Pico C/C++ SDK

Libraries and tools for C/C++ development on the RP2040 microcontroller

Colophon

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Chapter 1. About the Pico SDK

1.1. Introduction

The Pico SDK (Software Development Kit) provides the headers, libraries and build system necessary to write programs for the RP2040 based devices such as the Raspberry Pi Pico in C, C++ or assembly language.

The Pico SDK is designed to provide an API and programming environment that is familiar both to non-embedded C developers and embedded C developers alike. A single program runs on the device at a time with a conventional `main()` method. Standard C/C++ libraries are supported along with APIs for accessing the RP2040's hardware, including DMA, IRQs, and the wide variety fixed function peripherals and PIO (Programmable IO).

Additionally the Pico SDK provides higher level libraries for dealing with timers, USB, synchronization and multi-core programming, along with additional high level functionality built using PIO such as audio.

The Pico SDK can be used to build anything from simple applications, full fledged runtime environments such as MicroPython, to low level software such as the RP2040's on chip bootrom itself.

1.2. Design

The RP2040 is a powerful chip, however it is an embedded environment, so both RAM, and program space are at premium. Additionally the trade offs between performance and other factors (e.g. edge case error handling, runtime vs compile time configuration) are necessarily much more visible to the developer than they might be on other higher level platforms.

The intention within the SDK has been for features to just work out of the box, with sensible defaults, but also to give the developer as much control and power as possible (if they want it) to fine tune every aspect of the application they are building and the libraries used.

The following sections highlight some of the design of the Pico SDK:

1.2.1. The Build System

The Pico SDK uses CMake to manage the build. CMake is widely supported by IDEs (Integrated Development Environments), and allows a simple specification of the build (via `CMakeLists.txt` files), from which CMake can generate a build system (for use `make`, `ninja` or other build tools) customized for the platform and by any configuration variables the developer chooses (see [pico-sdk-cmake-vars] for a list of conifuration variables).

Apart from being a widely used build system for C/C++ development, CMake is fundamental to the way the Pico SDK is structured, and how applications are configured and built.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/hello_world/CMakeLists.txt Lines 1 - 9

```
1 add_executable(hello_world
2     hello_world.c
3 )
4
5 # Pull in our pico_stdlib which aggregates commonly used features
6 target_link_libraries(hello_world pico_stdlib m)
7
8 # create map/bin/hex/uf2 file etc.
9 pico_add_extra_outputs(hello_world)
```

Looking here at the hello_world example, we are defining a new executable `hello_world` with a single source file `hello_world.c`, with a single dependency `pico_stdlib`. We also are using a Pico SDK provided function `pico_add_extra_outputs` to ask additional files to be produced beyond the executable itself (`.uf2`, `.hex`, `.bin`, `.map`, `.dis`).

The Pico SDK builds an executable which is `bare metal`, i.e. it includes the entirety of the code needed to run on the device (other than floating point and other optimized code contained in the bootrom within the RP2040).

`pico_stdlib` is an *INTERFACE* library and provides all of the rest of the code and configuration needed to compile and link the `hello_world` application. You will notice if you do a build of hello_world TODO: add link that in addition to the single `hello_world.c` file, the inclusion of `pico_stdlib` causes about 40 other source files to be compiled to flesh out the hello_world application such that it can be run on the RP2040 device.

1.2.1.1. INTERFACE Libraries are key!

Within CMake, an *INTERFACE* library is a way of aggregating:

- Source files
- Include paths
- Compiler definitions (visible to code as `#defines`)
- Compile and link options
- Dependencies (on other *INTERFACE* libraries)

When building an executable with the Pico SDK, all of the code for the executable (including any SDK libraries) is (re)compiled for that executable from source.

NOTE

This does not include the C/C++ standard libraries provided by the compiler.

In the example `CMakeLists.txt` we declare a dependency on the (*INTERFACE*) library `pico_stdlib`. This *INTERFACE* library itself depends on other *INTERFACE* libraries (`pico_runtime`, `hardware_gpio`, `hardware_uart` and others). `pico_stdlib` provides all the basic functionality needed to get a simple application running and toggling GPIOs and printing to a UART.

The *INTERFACE* libraries form a tree of dependencies with each contributing source files, include paths, compiler definitions and compile/link options to the build. To build the application each source file is compiled with the combined include paths, compiler definitions and options and linked into an executable according to the provided link options.

Building in this way allows your build configuration to specify customized settings for those libraries (e.g. Pin or DMA channel settings) at compile time allowing for faster and smaller binaries in addition of course to the ability to remove support for unwanted features from your executable entirely.

INTERFACE libraries also make it easy to aggregate functionality into readily consumable chunks (such as `pico_stdlib`).

IMPORTANT

Pico SDK functionality is grouped into separate *INTERFACE* libraries, and each *INTERFACE* library contributes the code *and* include paths for that library. Therefore you must declare a dependency on the *INTERFACE* library you need directly (or indirectly thru another *INTERFACE* library) for the header files to be found during compilation of your source file (or for code completion in your IDE).

NOTE

As all libraries within the SDK are *INTERFACE* libraries, we will simply refer to them as libraries or SDK libraries from now on.

1.2.2. Library Structure

There are a number of layers of libraries within the Pico SDK. The follow section describes them from the lowest level to the highest level

1.2.2.1. Hardware Registers (`hardware_regs` library)

This library is a complete set of include files for all the RP2040 registers, autogenerated from the hardware itself. This is all you need if you want to peek or poke a memory mapped register directly, however higher level libraries provide more user friendly ways of achieving what you want.

1.2.2.2. Hardware Structures (`hardware_structs` library)

This library provides a set of C structures which represent the memory mapped layout of RP2040 registers in memory. This allows you to replace something like the following (which you'd use with `hardware_regs`)

```
*(volatile uint32_t *)(PIO0_BASE + PIO_SM1_SHIFTCTRL_OFFSET) |=
PIO_SM1_SHIFTCTRL_AUTOPULL_BITS;
```

with something like this…

```
pio0->sm[1].shiftctrl |= PIO_SM1_SHIFTCTRL_AUTOPULL_BITS;
```

or even this (which uses `pio0_set` which is a separately mapped alias allowing for atomic setting of bits - rather than a CPU based read-modify-write)

```
pio0_set->sm[1].shiftctrl = PIO_SM1_SHIFTCTRL_AUTOPULL_BITS;
```

The structures and associated pointers to memory mapped register blocks hide the complexity and potential error-proneness of dealing with individual memory locations, pointer types and volatile access.

1.2.2.3. Hardware Libraries (`hardware_xxx` libraries)

These are individual libraries (see [hardware_libraries]) providing actual APIs for interacting with each piece of physical hardware/peripheral.

These libraries generally provide functions for configuring or interacting with the peripheral at a functional level, rather than accessing registers directly, e.g.

```
pio_sm_set_wrap(pio, sm, bottom, top);
```

rather than:

```
pio->sm[sm].execctrl =
     (pio->sm[sm].execctrl & ~(PIO_SM0_EXECCTRL_WRAP_TOP_BITS |
PIO_SM0_EXECCTRL_WRAP_BOTTOM_BITS)) |
     (bottom << PIO_SM0_EXECCTRL_WRAP_BOTTOM_LSB) |
     (top << PIO_SM0_EXECCTRL_WRAP_TOP_LSB);
```

NOTE

`void pio_sm_set_wrap(PIO pio, uint sm, uint bottom, uint top) {}` is actually implemented as a `static inline` function in https://github.com/raspberrypi/pico-sdk/tree/pre_release/src/rp2_common/hardware_pio/include/hardware/pio.h directly as shown above. Using `static inline` functions is common in Pico SDK header files because such methods are often called with parameters that have fixed known values at compile time. In such cases, seemingly complex intializations or other calls can often be reduced (by the compiler) to a single register write in the calling code at compile time without need to pass arguments and call another overly general function (or in this case a read, AND with a constant value, OR with a constant value, and a write).

NOTE

The `hardware_` libraries are intended to have a very minimal runtime cost. They generally do not require any or much RAM, and do not rely on other runtime infrastructure. As such they can be used by low-level or other specialized applications that doesn't want to use the rest of the Pico SDK libraries and runtime.

1.2.2.3.1. Hardware Claiming

The hardware layer does provide one small abstraction which is the notion of claiming a piece of hardware. This minimal system allows registration of peripherals or parts of peripherals (e.g. DMA channels) that are in use, and the ability to atomically claim free ones at runtime. The common use of this system - in addition to allowing for safe runtime allocation of resources - provides a better runtime experience for catching software misconfigurations or accidental use of the same piece hardware by multiple independent libraries that would otherwise be very painful to debug.

1.2.2.4. Runtime Support (`pico_runtime`, `pico_standard_link`)

These are special libraries that bundle functionality which is common to most RP2040 based applications.

`pico_runtime` aggregates the libraries (see [pico_runtime]) that provide a familiar C environment for executing code, including:

- Runtime startup and initialization
- Choice of language level single/double precision float point support (and access to the fast on RP2040 implementations)
- Compact `printf` support, and mapping of `stdout`
- Language level `/` and `%` support for fast division using RP2040`s hardware dividers.

`pico_standard_link` encapsulates the standard linker setup needed to configure the type of application binary layout in memory, and link to any additional C and/or C++ runtime libraries.

TIP

Both `pico_runtime` and `pico_standard_link` are included with `pico_stdlib`

1.2.2.5. Higher level functionality (`pico_xxx`)

These libraries (see [pico_libraries]) provide higher level functionality and abstraction more commonly associated with Operating Systems. Here you will find:

- Alarms, timers and time functions
- Multi-core support and synchronization primitives
- Audio support (via PIO)
- Low-level Video support (via PIO)
- Utility functions and data structures

These libraries are generally built upon one or more underlying `hardware_` libraries, and often depend on each other

NOTE

More libraries will be forthcoming in the future (e.g. file system support, SDIO support via (PIO)), some of which can be found as works-in-progess at TODO: pico-extras

1.2.2.6. TinyUSB (`tinyusb_dev` and `tinyusb_host`)

We provide a RP2040 port of TinyUSB as the standard device and host USB support library within the Pico SDK. This will allow us to rapidly contribute to the growing.... TODO: blurrr, waffle, splechl....

The `tinyusb_dev` or `tinyusb_host` libraries within the Pico SDK allow you to add TinyUSB device or host support to you application by simply adding a dependency in your executable in `CMakeLists.txt`

1.2.3. Directory Structure

We have discussed libraries such as `pico_stdlib` and `hardware_uart` above. Imagine you wanted to add some code using RP2040's DMA controller to your hello_world sample. To do this you need to add a dependency on another library `hardware_dma` which is not included by default by `pico_stdlib` (`hardware_uart` is).

You would change your `CMakeLists.txt` such that you now did the following to add both `pico_stdlib` and `hardware_dma` to the `hello_world` target (executable) (note the line breaks are not required, but are perhaps clearer)

```
target_link_libraries(hello_world
    pico_stdlib
    hardware_dma)
```

And in your source code you would:

```
#include "hardware/dma.h"
```

This is the convention for all toplevel Pico SDK library headers. The library is call `foo_bar` and the associated header is `"foo/bar.h"`

NOTE

Some libraries have additional headers which are located in foo/bar/other.h

1.2.3.1. Location of files

Of course you may want to actually find the files in question (although most IDEs will do this for you). The on disk files are actually split into multiple toplevel directories…

Whilst you are probably currently focused on building a binary to run on Raspberry Pi Pico which uses a RP2040 the Pico SDK is structured in a more general way. This is for two reasons

1. To support other future chips in the RP2 family
2. To support testing of your code off device (this is *host* mode)

The latter is super useful for writing and running unit tests, but also as you develop your software (for example your debugging code or work in progress software might actually be too big or use too much RAM to fit on the device).

The code is thus split into top level directories as follows:

Table 1. Top-level directories

Path	Description
`src/rp2040/`	This contains the `hardware_regs` and `hardware_structs` libraries mentioned earlier, which are specific to the RP2040.
`src/rp2_common/`	This contains the `hardware_` library implementations for individual hardware components, and `pico_` libraries or library implementations that are closely tied to the RP2040 hardware. This are is separate from `/src/rp2040` as there may be future revision of the RP2040 or other chips in the *RP2* family which can use a common SDK and API, but may have subtly different register definitions.
`src/common/`	This is code that is common to all builds. This is generally headers providing hardware abstractions for functionality which are simulated in host mode, along with a lot of the `pico_` library implementations which to the extent they use hardware, do so only through those hardware abstractions.
`src/host/`	This is a basic set of replacement Pico SDK library implementations sufficient to get simple Raspberry Pi Pico applications running on your computer (Raspberry Pi OS, Linux, macOS or Windows using cygwin or TODO: lsw?). This is not intended to be a fully functional simulator, however it is possible to inject additional implementations of libraries to provide more complete functionality.

There is a CMake variable `PICO_PLATFORM` that controls the environment you are build for:

When doing a regular RP2040 build (`PICO_PLATFORM=rp2040` the default), you get code from `common`, `rp2_common` and `rp2040`; when doing a host build (`PICO_PLATFROM=host`), you get code from `common` and `host`.

