fortunately, MPLAB Harmony modules are written so that (where appropriate) their state machines can be run directly from an Interrupt Service Routine (ISR) or a RTOS thread. Using an ISR allows you to eliminate the latency of waiting for the execution of other modules in the loop to finish before a time-critical event is serviced, and it allows you to use the interrupt prioritization capabilities available on Microchip devices to ensure that your system responds to events in the real world in real-time.



Additionally, the ability to schedule and prioritize different tasks for different modules can be obtained for modules that are not associated with a specific processor interrupt (such as many middleware modules and your application) using a RTOS. In fact, that is one of the main reasons to use a RTOS. When your system becomes complex enough that you start struggling to meet your timing requirements using the super loop method, it's time to use a RTOS.

Fortunately, MPLAB Harmony module state machine functions can be called from a loop in a RTOS thread just as easily as they can be called from a polled "super loop" in a system without a RTOS. To allow this, modules are designed to be "thread safe" by calling semaphore, mutex, and critical section operations through an Operating System Abstraction Layer (OSAL). The OSAL provides a consistent set of functions to call, regardless of which RTOS is being used (or even if no RTOS is used). This method makes the choice of RTOS to use, if any, into a configuration option. MPLAB Harmony supports several OS and non-OS configurations and support for more operating systems is possible. All that is required is to implement the OSAL functions appropriately for the desired OS.

Configurability

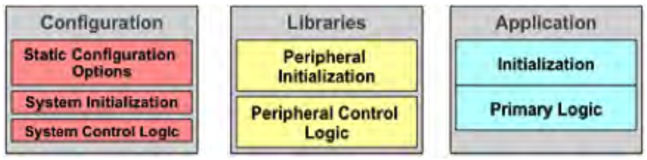
Most MPLAB Harmony libraries support a variety of build-time configuration options:

- Selection of the supported Microchip microcontroller
- Interrupt-driven or polled execution
- Static or Dynamic peripheral instance selection
- Single-client or Multi-client support
- Other library-specific options

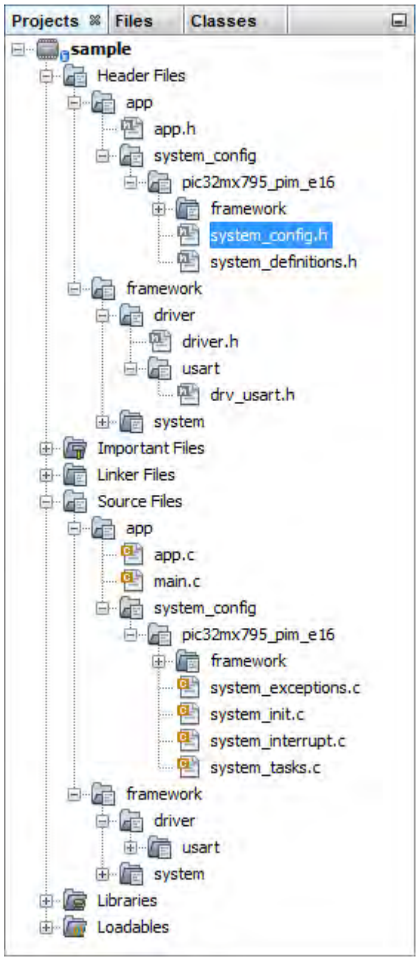
MPLAB Harmony libraries are designed to allow you to select a variety of configuration options to tailor them to your specific usage. For example, you may be able to select buffer sizes for data transfer modules or clock sources for timer modules. The set of configuration options for each library is identified and explained in the Help documentation (along with the interface and usage information) and the MPLAB Harmony Configurator (MHC) utility is provided to help simplify the process of configuring your system exactly the way you want and to get you started with a set of initial source files for your project.

Project Structure

To facilitate configurability, MPLAB Harmony projects are normally structured in a way that isolates the code necessary to configure a "system" from the library code and from your application code, as shown in the following figure.



The next figure shows how application, library, and configuration files are organized within the MPLAB X IDE project.



```
Projects   Files   Classes
sample
  Header Files
    app
      app.h
      system_config
        pic32mx795_pim_e16
          framework
          system_config.h
          system_definitions.h
    framework
      driver
        driver.h
        usart
          drv_usart.h
      system
  Important Files
  Linker Files
  Source Files
    app
      app.c
      main.c
      system_config
        pic32mx795_pim_e16
          framework
          system_exceptions.c
          system_init.c
          system_interrupt.c
          system_tasks.c
    framework
      driver
        usart
      system
  Libraries
  Loadables
```

In a MPLAB Harmony project, the main.c file is kept very simple and consistent (containing primarily, just the super loop previously discussed). The application files (`app.c` and `app.h` in the previous figure) are separate from configuration files in the `system_config` sub-folders, so it is possible for a single application to have more than one configuration. (Usage of this capability can be seen in example and demonstration projects included with the installation of MPLAB Harmony.) The library modules that make up the MPLAB Harmony framework (in the framework folder) use the definitions provided in the selected configuration header (`system_config.h`, highlighted with a gray background in the previous figure) to specify the configuration options you selected when you configured the project. Finally the processor-specific peripheral libraries are provided as both a prebuilt binary (`.a` linker file) and as in-line source code to allow for maximum build efficiency for your firmware projects.

Summary

MPLAB Harmony provides a complete framework for developing your firmware solutions using Microchip microcontrollers and development tools. The firmware libraries and tools that make up the MPLAB Harmony framework are modular and compatible, making them simple to use. They're flexible and configurable, making them easy to tailor to your specific needs. And, they're portable across the full range of Microchip PIC32 microcontrollers, so you are sure to find a supported device that meets your needs.

Project Layout

This topic explains how a MPLAB Harmony project is organized.

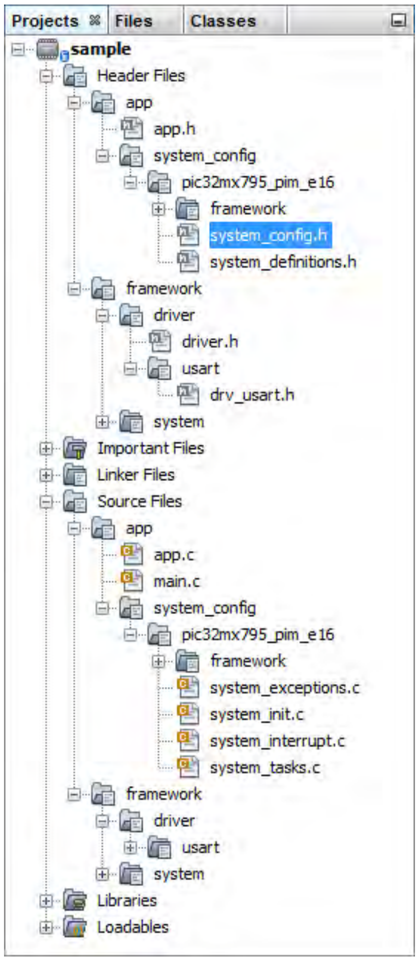
Description

A sample project has been created to show you the structure of a MPLAB Harmony project. The "sample" project is available in the following folder, within your MPLAB Harmony installation root folder:

`<install-dir>/apps/examples/sample/firmware/sample.X`

You should open this project in MPLAB X IDE and follow along with this guide.

A MPLAB Harmony project is organized within MPLAB X IDE, as shown in the following figure.



This organization consists of a few key "logical" folders and C language files, as follows.

The Header Files and Source Files Folders

The MPLAB X IDE separates C-language files into header (`.h`) files and source (`.c`) files by placing the header files in a top-level `Header Files` logical folder and the source files in a top-level `Source Files` logical folder. This distinction is for display only within the MPLAB X IDE and these folders do not appear on disk. Also, in most cases, logical folders that appear as sub-folders of these top-level folders are duplicated in both the `Header Files` and `Source Files` top-level logical folders because header and source files are kept together on disk.

The app Folder

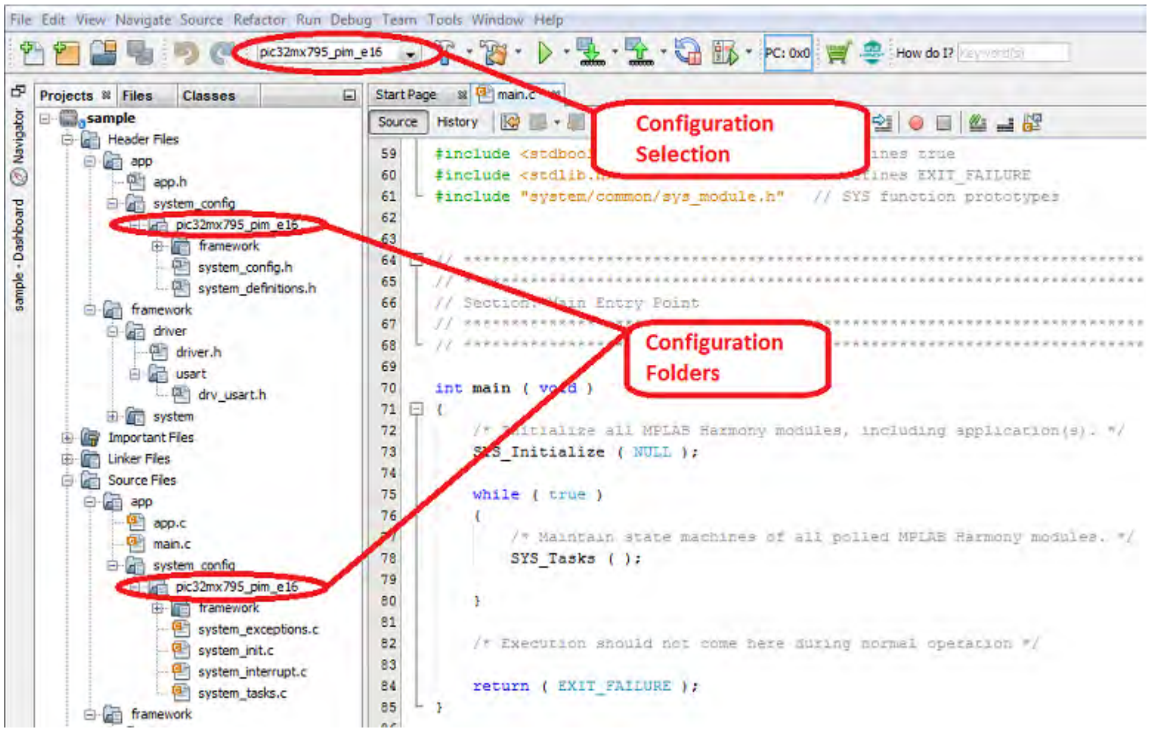
This folder contains the `main.c` and `app.c` source files and the `app.h` header file.

The `app` (i.e., application) folder and its sub-folders contain all of the project-specfic source and header files (but not the shared files stored in the framework folder, which are discussed later). In a simple project, the `app` folder contains the `main.c`, `app.c`, and `app.h` files and a `system_config` sub-folder. More complex projects will very likely contain additional files, as needed. In a MPLAB Harmony project, the `main.c` file normally contains the C language main function and little or nothing else. The logic of the `main` function is consistent across all MPLAB Harmony projects and should not need to be changed. The `app.c` file normally contains the logic of the application itself. This is where the desired overall behavior of your system is usually implemented (although complex systems may have multiple applications).

The `app.h` file defines data types and other definitions required by the application or interface prototypes for functions the application wants to share with other applications or the system.

The system_config Folder

The `system_config` folder contains one or more subdirectories, each of which corresponds to an individual configuration of your project. MPLAB Harmony projects may have multiple configurations. Each project configuration creates a different variation of your embedded system with potentially different hardware or features. In each configuration, you can select a different set of libraries or modules, select different build parameters for each module and even select different source files for your application(s). A configuration consists of a specific set of properties (tools settings) in MPLAB X IDE, a set of source files that define the build parameters, and a set of source and header files that control which modules are initialized and maintained in your system.



```
#include <stdboo                                  ines true
#include <stdlib.h                               efines EXIT_FAILURE
#include "system/common/sys_module.h"   // SYS function prototypes


// *****************************************************************
// *****************************************************************
// Section: Main Entry Point
// *****************************************************************
// *****************************************************************

int main ( void )
{
    /* Initialize all MPLAB Harmony modules, including application(s). */
    SYS_Initialize ( NULL );

    while ( true )
    {
        /* Maintain state machines of all polled MPLAB Harmony modules. */
        SYS_Tasks ( );

    }

    /* Execution should not come here during normal operation */

    return ( EXIT_FAILURE );
}
```

In MPLAB X IDE, the project configuration can be selected by using a pull-down menu in the tool bar at the top of the window or by right-clicking the project name and selecting **Properties**. In most example and demonstration projects distributed with MPLAB Harmony, the name of each MPLAB X IDE configuration will match the name of the associated folder within the `system_config` folder in the project (the 795_pim_e16 folder in the sample project). When a specific MPLAB X IDE configuration is selected, the configuration files for that configuration are included in the build and the configuration files in other configuration folders are excluded from the build.

Note: This is the project convention used by the example and demonstration projects provided with MPLAB Harmony. You, of course, may organize your own projects any way you desire. However, it is recommended to follow this convention if you use multiple configurations in your projects. We think you'll appreciate the power and flexibility it provides.

Configuration Files:

- `system_config.h`
- `system_init.c`
- `system_tasks.c`
- `system_interrupt.c`
- `system_exceptions.c`
- `system_definitions.h`

This set of files define a configuration of the system. The purpose of each of these files is described in more detail in the following sections. But, the basic idea is that you may want different configurations of your application for different hardware boards, different Microchip microcontrollers, or different feature sets, depending on your specific needs.

Allowing different configurations of the same application logic makes your application more flexible and provides a well-organized way to deal with the sort of variation that usually occurs in any project of sufficient size and complexity. This technique helps to eliminate the duplication of code (and labor) that would otherwise be necessary to manage multiple related projects. Of course, if you don't need or want that flexibility, all of these files are specifically created for your project and you can make any modifications to them that you like. The choice is always yours.

Note: The relative path, from the MPLAB X IDE project folder to the configuration folder (containing the `system_config.h` file) for each project configuration is automatically placed in the "Includes directories" list in the compiler properties for each configuration of the MPLAB X IDE project by the MHC.

The framework Folder

The `framework` logical folder contains the source files for the MPLAB Harmony framework and libraries. Depending on your project configuration, there can be many, many files and sub-folders within this folder. These files are for MPLAB Harmony libraries that you should not need to edit. In fact, the framework source files are not normally located in your project. Instead, these files are included in your project directly from the MPLAB Harmony installation (using relative directory paths). All of the actual files stay in the MPLAB Harmony installation folder, out of the way.

Notes:

1. You always have the option of copying the framework files directly into your project's source folder, if desired. In fact, doing so is a good idea if you plan to move or distribute your project separately from the MPLAB Harmony installation.
2. In most cases, the "logical folder" organization within the MPLAB X IDE project matches exactly with the physical directory organization within the MPLAB Harmony installation (and within your project directory) on your disk drive. This is done to keep things simple and consistent so you only need to learn a single layout. But, there are a couple of notable exceptions.
   - MPLAB X IDE has a convention of splitting out "Header Files" (`.h`) and "Source Files" (`.c`), so that the virtual folder organization in project separates the files in to these two groups and the physical directories on disk do not
   - In a MPLAB Harmony example or demonstration project, the `app` folder will correspond to the `src` directory on disk within the `firmware` folder of the project

The Main File

This topic describes the logic of the `main.c` file and the C language `main` function in a MPLAB Harmony project.

Description

The C language entry point for a MPLAB Harmony embedded application is the main function. This function is defined in the `main.c` file, generated in the project's `app` folder (or `src` directory on disk) by the MHC. The `main` function (see the following example) implements a simple "super loop", commonly used in embedded applications that do not make use of an operating system.

Example main Function Logic

```
int main ( void )
{
    /* Initialize all MPLAB Harmony modules, including application(s). */
    SYS_Initialize ( NULL );

    while ( true )
    {
        /* Maintain state machines of all polled MPLAB Harmony modules. */
        SYS_Tasks ( );
    }

    /* Execution should not come here during normal operation */
    return ( EXIT_FAILURE );
}
```

The SYS_Initialize Function

The first thing the main function does is to call a function named SYS_Initialize. The purpose of the SYS_Initialize function is to initialize every software module in the system. MPLAB Harmony is based upon a model of cooperating state machines. Therefore, this function must ensure that every module's state machine is placed in a valid initial state. The implementation of this function is one of the things generated by the MHC to configure a MPLAB Harmony system. This function's definition is generated in the `system_init.c` file, described in the system_init.c section.

Note: The SYS_Initialize function signature has a "`void *`" input parameter. This is so that it may later be implemented in a library and an arbitrary initialization data structure may be passed into it. However, for a statically implemented SYS_Initialize function (which will normally be the case if you implement it yourself), this parameter is unnecessary and can be passed as "NULL".