Within each top-level directory, the libraries have the following structure (reading `foo_bar` as something like `hardware_uart` or) `pico_time`)

```
top-level_dir/
top-level_dir/foo_bar/include/foo/bar.h      # header file
top-level_dir/foo_bar/CMakeLists.txt         # build configuration
top-level_dir/foo_bar/bar.c                  # source file(s)
```

NOTE

the directory `top-level_dir/foo_bar/include` is added as an include directory to the *INTERFACE* library foo_bar which is what allows you to include `"foo/bar.h"` in your application

1.2.4. Customization & Configuration using pre-processor variables

The Pico SDK allows use of compile time definitions to customize the behavior/capabilities of libraries, and to specify settings (e.g. physical pins) that are unlikely to be changed at runtime This allows for much smaller more efficient code, and avoids additional runtime overheads and the inclusion of code for configurations you *might* choose at runtime even though you actually don't (e.g. support PWM audio when you are only using I2S)!

Remember that because of the use of *INTERFACE* libraries, all the libaries your application(s) depend on are built from source for each application in your build, so you can even build multiple variants of the same application with different baked in behaviors.

Pre-processor variables may be specified in a number of ways, described in the following sections:

See TODO: config section for more information on configuration of individual libraries.

NOTE

Whether compile time configuration or runtime configuration or both is supported/required is dependent on the particular library itself. The general philosophy however, is to allow sensible default behavior without providing any settings (beyond those provided by the board config).

1.2.4.1. Pre-processor variables via "board configuration"

Many of the common configuration settings are actually related to the particular RP2040 board being used, and include default pin settings for various Pico SDK libraries. The board being used is specified via the `PICO_BOARD` CMake variable which may be specified on the CMake command line or in the environment. The default `PICO_BOARD` if not specified is `pico`.

The board configuration provides a header file which specifies defaults if not otherwise specified; for example https://github.com/raspberrypi/pico-sdk/tree/pre_release/src/boards/include/boards/pico.h specifies

```
#ifndef PICO_DEFAULT_LED_PIN
#define PICO_DEFAULT_LED_PIN 25
#endif
```

The header `my_board_name.h` is included by all other Pico SDK headers as a result of setting `PICO_BOARD=my_board_name`. You may wish to specify your own board configuration in which case you can set PICO_BOARD_HEADER_DIRS in the environment or CMake to a semicolon separated list of paths to search for `my_board_name.h`.

See [getting_started_cmake_vars] for more information on `PICO_BOARD`, `PICO_BOARD_HEADER_DIRS` and other Pico SDK CMake variables

1.2.4.2. Pre-processor variables per binary (or library) as part of the build

We could modify the https://github.com/raspberrypi/pico-examples/tree/pre_release/hello_world/CMakeLists.txt with `target_compile_definitions` to specify an alternate set of UART pins to use.

Modified hello_world CMakeLists.txt specifying different UART pins

```
add_executable(hello_world
```

```
    hello_world.c
)

# SPECIFY two preprocessor definitions for the target hello_world ①
target_compile_definitions(hello_world PRIVATE
   PICO_DEFAULT_UART_TX_PIN=16
   PICO_DEFAULT_UART_RX_PIN=17
)

# Pull in our pico_stdlib which aggregates commonly used features
target_link_libraries(hello_world pico_stdlib)

# create map/bin/hex/uf2 file etc.
pico_add_extra_outputs(hello_world)
```

1.2.5. Builder Pattern for Hardware Configuration APIs

Setting up hardware registers correctly can be messy; there is often a lot of shifting ORing and MASKing involved if you work with the hardware directly (e.g. using the `hardware_regs` library).

The Pico SDK uses a *builder pattern* for the more complex configurations, which provides the following benefits:

1. Readability of code (no more dozen integer/boolean parameter methods!)
2. Tiny runtime code (thanks to the compiler)
3. Less brittle (the addition of another item to a hardware configuration will not break existing code)

Take the following hypothetical code example to (quite extensively) configure a DMA channel:

Hypothetical example of DMA configuration code

```
int dma_channel = 3; ①
dma_channel_config config = dma_channel_default_config(dma_channel); ②
dma_config_read_increment(&config, true);
dma_config_write_increment(&config, true);
dma_config_dreq(&config, DREQ_SPI0_RX);
dma_config_transfer_data_size(&config, DMA_SIZE_8);
dma_set_config(dma_channel, &config, false);
```

The net effect, is the compiler actually produces the following code.

Effective code produced by the C compiler for the DMA configuration

```
*(volatile uint32_t *)(DMA_BASE + DMA_CH3_AL1_CTRL_OFFSET) = 0x00089831;
```

NOTE

The Pico SDK code is designed to make builder patterns efficient in both *Release* and *Debug* builds. Additionally, even if not all values are known constant at compile time, the compiler can still produce the most efficient code possible based on the values that are known.

1.2.6. Function Naming

Pico SDK functions follow a common naming convention for consistency and to avoid name conflicts. Some names are quite long, but that is deliberate to be as specific as possible about functionality, and of course because the Pico SDK API is a C API and does not support function overloading.

1.2.6.1. Name prefix

Functions are prefixed by the libarary/functional area they belong to; e.g. public functions in the `hardware_dma` library are prefixed with `dma_`. Sometime the prefix is extended to a sub group of library functionality (e.g. `dma_config_`)

1.2.6.2. Verb

A verb typically follows the prefix specifying that action performed by the function. `set_` and `get_` (or `is_` for booleans) are probably the most common and should always be present; i.e. a hypothetical method would be `oven_get_temperature()` and not `oven_temperature()`

1.2.6.3. Suffixes

1.2.6.3.1. Blocking/Non-Blocking Functions and Timeouts

Table 2. Pico SDK Suffixes for (non-)blocking functions and timeouts.

Suffix	Param	Description
(none)		The method is non-blocking, i.e. it does not wait on any external condition that could potentially take a long time.
`_blocking`		The method is blocking, and may potentially block indefinitely until some specific condition is met.
`_blocking_until`	`absolute_time_t until`	The method is blocking until some specific condition is met, however it will return early with a timeout condition (see Section 1.2.6.4) if the `until` time is reached.
`_timeout_ms`	`uint32_t timeout_ms`	The method is blocking until some specific condition is met, however it will return early with a timeout condition (see Section 1.2.6.4) after the specified number of milliseconds
`_timeout_us`	`uint64_t timeout_us`	The method is blocking until some specific condition is met, however it will return early with a timeout condition (see Section 1.2.6.4) after the specified number of microseconds

TODO: I know there's a few more suffixes

1.2.6.4. Return Codes and Error Handling

TODO: how to catch invalid arguments etc

TODO: ...

1.2.7. *static inline* Functions

As mentioned in Section 1.2.5, Pico SDK functions are often implemented as `static inline` functions in header files.

This is done for speed and code size! The code space needed to setup parameters for a regular call to a small function in another compilation unit can be bigger than the function implementation, and additionally the compiler can often infer the values of parameters at compile time, and so the inlined version of the function given those parameters is often significantly smaller and indeed faster than the generic version defined elsewhere. This is particularly true of functions with large numbers of arguments.

1.2.8. Floating-point support

1.2.9. Using C++

The Pico SDK has a C style API, however the Pico SDK headers may be safely included from C++ code, and the functions called (they are declared with C linkage).

To save space, exception handling is disabled by default; this can be overriden with the CMake environment variable PICO_CXX_ENABLE_EXCEPTIONS=1 todo: make a method per binary

TODO: C++ library support; destructors, wotnot

1.2.10. Stdout

TODO: The initial version of the Pico SDK does not include support for t

1.2.11. Multi-core support

Multi-core support should be familiar to those used to programming with threads in other environments. The second core is just treated as a second *thread* within your application; initially the second core (`core1` as it is usually referred to; the main application thread runs on `core0`) is halted, however you can start it executing some function in parallel from your main application thread.

Care should be taken with calling C library functions from both cores simultaneously as they are generally not designed to be thread safe. You can use the `mutex_` API provided by the SDK In `pico_sync` TODO: link from within your own code.

NOTE

That the Pico SDK version of printf is always safe to call from both cores. `malloc`, `calloc` and `free` are additionally wrapped to make it thread safe when you include the `pico_multicore` as a convenience for C++ programming, where some object allocations may not be obvious.

1.2.12. Hardware Divider

TODO:

1.3. Libraries

TODO: there is a similar section later, however I think a short table with descriptions and a link to the documentation sections (all of which are currently broken) is useful

Table 3. Pico SDK Hardware INTERFACE Libraries

Name	Description
hardware_adc	(see Hardware_adc)

Name	Description
hardware_claim	(see Lightweight Hardware Claiming API)
hardware_clocks	(see [group_hardware_clocks])
hardware_divider	(see [group_hardware_divider])
hardware_dma	(see hardware_dma: DMA Hardware API)
hardware_flash	(see [group_hardware_flash])
hardware_gpio	(see [group_hardware_gpio])
hardware_i2c	(see [group_hardware_i2c])
hardware_interp	(see [group_hardware_interp])
hardware_irq	(see hardware_irq: IRQ Hardware API)
hardware_pio	(see hardware_pio: Programmable (PIO) Hardware API)
hardware_pll	(see [group_hardware_pll])
hardware_pwm	(see [group_hardware_pwm])
hardware_resets	(see [group_hardware_resets])
hardware_rosc	(see [group_hardware_rosc])
hardware_rtc	(see [group_hardware_rtc])
hardware_sleep	(see [group_hardware_sleep])
hardware_spi	(see Hardware SPI API)
hardware_sync	(see [group_hardware_sync])
hardware_timer	(see Hardware timer API)
hardware_uart	(see [group_hardware_uart])
hardware_watchdog	(see Hardware Watchdog API)
hardware_xosc	(see [group_hardware_xosc])

Table 4. Pico SDK High-Level Libraries

Name	Description
pico_audio	(see [group_pico_audio])
pico_buffer	(see [group_pico_buffer])
pico_datetime	(see Datetime functions)
pico_divider	(see [group_pico_divider]) TODO: Note this is partly an infrastructure library, but also provides additional public API funcs
pico_double	(see [group_pico_double]) TODO: Note this is partly an infrastructure library, but also provides additional public API funcs
pico_float	(see [group_pico_float]) TODO: Note this is partly an infrastructure library, but also provides additional public API funcs
pico_multicore	(see [group_pico_multicore])
pico_pio_i2s_audio	(see [group_pico_pio_i2s_audio])
pico_pio_pwm_audio	(see [group_pico_pio_pwm_audio])
pico_sd_card	(see [group_pico_sd_card])

Name	Description
pico_sync	(see [group_pico_sync])
pico_stdlib	(see Pico standard library helpers (stdlib))
pico_time	(see Time/Sleep/Alarm/Timer API)
pico_util	(see [group_pico_util])
svideo TODO: needs rename	(see [group_svideo])
svideo_dbi TODO: needs removal	(see [group_svideo_dbi])
svideo_dpi TODO: needs rename	(see [group_svideo_dpi])
tinyusb	(see [group_tinyusb])

Table 5. Infrastructure Libraries

Name	Description
hardware_base	(see Memory Mapped Hardware Register Access)
pico_aeabi_bits TODO: needs rename	(see [group_pico_aeabi_bits])
pico_aeabi_i64 TODO: needs rename	(see [group_pico_aeabi_i64])
pico_base	(see [group_pico_base])
pico_bootrom	(see [group_pico_bootrom])
pico_memory	(see [group_pico_memory])
pico_malloc	(see [group_pico_malloc])
pico_platform	(see [group_pico_platform])
pico_standard_link	(see [group_pico_standard_link])
pico_runtime	(see [group_pico_runtime])

1.4. Getting Started

TODO: don't want to duplicate content with getting started book?

1.4.1. CMake (build) Configuration

TODO: This section is currently a bit of a dumping ground; gathering values to be documented

Note `NAME*` indicates a CMake variable that is made available to the preprocessoer as well, so is available during code compilation.

1.4.1.1. Output options

1.4.1.1.1. Board selection

PICO_BOARD*

PICO_BOARD_HEADER_DIRS (list)

PICO_BOARD_CMAKE_DIRS (list)

1.4.1.1.2. Configuration (advanced)

PICO_CONFIG_HEADER_FILES

PICO_<platform>_CONFIG_HEADER_FILES

1.4.1.1.3. Initialized by the Pico SDK

PICO_ON_DEVICE*

PICO_NO_HARDWARE*

1.4.1.1.4. Control of binary type produced (advanced)

These variables control how executables for the RP2040 are layed out in memory. The default is for the code and data to be entirely stored in flash with writable data (and some specifically marked) methods to copied into RAM at startup.

PICO_DEFAULT_BINARY_TYPE	default	The default is flash binaries which are stored in and run from flash.
	no_flash	This option selects a RAM only binaries, that does not require any flash. Note: this type of binary must be loaded on each device reboot via a UF2 file or from the debugger.
	copy_to_ram	This option selects binaries which are stored in flash, but copy themselves to RAM before executing.
	blocked_ram	
PICO_NO_FLASH*	0 / 1	Equivalent to PICO_DEFAULT_BINARY_TYPE=no_flash if 1
PICO_COPY_TO_RAM*	0 / 1	Equivalent to PICO_DEFAULT_BINARY_TYPE=copy_to_ram if 1
PICO_USE_BLOCKED_RAM*	0 / 1	Equivalent to PICO_DEFAULT_BINARY_TYPE=blocked_ram if 1

TIP

The binary type can be set on a per executable target (as created by `add_executable`) basis by calling `pico_set_binary_type(target type)` where type is the same as for `PICO_DEFAULT_BINARY_TYPE`

TODO

todo:Note we should reference which are persistent (at least as a heading) and mention `cmake /LH ..`

PICO_BOOT_STAGE2_FILE*

PICO_INCLUDE_DIRS (list)

PICO_BARE_METAL 0/1

PICO_PLATFORM_EXTRA_LIBRARIES

PICO_DEFAULT_DIVIDER_IMPL

#PICO_DIVIDER_HARDWARE

#PICO_DIVIDER_COMPILER

PICO_DEFAULT_FLOAT_IMPL

#PICO_FLOAT_NONE

#PICO_FLOAT_ROM

#PICO_FLOAT_COMPILER

PICO_DEFAULT_DOUBLE_IMPL

#PICO_DOUBLE_NONE

#PICO_DOUBLE_ROM

#PICO_DOUBLE_COMPILER

#PICO_MULTICORE

PICO_TOOLCHAIN_PATH

PICO_COMPILER

PICO_TINYUSB_PATH

PICO_PLATFORM_CMAKE_FILE

PICO_SYMLINK_ELF_AS_FILENAME

(PICO_SDK_PATH is set)

1.4.1.1.5. C++

PICO_CXX_ENABLE_EXCEPTIONS todo make a target method

PICO_CXX_ENABLE_RTTI todo make a target method

PICO_CXX_USE_CXA_ATEXIT todo make a target method

PICO_NO_GC_SECTIONS todo make a target method

Host specific

PICO_NO_PRINTF* todo: needs love

PICO_TIMER_NO_ALARM_SUPPORT

1.4.1.2. Debug/Release builds

CMAKE_BUILD_TYPE

1.4.2. CMake Example

1.4.3. misc preprocessor

#PICO_FLOAT_PROPAGATE_NANS

#PICO_DOUBLE_PROPAGATE_NANS

#PICO_ENTER_USB_BOOT_ON_EXIT

autoset:

#PICO_BUILD=1

Chapter 2. Library Documentation

TODO: This or the previous section need to be merged into eachother

Chapter 3. API Documentation

3.1. Base audio functionality

Base functions for audio support. More...

3.1.1. Modules

- `Audio support`
  Structures and macros for audio formats.
- `I2S audio support using the PIO`
- `PWM audio support using the PIO`

3.1.2. Functions

- `audio_buffer_pool_t * audio_new_producer_pool (audio_buffer_format_t *format, int buffer_count, int buffer_sample_count)`
  Allocate and initialise an audio producer pool. More...
- `audio_buffer_pool_t * audio_new_consumer_pool (audio_buffer_format_t *format, int buffer_count, int buffer_sample_count)`
  Allocate and initialise an audio consumer pool. More...
- `audio_buffer_t * audio_new_wrapping_buffer (audio_buffer_format_t *format, mem_buffer_t *buffer)`
  Allocate and initialise an audio wrapping buffer. More...
- `audio_buffer_t * audio_new_buffer (audio_buffer_format_t *format, int buffer_sample_count)`
  Allocate and initialise an new audio buffer. More...
- `void audio_init_buffer (audio_buffer_t *audio_buffer, audio_buffer_format_t *format, int buffer_sample_count)`
  Initialise an audio buffer. More...
- `void give_audio_buffer (audio_buffer_pool_t *ac, audio_buffer_t *buffer)` More...
- `audio_buffer_t * take_audio_buffer (audio_buffer_pool_t *ac, bool block)` More...
- `static void release_audio_buffer (audio_buffer_pool_t *ac, audio_buffer_t *buffer)` More...
- `void audio_upsample (int16_t *input, int16_t *output, uint output_count, uint32_t step)` More...
- `void audio_upsample_words (int16_t *input, int16_t *output_aligned, uint output_word_count, uint32_t step)` More...
- `void audio_upsample_double (int16_t *input, int16_t *output, uint output_count, uint32_t step)` More...
- `void audio_complete_connection (audio_connection_t *connection, audio_buffer_pool_t *producer, audio_buffer_pool_t *consumer)` More...
- `audio_buffer_t * get_free_audio_buffer (audio_buffer_pool_t *context, bool block)` More...
- `void queue_free_audio_buffer (audio_buffer_pool_t *context, audio_buffer_t *ab)` More...
- `audio_buffer_t * get_full_audio_buffer (audio_buffer_pool_t *context, bool block)` More...
- `void queue_full_audio_buffer (audio_buffer_pool_t *context, audio_buffer_t *ab)` More...
- `void consumer_pool_give_buffer_default (audio_connection_t *connection, audio_buffer_t *buffer)` More...
- `audio_buffer_t * consumer_pool_take_buffer_default (audio_connection_t *connection, bool block)` More...

- `void producer_pool_give_buffer_default (audio_connection_t *connection, audio_buffer_t *buffer)` More...
- `audio_buffer_t * producer_pool_take_buffer_default (audio_connection_t *connection, bool block)` More...
- `audio_buffer_t * mono_to_mono_consumer_take (audio_connection_t *connection, bool block)` More...
- `audio_buffer_t * mono_s8_to_mono_consumer_take (audio_connection_t *connection, bool block)` More...
- `audio_buffer_t * stereo_to_stereo_consumer_take (audio_connection_t *connection, bool block)` More...
- `audio_buffer_t * mono_to_stereo_consumer_take (audio_connection_t *connection, bool block)` More...
- `audio_buffer_t * mono_s8_to_stereo_consumer_take (audio_connection_t *connection, bool block)` More...
- `void stereo_to_stereo_producer_give (audio_connection_t *connection, audio_buffer_t *buffer)` More...

3.1.3. Detailed Description

Base functions for audio support.

3.1.4. Function Documentation

3.1.4.1. audio_complete_connection

```
void audio_complete_connection (audio_connection_t *connection,
       audio_buffer_pool_t *producer,
       audio_buffer_pool_t *consumer)
```

#TO DO: #

3.1.4.2. audio_init_buffer

```
void audio_init_buffer (audio_buffer_t *audio_buffer,
       audio_buffer_format_t *format,
       int buffer_sample_count)
```

Initialise an audio buffer.

#TO DO: #

Parameters

- `audio_buffer` Pointer to an audio_buffer
- `format` Format of the audio buffer
- `buffer_sample_count`

3.1.4.3. audio_new_buffer

```
audio_buffer_t* audio_new_buffer (audio_buffer_format_t *format,
       int buffer_sample_count)
```

Allocate and initialise an new audio buffer.

#TO DO: #

Parameters

- `format` Format of the audio buffer
- `buffer_sample_count`

Returns

- Pointer to an `audio_buffer`

3.1.4.4. audio_new_consumer_pool

```
audio_buffer_pool_t* audio_new_consumer_pool (audio_buffer_format_t *format,
        int buffer_count,
        int buffer_sample_count)
```

Allocate and initialise an audio consumer pool.

Parameters

- `format` Format of the audio buffer
- `buffer_count`
- `buffer_sample_count`

Returns

- Pointer to an `audio_buffer_pool`

3.1.4.5. audio_new_producer_pool

```
audio_buffer_pool_t* audio_new_producer_pool (audio_buffer_format_t *format,
        int buffer_count,
        int buffer_sample_count)
```

Allocate and initialise an audio producer pool.

#TO DO: # #TO DO: #

Parameters

- `format` Format of the audio buffer
- `buffer_count`
- `buffer_sample_count`

Returns

- Pointer to an `audio_buffer_pool`

3.1.4.6. audio_new_wrapping_buffer

```
audio_buffer_t* audio_new_wrapping_buffer (audio_buffer_format_t *format,
        mem_buffer_t *buffer)
```

Allocate and initialise an audio wrapping buffer.

#TO DO: #

Parameters

- `format` Format of the audio buffer
- `buffer`

Returns

- Pointer to an `audio_buffer`

3.1.4.7. audio_upsample

```
void audio_upsample (int16_t *input,
```

```
        int16_t *output,
        uint output_count,
        uint32_t step)
```

#TO DO: #

todo we are currently limited to 4095+1 input samples step is fraction of an input sample per output sample * 0x1000 and should be < 0x1000 i.e. we we are up-sampling (otherwise results are undefined)

3.1.4.8. audio_upsample_double

```
void audio_upsample_double (int16_t *input,
        int16_t *output,
        uint output_count,
        uint32_t step)
```

#TO DO: #

3.1.4.9. audio_upsample_words

```
void audio_upsample_words (int16_t *input,
        int16_t *output_aligned,
        uint output_word_count,
        uint32_t step)
```

#TO DO: # similar but the output buffer is word aligned, and we output an even number of samples.. this is slightly faster than the above todo we are currently limited to 4095+1 input samples step is fraction of an input sample per output sample * 0x1000 and should be < 0x1000 i.e. we we are up-sampling (otherwise results are undefined)

3.1.4.10. consumer_pool_give_buffer_default

```
void consumer_pool_give_buffer_default (audio_connection_t *connection,
        audio_buffer_t *buffer)
```

#TO DO: #

generally an pico_audio connection uses 3 of the defaults and does the hard work in one of them

3.1.4.11. consumer_pool_take_buffer_default

```
audio_buffer_t* consumer_pool_take_buffer_default (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.12. get_free_audio_buffer

```
audio_buffer_t* get_free_audio_buffer (audio_buffer_pool_t *context,
        bool block)
```

#TO DO: #

3.1.4.13. get_full_audio_buffer

```
audio_buffer_t* get_full_audio_buffer (audio_buffer_pool_t *context,
        bool block)
```

#TO DO: #

3.1.4.14. give_audio_buffer

```
void give_audio_buffer (audio_buffer_pool_t *ac,
        audio_buffer_t *buffer)
```

#TO DO: #

#TO DO: # #TO DO: #

Parameters

- `ac`
- `buffer`

Returns

- Pointer to an `audio_buffer`

3.1.4.15. mono_s8_to_mono_consumer_take

```
audio_buffer_t* mono_s8_to_mono_consumer_take (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.16. mono_s8_to_stereo_consumer_take

```
audio_buffer_t* mono_s8_to_stereo_consumer_take (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.17. mono_to_mono_consumer_take

```
audio_buffer_t* mono_to_mono_consumer_take (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.18. mono_to_stereo_consumer_take

```
audio_buffer_t* mono_to_stereo_consumer_take (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.19. producer_pool_give_buffer_default

```
void producer_pool_give_buffer_default (audio_connection_t *connection,
        audio_buffer_t *buffer)
```

#TO DO: #

3.1.4.20. producer_pool_take_buffer_default

```
audio_buffer_t* producer_pool_take_buffer_default (audio_connection_t *connection,
        bool block)
```

#TO DO: #

3.1.4.21. queue_free_audio_buffer

```
void queue_free_audio_buffer (audio_buffer_pool_t *context,
       audio_buffer_t *ab)
```

#TO DO: #

3.1.4.22. queue_full_audio_buffer

```
void queue_full_audio_buffer (audio_buffer_pool_t *context,
       audio_buffer_t *ab)
```

#TO DO: #

3.1.4.23. release_audio_buffer

```
static void release_audio_buffer (audio_buffer_pool_t *ac,
       audio_buffer_t *buffer)
```

#TO DO: #

3.1.4.24. stereo_to_stereo_consumer_take

```
audio_buffer_t* stereo_to_stereo_consumer_take (audio_connection_t *connection,
       bool block)
```

#TO DO: #

3.1.4.25. stereo_to_stereo_producer_give

```
void stereo_to_stereo_producer_give (audio_connection_t *connection,
       audio_buffer_t *buffer)
```

#TO DO: #

3.1.4.26. take_audio_buffer

```
audio_buffer_t* take_audio_buffer (audio_buffer_pool_t *ac,
       bool block)
```

#TO DO: #

Returns

- Pointer to an `audio_buffer`

3.2. Audio support

Structures and macros for audio formats. More...

3.2.1. Data Structures

- `struct audio_format`
  Audio format definition.
- `struct audio_buffer_format`
  Audio buffer format definition.

- struct audio_buffer
  Audio buffer definition.
- struct audio_buffer_pool
- struct audio_connection

3.2.2. Typedefs

- typedef struct audio_format audio_format_t
  Audio format definition.
- typedef struct audio_buffer_format audio_buffer_format_t
  Audio buffer format definition.
- typedef struct audio_buffer audio_buffer_t
  Audio buffer definition.
- typedef struct audio_connection audio_connection_t
- typedef struct audio_buffer_pool audio_buffer_pool_t

3.2.3. Macros

- #define AUDIO_BUFFER_FORMAT_PCM_S16 1
  signed 16bit PCM
- #define AUDIO_BUFFER_FORMAT_PCM_S8 2
  signed 8bit PCM
- #define AUDIO_BUFFER_FORMAT_PCM_U16 3
  unsigned 16bit PCM
- #define AUDIO_BUFFER_FORMAT_PCM_U8 4
  unsigned 16bit PCM

3.2.4. Detailed Description

Structures and macros for audio formats.

3.3. I2S audio support using the PIO

3.3.1. Data Structures

- struct pio_i2s_audio_config
  Base configuration structure used when setting up.

3.3.2. Typedefs

- typedef struct pio_i2s_audio_config pio_i2s_audio_config_t
  Base configuration structure used when setting up.

3.3.3. Functions

- const audio_format_t * pio_i2s_audio_setup (const audio_format_t *intended_audio_format, const pio_i2s_audio_config_t *config)

Set up system to output I2S audio. More...

- `bool pio_i2s_audio_connect_thru (audio_buffer_pool_t *producer, audio_connection_t *connection)` More...
- `bool pio_i2s_audio_connect (audio_buffer_pool_t *producer)` More...
- `bool pio_i2s_audio_connect_s8 (audio_buffer_pool_t *producer)` More...
- `bool pio_i2s_audio_connect_extra (audio_buffer_pool_t *producer, bool buffer_on_give, uint buffer_count, uint samples_per_buffer, audio_connection_t *connection)` More...
- `void pio_i2s_audio_enable (bool enable)`
  Set up system to output I2S audio. More...

3.3.4. Detailed Description

This library uses the pio system to implement a I2S audio interface

TO DO: Must be more we need to say here. certainly need an example

3.3.5. Function Documentation

3.3.5.1. pio_i2s_audio_connect