The "Super Loop"

After all of the modules in the system have been initialized, the main function executes an infinite loop to keep the system running. This is commonly called a "super loop" as it is the outer-most loop, within which the entire system operates. This loop never exits. So, the code that exists after the end of that loop should never be executed and is only included there for safety, clarity, and syntactical completeness.

The SYS_Tasks File and the SYS_Tasks Function

Inside of the "super loop", the `main` function calls the SYS_Tasks function. The purpose of the SYS_Tasks function is to poll every module in the system to ensure that it continues to operate. This is how the system maintains the state machines of all polled modules. (Note that some modules may be interrupt driven and thus, not called from the SYS_Tasks function.) The implementation of the SYS_Tasks function is generated by the MHC in the `system_tasks.c` file, which is described in the system_tasks.c section.

The Application File(s)

This topic describes the normal structure of MPLAB Harmony application files.

Description

From the point of view of a MPLAB Harmony system, an application consists of two basic functions:

- APP_Initialize
- APP_Tasks

The application's initialization function (APP_Initialize) is normally called from the SYS_Initialize function, which is called from `main` before entering the top-level loop. The application's "tasks" function (APP_Tasks) is normally called from the SYS_Tasks function, which is called from `main` from inside the top-level loop. This is how the application's state machine is initialized and "polled" so that it can do its job. The SYS_Initialize function is normally implemented in the `system_init.c` file and the SYS_Tasks function is normally implemented in the `system_tasks.c` file. That is the convention for example and demonstration projects distributed with MPLAB Harmony and that is the case for projects generated by the MHC. You may do as you choose in your own projects, but it is recommended to follow this convention as it will make it easier to manage multiple configurations if you need them and it will be consistent with the MHC and other tools.

Application Initialization

An application's initialization function places the application's state machine in its initial state and may perform additional initialization if necessary. This function must not block and it should not call the routines of any other modules that may block. If something needs to be initialized that may take time to complete, that initialization should be done in the application's state machine (i.e., in its "Tasks" function).

Sample Application Initialization Function:

```
void APP_Initialize ( void )
{
    /* Place the App state machine in its initial state. */
    appData.state       = APP_STATE_INIT;
    appData.usartHandle = DRV_HANDLE_INVALID;
}
```

The sample project's initialization function initializes an internal variable and places the application's state machine in its initial state by assigning the APP_STATE_INIT enumeration value into the "state" member of the data structure that contains all of the data required by the application (appData). This structure is defined globally, but is only ever accessed by the application itself. The application's initialization function is called from the SYS_Initialize function (defined in `system_init.c`), which is called from `main` after a system Reset. Using this technique, the application is initialized (along with the rest of the system) whenever the system comes out of Reset.

Application Tasks

The application's state machine breaks up the job that the application must do into several short "tasks" that it can complete quickly, but between which it must wait for some other module to complete some tasks of its own. (In this case the other module is the USART driver.) Once each short task has completed successfully, the application transitions to another state to perform the next short task.

Example Application Tasks Function:

```
void APP_Tasks ( void )
{
    /* Handle returned by USART for buffer submitted */
    DRV_HANDLE usartBufferHandle;

    /* Check the application's current state. */
    switch ( appData.state )
    {
        /* Keep trying to open the driver until we succeed. */
        case APP_STATE_INIT:
        {
            /* open an instance of USART driver */
            appData.usartHandle = DRV_USART_Open(APP_UART_DRIVER_INDEX,
                                                 DRV_IO_INTENT_WRITE);
            if (appData.usartHandle != DRV_HANDLE_INVALID )
            {
                /* Update the state */
                appData.state = APP_STATE_SEND_MESSAGE;
            }
            break;
        }

        /* Send the message when the driver is ready. */
        case APP_STATE_SEND_MESSAGE:
        {
            /* Submit message to USART */
            DRV_USART_BufferAddWrite(appData.usartHandle, &usartBufferHandle,
                                     APP_HELLO_STRING, strlen(APP_HELLO_STRING));
            if ( usartBufferHandle != DRV_HANDLE_INVALID )
            {
                /* Message is accepted. Driver will transmit. */
                appData.state = APP_STATE_IDLE;
            }
            break;
        }

        /* Idle state */
        case APP_STATE_IDLE:
        default:
        {
            /* Do nothing. */
            break;
        }
    }
}
```

Sample Application States

The sample application's "tasks" function breaks the operation of the application down in to the following states using a "switch" statement with the following "cases".

- APP_STATE_INIT
- APP_STATE_SEND_MESSAGE
- APP_STATE_IDLE

The sample application is placed into the APP_STATE_INIT state by the application's initialization function before the "tasks" function is ever called. So, the first time the APP_Tasks function is called, the switch statement executes the code under this case and the first short "task" the sample application attempts to do is open the USART driver to obtain a handle so that it can transfer data over the USART. Notice that the application checks the value of the handle returned from the DRV_USART_Open function to ensure that it is valid before it transitions to the APP_STATE_SEND_MESSAGE state. If the value of the handle retuned be the driver's "open" function is invalid (equal to DRV_HANDLE_INVALID), the application stays in the APP_STATE_INIT state and continues trying to open the USART driver every time its "tasks" function is called. his technique allows a polled state machine to wait for something that it requires before continuing to avoid making inappropriate transitions to new states.

Once the application has a valid handle to the USART driver, it executes the code under the APP_STATE_SEND_MESSAGE case the next time its APP_Tasks function is called. In this state, the application calls a USART driver data transfer routine (DRV_USART_BufferAdd) to send the data data buffer string defined by the `system_config.h` header. Then, it checks the handle returned by the DRV_USART_BufferAddWrite function to see if it is valid. If the buffer handle is valid, it indicates that the USART driver has accepted the buffer and will take responsibility for the data transfer from that point forward. The application does not have to do anything else to cause the data transfer to occur. However, if the buffer is not accepted by the driver (in which case the handle returned by the DRV_USART_BufferAddWrite function would be invalid), the application stays in the APP_STATE_SEND_MESSAGE and tries again the next time the APP_Tasks function is called.

Once the application has successfully passed the buffer to the USART driver, it transitions to the APP_STATE_IDLE state where it stays and does nothing any time its "tasks" function is called. Its job is done! A more complex application would go on to some other task or potentially begin the process again. But, this is a simple "Hello World" sample application.

Note: The application is normally initialized last, after all other modules in the system have been initialized. But, it should never assume that any other module has completed its initialization when the application is initialized or when its "tasks" function is first called. Instead, it should always check the return value or status from any other module it calls to ensure that the call succeeded before moving on to the next state. Following this rule makes applications more robust and allows them to handle errors more effectively.

System Configurations

This section describes the files that make up a system configuration.

Description

In MPLAB Harmony, a system configuration consists of a set of files that define the build options, how the system is initialized, and how it runs after it has been initialized. The purpose of each of these files is described in the topics in this section.

system_config.h

This topic describes the purpose of system configuration header file.

Description

System Configuration

In MPLAB Harmony, most library modules require a set of build time configuration options that define a variety of parameters (such as buffer sizes, maximum or minimum limits, and default behavior). To configure a library for your specific needs, its configuration options can be defined using C language preprocessor `#define` statements. The set of configuration options supported is described for each library in the "Configuring the Library" section of its help document and most libraries provide a template and example configuration header files in a `config` sub-folder within their `src` folder.

To obtain its build configuration options, every library includes the same common top-level configuration file that is named `system_config.h`, and it is generated by the MHC as part of your system configuration. The relative directory path to configuration directory that contains this file is defined in the build properties of your project configuration by the MHC so that the compiler can find it in its include file search path.

Example Configuration `system_config.h` Header

```
// *****************************************************************************
// *****************************************************************************
// Section: System Service Configuration
// *****************************************************************************
// *****************************************************************************

// *****************************************************************************
/* Common System Service Configuration Options
*/
#define SYS_VERSION_STR           "1.07"
#define SYS_VERSION               10700

// *****************************************************************************
/* Clock System Service Configuration Options
*/
#define SYS_CLK_FREQ                        80000000ul
#define SYS_CLK_BUS_PERIPHERAL_1            80000000ul
#define SYS_CLK_UPLL_BEFORE_DIV2_FREQ       7999992ul
#define SYS_CLK_CONFIG_PRIMARY_XTAL         8000000ul
#define SYS_CLK_CONFIG_SECONDARY_XTAL       32768ul

/*** Ports System Service Configuration ***/
#define SYS_PORT_AD1PCFG        ~0xffff
#define SYS_PORT_CNPUE          0x0
#define SYS_PORT_CNEN           0x0


// *****************************************************************************
// *****************************************************************************
// Section: Driver Configuration
// *****************************************************************************
// *****************************************************************************

// *****************************************************************************
/* USART Driver Configuration Options
*/

#define DRV_USART_INTERRUPT_MODE                    false
#define DRV_USART_BYTE_MODEL_SUPPORT                false
#define DRV_USART_READ_WRITE_MODEL_SUPPORT          true
#define DRV_USART_BUFFER_QUEUE_SUPPORT              true
#define DRV_USART_QUEUE_DEPTH_COMBINED              16
#define DRV_USART_CLIENTS_NUMBER                    1
#define DRV_USART_SUPPORT_TRANSMIT_DMA              false
#define DRV_USART_SUPPORT_RECEIVE_DMA               false
#define DRV_USART_INSTANCES_NUMBER                  1

#define DRV_USART_PERIPHERAL_ID_IDX0                USART_ID_2
#define DRV_USART_OPER_MODE_IDX0                    DRV_USART_OPERATION_MODE_NORMAL
#define DRV_USART_OPER_MODE_DATA_IDX0               0x00
#define DRV_USART_INIT_FLAG_WAKE_ON_START_IDX0      false
#define DRV_USART_INIT_FLAG_AUTO_BAUD_IDX0          false
#define DRV_USART_INIT_FLAG_STOP_IN_IDLE_IDX0       false
#define DRV_USART_INIT_FLAGS_IDX0                   0
#define DRV_USART_BRG_CLOCK_IDX0                    80000000
```

```
#define DRV_USART_BAUD_RATE_IDX0                    9600
#define DRV_USART_LINE_CNTRL_IDX0                   DRV_USART_LINE_CONTROL_8NONE1
#define DRV_USART_HANDSHAKE_MODE_IDX0               DRV_USART_HANDSHAKE_NONE
#define DRV_USART_XMIT_INT_SRC_IDX0                 INT_SOURCE_USART_2_TRANSMIT
#define DRV_USART_RCV_INT_SRC_IDX0                  INT_SOURCE_USART_2_RECEIVE
#define DRV_USART_ERR_INT_SRC_IDX0                  INT_SOURCE_USART_2_ERROR

#define DRV_USART_XMIT_QUEUE_SIZE_IDX0              10
#define DRV_USART_RCV_QUEUE_SIZE_IDX0               10

#define DRV_USART_POWER_STATE_IDX0                  SYS_MODULE_POWER_RUN_FULL


// *****************************************************************************
// *****************************************************************************
// Section: Application Configuration
// *****************************************************************************
// *****************************************************************************

#define APP_UART_DRIVER_INDEX            DRV_USART_INDEX_0
#define APP_HELLO_STRING                 "Hello World\r\n"
```

The previous example defines configuration options for the application, system services, and USART driver used in the "pic32mx795_pim_e16" configuration of the sample project.

system_init.c

This topic describes the purpose of the system initialization file.

Description

In a MPLAB Harmony project, the SYS_Initialization function is called from the `main` function in order to initialize all modules in the system. This function is implemented as part of a system configuration by the MHC in a file named `system_init.c`. This file may also include other necessary global system items that must be implemented in order to initialize a system such as processor configuration bits and module initialization global data structures.

Example `system_init.c` File

```
// ****************************************************************************
// ****************************************************************************
// Section: Configuration Bits
// ****************************************************************************
// ****************************************************************************

/*** DEVCFG0 ***/

#pragma config DEBUG =      OFF
#pragma config ICESEL =     ICS_PGx2
#pragma config PWP =        OFF
#pragma config BWP =        OFF
#pragma config CP =         OFF

/*** DEVCFG1 ***/

#pragma config FNOSC =      PRIPLL
#pragma config FSOSCEN =    OFF
#pragma config IESO =       ON
#pragma config POSCMOD =    XT
#pragma config OSCIOFNC =   OFF
#pragma config FPBDIV =     DIV_1
#pragma config FCKSM =      CSDCMD
#pragma config WDTPS =      PS1048576
#pragma config FWDTEN =     OFF

/*** DEVCFG2 ***/

#pragma config FPLLIDIV =   DIV_2
#pragma config FPLLMUL =    MUL_20
#pragma config FPLLODIV =   DIV_1
#pragma config UPLLIDIV =   DIV_12
#pragma config UPLLEN =     OFF
```

```
/*** DEVCFG3 ***/

#pragma config USERID =     0xffff
#pragma config FSRSSEL =    PRIORITY_7
#pragma config FMIIEN =     OFF
#pragma config FETHIO =     OFF
#pragma config FCANIO =     OFF
#pragma config FUSBIDIO =   OFF
#pragma config FVBUSONIO =  OFF


// *****************************************************************************
// *****************************************************************************
// Section: Driver Initialization Data
// *****************************************************************************
// *****************************************************************************

const DRV_USART_INIT drvUsart0InitData =
{
    .moduleInit.value = DRV_USART_POWER_STATE_IDX0,
    .usartID = DRV_USART_PERIPHERAL_ID_IDX0,
    .mode = DRV_USART_OPER_MODE_IDX0,
    .modeData.AddressedModeInit.address = DRV_USART_OPER_MODE_DATA_IDX0,
    .flags = DRV_USART_INIT_FLAGS_IDX0,
    .brgClock = DRV_USART_BRG_CLOCK_IDX0,
    .lineControl = DRV_USART_LINE_CNTRL_IDX0,
    .baud = DRV_USART_BAUD_RATE_IDX0,
    .handshake = DRV_USART_HANDSHAKE_MODE_IDX0,
    .interruptTransmit = DRV_USART_XMIT_INT_SRC_IDX0,
    .interruptReceive = DRV_USART_RCV_INT_SRC_IDX0,
    .queueSizeTransmit = DRV_USART_XMIT_QUEUE_SIZE_IDX0,
    .queueSizeReceive = DRV_USART_RCV_QUEUE_SIZE_IDX0,
};

// *****************************************************************************
// *****************************************************************************
// Section: Module Initialization Data
// *****************************************************************************
// *****************************************************************************

const SYS_DEVCON_INIT sysDevconInit =
{
    .moduleInit = {0},
};


// *****************************************************************************
// *****************************************************************************
// Section: System Data
// *****************************************************************************
// *****************************************************************************

/* Structure to hold the object handles for the modules in the system. */
SYSTEM_OBJECTS sysObj;


// ****************************************************************************
// ****************************************************************************
// Section: System Initialization
// ****************************************************************************
// ****************************************************************************

void SYS_Initialize ( void* data )
{
    /* Core Processor Initialization */
    SYS_CLK_Initialize( NULL );
    sysObj.sysDevcon = SYS_DEVCON_Initialize(SYS_DEVCON_INDEX_0, (SYS_MODULE_INIT*)&sysDevconInit);
    SYS_DEVCON_PerformanceConfig(SYS_CLK_SystemFrequencyGet());
    SYS_PORTS_Initialize();

    /* Initialize Drivers */
    sysObj.drvUsart0 = DRV_USART_Initialize(DRV_USART_INDEX_0, (SYS_MODULE_INIT *)&drvUsart0InitData);

    /* Initialize the Application */
    APP_Initialize();
}
```

In addition to the SYS_Initialize function implementation, the previous example, the `system_init.c` file from the "pic32mx_795_pim_e16" configuration of the "sample" project, defines the processor configuration bits, data structures used to initialize the USART driver and device control service, and a global sysObj data structure used for the USART driver Device Control System Service returned by their initialization functions.

Note the SYSTEM_OBJECTS data type for the sysObj date structure is defined in the system_definitions.h section.

system_tasks.c

This topic describes the purpose of the system tasks file.

Description

Since MPLAB Harmony modules are state machine driven, they each have a "Tasks" function that must be called repeatedly (from the system-wide "super loop" in `main` or from an ISR or OS thread). The "Tasks" functions are all called from the top-level SYS_Initialize function that is normally implemented in a file called `system_tasks.c` that is generated by the MHC as part of a system configuration.

Example `system_tasks.c` File

```
void SYS_Tasks ( void )
{
    /* Maintain system services */
    SYS_DEVCON_Tasks(sysObj.sysDevcon);

    /* Maintain Device Drivers */
    DRV_USART_TasksTransmit(sysObj.drvUsart0);
    DRV_USART_TasksReceive(sysObj.drvUsart0);
    DRV_USART_TasksError (sysObj.drvUsart0);

    /* Maintain the application's state machine. */
    APP_Tasks();
}
```

The `system_tasks.c` file for the "pic32mx_795_pim_e16" configuration of the "sample" project, contains only the implementation of the SYS_Tasks function for that configuration. This function calls the tasks function of the Device Control System Service, the USART driver's tasks functions (it has three, one each for transmitter, receiver, and error-handling tasks), passing in the object handle returned from the driver's initialization routine, and it calls the application's tasks function APP_Tasks to keep the state machines of all three modules running.

system_interrupt.c

This topic describes the purpose of the system interrupts file.