```
bool pio_i2s_audio_connect (audio_buffer_pool_t *producer)
```

#TO DO: #

Parameters

- `producer` todo make a common version (or a macro) .. we don't want to pull in unnecessary code by default

3.3.5.2. pio_i2s_audio_connect_extra

```
bool pio_i2s_audio_connect_extra (audio_buffer_pool_t *producer,
      bool buffer_on_give,
      uint buffer_count,
      uint samples_per_buffer,
      audio_connection_t *connection)
```

#TO DO: #

Parameters

- `producer`
- `buffer_on_give`
- `buffer_count`
- `samples_per_buffer`
- `connection`

Returns

*

3.3.5.3. pio_i2s_audio_connect_s8

```
bool pio_i2s_audio_connect_s8 (audio_buffer_pool_t *producer)
```

#TO DO: #

Parameters

- `producer`

3.3.5.4. pio_i2s_audio_connect_thru

```
bool pio_i2s_audio_connect_thru (audio_buffer_pool_t *producer,
       audio_connection_t *connection)
```

#TO DO: #

Parameters

- `producer`
- `connection`

3.3.5.5. pio_i2s_audio_enable

```
void pio_i2s_audio_enable (bool enable)
```

Set up system to output I2S audio.

Parameters

- `enable` true to enable I2S audio, false to disable.

3.3.5.6. pio_i2s_audio_setup

```
const audio_format_t* pio_i2s_audio_setup (const audio_format_t *intended_audio_format,
       const pio_i2s_audio_config_t *config)
```

Set up system to output I2S audio.

#TO DO: #

Parameters

- `intended_audio_format`
- `config` The configuration to apply.

3.4. PWM audio support using the PIO

3.4.1. Functions

- `const audio_format_t * pio_pwm_audio_setup (const audio_format_t *intended_audio_format, int32_t max_latency_ms, const pio_pwm_audio_channel_config_t *channel_config0,⋯)` More...
- `bool pio_pwm_audio_default_connect (audio_buffer_pool_t *producer_pool, bool dedicate_core_1)` More...
- `void pio_pwm_audio_enable (bool enable)` More...
- `bool pio_pwm_audio_set_correction_mode (enum audio_correction_mode mode)`
  Set the PWM correction mode. More...
- `enum audio_correction_mode pio_pwm_audio_get_correction_mode ()`

Get the PWM correction mode. More...

3.4.2. Detailed Description

This library uses the pio system to implement a PWM audio interface

TO DO: Must be more we need to say here. certainly need an example

3.4.3. Function Documentation

3.4.3.1. pio_pwm_audio_default_connect

```
bool pio_pwm_audio_default_connect (audio_buffer_pool_t *producer_pool,
       bool dedicate_core_1)
```

#TO DO: #

Parameters

- `producer_pool`
- `dedicate_core_1` attempt a default mapping of producer buffers to pio pwm pico_audio output dedicate_core_1 to have core 1 set aside entirely to do work offloading as much stuff from the producer side as possible todo also allow IRQ handler to do it I guess

3.4.3.2. pio_pwm_audio_enable

```
void pio_pwm_audio_enable (bool enable)
```

#TO DO: #

Parameters

- `enable` true to enable the PWM audio, false to disable

3.4.3.3. pio_pwm_audio_get_correction_mode

```
enum audio_correction_mode pio_pwm_audio_get_correction_mode ()
```

Get the PWM correction mode.

Returns

- mode

3.4.3.4. pio_pwm_audio_set_correction_mode

```
bool pio_pwm_audio_set_correction_mode (enum audio_correction_mode mode)
```

Set the PWM correction mode.

#TO DO: #

Parameters

- `mode`

3.4.3.5. pio_pwm_audio_setup

```
const audio_format_t* pio_pwm_audio_setup (const audio_format_t *intended_audio_format,
       int32_t max_latency_ms,
```

```
    const pio_pwm_audio_channel_config_t *channel_config0,
    ...)
```

#TO DO: #

max_latency_ms may be -1 (for don't care)

Parameters

- `intended_audio_format`
- `max_latency_ms`
- `channel_config0`
- `...`

Returns

*

3.5. Buffer

Simple buffer support. More...

3.5.1. Detailed Description

Simple buffer support.

Provides a wrapper around allocated or in place memory giving a consistent interface

3.6. Datetime functions

Functions for datetime support. More...

3.6.1. Data Structures

- `struct datetime_t`
  Structure containing date and time information.

3.6.2. Functions

- `void datetime_to_str (char *buf, uint buf_size, const datetime_t *t)`
  Convert a datetime_t structure to a string. More...

3.6.3. Detailed Description

Functions for datetime support.

3.6.4. Function Documentation

3.6.4.1. datetime_to_str

```
void datetime_to_str (char *buf,
       uint buf_size,
       const datetime_t *t)
```

Convert a datetime_t structure to a string.

Parameters

- `buf` character buffer to accept generated string
- `buf_size` The size of the passed in buffer
- `t` The datetime to be converted.

3.7. Critical Section API

3.7.1. Functions

- `void critical_section_init (critical_section_t *critsec)`
  Initialise a critical_section structure claiming a free spinlock. More...
- `static void critical_section_enter_blocking (critical_section_t *critsec)`
  Enter a critical_section. More...
- `static void critical_section_exit (critical_section_t *critsec)`
  Release a critical_section. More...

3.7.2. Detailed Description

TO DO: Blah... short lived safe for IRQs/core; wrapped spinlock.. autoclaiming

3.7.3. Function Documentation

3.7.3.1. critical_section_enter_blocking

```
static void critical_section_enter_blocking (critical_section_t *critsec)
```

Enter a critical_section.

This function will block until the `critical_section` becomes free

Parameters

- `critsec` Pointer to critical_section structure

3.7.3.2. critical_section_exit

```
static void critical_section_exit (critical_section_t *critsec)
```

Release a critical_section.

Parameters

- `critsec` Pointer to critical_section structure

3.7.3.3. critical_section_init

```
void critical_section_init (critical_section_t *critsec)
```

Initialise a critical_section structure claiming a free spinlock.

Parameters

- `critsec` Pointer to critical_section structure

3.8. Lock Core API

3.8.1. Detailed Description

TO DO: This section is incomplete should we should allow single core only locks... would save sev/wfe, but that isn't probably a big deal should be private really, but we want people to be able to have static ones

3.9. Mutex API

3.9.1. Macros

- `#define auto_init_mutex(name) static __attribute__((section(".mutex_array"))) mutex_t name`

3.9.2. Functions

- `void mutex_init (mutex_t *mtx)`
  Initialise a mutex structure. More...
- `void mutex_enter_blocking (mutex_t *mtx)`
  Enter a mutex. More...
- `bool mutex_try_enter (mutex_t *mtx, uint32_t *owner_out)`
  Check to see if a mutex is available. More...
- `bool mutex_enter_timeout_ms (mutex_t *mtx, uint32_t timeout_ms)` More...
- `void mutex_exit (mutex_t *mtx)`
  Release a mutex. More...

3.9.3. Detailed Description

Mutexes are application level locks usually used protecting data structures that might be used by multiple cores. Because they are not re-entrant on the same core, any blocking mutex method is NOT safe to call from within an IRQ handler.

Equally unlike critical sections the mutex protected code is not required/expected to complete quickly.

It is possible to use a mutex from within an IRQ handler, however only if you use mutex_try_enter to check whether a deadlock would occur and can skip whatever operation was intended in this case.

See critical_section.h for protecting access between multiple cores AND IRQ handlers

3.9.4. Function Documentation

3.9.4.1. mutex_enter_blocking

```
void mutex_enter_blocking (mutex_t *mtx)
```

Enter a mutex.

This function will block until the mutex becomes free

Parameters

- `mtx` Pointer to mutex structure

3.9.4.2. mutex_enter_timeout_ms

```
bool mutex_enter_timeout_ms (mutex_t *mtx,
       uint32_t timeout_ms)
```

Wait for the specific time for a mutex to become available. If the mutex becomes available within the time specified, the mutex will be grabbed and the function will return true. If not, the function will return after the timeout and return false.

Parameters

- `mtx` Pointer to mutex structure
- `timeout_ms` The timeout in milliseconds.

3.9.4.3. mutex_exit

```
void mutex_exit (mutex_t *mtx)
```

Release a mutex.

Parameters

- `mtx` Pointer to mutex structure

3.9.4.4. mutex_init

```
void mutex_init (mutex_t *mtx)
```

Initialise a mutex structure.

Parameters

- `mtx` Pointer to mutex structure

3.9.4.5. mutex_try_enter

```
bool mutex_try_enter (mutex_t *mtx,
       uint32_t *owner_out)
```

Check to see if a mutex is available.

Will return true if the mutex is available, false otherwise

Parameters

- `mtx` Pointer to mutex structure
- `owner_out` If mutex is not available, and this pointer is non-Zero, will be filled in with the core number of the current owner of the mutex

3.10. Semaphore API

3.10.1. Functions

- `void sem_init (semaphore_t *sem, int32_t initial_permits, int32_t max_permits)`
  Initialise a semaphore structure. More...
- `int32_t sem_available (semaphore_t *sem)`
  Return number of permits available on semaphore. More...
- `bool sem_release (semaphore_t *sem)`
  Release a permit on a semaphore. More...
- `void sem_reset (semaphore_t *sem, int32_t permits)`
  Reset semaphore to specific number of permits. More...
- `void sem_acquire_blocking (semaphore_t *sem)`
  Acquire a permit from the semaphore. More...
- `bool sem_acquire_timeout_ms (semaphore_t *sem, uint32_t timeout_ms)`
  Acquire a permit from a semaphore, with timeout. More...

3.10.2. Detailed Description

These may be safely used from anywhere (though it isn't advisable to block interrupts obviously)

3.10.3. Function Documentation

3.10.3.1. sem_acquire_blocking

```
void sem_acquire_blocking (semaphore_t *sem)
```

Acquire a permit from the semaphore.

This function will block and wait if no permits are available.

Parameters

- `sem` Pointer to semaphore structure

3.10.3.2. sem_acquire_timeout_ms

```
bool sem_acquire_timeout_ms (semaphore_t *sem,
       uint32_t timeout_ms)
```

Acquire a permit from a semaphore, with timeout.

This function will block and wait if no permits are available, until the defined timeout has been reached. If the timeout is reached the function will return false, otherwise it will return true.

#TO DO: #

Parameters

- `sem` Pointer to semaphore structure
- `timeout_ms`

Returns

- false if timeout reached, true if permit was acquired.

3.10.3.3. sem_available

```
int32_t sem_available (semaphore_t *sem)
```

Return number of permits available on semaphore.

Parameters

- `sem` Pointer to semaphore structure

Returns

- The number of permits available on the semaphore.

3.10.3.4. sem_init

```
void sem_init (semaphore_t *sem,
       int32_t initial_permits,
       int32_t max_permits)
```

Initialise a semaphore structure.

Parameters

- `sem` Pointer to semaphore structure
- `initial_permits` How many permits are already allocated to the semaphore
- `max_permits` Total number of permits allowed for this semaphore

3.10.3.5. sem_release

```
bool sem_release (semaphore_t *sem)
```

Release a permit on a semaphore.

Parameters

- `sem` Pointer to semaphore structure

Returns

- true if successful

3.10.3.6. sem_reset

```
void sem_reset (semaphore_t *sem,
       int32_t permits)
```

Reset semaphore to specific number of permits.

Reset value should be from to the max_permits specified in the init function

Parameters

- `sem` Pointer to semaphore structure
- `permits` Reset value

3.11. Synchronisation API

Module containing synchronisation functions: semaphores, mutexes, locks. More...

3.11.1. Typedefs

- `typedef uint32_t spin_lock_t`
  A spin lock identifier.

3.11.2. Functions

- `int dma_channel_claim_unused (bool required)`
  Claim a free dma channel. More...
- `static void __sev ()`
  Insert a SEV instruction in to the code path. More...
- `static void __wfe ()`
  Insert a WFE instruction in to the code path. More...
- `static void __wfi ()`
  Insert a WFI instruction in to the code path. More...
- `static void __dmb ()`
  Insert a DMB instruction in to the code path. More...
- `static void __isb ()`
  Insert a ISB instruction in to the code path. More...
- `static void __mem_fence_acquire ()`
  Acquire a memory fence.
- `static void __mem_fence_release ()`
  Release a memory fence.
- `static uint32_t save_and_disable_interrupts ()`
  Save and disable interrupts. More...
- `static void restore_interrupts (uint32_t status)`
  Restore interrupts to a specified state. More...
- `static spin_lock_t * spin_lock_addr (uint lock_num)`
  Get HW Spinlock instance from number. More...
- `static void unprotected_spin_lock (volatile spin_lock_t *lock)`
  Acquire a spin lock. More...
- `static void unprotected_spin_unlock (volatile spin_lock_t *lock)`
  Release a spin lock. More...
- `static uint32_t safe_spin_lock (spin_lock_t *lock)`
  Acquire a spin lock safely. More...
- `static bool is_spin_locked (const spin_lock_t *lock)`
  Check to see if a spinlock is currently acquired elsewhere. More...
- `static void safe_spin_unlock (spin_lock_t *lock, uint32_t saved_irq)`
  Release a spin lock safely. More...
- `static uint get_core_num ()`
  Get the current core number. More...
- `spin_lock_t * spin_lock_init (uint lock_num)`
  Initialise a numbered spin lock. More...
- `void clear_spin_locks (void)`
  Release all spin locks.
- `int spin_lock_claim_unused (bool required)`
  Claim a free spin lock. More...

3.11.3. Detailed Description

Module containing synchronisation functions: semaphores, mutexes, locks.

Functions for synchronisation between core's, HW, etc.

The RP2040 provides 32 hardware spinlocks, which can be used to manage mutually-exclusive access to shared software resources.

3.11.4. Function Documentation

3.11.4.1. __dmb

```
static void __dmb ()
```

Insert a DMB instruction in to the code path.

The DMB (data memory barrier) acts as a memory barrier, all memory accesses prior to this instruction will be observed before any explicit access after the instruction.

3.11.4.2. __isb

```
static void __isb ()
```

Insert a ISB instruction in to the code path.

ISB acts as an instruction synchronization barrier. It flushes the pipeline of the processor, so that all instructions following the ISB are fetched from cache or memory again, after the ISB instruction has been completed.

3.11.4.3. __mem_fence_acquire

```
static void __mem_fence_acquire ()
```

Acquire a memory fence.

3.11.4.4. __mem_fence_release

```
static void __mem_fence_release ()
```

Release a memory fence.

3.11.4.5. __sev

```
static void __sev ()
```

Insert a SEV instruction in to the code path.

The SEV (send event) instruction sends an event to the other core.

3.11.4.6. __wfe

```
static void __wfe ()
```

Insert a WFE instruction in to the code path.

The WFE (wait for event) instruction waits for a SEV instructions from the other core.

3.11.4.7. __wfi

```
static void __wfi ()
```

Insert a WFI instruction in to the code path.

The WFI (wait for interrupt) instruction waits for a interrupt to wake up the core.

3.11.4.8. clear_spin_locks

```
void clear_spin_locks (void)
```

Release all spin locks.

3.11.4.9. dma_channel_claim_unused

```
int dma_channel_claim_unused (bool required)
```

Claim a free dma channel.

Parameters

- `required` if true the function will panic if none are available

Returns

- the spin lock number or -1 if required was false, and none were free

3.11.4.10. get_core_num

```
static uint get_core_num ()
```

Get the current core number.

Returns

- The core number the call was made from

3.11.4.11. is_spin_locked

```
static bool is_spin_locked (const spin_lock_t *lock)
```

Check to see if a spinlock is currently acquired elsewhere.

Parameters

- `lock` Spinlock instance

3.11.4.12. restore_interrupts

```
static void restore_interrupts (uint32_t status)
```

Restore interrupts to a specified state.

Parameters

- `status` Previous interrupt status from save_and_disable_interrupts()

Returns

- The current interrupt enable status

3.11.4.13. safe_spin_lock

```
static uint32_t safe_spin_lock (spin_lock_t *lock)
```

Acquire a spin lock safely.

This function will disable interrupts prior to acquiring the spinlock

Parameters

- `lock` Spinlock instance

Returns

- interrupt status to be used when unlocking, to restore to original state

3.11.4.14. safe_spin_unlock

```
static void safe_spin_unlock (spin_lock_t *lock,
       uint32_t saved_irq)
```

Release a spin lock safely.

This function will reenable interrupts according to the parameters.

Parameters

- `lock` Spinlock instance
- `saved_irq` Return value from the

Returns

- interrupt status to be used when unlocking, to restore to original state

See also

- safe_spin_lock()
- safe_spin_lock() function.

3.11.4.15. save_and_disable_interrupts

```
static uint32_t save_and_disable_interrupts ()
```

Save and disable interrupts.

Returns

- The current interrupt enable status

3.11.4.16. spin_lock_addr

```
static spin_lock_t* spin_lock_addr (uint lock_num)
```

Get HW Spinlock instance from number.

Parameters

- `lock_num` Spinlock ID

Returns

- The spinlock instance

3.11.4.17. spin_lock_claim_unused

```
int spin_lock_claim_unused (bool required)
```

Claim a free spin lock.

Parameters

- `required` if true the function will panic if none are aviailable

Returns

- the spin lock number or -1 if required was false, and none were free

3.11.4.18. spin_lock_init

```
spin_lock_t* spin_lock_init (uint lock_num)
```

Initialise a numbered spin lock.

Parameters

- `lock_num` The spin lock number

Returns

- The spin lock instance

3.11.4.19. unprotected_spin_lock

```
static void unprotected_spin_lock (volatile spin_lock_t *lock)
```

Acquire a spin lock.

Parameters

- `lock` Spinlock instance

3.11.4.20. unprotected_spin_unlock

```
static void unprotected_spin_unlock (volatile spin_lock_t *lock)
```

Release a spin lock.

Parameters

- `lock` Spinlock instance

3.12. Time/Sleep/Alarm/Timer API

API for accurate timestamps, sleeping, and receiving delayed callbacks. More...

3.12.1. Data Structures

- `struct repeating_timer`
  Information about a repeating timer.

3.13. Timestamp Functions

These are functions for dealing with timestamps (i.e. instants in time) represented by the type absolute_time_t. This opaque type is provided to help prevent accidental mixing of timestamps and relative time values.

3.13.1. Variables

- `const absolute_time_t at_the_end_of_time`
  The timestamp representing the end of time; no timestamp is after this.
- `const absolute_time_t nil_time`
  The timestamp representing a null timestamp.

3.13.2. Functions

- `static absolute_time_t get_absolute_time ()`
  Return a representation of the current time. More...
- `static uint32_t to_ms_since_boot (absolute_time_t t)`
  Convert a timestamp into a number of milliseconds since boot. More...
- `static absolute_time_t delayed_by_us (const absolute_time_t t, uint64_t us)`
  Return a timestamp value obtained by adding a number of microseconds to another timestamp. More...
- `static absolute_time_t delayed_by_ms (const absolute_time_t t, uint32_t ms)`
  Return a timestamp value obtained by adding a number of milliseconds to another timestamp. More...
- `static absolute_time_t make_timeout_time_us (uint64_t us)`
  Convenience method to get the timestamp a number of microseconds from the current time. More...
- `static absolute_time_t make_timeout_time_ms (uint32_t ms)`
  Convenience method to get the timestamp a number of milliseconds from the current time. More...
- `static int64_t absolute_time_diff_us (absolute_time_t from, absolute_time_t to)`
  Return the difference in microseconds between two timestamps. More...
- `static bool is_nil_time (absolute_time_t t)`
  Determine if the given timestamp is nil. More...
- `static uint32_t us_to_ms (uint64_t us)`

3.14. Sleep Functions

These functions allow the calling core to sleep. This is a lower powered sleep; waking and re-checking time on every processor event (WFE)

NOTE

These functions should not be called from an IRQ handler.

NOTE

Lower powered sleep requires use of the default alarm pool which may be disabled by the PICO_TIME_DEFAULT_ALARM_POOL_DISABLED define or currently full in which case these functions become busy waits instead.

NOTE

Whilst *sleep_* functions are preferable to *busy_wait* functions from a power perspective, the *busy_wait* equivalent function may return slightly sooner after the target is reached.

See also

- busy_wait_until()
- busy_wait_us()
- busy_wait_us_32()

3.14.1. Functions

- `void sleep_until (absolute_time_t target)`
  Wait until after the given timestamp to return. More...
- `void sleep_us (uint64_t us)`
  Wait for the given number of microseconds before returning. More...
- `void sleep_ms (uint32_t ms)`
  Wait for the given number of milliseconds before returning. More...
- `bool best_effort_wfe_or_timeout (absolute_time_t timeout_timestamp)`
  Helper method for blocking on a timeout. More...

3.15. Alarm Functions

Alarms provide for calling a user provided callback at a given timestamp.

Alarms are added to alarm pools, which may hold a certain fixed number of active alarms. Each alarm pool utilizes one of four underlying hardware alarms, thus you may have up to four alarm pools. An alarm pool calls (except when the callback would happen before or during being set) the callback on the core from which the alarm pool was created. Callbacks are called from the hardware alarm IRQ handler, so care must be taken in their implementation.

A default pool is created (todo unless not) on the core specified by PICO_TIME_DEFAULT_ALARM_POOL_HARDWARE_ALARM_NUM on core 0, and may be used by the method variants that take no alarm pool parameter.

See also

- struct alarm_pool
- Hardware timer API

3.15.1. Typedefs

- `typedef int32_t alarm_id_t`
  The identifier for an alarm. More...
- `typedef int64_t(* alarm_callback_t )(alarm_id_t id, void *user_data)`
  User alarm callback. More...
- `typedef struct alarm_pool alarm_pool_t`

3.15.2. Macros

- `#define PICO_TIME_DEFAULT_ALARM_POOL_DISABLED 0`
  If 1 then the default alarm pool is disabled (so no hardware alarm needs to be claimed) More...

- `#define PICO_TIME_DEFAULT_ALARM_POOL_HARDWARE_ALARM_NUM 3`
  Selects which hardware alarm is used for the default alarm pool. More...
- `#define PICO_TIME_DEFAULT_ALARM_POOL_MAX_TIMERS 16`
  Selects the maximum number of concurrent timers in the default alarm pool. More...

3.15.3. Functions

- `void alarm_pool_init_default ()`
  Create the default alarm pool (if not already created or disabled)
- `alarm_pool_t * alarm_pool_default ()`
  The default alarm pool used when alarms are added without specifying an alarm pool, and also used by the Pico SDK to support lower power sleeps and timeouts. More...
- `alarm_pool_t * alarm_pool_create (uint hardware_alarm_num, uint max_timers)`
  Create an alarm pool. More...
- `uint alarm_pool_hardware_alarm_num (alarm_pool_t *pool)`
  Return the hardware alarm used by an alarm pool. More...
- `void alarm_pool_destroy (alarm_pool_t *pool)`
  Destroy the alarm pool, cancelling all alarms and freeing up the underlying hardware alarm. More...
- `alarm_id_t alarm_pool_add_alarm_at (alarm_pool_t *pool, absolute_time_t time, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called at a specific time. More...
- `static alarm_id_t alarm_pool_add_alarm_in_us (alarm_pool_t *pool, uint64_t us, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called after a delay specified in microseconds. More...
- `static alarm_id_t alarm_pool_add_alarm_in_ms (alarm_pool_t *pool, uint32_t ms, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called after a delay specified in milliseconds. More...
- `bool alarm_pool_cancel_alarm (alarm_pool_t *pool, alarm_id_t alarm_id)`
  Cancel an alarm. More...
- `static alarm_id_t add_alarm_at (absolute_time_t time, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called at a specific time. More...
- `static alarm_id_t add_alarm_in_us (uint64_t us, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called after a delay specified in microseconds. More...
- `static alarm_id_t add_alarm_in_ms (uint32_t ms, alarm_callback_t callback, void *user_data, bool fire_if_past)`
  Add an alarm callback to be called after a delay specified in milliseconds. More...
- `static bool cancel_alarm (alarm_id_t alarm_id)`
  Cancel an alarm from the default alarm pool. More...

3.16. Timer Functions

Utility methods for setting up repeating timers.

NOTE

The regular *alarm_* functionality can be used to make repeating alarms (by return non zero from the callback), however these methods abstract that further (at the cost of a user structure to store the repeat delay in (which the alarm framework does not have space for).

3.16.1. Typedefs

- `typedef bool(* repeating_timer_callback_t )(repeating_timer_t *rt)`
  Callback for a repeating timer. More...

3.16.2. Functions

- `bool alarm_pool_add_repeating_timer_us (alarm_pool_t *pool, int64_t delay_us, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)`
  Add a repeating timer that is called repeatedly at the specified interval in microseconds. More...
- `static bool alarm_pool_add_repeating_timer_ms (alarm_pool_t *pool, int32_t delay_ms, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)`
  Add a repeating timer that is called repeatedly at the specified interval in milliseconds. More...
- `static bool add_repeating_timer_us (int64_t delay_us, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)`
  Add a repeating timer that is called repeatedly at the specified interval in microseconds. More...
- `static bool add_repeating_timer_ms (int32_t delay_ms, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)`
  Add a repeating timer that is called repeatedly at the specified interval in milliseconds. More...
- `bool cancel_repeating_timer (repeating_timer_t *timer)`
  Cancel a repeating timer. More...

3.16.3. Detailed Description

API for accurate timestamps, sleeping, and receiving delayed callbacks.

NOTE

The functions defined here provide a much more powerful and user friendly wrapping around the low level hardware timer functionality. For these functions (and any other Pico SDK functionality e.g. timeouts, that relies on them) to work correctly, the hardware timer should not be modified. i.e. it is expected to be monotonically increasing once per microsecond. Fortunately there is no need to modify the hardware timer as any functionality you can think of that isn't already covered here can easily be modeled by adding or subtracting a constant value from the unmodified hardware timer.

See also

- Hardware timer API

3.17. Memory Mapped Hardware Register Access

This file defines the low level types and access functions for memory mapped hardware registers. More...

3.17.1. Functions

- `static void hw_set_bits (io_rw_32 *addr, uint32_t mask)`
  Atomically set the specified bits to 1 in a HW register. More...
- `static void hw_clear_bits (io_rw_32 *addr, uint32_t mask)`
  Atomically clear the specified bits to 0 in a HW register. More...
- `static void hw_xor_bits (io_rw_32 *addr, uint32_t mask)`
  Atomically flip the specified bits in a HW register. More...
- `static void hw_write_field (io_rw_32 *addr, uint32_t values, uint32_t write_mask)`
  Set new values for a sub-set of the bits in a HW register. More...

3.17.2. Detailed Description

This file defines the low level types and access functions for memory mapped hardware registers.

The types register access typedefs codify the access type (read/write) and the bus size (8/16/32) of the hardware register. The register type names are formed by concatenating one from each of the 3 parts A, B, C

A	B	C	Meaning
io_			A Memory mapped IO register
	ro_		read-only access
	rw_		read-write access
	wo_		write-only access (can't actually be enforced via C API)
		8	8-bit wide access
		16	16-bit wide access
		32	32-bit wide access

When dealing with these types, you will always using a pointer, i.e. io_rw_32 *some_reg is a pointer to a read/write 32 bit register that you can write with *some_reg = value, or read with value = *some_reg.

RP2040 hardware is also aliased to provide atomic setting, clear or flipping of a subset of the bits within a hardware register so that concurrent access by two cores is always consistent with one atomic operation being performed first, followed by the second.

See hw_set_bits(), hw_clear_bits() and hw_xor_bits() provide for atomic access via a pointer to a 32 bit register

Additionally given a pointer to a structure representing a piece of hardware (e.g. dma_hw_t *dma_hw for the DMA controller), you can get an alias to the entire structure such that writing any member (register) within the structure is equivalent to an atomic operation via hw_set_alias(), hw_clear_alias() or hw_xor_alias()...

For example hw_set_alias(dma_hw)→inte1 = 0x80; will set bit 7 of the INTE1 register of the DMA controller, leaving the other bits unchanged.

3.17.3. Function Documentation

3.17.3.1. hw_clear_bits