Description

In an interrupt-driven configuration, any modules (such as drivers or system services) that can be driven from an interrupt must have their interrupt-capable tasks function(s) called from an Interrupt Service Routine (ISR) "vector" function instead of from the SYS_Tasks function. The form of the definition of the ISR vector function is dependent on what type of PIC32 microcontroller on which the system is running. So, any vector functions required are normally implemented as part of the a specific system configuration in a file normally named `system_interrupt.c`.

Since the sample application is entirely polled, its `system_interrupt.c` file does not contain any ISR vector functions. Refer to any interrupt-driven demonstration or example application to see how vector functions are implemented.

system_definitions.h

This topic describes the purpose of the system definitions header file.

Description

The system configuration source files (`system_init.c`, `system_tasks.c`, and `system_interrupt.c`) all require a definition of the system objects data structure and an `extern` declaration of it. The MHC generates these items in the `system_definitions.h` header file and the system source files all include that header file.

For example, the sample application defines the following structure definition and extern declaration.

```
typedef struct
{
```

```
SYS_MODULE_OBJ sysDevcon;
SYS_MODULE_OBJ drvUsart0;

} SYSTEM_OBJECTS;

extern SYSTEM_OBJECTS sysObj;
```

This structure holds the object handles returned by the Initialize functions for the device control and USART modules (in `system_init.c`) because they must be passed into the associated Tasks functions (called in `system_tasks.c`), which is why the system global sysObj structure requires an `extern` declaration. The MHC generates object handle variables in this structure for every instance of an active module in the system.

Additionally, the system configuration source files require the interface headers for all libraries and applications included in the system so that they have prototypes for their Initialize and Tasks functions. In the sample application, the `system_definitions.h` file includes the following interface headers (and standard C headers).

```
#include <stdint.h>
#include <stddef.h>
#include <stdbool.h>
#include "system/common/sys_common.h"
#include "system/common/sys_module.h"
#include "system/clk/sys_clk.h"
#include "system/clk/sys_clk_static.h"
#include "system/devcon/sys_devcon.h"
#include "driver/usart/drv_usart.h"
#include "system/ports/sys_ports.h"
```

Note: The `system_configuration.h` header file should not be included by the application (`app.c`, `app.h` , or other) source files because it provides direct `extern` access to system objects and these objects should not be utilized by the application directly. The application (or other modules) should only interact with a module through its defined Application Program Interface (API), or client interface, not through the system objects or system functions that require that object.

system_exceptions.c

This topic describes the purpose of the system exceptions source file.

Description

The `system_exceptions.c` source file provides a skeletal implementation of the general exception handler function (shown below), overriding the weak function implementation provide by the MPLAB XC32 C/C++ Compiler that simply hangs in an endless loop.

```
void _general_exception_handler ( void )
{
   /* Mask off the ExcCode Field from the Cause Register.
   Refer to the MIPs Software User's manual. */
   _excep_code = (_CP0_GET_CAUSE() & 0x0000007C) >> 2;
   _excep_addr = _CP0_GET_EPC();
   _cause_str = cause[_excep_code];

   SYS_DEBUG_PRINT(SYS_ERROR_ERROR,
   "\nGeneral Exception %s (cause=%d, addr=%x).\n",
   _cause_str, _excep_code, _excep_addr);

   while (1)
      {
          SYS_DEBUG_BreakPoint();
      }
}
```

If a general exception occurs, this implementation will capture the address of the instruction that caused the exception in the `_excep_addr` variable, the cause code in the `_excep_code` variable and use a look-up table indexed by the cause to provide a debug message describing the exception if debug message support is enabled. Then, the function will hit a hard-coded debug breakpoint (in Debug mode) and hang in a loop to prevent runaway execution.

This implementation is provided to assist with development and debugging. The user is encouraged to modify this implementation to suit the needs of their system.

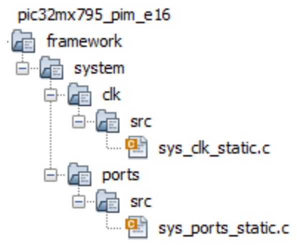
The Configuration-specific "framework" Folder

This topic describes the configuration-specific `framework` folder.

Description

The interface (i.e., API) headers and the source files for the dynamic implementations of all MPLAB Harmony libraries are contained in the main framework folder (`<install-dir>\framework`). However, the MHC generates any static implementations of the MPLAB Harmony libraries. These generated source files are all configuration specific because they are generated with knowledge of the configuration selections. Thus, they are placed in a configuration-specific framework folder. For consistency, the organization of the sub-folder tree of the configuration-specific framework folder matches the organization of the main framework folder.

For example, the configuration-specific `framework` folder for the pic32mx795_pim_e16 configuration of the sample project contains the source files for the static, MHC-generated implementations of the Clock System Service and the Ports System Service, as shown in the following figure.



Other Configuration-specific Files

This topic describes two other (non C-language) configuration-specific files.

Description

There are two additional (non-C language) files generated by the MHC and placed into the configuration-specific folder. The first file, `<config-name>.mhc`, captures the configuration selections made by the user. The second file, which is always named `configuration.xml`, captures the various checksums and additional information required by the MHC to identify which generated files have been edited externally and to store miscellaneous other information it requires (such as the path to the MPLAB Harmony installation).

MPLAB Harmony Compatibility Guide

This section provides information for making software libraries compatible with MPLAB Harmony.

1: Objective

The objective of this document is to provide a set of design, implementation, and porting guidelines for making software libraries compatible with MPLAB Harmony.

Description

Following 2: Overview, MPLAB Harmony compatibility guidelines are broken down into the following primary subsets.

- 3: Modularity Guidelines
- 4: Flexibility Guidelines
- 5: Testing Guidelines
- 6: Documentation Guidelines

Modularity guidelines ensure that libraries do not interfere with each other. Adherence to modularity guidelines is essential to making libraries compatible and interoperable with other MPLAB Harmony libraries. Flexibility guidelines affect the number of different environments in which a library can be used as well as the ability of a library to be customized for any particular solution. Testing guidelines make recommendations on how to verify correct and robust behavior of libraries. And, documentation guidelines describe the recommended documentation support for MPLAB Harmony compatible libraries.

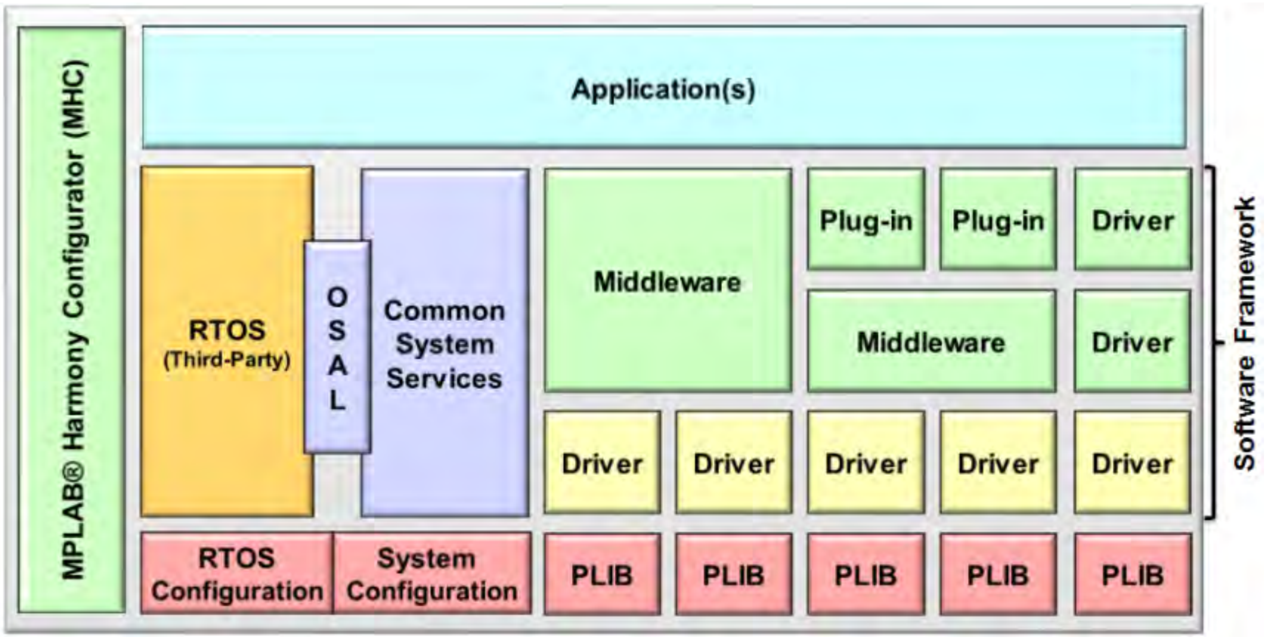
A range of compatibility and compliance to these guidelines is possible. One key example is that it is not necessary that a library support all possible execution models to be considered MPLAB Harmony compatible. However, it does affect the level of flexibility supported and restrictions must be clearly documented. Another key example is that libraries that are released as part of the MPLAB Harmony framework follow more stringent coding style and naming convention guidelines than can be required of pre-existing libraries. This document describes the acceptable levels of compatibility with each rule.

2: Overview

This section provides an overview of MPLAB Harmony and describes libraries and the execution model.

Description

MPLAB Harmony is a modular, layered, cross-microcontroller, RTOS-friendly, integrated software framework, illustrated by the following block diagram.



2.1: Libraries

MPLAB Harmony libraries provide simple C-language application software interfaces to peripherals and middleware supported by Microchip microcontrollers

Description

A MPLAB Harmony library can be an active state machine driven module or a fully re-entrant library with no internal state of its own. Libraries are highly adaptable to support a wide variety of hardware, RTOS, and functional configurations. All modules are designed to be fully interoperable, respecting the abstractions of other modules in the system. Modules only access the resources owned by other modules through the interfaces provided by them, never directly. Libraries may be dynamic, supporting multiple client modules and/or multiple identical instances of themselves, or they may be static, supporting a single client and/or single instance operation, saving code size when dynamic behavior is not required.

Device drivers are library modules that support internal (on-chip) or external (off-chip) peripherals and provide abstracted file-system like interfaces that stay consistent across different implementations to simplify porting from one Microchip microcontroller or system configuration to another. System services help prevent conflicts between modules by providing access to common resources such as interrupts, clocks, and I/O ports. Drivers and services may be built upon part-specific Peripheral Libraries (PLIBs) or they may use other driver and/or service modules if they need the resources owned by them. PLIBs provide a functional breakdown of internal (on-chip) peripherals and hide register details while providing direct (unprotected) low-level access to microcontroller hardware. PLIBs do not maintain any internal state data, except that which is maintained by the hardware itself, and are primarily implemented as inline functions. Middleware libraries support complex protocols such as USB and TCP/IP, or advanced functionality, such as generation of display graphics and cryptographic capabilities. Finally, the Operating System Abstraction Layer (OSAL) enables execution of MPLAB Harmony libraries in supported third-party RTOS environments and it can be effectively removed to support non-RTOS environments.

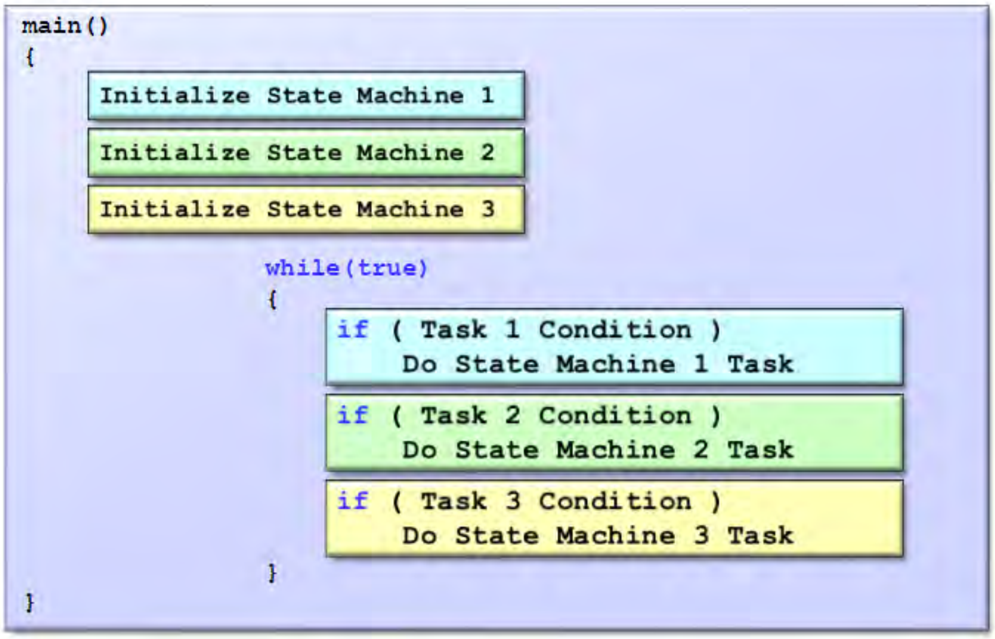
2.2: Execution Model

Describes the Polled Execution Model.

Description

In its most basic configuration, the MPLAB Harmony framework follows a polled non-blocking (cooperative multi-tasking) execution model within a system-wide "super loop" as shown in the following pseudo-code example.

MPLAB Harmony Polled Execution Model



```
main()
{
        Initialize State Machine 1
        Initialize State Machine 2
        Initialize State Machine 3

                    while(true)
                    {
                        if ( Task 1 Condition )
                            Do State Machine 1 Task
                        if ( Task 2 Condition )
                            Do State Machine 2 Task
                        if ( Task 3 Condition )
                            Do State Machine 3 Task
                    }
}
```

Each module (library or application) can implement its own state machine functions, which can be called from the main “super loop" (or from an appropriate interrupt service routine, for libraries that support an interrupt-driven execution model). Libraries can support task/thread safety and blocking behavior by calling OSAL functions, allowing them to be used with any OS for which the OSAL has been implemented. However, MPLAB Harmony does not get between the OS and the application. The application is free to utilize any functionality provided by the selected RTOS and the system can be configured to use almost any desired thread or task model simply by breaking up the super loop into separate loops, each in its own thread with its own priorities. Projects can support one or more configurations, allowing a single application project to be easily supported on different hardware platforms or to support different related feature sets.

Note: MPLAB Harmony has no process-space awareness. It assumes kernel-level access to all resources (although it does perform virtual-to-physical and physical-to-virtual address translation when necessary). Thus, libraries may require proxy support if used in operating environments that provide task-or-process address space protection.

This framework architecture reduces the amount of microcontroller support code that must be must be implemented for each new embedded design, allowing MPLAB Harmony developers to focus on application development instead of infrastructure work.

3: Modularity Guidelines

This section provides a modularity overview and related topics.

Description

The fundamental principal of MPLAB Harmony is one of modularity, at a source code level. This means that changes to the implementation of a library must not cause subsequent changes in the source code of an application or client module that uses the interface of that library. However, it is acceptable for changes in the implementation of a library to require recompilation of clients that use it. Also if necessary, modules may be written that integrate the functionality of other modules as long as it is clearly documented so that the user will not accidentally use conflicting modules in the same system at the same time.

3.1: Isolate Interface From Implementation

This topic introduces the functional interface, which is required for MPLAB Harmony modules.

Description

All MPLAB Harmony modules must have a clearly defined and well-documented "functional" interface. The documented interface should define function prototypes and any necessary data types and macros, but it must not utilize direct access to global data, internal resources or implementation details. Use of C-language functions is preferred (to support binary compatibility), but inline functions and macros are acceptable because they provide source-code compatibility. For example, if a module has internal global variables (as shown in the following example), it is legal to expose the values of these variables through a function, inline function, or macro. However, it is not legal to use direct access to the variables as part of the interface.

Example (mylib.h): Library Interface Header

```
/*************************** Legal Interfaces ********************/

/* Function Access */
int MYLIB_Counter1Get ( void );

/* Warning!  Do not use counter2 or counter3 variables directly. */
extern int counter2;
extern int counter3;

/* Inline Function Access */
inline int MYLIB_Counter2Get ( void )
{
     return counter2;
}

/* Macro Access */
#define MYLIB_Counter3Get()  counter3;

/**************************** Illegal Interface ********************/

/* Direct Global Variable Access */
extern int counter4;
```

Example (mylib.c): Library Implementation

```
int counter1;
int counter2;
int counter3;
int counter4;


int MYLIB_Counter1Get ( void )
{
    return counter1;
}
```

Example (myapp.c): Client Implementation

```
#include "mylib.h"

int c1, c2, c3, c4;
```

```
/***** Legal Interface Use *****/

c1 = MYLIB_Counter1Get();
c2 = MYLIB_Counter2Get();
c3 = MYLIB_Counter3Get();

/***** Illegal Interface Use ****/

c4 = counter4;
```

Any access that requires the client source code to use function call syntax allows for an implementation that can protect owned resources. Direct global access to owned resources does not allow such protection.