```
static void hw_clear_bits (io_rw_32 *addr,
      uint32_t mask)
```

Atomically clear the specified bits to 0 in a HW register.

Parameters

- `addr` Address of writable register
- `mask` Bit-mask specifying bits to clear

3.17.3.2. hw_set_bits

```
static void hw_set_bits (io_rw_32 *addr,
       uint32_t mask)
```

Atomically set the specified bits to 1 in a HW register.

Parameters

- `addr` Address of writable register
- `mask` Bit-mask specifying bits to set

3.17.3.3. hw_write_field

```
static void hw_write_field (io_rw_32 *addr,
       uint32_t values,
       uint32_t write_mask)
```

Set new values for a sub-set of the bits in a HW register.

Sets destination bits to values specified in `values`, if and only if corresponding bit in `write_mask` is set

Note: this method allows safe concurrent modification of bits of a register, but multiple concurrent access to the same bits is still unsafe.

Parameters

- `addr` Address of writable register
- `values` Bits values
- `write_mask` Mask of bits to change

3.17.3.4. hw_xor_bits

```
static void hw_xor_bits (io_rw_32 *addr,
       uint32_t mask)
```

Atomically flip the specified bits in a HW register.

Parameters

- `addr` Address of writable register
- `mask` Bit-mask specifying bits to invert

3.18. Lightweight Hardware Claiming API

3.18.1. Functions

- `uint32_t hw_claim_lock ()`
  Claim a HW spinlock todo not true. More...

3.18.2. Function Documentation

3.18.2.1. hw_claim_lock

`uint32_t hw_claim_lock ()`

Claim a HW spinlock todo not true.

Use this when you need to access HW exclusively

3.19. Hardware Divider API

The SIO contains an 8-cycle signed/unsigned divide/modulo circuit, per core. Calculation is started by writing a dividend and divisor to the two argument registers, DIVIDEND and DIVISOR. The divider calculates the quotient / and remainder % of this division over the next 8 cycles, and on the 9th cycle the results can be read from the two result registers DIV_QUOTIENT and DIV_REMAINDER. A 'ready' bit in register DIV_CSR can be polled to wait for the calculation to complete, or software can insert a fixed 8-cycle delay. More...

3.19.1. Functions

- `static void __hw_div_s32_start (int32_t a, int32_t b)`
  Start a signed asynchronous divide. More...
- `static void __hw_div_u32_start (uint32_t a, uint32_t b)`
  Start an unsigned asynchronous divide. More...
- `static void __hw_div_wait_ready ()`
  Wait for a divide to complete. More...
- `static hw_div_result_t __hw_div_result_nowait ()`
  Return result of HW divide, nowait. More...
- `static hw_div_result_t __hw_div_result_wait ()`
  Return result of last asynchronous HW divide. More...
- `static uint32_t __hw_div_u32_quotient_wait ()`
  Return result of last asynchronous HW divide, unsigned quotient only. More...
- `static int32_t __hw_div_s32_quotient_wait ()`
  Return result of last asynchronous HW divide, signed quotient only. More...
- `static uint32_t __hw_div_u32_remainder_wait ()`
  Return result of last asynchronous HW divide, unsigned remainder only. More...
- `static int32_t __hw_div_s32_remainder_wait ()`
  Return result of last asynchronous HW divide, signed remainder only. More...
- `hw_div_result_t __hw_div_s32 (int32_t a, int32_t b)`
  Do a signed HW divide and wait for result. More...
- `hw_div_result_t __hw_div_u32 (uint32_t a, uint32_t b)`
  Do an unsigned HW divide and wait for result. More...
- `static uint32_t quotient_u32 (hw_div_result_t r)`
  Efficient extraction of unsigned quotient from 32p32 fixed point. More...
- `static int32_t quotient_s32 (hw_div_result_t r)`
  Efficient extraction of signed quotient from 32p32 fixed point. More...
- `static uint32_t remainder_u32 (hw_div_result_t r)`
  Efficient extraction of unsigned remainder from 32p32 fixed point. More...

- `static int32_t remainder_s32 (hw_div_result_t r)`
  Efficient extraction of signed remainder from 32p32 fixed point. More...
- `static uint32_t __hw_div_u32_quotient (uint32_t a, uint32_t b)`
  Do an unsigned HW divide, wait for result, return quotient. More...
- `static uint32_t __hw_div_u32_remainder (uint32_t a, uint32_t b)`
  Do an unsigned HW divide, wait for result, return remainder. More...
- `static int32_t __hw_div_quotient_s32 (int32_t a, int32_t b)`
  Do a signed HW divide, wait for result, return quotient. More...
- `static int32_t __hw_div_remainder_s32 (int32_t a, int32_t b)`
  Do a signed HW divide, wait for result, return remainder. More...
- `static void __hw_div_pause ()`
  Pause for exact amount of time needed for a asynchronous divide to complete.
- `static uint32_t __hw_div_u32_quotient_inlined (uint32_t a, uint32_t b)`
  Do a hardware unsigned HW divide, wait for result, return quotient. More...
- `static uint32_t __hw_div_u32_remainder_inlined (uint32_t a, uint32_t b)`
  Do a hardware unsigned HW divide, wait for result, return remainder. More...
- `static int32_t __hw_div_s32_quotient_inlined (int32_t a, int32_t b)`
  Do a hardware signed HW divide, wait for result, return quotient. More...
- `static int32_t __hw_div_s32_remainder_inlined (int32_t a, int32_t b)`
  Do a hardware signed HW divide, wait for result, return remainder. More...

3.19.2. Detailed Description

The SIO contains an 8-cycle signed/unsigned divide/modulo circuit, per core. Calculation is started by writing a dividend and divisor to the two argument registers, DIVIDEND and DIVISOR. The divider calculates the quotient / and remainder % of this division over the next 8 cycles, and on the 9th cycle the results can be read from the two result registers DIV_QUOTIENT and DIV_REMAINDER. A 'ready' bit in register DIV_CSR can be polled to wait for the calculation to complete, or software can insert a fixed 8-cycle delay.

This header provides low level macros and inline functions for accessing the hardware dividers directly, and perhaps most usefully peforming asynchronous divides. These functions however do not follow the regular Pico SDK conventions for saving/restoring the divder state, so are not generally safe to call from interrupt handlers

The pico_divider library (and pico/divider.h) provide a more user friendly set of APIs over the divider (and support for 64 bit divides), and of course by default regular C language integer divisions are redirected thru that library.

That standard functions to use will be the *hw_div() and* hw_udiv(), although if you just need the quotient, *hw_signed_quotient() or perhaps* hw_signed_quotient_inlined() or their unsigned equivilents could be used.

3.19.3. Function Documentation

3.19.3.1. __hw_div_pause

```
static void __hw_div_pause ()
```

Pause for exact amount of time needed for a asynchronous divide to complete.

3.19.3.2. __hw_div_quotient_s32

```
static int32_t __hw_div_quotient_s32 (int32_t a,
       int32_t b)
```

Do a signed HW divide, wait for result, return quotient.

Divide `a` by `b`, wait for calculation to complete, return quotient.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Quotient results of the divide

3.19.3.3. __hw_div_remainder_s32

```
static int32_t __hw_div_remainder_s32 (int32_t a,
       int32_t b)
```

Do a signed HW divide, wait for result, return remainder.

Divide `a` by `b`, wait for calculation to complete, return remainder.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Remainder results of the divide

3.19.3.4. __hw_div_result_nowait

```
static hw_div_result_t __hw_div_result_nowait ()
```

Return result of HW divide, nowait.

Note, this is UNSAFE in that the calculation may not have been completed.

Returns

- Current result. Most significant 32 bits are the remainder, lower 32 bits are the quotient.

3.19.3.5. __hw_div_result_wait

```
static hw_div_result_t __hw_div_result_wait ()
```

Return result of last asynchronous HW divide.

This function waits for the result to be ready by calling `__hw_div_wait_ready()`.

Returns

- Current result. Most significant 32 bits are the remainder, lower 32 bits are the quotient.

3.19.3.6. __hw_div_s32

```
hw_div_result_t __hw_div_s32 (int32_t a,
       int32_t b)
```

Do a signed HW divide and wait for result.

Divide `a` by `b`, wait for calculation to complete, return result as a fixed point 32p32 value.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Results of divide as a 32p32 fixed point value.

3.19.3.7. __hw_div_s32_quotient_inlined

```
static int32_t __hw_div_s32_quotient_inlined (int32_t a,
       int32_t b)
```

Do a hardware signed HW divide, wait for result, return quotient.

Divide `a` by `b`, wait for calculation to complete, return quotient.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Quotient result of the divide

3.19.3.8. __hw_div_s32_quotient_wait

```
static int32_t __hw_div_s32_quotient_wait ()
```

Return result of last asynchronous HW divide, signed quotient only.

This function waits for the result to be ready by calling `__hw_div_wait_ready()`.

Returns

- Current signed quotient result.

3.19.3.9. __hw_div_s32_remainder_inlined

```
static int32_t __hw_div_s32_remainder_inlined (int32_t a,
       int32_t b)
```

Do a hardware signed HW divide, wait for result, return remainder.

Divide `a` by `b`, wait for calculation to complete, return remainder.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Remainder result of the divide

3.19.3.10. __hw_div_s32_remainder_wait

```
static int32_t __hw_div_s32_remainder_wait ()
```

Return result of last asynchronous HW divide, signed remainder only.

This function waits for the result to be ready by calling `__hw_div_wait_ready()`.

Returns

- Current remainder results.

3.19.3.11. __hw_div_s32_start

```
static void __hw_div_s32_start (int32_t a,
       int32_t b)
```

Start a signed asynchronous divide.

Start a divide of the specified signed parameters. You should wait for 8 cycles (*div_pause()) or wait for the ready bit to be set (hw_div_wait_ready()*) prior to reading the results.

Parameters

- `a` The dividend
- `b` The divisor

3.19.3.12. __hw_div_u32

```
hw_div_result_t __hw_div_u32 (uint32_t a,
       uint32_t b)
```

Do an unsigned HW divide and wait for result.

Divide `a` by `b`, wait for calculation to complete, return result as a fixed point 32p32 value.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Results of divide as a 32p32 fixed point value.

3.19.3.13. __hw_div_u32_quotient

```
static uint32_t __hw_div_u32_quotient (uint32_t a,
       uint32_t b)
```

Do an unsigned HW divide, wait for result, return quotient.

Divide `a` by `b`, wait for calculation to complete, return quotient.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Quotient results of the divide

3.19.3.14. __hw_div_u32_quotient_inlined

```
static uint32_t __hw_div_u32_quotient_inlined (uint32_t a,
       uint32_t b)
```

Do a hardware unsigned HW divide, wait for result, return quotient.

Divide `a` by `b`, wait for calculation to complete, return quotient.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Quotient result of the divide

3.19.3.15. __hw_div_u32_quotient_wait

```
static uint32_t __hw_div_u32_quotient_wait ()
```

Return result of last asynchronous HW divide, unsigned quotient only.

This function waits for the result to be ready by calling `__hw_div_wait_ready()`.

Returns

- Current unsigned quotient result.

3.19.3.16. __hw_div_u32_remainder

```
static uint32_t __hw_div_u32_remainder (uint32_t a,
       uint32_t b)
```

Do an unsigned HW divide, wait for result, return remainder.

Divide `a` by `b`, wait for calculation to complete, return remainder.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Remainder results of the divide

3.19.3.17. __hw_div_u32_remainder_inlined

```
static uint32_t __hw_div_u32_remainder_inlined (uint32_t a,
       uint32_t b)
```

Do a hardware unsigned HW divide, wait for result, return remainder.

Divide `a` by `b`, wait for calculation to complete, return remainder.

Parameters

- `a` The dividend
- `b` The divisor

Returns

- Remainder result of the dividearm

3.19.3.18. __hw_div_u32_remainder_wait