Note: The previous examples do not show any sort of protection mechanism. They only show the form of the interface.

3.2: Respect Abstractions

This topic provides information on preventing abstraction violations.

Description

Any code that is expected to be MPLAB Harmony compatible must not violate the abstraction provided by another MPLAB Harmony module in use in the system.

No module may access the internal modifiable resources (data or hardware) of another module except through a legal supported interface that allows the module to control all access to that resource in a safe and correct manner within the supported usage configuration and environment.

For example, the direct client access to "counter4" in the `myapp.c` example (see 3.1: Isolate Interface From Implementation) is a violation of the "mylib" interface abstraction because it directly accesses an internal resource owned by "mylib" without going through a legal interface. Calling a PLIB function for a different module’s peripheral is another example of violating an abstraction because it constitutes "direct" access to owned resources. PLIBs cannot utilize any sort of protection mechanism (which may require OS support). Therefore, if a timer module owns a specific timer instance, it can call that timer’s PLIB directly (see the following example). But, if it also calls the interrupt PLIB, then it is violating the Interrupt System Service’s abstraction.

Example: PLIB Application

```
/******* Legal.  Module "owns" Timer2 *******/

/* Set up Timer2 - PBCLK as the source, prescaler is 256 (PBCLK / 256),
   enable 32-bit counter mode, clear the counter, set the period to 312,500
   - 80 MHz PBCLK / 256 = 312,500 Hz Timer2 clock, so period is set to
   - 312,500 to trigger an interrupt every 1 second */

PLIB_TMR_ClockSourceSelect(TMR_ID_2, TMR_CLOCK_SOURCE_PERIPHERAL_CLOCK);
PLIB_TMR_PrescaleSelect(TMR_ID_2, TMR_PRESCALE_VALUE_256);
PLIB_TMR_Mode32BitEnable(TMR_ID_2);
PLIB_TMR_Counter32BitClear(TMR_ID_2);
PLIB_TMR_Period32BitSet(TMR_ID_2, 312500);

/***** Illegal! Module does not "own" the Interrupt Controller  *****/

/* Enable the Timer 2 interrupt source (Timer2 is used for interrupts in
   32-bit mode), set its priority level to 2, set its sub-priority level to 0 */

PLIB_INT_SourceEnable(INT_ID_0, INT_SOURCE_TIMER_2);
PLIB_INT_VectorPrioritySet(INT_ID_0, INT_VECTOR_T2, INT_PRIORITY_LEVEL2);
PLIB_INT_VectorSubPrioritySet(INT_ID_0, INT_VECTOR_T2, INT_SUBPRIORITY_LEVEL0);
```

In the previous example, this application must use the Interrupt System Service Library (which can control access to the Interrupt Controller), instead of direct access via the PLIB (unless it is the only module in the system that uses the Interrupt Controller).

3.3: Protect Owned Resources

This provides details on protecting owned resources.

Description

With the singular exception of PLIBs (which implement a hardware access layer and are not technically MPLAB Harmony "modules"), every module owns all internal resources that it modifies directly or by using a PLIB.

Owned resources include global data structures, static or dynamically allocated RAM (including client buffers whose ownership is temporarily passed to the module) and special function registers (accessed via PLIBs). This covers any addressable memory space not allocated on the program stack. The intended usage model of all MPLAB Harmony compatible libraries must provide for the protection of all modifiable, non-stack resources owned by library from potential corruption.

Owned resources are protected from direct intentional access by the rules governing the respect of each module's abstraction. However, there are protected a few other specific possibilities addressed in the following sections.

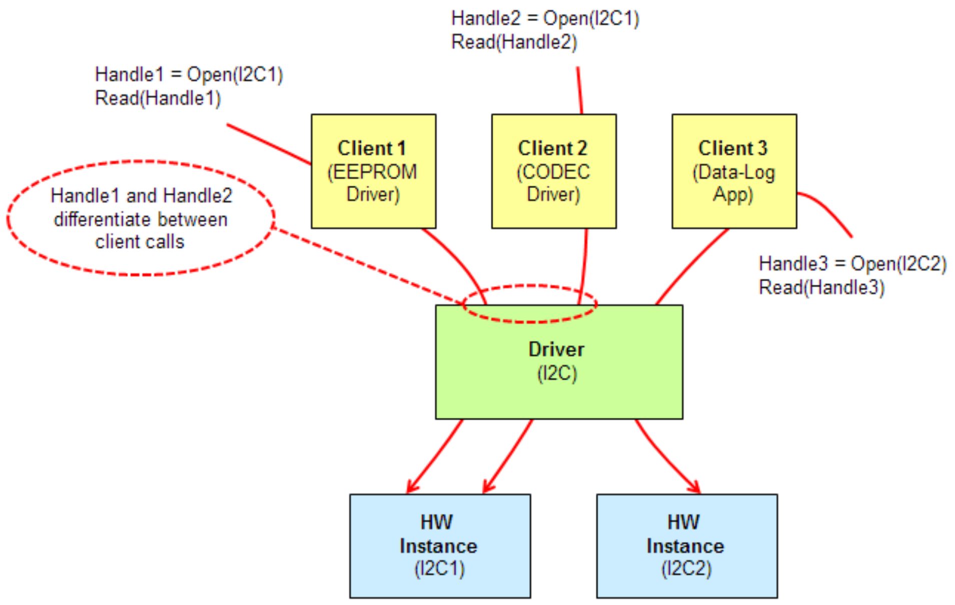
3.3.1: Protect Owned Resources From Accesses by Multiple Clients

This topic provides details on protecting owned resources from accesses by multiple clients.

Description

If more than one module is allowed to interact with a library's interface at a time, that library must implement a mechanism to identify the calling client and prevent requests from one client from interfering with requests from another client. For example, a dynamic multi-client MPLAB Harmony driver requires the client to call an "Open" function and obtain a "handle" value that identifies the client (and the hardware instance if the driver dynamically manages multiple instances of the hardware, as shown in the following example).

Example: Driver Handle Mechanism



The handle obtained from the "Open" function must be passed into all other functions provided by the driver's client interface. If a client interface function, such as the "Read" example shown above, is called with an invalid handle the driver must fail the request. Using this mechanism, a driver can prevent requests from one client from interfering with requests from another client by failing the conflicting request (which must then be retried by the client), by temporarily suspending/blocking the request using operating system capabilities, or by queuing the request and servicing it when the hardware resource becomes available.

3.3.2: Protect Owned Resources From Accesses by Multiple Threads

This topic provides details on protecting owned resources from accesses by multiple threads.

Description

Any library that supports operation in one or more multi-threading RTOS environments must use operating system methods to protect non-atomic accesses to modifiable resources that it owns.

The preferred method for doing this is to use the appropriate MPLAB Harmony OSAL functions, unless the library is restricted to use within a specific operating system (in which case OS-specific methods may be used). For example, if multiple clients can use a module (as shown in the diagram in 3.3.1: Protect Owned Resources From Accesses by Multiple Clients), it may be called from multiple operating system threads. If that is the case, the module must protect its shared resources using operating system methods. For example, the MPLAB Harmony OSAL provides a mutex mechanism that can be used to protect access to a shared data structure, as shown in the following example.

Example: OSAL Mutex Protecting Shared Data Structure
```
/* Perform operations on a shared data structure */
struct myDataStructure
{
    uint16_t  x;
    uint8_t   y;

} myDataStructure;

...
```

```
OSAL_MUTEX_DECLARE(mutexDS);
OSAL_MUTEX_Create(&mutexDS);

...
/* Wait 2 seconds to obtain the mutex */
if (OSAL_MUTEX_Lock(mutexDS, 2000) == OSAL_RESULT_TRUE)
{
    /* Operate on the data structure */
    myDataStructure.x = 32;
    myDataStructure.y = 42;
    OSAL_MUTEX_Unlock(mutexDS);
}
```

3.3.3: Protect Owned Resources From Accesses by ISR

This topic provides details on protecting own resources from accesses by an Interrupt Service Routine.

Description

Any library that supports calling of one or more of its functions from within an Interrupt Service Routine (ISR) context must implement a mechanism by which it prevents that interrupt from corrupting modifiable resources owned by that library that may be accessed non-atomically by non-ISR routines. For example, the following code sequence example shows how this can be done using the MPLAB Harmony Interrupt System Service.

Example: Protecting Critical of Code from an Interrupt

```
bool interruptWasEnabled;

/* Saves interrupt source enable status before disabling it. */
interruptWasEnabled = SYS_INT_SourceDisable(MY_DRIVER_INTERRUPT_SOURCE);

/* Do something critical. */

/* Re-enable interrupt source if it was enabled before. */
if (interruptWasEnabled)
{
    SYS_INT_SourceEnable(MY_DRIVER_INTERRUPT_SOURCE);
}
```

Note: Normally, only a device driver or system service library’s state machine "Tasks" function (as described in Support One or More "Tasks" Functions if Required) can be called from an ISR. In these cases, the library’s other routines may use the MPLAB Harmony Interrupt System Service to temporarily disable the interrupt in question (and only that interrupt). However, care must be taken if other interface or callback routines can be called from within another module’s interrupt context to not make non-atomic accesses to resources as one module may not disable another module’s interrupt.

3.4: Access Shared System Resources Only Through MPLAB Harmony Drivers and System Services

This provides information on shared system resources.

Description

Shared system resources such as the interrupt controller, I/O ports, timers, and other peripherals are common resources that must be owned by a MPLAB Harmony system service or a device driver module to be shared by other modules (including middleware libraries and applications).

Access to these shared system resources must only occur via the controlling module’s interface, never by direct access (which is a violation of the abstraction, as described in 3.2: Respect Abstractions) unless that resource is dedicated to the module accessing it.

System services provide interfaces to allocate, access, and control resources for which an active link need not normally be opened between the library and the client. This is because once a resource is allocated to a specific client; no other client may attempt to use it.

Device drivers provide a mechanism for clients to maintain open link to a shared resource and share its ongoing use with other clients or use it until done and close the link to allow the resource to be used by other clients.

3.5: Support MPLAB Harmony System Module Model When Applicable

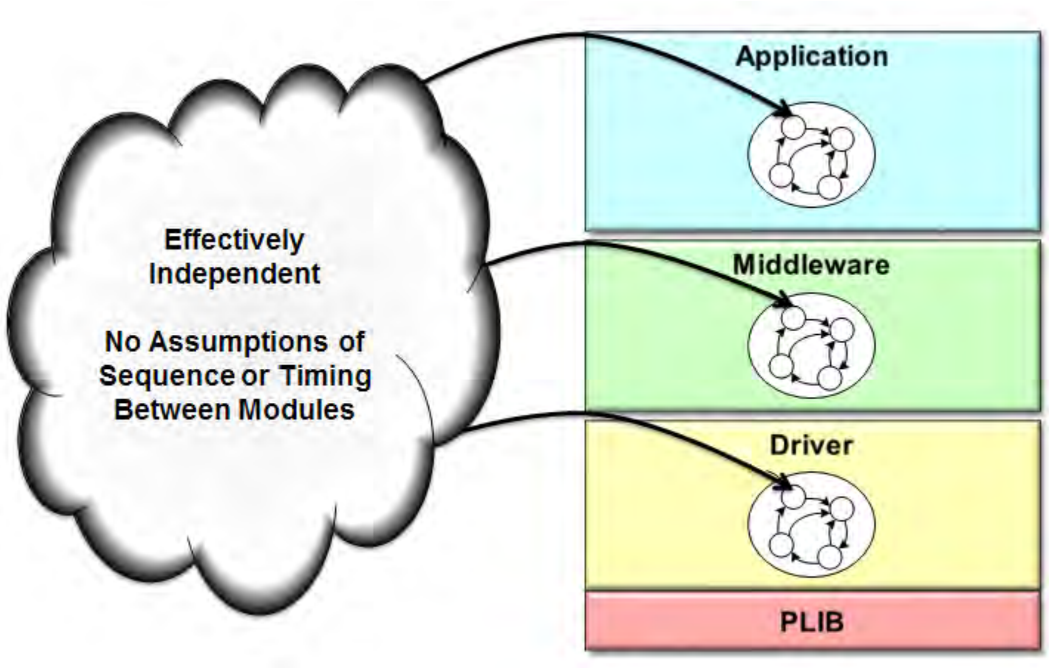
This describes the MPLAB Harmony system module model.

Description

As mentioned in the introduction, a MPLAB Harmony library can be an active state machine driven module or a fully re-entrant library with no internal state of its own. If a library does not need to be initialized (i.e., it is fully re-entrant and owns no internal modifiable resources), it does not need to implement an initialization routine and it is not considered a MPLAB Harmony "module".

Any library or application that requires initialization, that owns any internal resources (that are not automatically allocated on the stack), or that maintains any sort of state machine is considered a "module" and must implement some portion of the MPLAB Harmony "system module" interface. This interface defines the function signatures of specific routines used by the system configuration code (and/or system libraries) to initialize and maintain correct operation of the module within the overall system.

Horizontal "System" Interface



Clients of the module do not use this interface; only the system uses it to keep the module "running".

3.5.1: Support an "Initialize" Function if Required

This topic describes the Initialize function.

Description

Support of an "Initialize" function is the minimal criterion for a MPLAB Harmony library to be considered a module.

The primary purpose of the "Initialize" function is to place an instance of a module into its initial state and return an object handle used by the other system interface functions to access the instance of the module that was initialized. The "Initialize" routine must store any required data passed to it, place the module's state machine into its initial state and return immediately (without blocking). Any initialization that may take significant time to complete must be carried out in the module's state machine.

Function

```
SYS_MODULE_OBJ <module>_Initialize( const SYS_MODULE_INDEX index,
                                    const SYS_MODULE_INIT * const data )
```

Summary

Initializes the module with data for the index instance of the `<module>` module.

Description

This routine initializes the module for the index instance of the <module> module, using the initialization given data, placing the module in its initial state. It will be called only once, at system initialization and will not be called again unless the system first calls the module's "Deinitialize" routine, if supported.

Required or Optional?

Optional – if the library does not require any initialization.

Preconditions

The low-level processor and board initialization must be completed before the system will call the initialization routine for any modules.

Parameters

index	Zero-based index, identifying the instance of the module to be initialized.
data	Pointer to a module implementation specific data structure. Although the data type of this pointer is to a standard structure, structure actually used can (and usually will) be extended to include additional implementation-specific data as long as the first member of the structure is a SYS_MODULE_INIT structure. If this pointer is NULL, then build-time configuration options must be given to override the items contained in the structure.

Returns

A handle to the instance of the system module that was initialized or SYS_MODULE_OBJ_INVALID if an error occurred. This handle is a necessary parameter to all of the other system-module interface routines for that module.

Code Example

```
// Initialize the I2C driver
sysObjects.i2cDriver = DRV_I2C_Initialize(I2C_ID_1, &i2c_init_data);
```

Blocking Behavior

This function must not block waiting for external I/O, other modules, or anything that may take significant time.

Remarks

The "Status" operation will return SYS_STATUS_READY when the module is fully initialized and ready for client access.

Every module should define its own initialization data structure type named <*module*>_INIT, where <*module*> is the abbreviation identifying the module to be initialized. This structure must be an extension of the SYS_MODULE_INIT structure (i.e., its first member must be the SYS_MODULE_INIT structure or equivalent). Any parameter that can change the power state of the module must be included in the data structure.

Once the Initialize operation has been called, the Deinitialize operation must be called before the Initialize operation can be called again.

Refer to the `<install-dir>/framework/system/common/sys_module.h` header file or System Service Library Introduction for additional information and definitions of the additional data types used.

3.5.2: Support One or More "Tasks" Functions if Required

This topic describes the Tasks function(s).

Description

If a module is an active component of the system, it will implement one or more "Tasks" functions.

Task functions manage the state of a module and perform the "background" work of a module (any work that does not occur in a client interface routine). Task routines can be called from a system-wide super loop, from OS threads, or possibly from ISRs, depending on the specific requirements and configuration of the module. Tasks routines must not make any implicit assumptions about state. They must always check the module’s current state data (be that state stored in variables or in registers) and take any appropriate actions necessary to move to the next appropriate state. If no action is necessary, the tasks routine may stay in the same state and should return as quickly as possible.

Most device drivers (and some system services) use ISR safe tasks routines to manage their state. If a tasks routine is designed to be called from an ISR, it must not call any potentially blocking routines. A module may implement both ISR-safe tasks functions and non-ISR-safe tasks functions if necessary.

Function

```
void <module>_Tasks ( SYS_MODULE_OBJ object )
```

Summary

Used to maintain the module’s state machine and/or implement its ISR logic.

Description

This routine is used to maintain the module’s internal state machine and/or implement its ISR logic for interrupt-driven tasks.

Required or Optional?

Optional – But required for any module that requires a state machine.

Preconditions

The driver module’s "Initialize" operation must have completed.

Parameters

object	Module’s instance data handle.

Returns

None.

Code Example

```
DRV_I2C_Tasks(sysObjects.i2cDriver);
```

Blocking Behavior

If intended to be called from an ISR this routine must NEVER block. If polled this routine may block on OS objects, but not on external I/O.

Remarks

This routine is not called by a client application. It is only called by the super loop, from an RTOS thread, or from an ISR by the system’s configuration code.

Refer to the `<install-dir>/framework/system/common/sys_module.h` header file or the System Service Library Introduction for additional information and definitions of the additional data types used.

3.5.3: Support a "Deinitialize" Function if Required

This topic describes the Deinitialize function.

Description

Some modules are always required for a working system and do not support a "Deinitialize" function. However, if a module is intended to support calling of its "Initialize" function a second or subsequent time (without first going through an entire system reset), it must implement a "Deinitialize" function that stops all current activity, frees any allocated resources, and disables all operations.

Task functions manage the state of a module and perform the "background" work of a module (any work that does not occur in a client interface routine). Task routines can be called from a system-wide super loop, from OS threads, or possibly from ISRs, depending on the specific requirements and configuration of the module. Tasks routines must not make any implicit assumptions about state. They must always check the module’s current state data (be that state stored in variables or in registers) and take any appropriate actions necessary to move to the next appropriate state. If no action is necessary, the tasks routine may stay in the same state and should return as quickly as possible.

Most device drivers (and some system services) use ISR safe tasks routines to manage their state. If a tasks routine is designed to be called from an ISR, it must not call any potentially blocking routines. A module may implement both ISR-safe tasks functions and non-ISR-safe tasks functions if necessary.

Function

```
void <module>_Deinitialize( SYS_MODULE_OBJ object )
```

Summary

Deinitializes the specified instance of the module

Description

This routine deinitializes the specified instance of the module, stopping all current activity, freeing any allocated resources, and disabling all operations.

Required or Optional?

Optional – unless the module can be disabled and initialized a second or subsequent time (without performing an entire system reset), which means it is required.

Preconditions

The module’s "Initialize" function must have been called once and returned a valid object handle, before this routine may be called.

Parameters

object	Module’s instance data handle.

Returns

None.

Code Example

```
DRV_I2C_Deinitialize(sysObjects.i2cDriver);
```

Blocking Behavior

This function must not block or wait for ongoing operations to complete. If time is required to complete the deinitialization operation, then the process must be completed by the module's state machine and the module's "Status" must indicate a status greater than SYS_STATUS_UNINITIALIZED until the operation is complete.

Remarks

The Status operation will return SYS_STATUS_UNINITIALIZED when this operation has completed.

This routine may abort any queued operations, and possibly even operations in progress (if it they can be aborted without adverse effect on the interface) or it may allow them to complete, but it must prevent any new operations from being initiated by any clients.

Once the Initialize operation has been called, the Deinitialize operation must be called before the Initialize operation can be called again and vice versa.

Refer to the `<install-dir>/framework/system/common/sys_module.h` header file or the System Service Library Introduction for additional information and definitions of the additional data types used.

3.5.4: Support a "Status" Function if Required

This topic describes the Status function.

Description

If a module implements the "Deinitialize" or "Reinitialize" system interface functions, it must also implement the "Status" function. A module may also implement the "Status" function if it provides error status reporting to the system.

Function

```
SYS_STATUS <module>_Status( SYS_MODULE_OBJ object )
```

Summary

Provides the current status of the identified instance of the module.

Description

This routine provides the current status of the instance of the module identified by the object handle.

Required or Optional?

Optional – But, required if the module implements either of the "Deinitialize" or "Reinitialize" routines.

Preconditions

None. (The "Status" routine must return SYS_STATUS_UNINITIALIZED if called before the module has been initialized.)

Parameters

object	Module's instance data handle.

Returns

- SYS_STATUS_ERROR_EXTENDED = -10 - Any value less or equal to this indicates that a non-system defined (module specific) error has occurred.
- SYS_STATUS_ERROR = -1 - Indicates that the specified module is in an error state. Any value less or equal to this value indicates an error has occurred.
- SYS_STATUS_UNINITIALIZED = 0 - Indicates that the module has not yet been initialized (its "Initialize" function has not been called).
- SYS_STATUS_BUSY = 1 - Indicates that a previous system operation for the specified module instance has not yet completed and the module is not yet ready to receive calls to other system interface operations.
- SYS_STATUS_READY = 2 - Indicates that any previous module operation for the specified module has completed. Any value greater than or equal to value this indicates that the module is ready to receive calls to other operations.
- SYS_STATUS_READY_EXTENDED = 10 - Any value greater or equal to this indicates that the specified module is in a non-system defined (module specific) ready or running state.

Code Example

```
// Initialize the I2C driver module
sysObjects.i2cDriver = DRV_I2C_Initialize(I2C_ID_1, &i2c_init_data);
```

```
// Check driver’s status
status = DRV_I2C_Status(sysObjects.i2cDriver);
if (status <= SYS_STATUS_ERROR)
{
    // Handle error
}
else if (status < SYS_STATUS_READY)
{
    // Module not ready yet, check again later
}
```

Blocking Behavior

This function must not block waiting for external I/O, other modules, or anything that may take significant time.

Remarks

This operation can be used to determine when other system operations have completed, if a module has been initialized, or if an error has occurred. If the Status operation returns SYS_STATUS_BUSY, the previous operation has not yet completed. Once the Status operation returns SYS_STATUS_READY (or greater), any previous operations have completed.

The value of SYS_STATUS_READY is 2. Values between 2 and 10 are reserved for system defined "ready" states. A module may define module-specific "ready" or "run" states greater than or equal to 10 (SYS_STATUS_READY_EXTENDED).

The value of SYS_STATUS_ERROR is -1. Values between -1 and -10 are reserved for system-defined errors. A module may define module-specific error values of less than or equal to -10 (SYS_STATUS_ERROR_EXTENDED).

If the Status operation returns an error value, the error may be cleared by calling the reinitialize operation. If that fails, the Deinitialize operation will need to be called, followed by the initialize operation to return to normal operations. (The system must check the value returned by the Status routine after calling any of the module operations to find out when they have completed.)

Refer to the `<install-dir>/framework/system/common/sys_module.h` header file or the System Service Library Introduction for additional information and definitions of the additional data types used.

3.5.5: Support a "Reinitialize" Function if Required

This topic describes the Reinitialize function.

Description

A module may support a "Reinitialize" function if it provides the ability to change initialization parameters dynamically, while the system is running.

The primary purpose of this operation is to support dynamic power management by allowing initial power states and parameters to be changed without damaging ongoing client activity. If supported, this operation must either temporarily suspend ongoing client activity (but not invalidate opened client handles or ongoing requests) before making the requested change in initial parameters or it must make the change in a safe (non-destructive) way while client operations are ongoing (if that is possible).

This operation will primarily be used by a system power management module (if utilized) or by safety monitoring system module to guarantee active modules are in the correct power state.

Function

```
void <module>_Reinitialize (SYS_MODULE_OBJ object,
const SYS_MODULE_INIT * const data )
```

Summary

Reinitializes and refreshes the state data for the identified instance of the module.

Description

This routine reinitializes and refreshes the state data (particularly the hardware settings) for the identified instance of the module using the initialization given data. It does this in a client safe manner, not by arbitrarily clearing or reinitializing internal data structures and it does not disconnect or interrupt any ongoing client operations (although, it may temporarily suspend them).

Required or Optional?

Optional – not required if the module is not power-state aware or safety critical.

Preconditions

The associated initialization routine must have been called and the module’s state machine(s) must be running.

Parameters

object	Module's instance data handle.
data	Pointer to a module implementation specific data structure. This is identical to the structure passed to the module's "Initialize" function.

Returns

None.

Code Example

```
DRV_I2C_Reinitialize(sysObjects.i2cDriver, &i2c_init_low_power_state);
```

Blocking Behavior

This function must not block or wait for ongoing operations to complete. If time is required to complete the re-initialization operation, then the process must be completed by the module's state machine and the module's "Status" must indicate a status less than SYS_STATUS_READY until the operation is complete.

Remarks

The Status operation will return SYS_STATUS_READY (or greater) when this operation has completed.

This operation uses the same initialization data structure as the Initialize operation.

This operation can be used to change the power state of the peripheral the module manages.

This operation will not interrupt any ongoing client operations. (Effects on queued operations are module dependent, but the module must provide a way to identify and handle any errors in queued operations that it allows to occur.)

This operation must refresh the hardware and state data (as affected by the initialization data) to ensure that the module operates using the new settings.

Refer to the `<install-dir>/framework/system/common/sys_module.h` header file or the System Service Library Introduction for additional information and definitions of the additional data types used.

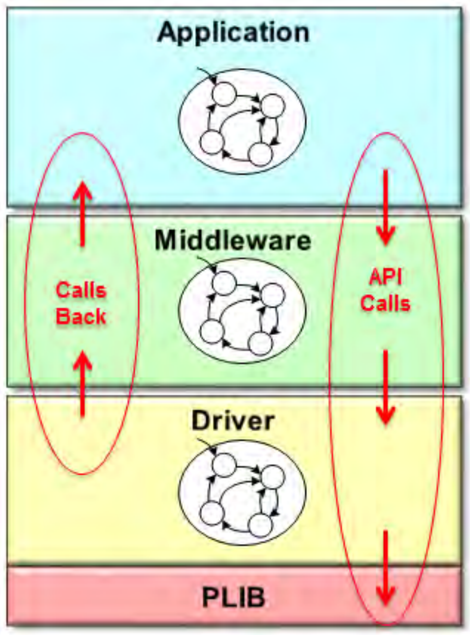
3.6: Drivers Use Driver-Client Model

This describes the Driver-Client model used by drivers.

Description

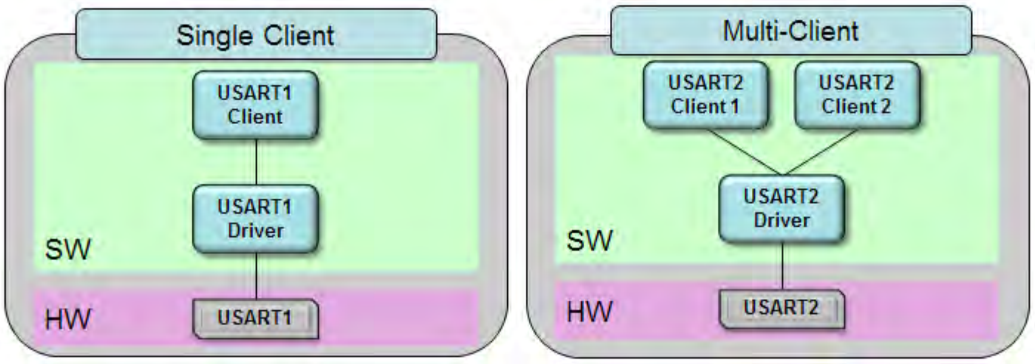
All libraries implement a vertical "client" interface through which clients of the library interact with it. This allows libraries, especially active modules in the system, to be "stacked" so that their state machines work together.

Vertical "Client" Interface



Any MPLAB Harmony module that can be considered a device "driver" must implement the MPLAB Harmony driver interface. The driver interface defines function signatures of open and close routines to allow a client module to open an individual link to a driver before using it. It must hold onto the link as long as required and then close the link after it has finished using it. This allows drivers to identify requests from different clients so that it may be implemented in a way that allows clients to safely share the resources managed by the driver without interfering with each other.

Single Client Versus Multi-client Drivers



Drivers can also be designed to only support a single client at a time, but the driver must still emulate the multi-client interface even if it does so by providing macros or inline functions that effectively "throw away" the call to the "Open" and "Close" functions to provide source-code level compatibility with the multi-client dynamic interface.

3.6.1: Support Driver "Open" Function

This topic describes the Open driver function.

Description

The purpose of a driver’s "Open" function is to initialize a link between the driver and the client and provide the client a "handle" that identifies that link.

The "Open" function is modeled after a POSIX file system "open" and "fopen" functions and it allows the client to indicate the intended usage of the driver for input and/or output, as well as the desired level of sharing with other modules.

Function

```
DRV_HANDLE DRV_<module>_Open (const SYS_MODULE_INDEX index,
                              const DRV_IO_INTENT intent )
```

Summary

Opens a driver for client use and provides an "open-instance" handle.

Description

This routine opens a driver for use by a client module and provides an "open-instance" handle that must be provided to any of the driver’s other client operations to identify the caller and the instance of the driver module.

Required or Optional?

Required by any driver module.

Preconditions

The driver module’s "Initialize" operation must have completed (meaning that the DRV_<module>_Status routine should have returned SYS_STATUS_READY (or greater)).

Parameters

index	Index, identifying the instance of the driver module to be opened (example DRV_I2C_1, or DRV_I2C_2).
intent	Flags parameter identifying the intended use of the driver:

One of:

- DRV_IO_INTENT_READ – Driver opened in read-only mode
- DRV_IO_INTENT_WRITE – Driver opened in write-only mode
- DRV_IO_INTENT_READWRITE – Driver opened in read-write mode, equivalent to DRV_IO_INTENT_READ|DRV_IO_INTENT_WRITE

One of:

- DRV_IO_INTENT_NONBLOCKING – Routines return immediately
- DRV_IO_INTENT_BLOCKING – Routines return after operation is complete

One of:

- DRV_IO_INTENT_EXCLUSIVE – Driver does no SW buffering
- DRV_IO_INTENT_SHARED – Driver buffers reads internally

One flag from each group may be ORed together to fully define the intended use.

Returns

If successful, the routine returns a valid open-instance handle (a number identifying both the caller and the module instance). If an error occurs, the routine value is DRV_HANDLE_INVALID.

Code Example

```
handle = DRV_I2C_Open(DRV_I2C_1, DRV_IO_INTENT_READWRITE|
                                 DRV_IO_INTENT_NONBLOCKING|
                                 DRV_IO_INTENT_SHARED);
if (DRV_HANDLE_INVALID == handle)
{
    // Handle error
}
```

Blocking Behavior

This function may block when operating in an OS environment. It must never block waiting on I/O in a non-OS environment (i.e., blocking is only supported in an OS environment).

Remarks

To support blocking behavior, the driver must be appropriately configured and built.

Drivers that are opened with a mode that is not supported must fail the open call by returning DRV_HANDLE_INVALID.

The default mode (if no flags are set (i.e., zero (0) is passed in the intent parameter), is non-blocking, no read access, no write access, and shared access so the mode parameter is usually required to do anything useful with a driver.

Refer to the `<install-dir>/framework/driver/driver_common.h` header file or the Driver Library Introduction for additional information and definitions of the additional data types used.

3.6.2: Support Driver Handle

This topic provides information on driver handle usage.

Description

To use a driver, an application (or other client) must first call the driver’s open routine to get an "open-instance" handle to the driver for the desired peripheral instance. This handle must be passed into all of the driver’s other client interface routines to identify both the caller and the specific instance of the driver (or peripheral hardware or other resource owned by it).

Once the driver has been initialized and opened, the application (or other client layer) can use the other operations provided by the driver to read or write data and generally control the device in question. Normally, an application will open a driver, keep it open while it needs the device, and then close the device only when it’s done with the device. In simple systems, a client might never close the driver.

3.6.3: Support Driver "Close" Function

This topic describes the Close driver function.

Description

The purpose of the driver "Close" function is to allow a client module to release an opened link to a driver module, freeing any allocated resources and making the link available to other modules.

Simple drivers might not support this operation if they are normally never closed without a complete system reset.

Function

```
void DRV_<module>_Close ( const DRV_HANDLE handle )
```

Summary

Closes an opened-instance of a driver.

Description

This routine closes an opened-instance of a driver, invalidating the given handle and freeing any allocated resources.

Required or Optional?

Optional – Not required if the driver is designed to never be closed.

Preconditions

The driver module’s "Initialize" operation must have completed (meaning that the DRV_<module>_Status routine should have returned SYS_STATUS_READY (or greater)) and the driver’s "Open" routine must have returned a valid device handle.

Parameters

handle	A valid open-instance handle, returned from the driver’s open routine

Returns

None.

Code Example

```
// Close the driver
DRV_I2C_Close(handle);
```

Blocking Behavior

This routine can block until all pending driver operations have completed if the driver was appropriately configured and built and if the system is OS-based. Otherwise, it must not block.

Remarks

Once this routine has been called, the given handle will become invalid.

In non-blocking configurations, a closed driver may go into a "zombie" mode until the driver’s state machine has finished closing out any ongoing client operations. In "zombie" mode, a client may continue to use the handle only to call a driver’s ClientStatus routine (if supported). When the client link has been successfully closed, the ClientStatus routine will return the DRV_CLIENT_STATUS_CLOSED value from the DRV_CLIENT_STATUS enumeration.