```
static uint32_t __hw_div_u32_remainder_wait ()
```

Return result of last asynchronous HW divide, unsigned remainder only.

This function waits for the result to be ready by calling `__hw_div_wait_ready()`.

Returns

- Current unsigned remainder result.

3.19.3.19. __hw_div_u32_start

```
static void __hw_div_u32_start (uint32_t a,
      uint32_t b)
```

Start an unsigned asynchronous divide.

Start a divide of the specified unsigned parameters. You should wait for 8 cycles (*div_pause()) or wait for the ready bit to be set (hw_div_wait_ready()*) prior to reading the results.

Parameters

- `a` The dividend
- `b` The divisor

3.19.3.20. __hw_div_wait_ready

```
static void __hw_div_wait_ready ()
```

Wait for a divide to complete.

Wait for a divide to complete

3.19.3.21. quotient_s32

```
static int32_t quotient_s32 (hw_div_result_t r)
```

Efficient extraction of signed quotient from 32p32 fixed point.

Parameters

- `r` 32p32 fixed point value.

Returns

- Unsigned quotient

3.19.3.22. quotient_u32

```
static uint32_t quotient_u32 (hw_div_result_t r)
```

Efficient extraction of unsigned quotient from 32p32 fixed point.

Parameters

- `r` 32p32 fixed point value.

Returns

- Unsigned quotient

3.19.3.23. remainder_s32

```
static int32_t remainder_s32 (hw_div_result_t r)
```

Efficient extraction of signed remainder from 32p32 fixed point.

Note on arm this is just a 32 bit register move or a nop

Parameters

- `r` 32p32 fixed point value.

Returns

- Signed remainder

3.19.3.24. remainder_u32

```
static uint32_t remainder_u32 (hw_div_result_t r)
```

Efficient extraction of unsigned remainder from 32p32 fixed point.

Note on Arm this is just a 32 bit register move or a nop

Parameters

- `r` 32p32 fixed point value.

Returns

- Unsigned remainder

3.20. hardware_dma: DMA Hardware API

The RP2040 Direct Memory Access (DMA) master performs bulk data transfers on a processor's behalf. This leaves processors free to attend to other tasks, or enter low-power sleep states. The data throughput of the DMA is also significantly higher than one of RP2040's processors. More...

3.20.1. Modules

- `DMA Channel Configuration`
  Functions for modifying DMA channel configurations.

3.20.2. Enumerations

- `enum dma_channel_transfer_size { DMA_SIZE_8 = 0, DMA_SIZE_16 = 1, DMA_SIZE_32 = 2 }`
  Enumeration of available DMA channel transfer sizes. More...

3.20.3. Functions

- `void dma_channel_claim (uint channel)`
  Mark a dma channel as used. More...
- `void dma_claim_mask (uint32_t channel_mask)`
  Mark multiple dma channels as used. More...
- `void dma_channel_unclaim (uint channel)`
  Mark a dma channel as no longer used. More...
- `static uint32_t get_ctrl_value (const dma_channel_config *config)`
  Get the raw configuration register from a channel configuration. More...
- `static void dma_set_config (uint channel, const dma_channel_config *config, bool trigger)`
  Set a channel configuration. More...
- `static void dma_set_read_addr (uint channel, const volatile void *read_addr, bool trigger)`
  Set the DMA initial read address. More...
- `static void dma_set_write_addr (uint channel, volatile void *write_addr, bool trigger)`
  Set the DMA initial read address. More...
- `static void dma_set_trans_count (uint channel, uint32_t trans_count, bool trigger)`
  Set the number of bus transfers the channel will do. More...

- `static void dma_configure (uint channel, const dma_channel_config *config, volatile void *write_addr, const volatile void *read_addr, uint transfer_count, bool trigger)`
  Configure all DMA parameters and optional start transfer. More...
- `static void dma_transfer_from_buffer_now (uint channel, void *read_addr, uint32_t transfer_count)`
  Start a DMA transfer from a buffer immediately. More...
- `static void dma_transfer_to_buffer_now (uint channel, void *write_addr, uint32_t transfer_count)`
  Start a DMA transfer to a buffer immediately. More...
- `static void dma_start_multiple (uint32_t chan_mask)`
  Start one or more channels simultaneously. More...
- `static void dma_start (uint channel)`
  Start a single DMA channel. More...
- `static void dma_abort (uint channel)`
  Stop a DMA transfer. More...
- `static void dma_enable_irq0 (uint channel, bool enable)`
  Enable single DMA channel interrupt 0. More...
- `static void dma_enable_irq0_mask (uint32_t channel_mask, bool enable)`
  Enable multiple DMA channels interrupt 0. More...
- `static void dma_enable_irq1 (uint channel, bool enable)`
  Enable single DMA channel interrupt 1. More...
- `static bool dma_busy (uint channel)`
  Check if DMA channel is busy. More...
- `static void dma_wait_for_finish_blocking (uint channel)`
  Wait for a DMA channel transfer to complete. More...
- `static void dma_enable_sniffer (uint channel, uint mode, bool set_ctrl)`
  Enable the DMA sniffer. More...
- `static void dma_enable_sniffer_byte_swap (bool swap)`
  Enable the Sniffer byte swap function. More...
- `static void dma_disable_sniffer ()`
  Disable the DMA sniffer.

3.20.4. Detailed Description

The RP2040 Direct Memory Access (DMA) master performs bulk data transfers on a processor's behalf. This leaves processors free to attend to other tasks, or enter low-power sleep states. The data throughput of the DMA is also significantly higher than one of RP2040's processors.

The DMA can perform one read access and one write access, up to 32 bits in size, every clock cycle. There are 12 independent channels, which each supervise a sequence of bus transfers, usually in one of the following scenarios:

- Memory to peripheral
- Peripheral to memory
- Memory to memory

3.20.5. Function Documentation

3.20.5.1. dma_abort

```
static void dma_abort (uint channel)
```

Stop a DMA transfer.

Function will only return once the DMA has stopped.

Parameters

- `channel` DMA channel

3.20.5.2. dma_busy

```
static bool dma_busy (uint channel)
```

Check if DMA channel is busy.

Parameters

- `channel` DMA channel

Returns

- true if the channel is currently busy

3.20.5.3. dma_channel_claim

```
void dma_channel_claim (uint channel)
```

Mark a dma channel as used.

Method for cooperative claiming of hardware. Will cause a panic if the channel is already claimed. Use of this method by libraries detects accidental configurations that would fail in unpredictable ways.

Parameters

- `channel` the dma channel

3.20.5.4. dma_channel_unclaim

```
void dma_channel_unclaim (uint channel)
```

Mark a dma channel as no longer used.

Method for cooperative claiming of hardware.

Parameters

- `channel` the dma channel to release

3.20.5.5. dma_claim_mask

```
void dma_claim_mask (uint32_t channel_mask)
```

Mark multiple dma channels as used.

Method for cooperative claiming of hardware. Will cause a panic if any of the channels are already claimed. Use of this method by libraries detects accidental configurations that would fail in unpredictable ways.

Parameters

- `channel_mask` Bitfield of all required channels to claim (bit 0 == channel 0, bit 1 == channel 1 etc)

3.20.5.6. dma_configure

```
static void dma_configure (uint channel,
       const dma_channel_config *config,
       volatile void *write_addr,
       const volatile void *read_addr,
       uint transfer_count,
       bool trigger)
```

Configure all DMA parameters and optional start transfer.

Parameters

- `channel` DMA channel
- `config` Pointer to DMA config structure
- `write_addr` Initial write address
- `read_addr` Initial read address
- `transfer_count` Number of transfers to perform
- `trigger` True to start the transfer immediately

3.20.5.7. dma_disable_sniffer

```
static void dma_disable_sniffer ()
```

Disable the DMA sniffer.

3.20.5.8. dma_enable_irq0

```
static void dma_enable_irq0 (uint channel,
       bool enable)
```

Enable single DMA channel interrupt 0.

Parameters

- `channel` DMA channel
- `enable` true to enable interrupt 0 on specified channel, false to disable.

3.20.5.9. dma_enable_irq0_mask

```
static void dma_enable_irq0_mask (uint32_t channel_mask,
       bool enable)
```

Enable multiple DMA channels interrupt 0.

#TO DO: #

Parameters

- `channel_mask` Bitmask of all the channels to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- `enable`

3.20.5.10. dma_enable_irq1

```
static void dma_enable_irq1 (uint channel,
       bool enable)
```

Enable single DMA channel interrupt 1.

Parameters

- `channel` DMA channel
- `enable` true to enable interrupt 1 on specified channel, false to disable.

3.20.5.11. dma_enable_sniffer

```
static void dma_enable_sniffer (uint channel,
       uint mode,
       bool set_ctrl)
```

Enable the DMA sniffer.

The mode can be one of the following:

0x0 → Calculate a CRC-32 (IEEE802.3 polynomial) 0x1 → Calculate a CRC-32 (IEEE802.3 polynomial) with bit reversed data 0x2 → Calculate a CRC-16-CCITT 0x3 → Calculate a CRC-16-CCITT with bit reversed data 0xe → XOR reduction over all data. == 1 if the total 1 population count is odd. 0xf → Calculate a simple 32-bit checksum (addition with a 32 bit accumulator)

TO DO: Needs more explanation

Parameters

- `channel` DMA channel
- `mode` See description
- `set_ctrl` Set true to give channel access

3.20.5.12. dma_enable_sniffer_byte_swap

```
static void dma_enable_sniffer_byte_swap (bool swap)
```

Enable the Sniffer byte swap function.

Locally perform a byte reverse on the sniffed data, before feeding into checksum.

Note that the sniff hardware is downstream of the DMA channel byteswap performed in the read master: if `dma_config_bswap()` and `dma_enable_sniffer_byte_swap()` are both enabled, their effects cancel from the sniffer's point of view.

Parameters

- `swap` Set true to enable byte swapping

3.20.5.13. dma_set_config

```
static void dma_set_config (uint channel,
       const dma_channel_config *config,
       bool trigger)
```

Set a channel configuration.

Parameters

- `channel` DMA channel
- `config` Pointer to a config structure with required configuration
- `trigger` True to trigger the transfer immediately

3.20.5.14. dma_set_read_addr

```
static void dma_set_read_addr (uint channel,
       const volatile void *read_addr,
       bool trigger)
```

Set the DMA initial read address.

Parameters

- `channel` DMA channel
- `read_addr` Initial read address of transfer.
- `trigger` True to start the transfer immediately

3.20.5.15. dma_set_trans_count

```
static void dma_set_trans_count (uint channel,
       uint32_t trans_count,
       bool trigger)
```

Set the number of bus transfers the channel will do.

Parameters

- `channel` DMA channel
- `trans_count` The number of transfers (not NOT bytes, see dma_config_transfer_data_size)
- `trigger` True to start the transfer immediately

3.20.5.16. dma_set_write_addr

```
static void dma_set_write_addr (uint channel,
       volatile void *write_addr,
       bool trigger)
```

Set the DMA initial read address.

Parameters

- `channel` DMA channel
- `write_addr` Initial write address of transfer.
- `trigger` True to start the transfer immediately

3.20.5.17. dma_start

```
static void dma_start (uint channel)
```

Start a single DMA channel.

Parameters

- `channel` DMA channel

3.20.5.18. dma_start_multiple

```
static void dma_start_multiple (uint32_t chan_mask)
```

Start one or more channels simultaneously.

Parameters

- `chan_mask` Bitmask of all the channels requiring starting. Channel 0 = bit 0, channel 1 = bit 1 etc.

3.20.5.19. dma_transfer_from_buffer_now

```
static void dma_transfer_from_buffer_now (uint channel,
       void *read_addr,
       uint32_t transfer_count)
```

Start a DMA transfer from a buffer immediately.

Parameters

- `channel` DMA channel
- `read_addr` Sets the initial read address
- `transfer_count` Number of transfers to make. Not bytes, but the number of transfers of dma_config_transfer_data_size() to be sent.

3.20.5.20. dma_transfer_to_buffer_now

```
static void dma_transfer_to_buffer_now (uint channel,
       void *write_addr,
       uint32_t transfer_count)
```

Start a DMA transfer to a buffer immediately.

Parameters

- `channel` DMA channel
- `write_addr` Sets the initial write address
- `transfer_count` Number of transfers to make. Not bytes, but the number of transfers of dma_config_transfer_data_size() to be sent.

3.20.5.21. dma_wait_for_finish_blocking

```
static void dma_wait_for_finish_blocking (uint channel)
```

Wait for a DMA channel transfer to complete.

Parameters

- `channel` DMA channel

3.20.5.22. get_ctrl_value