Refer to the `<install-dir>/framework/driver/driver_common.h` header file or the Driver Library Introduction for additional information and definitions of the additional data types used.

3.7: Use Common Data Transfer Models When Applicable

This describes common data transfer models.

Description

The primary purpose of many different types of modules is to transfer data into or out of client accessible buffers. MPLAB Harmony drivers (and other modules) provide a consistent set of programming models (described in the following section) for accomplishing this transfer of data. If possible (and appropriate), it is best to use a data transfer model that is similar to one used by other modules. This consistency makes MPLAB Harmony libraries easier to use and improves overall quality by using tried and true methods.

When these methods are used, they should be identified as such in the documentation.

3.7.1: Support Byte-by-Byte for FIFO-based Data Transfer Model

This topic describes byte-by-byte data transfers.

Description

A byte-by-byte data transfers data one byte or word at a time in small batches.

In pseudo-code, this model appears as follows (from the client point of view).

Reading Data:
```
while ( DataIsAvailable() )
{
    DataWord[i++] = DataWordGet();
}
```

Writing Data:
```
while ( !TransmitterIsFull() )
{
    DataWordSend(DataWord[i++]);
}
```

The exact function names, parameters, and data types for the operations shown, which are shown in bold type in the previous examples, may vary, but the basic usage is consistent. Modules that use this transfer model may also provide operations to tell when all data transmission is complete (effectively a transmitter under run) and when the receive FIFO buffer is full and new data is received (effectively a receiver overrun).

This data transfer has the advantage of being useful for lightweight systems or whenever data is transferred a single data byte (or data word) at a time through a relatively small FIFO buffer. However, it has the disadvantage of encouraging use of potentially blocking loops, forcing the client to provide the loop to transfer multiple data words, and only working when a single client has exclusive access to a module. It is best used only when the data words are internally buffered (in hardware or software) in a small FIFO or queue. The operations should not block waiting on the actual transfer of data, instead they should only access the FIFO buffer and return FIFO full (or empty) so that the client stops looping when there is no more space (or data) in the FIFO. However, depending upon the exact parameters and return values used, the data transfer operations may still result in incorrect data being sent or received if an error occurs because there is no way to detect from within the loop it unless the client checks the status between every byte or word transferred.

3.7.2: Support File System Style Read-Write Data Transfer Model

This topic describes the File System style read/write data transfer model.

Description

The File System style read/write data transfer model is intended to be similar to the POSIX read/write and fread/fwrite operations. This is the most basic data transfer model that any data source or sink driver should support, if feasible. In pseudo-code, this model appears as follows (from the client point of view).

Reading Data:
```
Count = Read(&DataBuffer[SIZE], SIZE);
```

Writing Data:
```
Count = Write(&DataBuffer[SIZE], SIZE) )
```

The exact function names, parameters, and data types for the operations shown (in bold in the previous examples) may vary, but the basic usage is consistent. This model has the advantage that it may allow clients to use the file system abstraction layer to read and/or write data to a peripheral without the need to know the actual function names of the module (as long as that module is mounted to the file system). However, it has the disadvantage that, in non-blocking configurations, it may only transfer the amount of data that can be buffered by the driver or hardware, thus the client may need to check the return count and call the function again (potentially several times) to complete the transfer. Also, like the byte-by-byte model, this method requires the client to respond within the time it takes to fill or empty the FIFO to keep a continuous stream of data transfers. This model is most useful in a blocking environment where it can block and only return when the entire transfer is complete.

3.7.3: Support Buffer Queuing Data Transfer Model

This topic describes the buffer queuing data transfer model.

Description

The buffer queuing data transfer model is similar to a network packet method.

In pseudo-code, this model appears as follows (from the client point of view).

Reading Data:
```
TransferHandle = BufferAddRead(&DataBuffer[SIZE], SIZE);
```

Writing Data:
```
TransferHandle = BufferAddWrite(&DataBuffer[SIZE], SIZE) )
```

The exact function names, parameters, and data types for the operations shown (in bold in the previous examples, above) may vary, but the basic usage is consistent. Some modules may combine the operations into one and identify the direction of the transfer in a parameter or packet header. Most modules will provide a callback mechanism and possibly a status function to allow the client to identify when the buffer has been transferred. The operations can be called multiple times to queue up multiple buffers. Each call will return a handle identifying the transfer buffer (or an invalid handle indicating the queue was full).

This model has the advantage that it is easier to use and it allows the client the ability to easily maintain a continuous stream of data, if desired.

(The client only needs to respond before all queued buffers have been transferred to avoid over run or under run situations.) However, it has the disadvantage that it usually requires a larger more complex implementation.

3.8: Use Existing Abstraction Models When Applicable

This describes abstraction model usage.

Description

Key benefits of a layered, modular software framework are the ability to easily interchange one implementation of a module for another and the ability to treat similar modules in a common way. This allows use of implementations that are optimized for specific purposes (or that have added features) without the need to change existing client code. In addition, it allows higher abstraction layers to use different modules without requiring modifications. Whenever a new module is intended to support an existing library stack or application, it must support the existing abstraction model.

3.8.1: File System Modules Use the SYS FS Plug-in Interface

This topic describes the SYS FS Plug-in interface.

Description

Modules that implement a file system used to organize data on a storage medium must provide the interface required by the MPLAB Harmony virtual file system layer (SYS FS) and they must use the MPLAB Harmony File System Media Manager interface to access supported storage media. Refer to the `<install-dir>/framework/system/fs/sys_fs.h` and `<install-dir>/framework/system/fs/sys_fs_media_manager.h` header files and the File System Service Library for a complete description of this interface.

3.8.2: Media Drivers Use the File System Media Manager Driver Model

This topic describes the File System Media Manager Driver model.

Description

Modules that implement a storage media driver to be used with the MPLAB Harmony virtual file system layer (SYS FS) must provide a media manager driver interface. Refer to the `<install-dir>/framework/system/fs/sys_fs_media_manager.h` header file and the File System Service Library for a complete description of this interface.

3.8.3: TCPIP MAC Drivers Use the TCPIP Virtual MAC Driver Model

This topic describes the TCP/IP virtual MAC Driver model.

Description

Modules that implement a network Media Access Controller (MAC) driver to be used with the MPLAB Harmony TCP/IP library stack must provide a MAC driver interface as required by the virtual MAC layer. Refer to the `<install-dir>/framework/tcpip/tcpip_mac*.h` header files and the MAC Driver Module for a complete description of this interface.

3.8.4: Graphics Display Drivers Use the Graphics Display Driver Model

This topic describes the Graphics Display Driver model.

Description

Modules that implement a graphics display driver to be used with the MPLAB Harmony graphics library must provide a display driver interface as required by the graphics primitives layer. Refer to the `<install-dir>/framework/driver/gfx/drv_gfx_display.h` header file and the Graphics Driver Library for a complete description of this interface.

3.9: Emulate and Extend Existing Interface Models When Applicable

This provides information on emulating and extending existing interface models.

Description

Even if a new module is not intended to replace an existing module or to "plug in" to an existing library stack, it should attempt to emulate an existing interface and extend it if required. To emulate an existing interface the module should provide functions, whose names are different, but whose parameters, return values, and functionality are identical (if possible) or very similar to those of an existing module or set of modules. If additional functionality is required that existing modules do not similarly support, then it is acceptable to extend the existing interface model with additional features. It is unacceptable for modules with similar functionality to use completely dissimilar interface models.

4: Flexibility Guidelines

This section provides guidelines for flexibility when creating a MPLAB Harmony library.

Description

To address a broad range of individual customer’s needs, MPLAB Harmony libraries provide a high degree of flexibility and configurability, supporting a wide range of user-selectable build options and execution environments. Libraries can be compatible with MPLAB Harmony without necessarily supporting all of the options and execution environments for which fully flexible libraries can be configured as long as any restrictions are fully understood and clearly documented.

4.1: Support One or More Execution Environments

This topic provides information on support for one or more execution environments.

Description

There are three fundamental execution models that may be supported by MPLAB Harmony libraries:

- Polled
- Interrupt-driven
- RTOS multi-threaded

It is generally preferable for libraries to be fully flexible, use the abstracted state machine model and OSAL provided by MPLAB Harmony to allow them to be appropriately configured for any of these three of execution models in any supported execution environment. However, it is acceptable for a library to be optimized and implemented specifically for one such execution environment and not support one or more of the others as long as the restrictions are clearly documented.

4.1.1: Execution in One or More RTOS Environment

This topic describes execution in an RTOS environment.

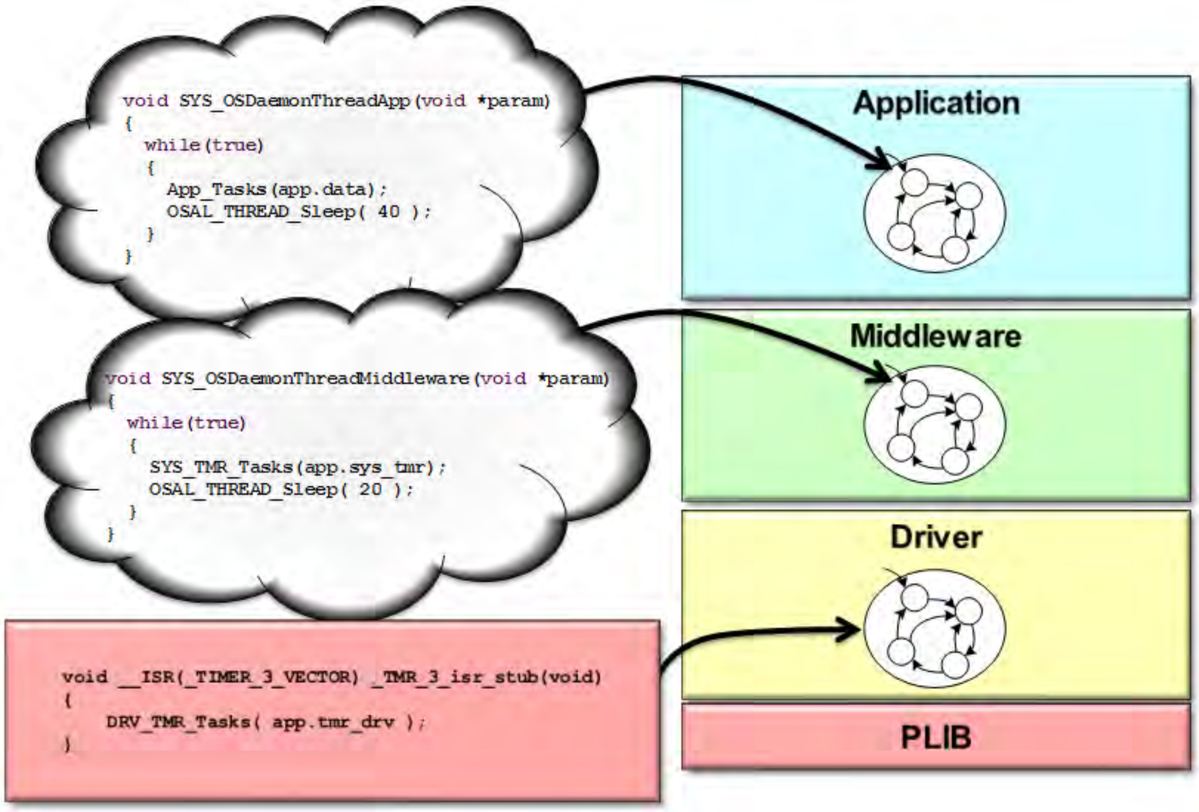
Description

The MPLAB Harmony OSAL defines a set of functions that libraries can call to provide thread safety and blocking behavior when executing in a supported OS environment. MPAB Harmony libraries call the appropriate OSAL functions to provide thread safety when accessing shared resources or providing blocking functionality. For non-OS environments, MPLAB Harmony provides "basic" and "none" implementations of the OSAL, allowing the OSAL calls (or "hooks") to remain in the library code.

The OSAL can be implemented for most OS or non-OS environments. So, using the OSAL provides maximum flexibility for MPLAB Harmony compatible libraries and is highly recommended. However, a library can be implemented for a specific OS (or for no OS) and still be MPLAB Harmony compatible in the environment for which it was designed as long as the library’s documentation clearly and conspicuously identifies the OS (or non-OS) environment(s) it supports, if it does not make use of the MPLAB Harmony OSAL.

It is preferable that a module that supports execution in one or more RTOS environments should utilize the MPLAB Harmony abstracted state machine architecture and that the module’s tasks functions be called from a loop in an OS thread (if polled) or from an ISR (if interrupt driven), as illustrated in the following diagram.

OS-Based Execution



```
void SYS_OSDaemonThreadApp(void *param)
{
  while(true)
  {
    App_Tasks(app.data);
    OSAL_THREAD_Sleep( 40 );
  }
}
```

```
void SYS_OSDaemonThreadMiddleware(void *param)
{
  while(true)
  {
    SYS_TMR_Tasks(app.sys_tmr);
    OSAL_THREAD_Sleep( 20 );
  }
}
```

```
void __ISR(_TIMER_3_VECTOR) _TMR_3_isr_stub(void)
{
    DRV_TMR_Tasks( app.tmr_drv );
}
```

But, it is acceptable to use any desired method of implementing the module if it is restricted to an RTOS environment and all restrictions are clearly and conspicuously documented.

4.1.2: Interrupt Driven Execution

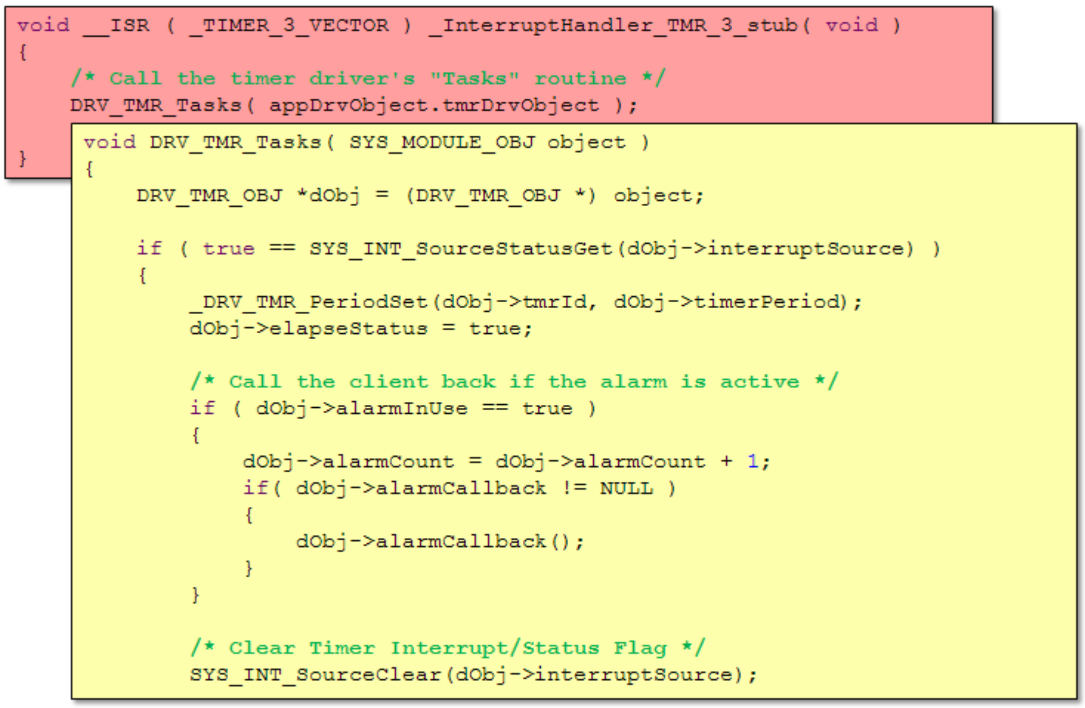
This topic describes interrupt driven execution.

Description

Different microcontrollers handle interrupts in different ways. Some support multi-vectored interrupts so that each instance of each device can have its own interrupt vector function. Some microcontrollers only have a single interrupt vector function and the ISR that implements the vector function must interrogate the interrupt controller and/or peripherals to identify which peripheral caused the interrupt. Other microcontrollers do something in between; grouping some interrupts so that the ISR may need to identify which specific flag from a group caused the interrupt.

In all cases, the ISR itself is only responsible for identifying the specific source of the interrupt and for calling the appropriate driver tasks function. But, since the exact combination of interrupt-source flags and vector functions is always processor-specific, the actual interrupt vector functions must be implemented as part of the system configuration code. However, the driver's tasks function is the routine that actually services the peripheral as required and clears the interrupt flag. So, the ISR must call the appropriate tasks function to service the interrupt, as shown in the following example.

Interrupt-Driven Execution



```
void __ISR ( _TIMER_3_VECTOR ) _InterruptHandler_TMR_3_stub( void )
{
    /* Call the timer driver's "Tasks" routine */
    DRV_TMR_Tasks( appDrvObject.tmrDrvObject );

}
```

```
void DRV_TMR_Tasks( SYS_MODULE_OBJ object )
{
    DRV_TMR_OBJ *dObj = (DRV_TMR_OBJ *) object;

    if ( true == SYS_INT_SourceStatusGet(dObj->interruptSource) )
    {
        _DRV_TMR_PeriodSet(dObj->tmrId, dObj->timerPeriod);
        dObj->elapseStatus = true;

        /* Call the client back if the alarm is active */
        if ( dObj->alarmInUse == true )
        {
            dObj->alarmCount = dObj->alarmCount + 1;
            if( dObj->alarmCallback != NULL )
            {
                dObj->alarmCallback();
            }
        }

        /* Clear Timer Interrupt/Status Flag */
        SYS_INT_SourceClear(dObj->interruptSource);
```

It is preferable that any driver or module that supports interrupt-driven operation supports this mechanism, making it flexible enough to be easily configured for any microcontroller that supports the peripheral in question. However, it is acceptable to embed the ISR vector function into the driver or module's implementation. But, doing so will likely restrict the driver to only supporting a single instance of a single module on a small set of microcontrollers. So, all resulting restrictions must be clearly and conspicuously documented.

Additionally, it is preferable any tasks routine that is designed so that it can be called from an ISR, should also be configurable so that it can be called from a polled loop. At a minimum, testing ISR tasks functions in a polled environment will improve the robustness of the function by ensuring that it correctly handles spurious interrupts (since a polled tasks routine will be called many times when it has no actual task to perform and it must be able to distinguish when it does and does not have anything to do).

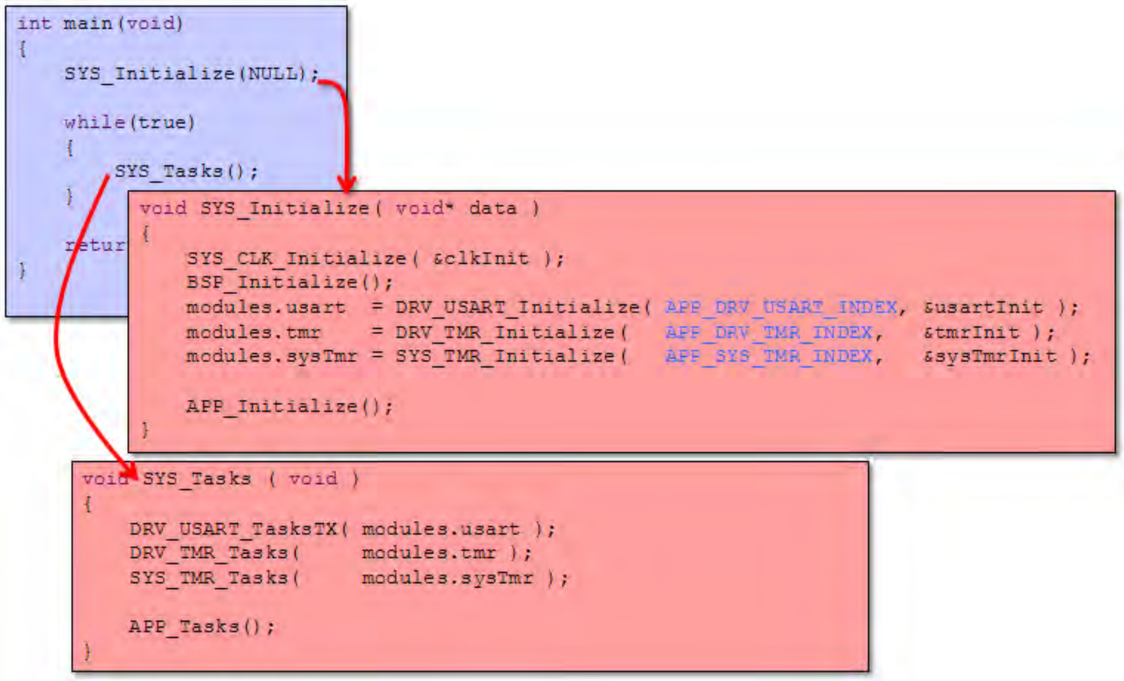
4.1.3: Polled Execution in a Super Loop With No RTOS

This topic describes Polled execution.

Description

The simplest MPLAB Harmony execution environment (for systems with relaxed timing requirements) is a polled "super loop" environment, as illustrated in the following example.

Polled Execution



```
int main(void)
{
    SYS_Initialize(NULL);

    while(true)
    {
        SYS_Tasks();
    }

    retur
}
```

```
void SYS_Initialize( void* data )
{
    SYS_CLK_Initialize( &clkInit );
    BSP_Initialize();
    modules.usart  = DRV_USART_Initialize( APP_DRV_USART_INDEX, &usartInit );
    modules.tmr    = DRV_TMR_Initialize(   APP_DRV_TMR_INDEX,   &tmrInit );
    modules.sysTmr = SYS_TMR_Initialize(   APP_SYS_TMR_INDEX,   &sysTmrInit );

    APP_Initialize();
}
```

```
void SYS_Tasks ( void )
{
    DRV_USART_TasksTX( modules.usart );
    DRV_TMR_Tasks(     modules.tmr );
    SYS_TMR_Tasks(     modules.sysTmr );

    APP_Tasks();
}
```

It is preferable that all modules support execution in this environment and that any tasks functions provided by the module be callable using a polled method. At a minimum, testing tasks functions in a polled environment will improve the robustness of the function, ensuring that it correctly handles spurious calls. However, it is acceptable for a module to be limited to an interrupt-driven or RTOS-based configuration as long as all restrictions are clearly and conspicuously documented.

4.2: Support a Broad Set of PIC32 Microcontrollers

This topic discusses PIC32 MCU support.

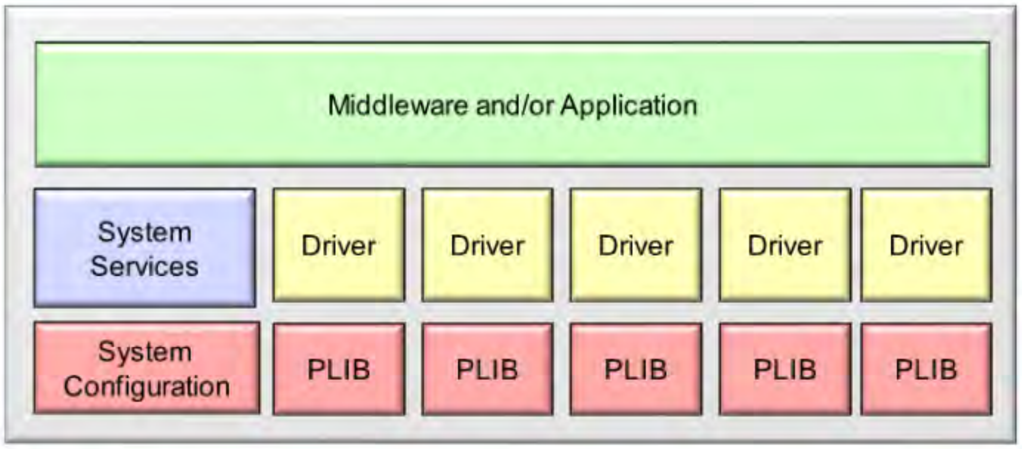
Description

Different PIC32 microcontrollers support different features and different sets of peripherals. These differences are abstracted away from middleware and application modules by three different layers in the MPLAB Harmony framework:

- Device Drivers
- System Services
- Peripheral Libraries

Device drivers provide highly abstracted file-system like interfaces to most types of peripherals. System services provide highly abstracted interfaces to common system-resource types of peripherals, like interrupt controllers, I/O ports, and DMA. Above these interfaces, any part-specific knowledge that is required is contained in parameters that can be defined at build time by the system configuration header (`system_config.h`) or passed into an initialization function at system boot/reset time. So, MPLAB Harmony drivers and system services together can be thought of as a Hardware Abstraction Layer (HAL) as shown by the following block diagram.

Drivers and Services Abstract Peripherals

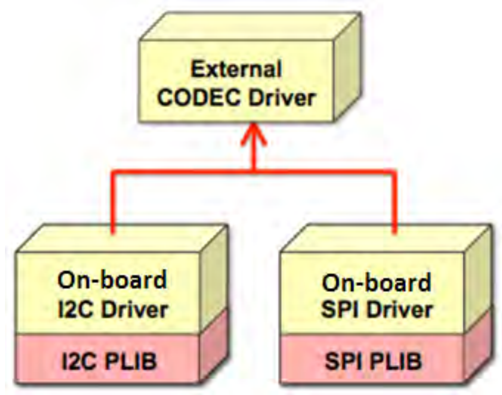


Note: Some driver or system services features may not be supported on specific microcontrollers as MPLAB Harmony libraries do not usually emulate hardware features in software.

Beneath the module's interface, device drivers and system services may have different implementations for different microcontroller families. However, to dramatically reduce the number of implementations required, drivers and system services are normally implemented using peripheral libraries (or by using other drivers or system services in a "stack"). Peripheral libraries provide consistent interfaces for each type of peripheral supported on Microchip microcontrollers, but they may have different implementations for the different variants of that peripheral that are available on different part families.

Note: Peripheral libraries are only supported for internal (on board) microcontroller peripherals. External peripherals are always connected to the microcontroller through one or more internal peripheral interfaces and therefore do not require peripheral library support. They usually use a driver for an on-board peripheral (that does use a PLIB) to access the external device, as shown in the following diagram.

Example External Driver "Stack"



It is preferable that other library or application modules interact with microcontroller peripherals only through abstracted device driver and system service interfaces for portability across the widest range of PIC32 microcontrollers and usages. However, it is possible to obtain portability across one or more PIC32 families (assuming they support the same type of peripheral) by interacting directly with the peripheral library. However, if library modules access peripheral registers directly, they will be restricted to usage only on the set of microcontrollers that support the specific registers used. While direct register access is not advised, it is still possible to us that method and be MPLAB Harmony-compatible as long as all restrictions are clearly and conspicuously documented and the following two key rules are followed.

Key Rules:

1. Any library that directly accesses a peripheral (either through a PLIB or by its registers) "owns" that peripheral and no other code may access the peripheral except through the interface to the library that owns it.
2. The library that "owns" a peripheral (usually a driver for that peripheral) is responsible for ensuring that clients only access that peripheral in safe ways that prevent them from interfering with each other. (Explicit tests and protection can be implemented in the driver in ways that are available for testing and debugging, but can be removed in production builds to reduce run-time overhead.)

Ultimately, PLIB usage is not a MPLAB Harmony requirement. PLIBs are used to support implementations of drivers and services that are flexible enough to be easily configured for different part families. However, ownership and encapsulation of peripherals by a driver or service that allows it to be shared (either one client at a time or multiple clients at once) is a requirement.

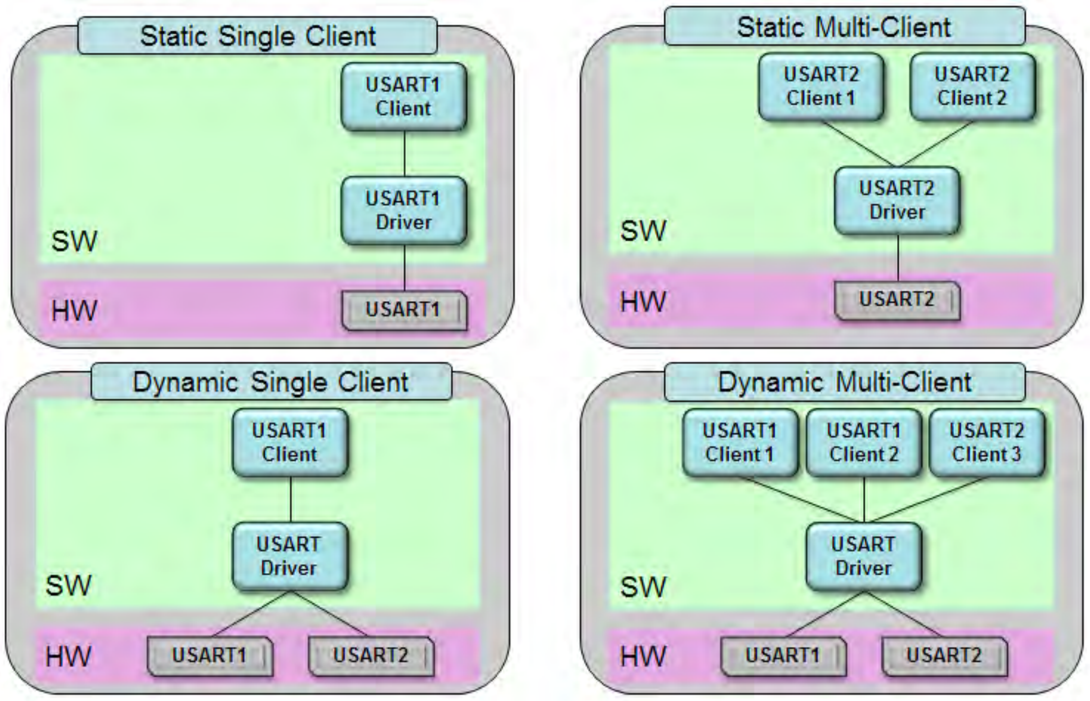
4.3: Support a Dynamic Interface

This topic discusses support for a dynamic interface.

Description

Most MPLAB Harmony library modules are intended to support multiple instances of themselves, each of which may support multiple clients.

Dynamic Versus Static and Single-Client Versus Multi-Client Modules



The previous diagram represents examples all four possible implementations for a USART driver. The top-Left example is a single driver that supports a single client (or user) of a single USART peripheral. The one to the Right of it shows a driver that would allow two clients (individual modules, completely unaware of each other) to share the same USART peripheral. The bottom-Right diagram shows a single driver that allows multiple clients to share multiple USART peripherals (notice that there are two clients to the USART1 instance and a third client for the USART2 instance). The last combination (to the bottom-Left), where a driver can support multiple hardware instances, but only one client at a time, is a special case of a fully dynamic, multi-client driver and not usually a separate implementation.

To support the ability to dynamically manage multiple instances, each potentially having multiple independent clients, the set of interface (or API) routines must support the ability to initialize each instance of the module and the ability to create a logical link between different clients for each instance of the module. MPLAB Harmony modules all require an "Initialize" function (which use standard return values and parameters) that must be called once during system initialization for each instance of the module to be used in the system. MPLAB Harmony device drivers all require the use of an "Open" function (which also uses standard return values and parameters) that provides a "handle" which links each client to a specific instance of the module. Other libraries (such as system services and middleware) may use different methods, but the interface must allow a fully dynamic implementation of the module to manage both multiple instances and multiple clients effectively.

However, it is acceptable for a specific implementation of a module may support only a single static instance of itself and/or support only a single client as long as the interface to the module allows for the ability to provide a fully dynamic (multi-instance, multi-client) implementation. The interface must not need to be changed if such an implementation is required in the future.

Note: It is acceptable to expose a static (single-instance or single-client) interface as long as macros or inline functions are provided that translate calls to the dynamic interface into calls to the static interface. This method provides for source level compatibility, but may require a client to be rebuilt when switching from a dynamic to a static implementation (or vice versa).

4.4: Support Dynamic, Static, and Feature Implementation Variants

This topic discusses support for dynamic, static, and feature implementations.

Description

The basic implementation of a MPLAB Harmony library module is assumed to be fully dynamic (multi-instance and multi-client) and fully featured module, unless otherwise documented. However, it is possible (and usually desirable) to provide different implementation variants so that a user can select the specific implementation or set of features that suits their needs.

Different variants of the same feature(s) can be implemented in different source (`.c`) files (and potentially, in associated header (`.h`) files). The user must select the correct set of source files to build the version of the library he or she desires. Thus, the purpose or use of each source file must be clearly documented. If an implementation is provided that is static or single client, it must be clearly documented as such. If optional features are implemented in separate source files (a practice that is recommended over using `#if` statements to add or remove code from source files that are always included), then the purpose of each file must be clearly documented so that the user knows which files to include in their project. Also, if project configuration tools are available, it is recommended that they be supported.

4.5: Support Build Time Configuration Options

This topic describes build time configuration options.

Description

MPLAB Harmony libraries usually support several different types of build-time configuration options.

Types of Configuration Options

- Selection of supported Microchip microcontroller
- Interrupt-driven or polled execution
- Static or dynamic peripheral instance selection (for drivers)
- Single- or multi-client support (for drivers)
- Library-specific options

MPLAB Harmony drivers and some system services are built upon MPLAB Harmony PLIBs. The appropriate PLIB implementation is selected when the specific microcontroller is selected in the build environment. Selection of the supported microcontroller is done from within the MPLAB X IDE (and, ultimately, by passing the correct build switch on the compiler command line). This mechanism supports easy porting from one Microchip microcontroller to another when using PLIBs, provided the required features are supported. Selection of all other options is done using static configuration options that need to be defined as C-language macros (`#define` statements) by the user in the `system_config.h` header (a file that is included by all libraries) or by selection of appropriate implementation (`.c`) files.

Drivers should be easily configured to operate in an interrupt-driven mode or in a polled mode. If the driver (or other library) is configured to be interrupt driven, then the driver’s "Tasks" routine will be called from the appropriate ISR. If the driver is configured for polled operation, then the driver’s "Tasks" routine will be called from the main super loop (or an RTOS thread). The selection of which method is used is usually a required configuration option.

The interfaces to MPLAB Harmony drivers are designed to support dynamic (run-time) selection of the specific instance of a peripheral with which the driver interacts. However, since drivers can be implemented so that they are statically associated with a specific instance of a peripheral, the mechanism used to make this choice must be clearly documented.

Similarly, since a driver can allow only a single client to open and use it at one time or it can allow multiple clients to open and use it at the same time, the mechanism used to make this choice must be clearly documented.

Finally, there may be any number of driver or library-specific (build time) configuration options that can be supported. The meaning and usage of each option must be clearly documented.

4.5.1: Support Required Configuration Options

This topic discusses required configuration options.

Description

Required configuration options do not have default definitions. The user must define them to build the library or application. Use of such options must be minimized and clearly documented. It is preferable to utilize the compiler’s preprocessor capabilities to test for appropriate definition of required configuration options before they are used and provide a meaningful explanation to the user (via `#error` or `#warning` directives) if they are not correctly defined (see the following example).

Example: Providing an Error for Required Options

```
/* The DRV_USART_INTERRUPT_DRIVEN option must be defined as "true" if this driver is
   used in a interrupt-driven mode or as "false" if used in a polled mode. */
#ifndef DRV_USART_INTERRUPT_DRIVEN
    #error "DRV_USART_INTERRUPT_DRIVEN must be defined as either true or false"
#endif
```

4.5.2: Support Optional Configuration Options

This topic discusses optional configuration options.

Description

Optional configuration options must have default definitions that provide the most commonly desired or safe definitions so that the user need not explicitly define them. These options are normally used to "fine tune" a library to optimize resource usage or performance. The default definitions should allow the expected functionality of a library to be available. Optional configuration options must still be clearly documented.

Example: Supporting an Optional Configuration Option

```
/* This default value of the DRV_USART_READ_BUFFER_SIZE option can be overridden
   to select a different buffer size (in bytes). */
#ifndef DRV_USART_READ_BUFFER_SIZE
    #define DRV_USART_READ_BUFFER_SIZE  10
#endif
```

5: Testing Guidelines

This describes testing guidelines.

Description

Testing is necessary to verify that a library functions as designed and that it follows the compatibility guidelines in this document. While no amount of testing can guarantee the absence of all possible issues, this makes recommendations on key types of testing that will help identify common issues.

Errors in behavior must be reported in release documentation if they cannot be fixed in time for a specific release. Reasonable efforts must be made to correct all reproducible errors in behavior. Reporting the complete results of all tests in published documentation is recommend so that customers can make informed decisions on the suitability of a specific solution. If feasible it is also recommended to publish the tests themselves (and descriptions of the required test platforms) so that customers can reproduce the results themselves if they so desire.

Generation of a suite of tests is also recommended. Each test should be designed as a MPLAB Harmony state-driven module that can be easily integrated with other tests or applications and that can be easily configured to operate in multiple different execution environments so that a multitude of possible uses can be tested. Such a suite of tests will help simplify the task of implementing and executing the tests recommended in this section.

5.1: Test All Possible Build Configurations

This topic discusses testing all possible build configurations.

Description

It is not acceptable to publish source code that does not build correctly in all supported configurations. So, it is recommended that build tests be performed that verify all superset combinations of supported configuration settings. It is not usually practical to build test all possible combinations. However, it is much more feasible to build configurations that define the largest sets of all compatible options. Some configurations may be incompatible with each other (for example, you cannot simultaneously configure a library to run both interrupt driven and polled). Therefore, it may take more than one build test to verify all supersets of configuration options.

MPLAB Harmony compatible libraries (distributed in source code) are expected to build with zero errors and warnings on the MPLAB XC32 C/C++ Compiler with all warnings enabled (i.e., with the `-Wall` switch defined on the command line).

5.2: Test for Correct Functionality

This topic discusses testing for correct functionality.

Description

To validate that a library provides the intended functionality, it is necessary to create applications that exercise that functionality. With the potential flexibility of MPLAB Harmony compatible libraries, there may be many possible environments and platforms on which the tests may be executed. It is best to develop test applications that follow the guidelines for Harmony modules so that these applications can be easily integrated into different test harnesses in different environments. In all cases, the tests should verify that the library meets the desired requirements.

5.3: Stress Test and Measure Performance

This topic discusses stress testing and measuring for performance.

Description

So that customers can select the appropriate hardware platform and verify that a library meets their performance needs, tests must be developed that measure the performance of a library (using appropriate metrics) and that execute the tests in both lightly loaded and heavily loaded environments. To do this, it may be necessary to measure any number of metrics (especially time) and to artificially generate processor or bus-loading conditions, spurious interrupts, and other resource restrictions or optimization levels.

5.4: Test Error Handling

This topic discusses error handling testing.

Description

Testing error handling will help ensure that libraries fail "gracefully" when passed bad parameters or used incorrectly. To do this, call library functions with incorrect parameter values or in incorrect sequences. Verify that the library provides an acceptable mechanism for detecting and recovering from the error (if possible) and that it does not respond in an unacceptable way. Key things to look for are potential causes of exceptions, lockups and memory violations. Sometimes it is best to perform error tests and stress tests in combination to help identify any possible transitory error conditions.

5.5: Test All Supported Execution Environments

This topic discusses testing libraries for all environments.

Description

Fully compliant MPLAB Harmony Libraries can be configured to execute in three fundamentally different ways:

- Under a supported RTOS
- Interrupt-driven (when an appropriate interrupt is supported)
- Polled in a non-RTOS "bare metal" super loop environment

Libraries may or may not support all three environments, but it is important to test libraries in all of the environments that they do support to validate correct behavior. If feasible, test for correct functionality, acceptable performance, and robust error handling in all supported environments.

5.5.1: Test for Thread Safe Execution in All Supported RTOS Configurations

This topic discusses testing for thread safe execution in RTOS configurations.

Description

There are several different possible situations that may occur that are unique to execution in an RTOS environment.

- Some library "Tasks" functions may be executed interrupt-driven or polled from an RTOS thread
- For libraries that support multiple "Tasks" functions:
  - Each tasks function may be called from a different thread,
  - Multiple tasks functions may be called from the same thread, or
  - Some tasks functions may be called from an ISR and some called from threads
- Interface functions may be called from the same thread as tasks functions
- Interface functions may be called from different threads than tasks functions
- Interface functions may be called from multiple different threads that are different from tasks functions
- Interface functions may be called from threads while some tasks functions are called from an ISR

Libraries must be tested for correct operation within each of these situations under each supported RTOS. Also, it is necessary to test with different combinations of priorities for each of the previously mentioned threading models and document any restrictions on relative thread priorities.

5.5.2: Test for Correct Interrupt-driven Execution (if Supported)

This topic discusses testing interrupt driven execution.

Description

Some libraries (especially device drivers) are designed such that one or more of their "Tasks" functions can be called from an ISR. For libraries that support such execution, configurations must be tested where these tasks functions are called from the appropriate ISR. This must be tested in all supported RTOS and bare-metal (non-OS) environments. These ISR-supporting tasks functions must also be tested in a polled execution model, if that model is supported.

5.5.3: Test for Correct Polled Execution

This topic discusses testing polled execution.

Description

Libraries that support execution in a bare-metal (non-RTOS) "super loop" environment must be tested in this configuration. This is the most basic execution model for MPLAB Harmony compliant execution, but it is also the most restrictive due to potential timing requirements. Thus, testing in this environment should measure and report execution time of module "Tasks" functions and interface functions.

5.6: Test Multi-instance Support (if Supported)

This topic discusses multi-instance support testing.

Description

Libraries that support dynamically managing multiple instances of themselves (and potentially multiple instances of peripheral hardware) must be tested to verify that they behave correctly when instantiated multiple times. Multiple instance configurations should be tested in all supported execution environments.

5.7: Test Multi-client Support (if Supported)

This topic discusses multi-client support testing.

Description

Libraries that are intended to support multiple clients must be tested for correct behavior when used by multiple clients at the same time in all supported execution environments.

5.8: Test for Correct Interoperability With Other MPLAB Harmony Modules

This topic discusses interoperability testing with other MPLAB Harmony modules.

Description

While it may not practical to test a specific library with every other MPLAB Harmony library available, it is recommended to test libraries with each of the major middleware stacks and commonly used drivers and system services. If tests for middleware, drivers, and services are not available, interoperability testing may be performed by integrating the specific library’s tests into demonstration programs provided in the MPLAB Harmony release.

5.9: Test On All Major PIC32 Device Families

This topic discusses testing libraries on the major PIC32 device families.

Description

While it may not be practical to test a library on every supported PIC32 processor, it is recommended to test libraries on the largest members of each major PIC32 family.

6: Documentation Guidelines

This provide guidelines for creating documentation.

Description

Libraries released as part of the MPLAB Harmony installation follow specific documentation guidelines. At a minimum, any third-party MPLAB Harmony compatible libraries or applications that do not support the recommended MPLAB Harmony capabilities or requirements must clearly and conspicuously document the restrictions. However, it is recommended that third-party documentation for MPLAB Harmony compatible libraries provide similar information to that provided by MPLAB Harmony's own libraries.

In addition to documenting the functions, data types, and other C-language elements, the interface documentation must explain (or provide a reference to) any intrinsic knowledge necessary to use the library interface.

Recommended Help Document Hierarchy

Introduction

Give a brief introduction of the module. This should include a brief description basic concepts of the module, but do not attempt to explain detailed standards or protocols. Instead provide links to specifications or detailed explanations. Use simple diagrams (if applicable).

See the Timer Driver Library Introduction section for an example.

Using the Library

This topic describes the basic architecture of the library and provides information and examples on how to use the functions provided by the library to satisfy common usage scenarios.

See the Timer Driver Library Using the Library section for an example.

Abstraction Model (sub-topic)

Briefly describe the abstraction model or usage model of the library. For example, a device driver library abstracts a peripheral device and presents a file-system like interface with one or more data transfer and control models. Briefly explain each model or refer to more detailed usage topics.

See the Timer Driver Library Abstraction Model section for an example.

How the Library Works (sub-topic)

Explain the common usages. Describe how to use the library's interface functions to perform common tasks. Provide a subtopic for each common usage scenario (especially initializing the library and setting it up for common usage models).

See the Timer Driver Library How the Library Works section for an example.

Configuring the Library

List and explain the build-time configuration requirements and options of the library.

See the Timer Driver Library Configuring the Library section for an example.

Building the Library

List and explain the source files necessary to build this library. If some files are optional (i.e., implement optional features) explain why the user would want to include then in the build. Also list all modules on which the library depends (but let the documentation for those modules explain how to build them).

See the Timer Driver Library Building the Library section for an example.

Library Interface

Logically partition the interface routines in the sets and provide a "programmer's reference" for each that describes its purpose, behavior, usage, parameters, return values, and side effects. A good guideline for partitioning of the library interface is that, if the library abstraction model can be drawn using a block diagram, then partition the library interface routines in similar sets.

See the Timer Driver Library Library Interface section for an example.

7: MPLAB Harmony Version Compatibility

This discusses version compatibility.

Description

It is common for one library to use (or depend upon) another. Any library distributed as part of a MPLAB Harmony installation it tested with the libraries (on which it depends) that are also part of the same installation. However, any library distributed separately (from an installation of MPLAB Harmony) must identify the version of MPLAB Harmony with which it was tested and is known to be compatible. Future versions of such libraries should maintain equivalent "backward" compatibility (i.e., the newly released library should still be compatible with the version of MPLAB Harmony with which it was originally tested.)

However, if the library is later updated to use new MPLAB Harmony functionality (functionality that is available in a newer release and was not available in the MPLAB Harmony release with which it was originally tested) then the updated library has the following options, in order of preference.

- Maintain backward compatibility to the older MPLAB Harmony version if the new functionality is not used
- Maintain backward compatibility to the older MPLAB Harmony version as a build or installation option
- Update the minimum MPLAB Harmony version number with which the library is compatible, but provide a reasonable transition period where the older version of the library is still made available and supported

It is not acceptable for an updated version of the library to simply stop working with the older version of MPLAB Harmony without a warning or explanation to the user.

8: Compatibility Worksheet

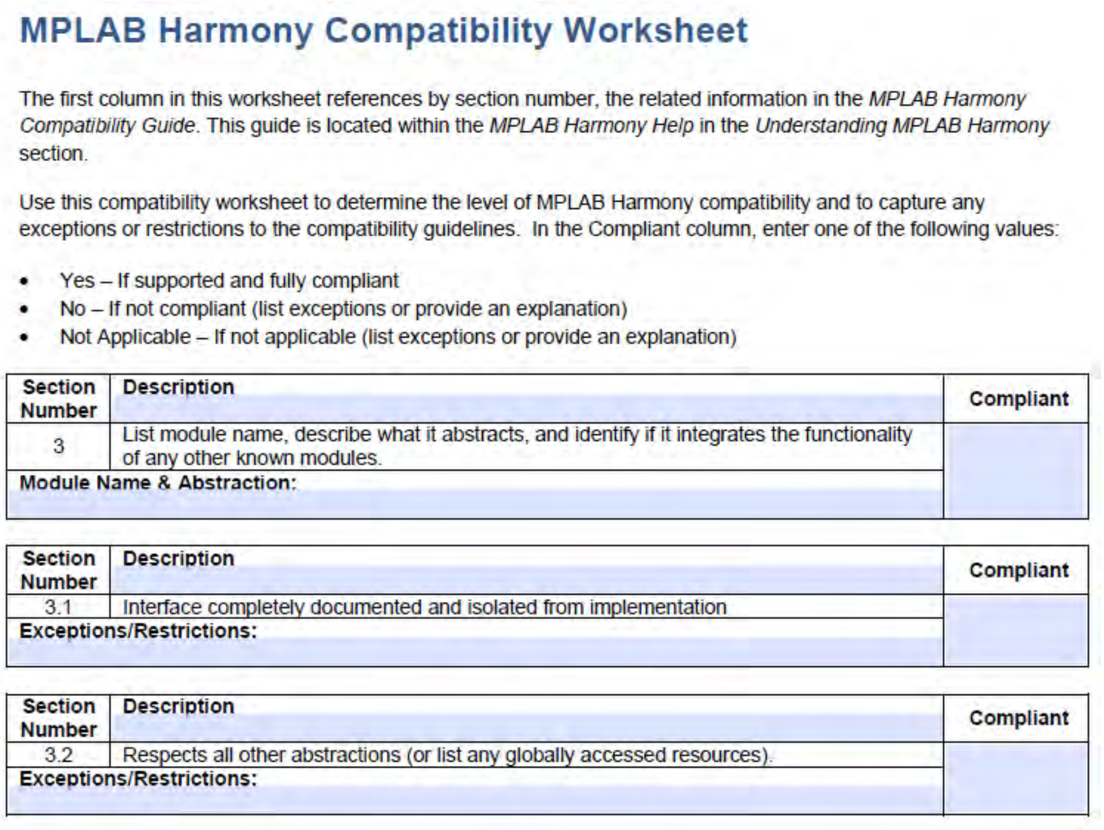
This provides information on the compatibility worksheet.

Description

Use this fillable and printable PDF form to determine the level of MPLAB Harmony compatibility and to capture any exceptions or restrictions to the compatibility guidelines. The form allows you to enter and save information as you progress with your library.

A copy of the worksheet is available in the `<install-dir>/doc` folder. It is suggested to make a personal copy of the original form for your own use. The following image shows a portion of the first page of the worksheet form. The blue shaded areas indicate the portions of the worksheet that can be filled in.

Portion of First Page of the Worksheet



MPLAB Harmony Compatibility Worksheet

The first column in this worksheet references by section number, the related information in the *MPLAB Harmony Compatibility Guide*. This guide is located within the *MPLAB Harmony Help* in the *Understanding MPLAB Harmony* section.

Use this compatibility worksheet to determine the level of MPLAB Harmony compatibility and to capture any exceptions or restrictions to the compatibility guidelines. In the Compliant column, enter one of the following values:

- Yes – If supported and fully compliant
- No – If not compliant (list exceptions or provide an explanation)
- Not Applicable – If not applicable (list exceptions or provide an explanation)

Section Number	Description	Compliant
3	List module name, describe what it abstracts, and identify if it integrates the functionality of any other known modules.	
Module Name & Abstraction:		

Section Number	Description	Compliant
3.1	Interface completely documented and isolated from implementation	
Exceptions/Restrictions:		

Section Number	Description	Compliant
3.2	Respects all other abstractions (or list any globally accessed resources).	
Exceptions/Restrictions:		

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