```
static uint32_t get_ctrl_value (const dma_channel_config *config)
```

Get the raw configuration register from a channel configuration.

Parameters

- `config` Pointer to a config structure.

Returns

- Register content

3.21. DMA Channel Configuration

Functions for modifying DMA channel configurations. More...

3.21.1. Functions

- `static void dma_config_read_increment (dma_channel_config *c, bool incr)`
  Set DMA channel read increment. More...
- `static void dma_config_write_increment (dma_channel_config *c, bool incr)`
  Set DMA channel write increment. More...
- `static void dma_config_dreq (dma_channel_config *c, uint dreq)`
  Select a transfer request signal. More...
- `static void dma_config_chain_to (dma_channel_config *c, uint chain_to)`
  Set DMA channel completion channel. More...
- `static void dma_config_transfer_data_size (dma_channel_config *c, enum dma_channel_transfer_size size)`
  Set the size of each DMA bus transfer. More...
- `static void dma_config_ring (dma_channel_config *c, bool write, uint size_bits)`
  Set address wrapping parameters. More...
- `static void dma_config_bswap (dma_channel_config *c, bool bswap)`
  Set DMA byte swapping. More...
- `static void dma_config_irq_quiet (dma_channel_config *c, bool irq_quiet)`
  Set IRQ quiet mode. More...
- `static void dma_config_enabled (dma_channel_config *c, bool enabled)`
  Enable a DMA channel. More...
- `static void dma_config_sniff_enabled (dma_channel_config *c, bool sniff_enabled)`
  Enable access to channel by sniff hardware. More...
- `static dma_channel_config dma_channel_default_config (uint channel)`
  Set a channel to default DMA settings. More...
- `static dma_channel_config dma_get_config (uint channel)`
  Get the current configuration for the specified channel. More...

3.21.2. Detailed Description

Functions for modifying DMA channel configurations.

A DMA channel needs to be configured, these functions provide handy helpers to set up configuration structures. See dma_channel_config

3.21.3. Function Documentation

3.21.3.1. dma_channel_default_config

`static dma_channel_config dma_channel_default_config (uint channel)`

Set a channel to default DMA settings.

Setting	Default
Read Increment	true

Setting	Default
Write Increment	false
DReq	Force
Chain to	0
Data size	32 bits
ring	false
byte swap	false
Quiet IRQs	false
Channel enable	true
Sniff	false

Parameters

- `channel` DMA channel

3.21.3.2. dma_config_bswap

```
static void dma_config_bswap (dma_channel_config *c,
       bool bswap)
```

Set DMA byte swapping.

No effect for byte data, for halfword data, the two bytes of each halfword are swapped. For word data, the four bytes of each word are swapped to reverse their order.

Parameters

- `c` Pointer to channel configuration data
- `bswap` True to enable byte swapping

3.21.3.3. dma_config_chain_to

```
static void dma_config_chain_to (dma_channel_config *c,
       uint chain_to)
```

Set DMA channel completion channel.

When this channel completes, it will trigger the channel indicated by chain_to. Disable by setting chain_to to itself (the same channel)

Parameters

- `c` Pointer to channel configuration data
- `chain_to` Channel to trigger when this channel completes.

3.21.3.4. dma_config_dreq

```
static void dma_config_dreq (dma_channel_config *c,
       uint dreq)
```

Select a transfer request signal.

The channel uses the transfer request signal to pace its data transfer rate. Sources for TREQ signals are internal (TIMERS) or external (DREQ, a Data Request from the system). 0x0 to 0x3a → select DREQ n as TREQ 0x3b → Select Timer 0 as TREQ 0x3c → Select Timer 1 as TREQ 0x3d → Select Timer 2 as TREQ (Optional) 0x3e → Select Timer 3 as

TREQ (Optional) 0x3f → Permanent request, for unpaced transfers.

Parameters

- `c` Pointer to channel configuration data
- `dreq` Source (see description)

3.21.3.5. dma_config_enabled

```
static void dma_config_enabled (dma_channel_config *c,
       bool enabled)
```

Enable a DMA channel.

When false, the channel will ignore triggers, stop issuing transfers, and pause the current transfer sequence (i.e. BUSY will remain high if already high)

Parameters

- `c` Pointer to channel configuration data
- `enabled` True to enable the DMA channel. Channel will respond to triggering events, and start transferring data.

3.21.3.6. dma_config_irq_quiet

```
static void dma_config_irq_quiet (dma_channel_config *c,
       bool irq_quiet)
```

Set IRQ quiet mode.

In QUIET mode, the channel does not generate IRQs at the end of every transfer block. Instead, an IRQ is raised when NULL is written to a trigger register, indicating the end of a control block chain.

Parameters

- `c` Pointer to channel configuration data
- `irq_quiet` True to enable quiet mode, false to disable.

3.21.3.7. dma_config_read_increment

```
static void dma_config_read_increment (dma_channel_config *c,
       bool incr)
```

Set DMA channel read increment.

Parameters

- `c` Pointer to channel configuration data
- `incr` True to enable read address increments, if false, each read will be from the same address Usually disabled for peripheral to memory transfers

3.21.3.8. dma_config_ring

```
static void dma_config_ring (dma_channel_config *c,
       bool write,
       uint size_bits)
```

Set address wrapping parameters.

Size of address wrap region. If 0, don't wrap. For values n > 0, only the lower n bits of the address will change. This wraps the address on a (1 << n) byte boundary, facilitating access to naturally-aligned ring buffers. Ring sizes between 2 and 32768 bytes are possible (size_bits from 1 - 15)

0x0 → No wrapping.

Parameters

- `c` Pointer to channel configuration data
- `write` True to apply to write addresses, false to apply to read addresses
- `size_bits` 0 to disable wrapping. Otherwise the size in bits of the changing part of the address. Effectively wraps the address on a (1 << size_bits) byte boundary.

3.21.3.9. dma_config_sniff_enabled

```
static void dma_config_sniff_enabled (dma_channel_config *c,
       bool sniff_enabled)
```

Enable access to channel by sniff hardware.

Sniff HW must be enabled and have this channel selected.

Parameters

- `c` Pointer to channel configuration data
- `sniff_enabled` True to enable the Sniff HW access to this DMA channel.

3.21.3.10. dma_config_transfer_data_size

```
static void dma_config_transfer_data_size (dma_channel_config *c,
       enum dma_channel_transfer_size size)
```

Set the size of each DMA bus transfer.

Set the size of each bus transfer (byte/halfword/word). The read and write addresses advance by the specific amount (1/2/4 bytes) with each transfer.

Parameters

- `c` Pointer to channel configuration data
- `size` See enum for possible values.

3.21.3.11. dma_config_write_increment

```
static void dma_config_write_increment (dma_channel_config *c,
       bool incr)
```

Set DMA channel write increment.

Parameters

- `c` Pointer to channel configuration data
- `incr` True to enable write address increments, if false, each write will be to the same address Usually disabled for memory to peripheral transfers Usually disabled for memory to peripheral transfers

3.21.3.12. dma_get_config

```
static dma_channel_config dma_get_config (uint channel)
```

Get the current configuration for the specified channel.

Parameters

- `channel` DMA channel

Returns

- The current configuration as read from the HW register (not cached)

3.22. Flash helpers

Functions for calling the flash programming/erase functions in the ROM. More...

3.22.1. Functions

- `void flash_range_erase (uint32_t flash_offs, size_t count)`
  Erase areas of flash. More...
- `void flash_range_program (uint32_t flash_offs, const uint8_t *data, size_t count)`
  Program flash. More...

3.22.2. Detailed Description

Functions for calling the flash programming/erase functions in the ROM.

Note these functions are *unsafe* if you have two cores concurrently executing from flash. In this case you must perform your own synchronisation to make sure no XIP accesses take place during flash programming.

If PICO_NO_FLASH=1 is not defined (i.e. if the program is built to run from flash) then these functions will make a static copy of the second stage bootloader in SRAM, and use this to reenter execute-in-place mode after programming or erasing flash, so that they can safely be called from flash-resident code.

Example

```
#include <stdio.h>
#include <stdlib.h>

#include "pico/stdlib.h"
#include "hardware/flash.h"

// We're going to erase and reprogram a region 256k from the start of flash.
// Once done, we can access this at XIP_BASE + 256k.
#define FLASH_TARGET_OFFSET (256 * 1024)

const uint8_t *flash_target_contents = (const uint8_t *) (XIP_BASE +
FLASH_TARGET_OFFSET);

void print_buf(const uint8_t *buf, size_t len) {
    for (size_t i = 0; i < len; ++i) {
        printf("%02x", buf[i]);
        if (i % 16 == 15)
            printf("\n");
        else
            printf(" ");
    }
}

int main() {
    setup_default_uart();
    uint8_t random_data[FLASH_PAGE_SIZE];
    for (int i = 0; i < FLASH_PAGE_SIZE; ++i)
```

```
27          random_data[i] = rand() >> 16;
28
29      printf("Generated random data:\n");
30      print_buf(random_data, FLASH_PAGE_SIZE);
31
32      // Note that a whole number of sectors must be erased at a time.
33      printf("\nErasing target region...\n");
34      flash_range_erase(FLASH_TARGET_OFFSET, FLASH_SECTOR_SIZE);
35      printf("Done. Read back target region:\n");
36      print_buf(flash_target_contents, FLASH_PAGE_SIZE);
37
38      printf("\nProgramming target region...\n");
39      flash_range_program(FLASH_TARGET_OFFSET, random_data, FLASH_PAGE_SIZE);
40      printf("Done. Read back target region:\n");
41      print_buf(flash_target_contents, FLASH_PAGE_SIZE);
42
43      bool mismatch = false;
44      for (int i = 0; i < FLASH_PAGE_SIZE; ++i) {
45          if (random_data[i] != flash_target_contents[i])
46              mismatch = true;
47      }
48      if (mismatch)
49          printf("Programming failed!\n");
50      else
51          printf("Programming successful!\n");
52  }
```

3.22.3. Function Documentation

3.22.3.1. flash_range_erase

```
void flash_range_erase (uint32_t flash_offs,
      size_t count)
```

Erase areas of flash.

Parameters

- `flash_offs` Offset into flash, in bytes, to start the erase. Must be aligned to a 4096-byte flash sector.
- `count` Number of bytes to be erased. Must be a multiple of 4096 bytes (one sector).

3.22.3.2. flash_range_program

```
void flash_range_program (uint32_t flash_offs,
      const uint8_t *data,
      size_t count)
```

Program flash.

Parameters

- `flash_offs` Flash address of the first byte to be programmed. Must be aligned to a 256-byte flash page.
- `data` Pointer to the data to program into flash
- `count` Number of bytes to program. Must be a multiple of 256 bytes (one page).

3.23. Hardware GPIO API

RP2040 has 36 multi-functional General Purpose Input / Output (GPIO) pins, divided into two banks. In a typical use case, the pins in the QSPI bank (QSPI_SS, QSPI_SCLK and QSPI_SD0 to QSPI_SD3) are used to execute code from an external flash device, leaving the User bank (GPIO0 to GPIO29) for the programmer to use. All GPIOs support digital input and output, but GPIO26 to GPIO29 can also be used as inputs to the chip's Analogue to Digital Converter (ADC). Each GPIO can be controlled directly by software running on the processors, or by a number of other functional blocks. More...

3.23.1. Modules

- `GPIO Selectors`
  GPIO function definitions for use with function select.
- `GPIO Interrupt levels`
  GPIO Interrupt level definitions.
- `GPIO Overrides`
  GPIO Override definitions.

3.23.2. Functions

- `void gpio_funcsel (uint i, uint fn)`
  Select GPIO function. More...
- `void gpio_pull_up (uint i)`
  Set specified GPIO to be pulled up. More...
- `void gpio_pull_down (uint i)`
  Set specified GPIO to be pulled down. More...
- `void gpio_disable_pulls (uint i)`
  Disable pulls on specified GPIO. More...
- `void gpio_set_pulls (uint i, bool up, bool down)`
  Select up and down pulls on specific GPIO. More...
- `void gpio_outover (uint i, int value)`
  Set GPIO output override. More...
- `void gpio_inover (uint i, int value)`
  Select GPIO input override. More...
- `void gpio_oeover (uint i, int value)`
  Select GPIO output enable override. More...
- `void gpio_input_enable (uint i, bool enable)`
  Enable GPIO input. More...
- `void gpio_irq_enable (uint gpio, uint32_t events, bool enable)`
  Enable interrupts for specified GPIO. More...
- `void gpio_irq_enable_with_callback (uint gpio, uint32_t events, bool enable, gpio_irq_callback_t callback)`
  Enable interrupts for specified GPIO. More...
- `void gpio_dormant_irq_enable (uint gpio, uint32_t events, bool enable)`
  Enable dormant wake up interrupt for specified GPIO. More...
- `void gpio_irq_acknowledge (uint gpio, uint32_t events)`
  Acknowldege a GPIO interrupt. More...
- `static void gpio_init (uint gpio)`
  Configure a GPIO. More...

- `static int gpio_get (uint gpio)`
  Get state of a single specified GPIO. More...
- `static uint32_t gpio_get_all ()`
  Get raw value of all GPIOs. More...
- `static void gpio_set_mask (uint32_t mask)`
  Drive high every GPIO appearing in mask. More...
- `static void gpio_clr_mask (uint32_t mask)`
  Drive low every GPIO appearing in mask. More...
- `static void gpio_xor_mask (uint32_t mask)`
  Toggle every GPIO appearing in mask. More...
- `static void gpio_put_mask (uint32_t mask, uint32_t value)`
  Drive GPIO high/low depending on parameters. More...
- `static void gpio_put_all (uint32_t value)`
  Drive all pins simultaneously. More...
- `static void gpio_put (uint gpio, bool value)`
  Drive a single GPIO high/low. More...
- `static void gpio_dir_out_mask (uint32_t mask)`
  Set a number of GPIOs to output. More...
- `static void gpio_dir_in_mask (uint32_t mask)`
  Set a number of GPIOs to input. More...
- `static void gpio_dir_mask (uint32_t mask, uint32_t value)`
  Set multiple GPIO directions. More...
- `static void gpio_dir_all (uint32_t value)`
  Set direction of all pins simultaneously. More...
- `static void gpio_dir (uint gpio, int dir)`
  Set a single GPIO direction. More...

3.23.3. Detailed Description

RP2040 has 36 multi-functional General Purpose Input / Output (GPIO) pins, divided into two banks. In a typical use case, the pins in the QSPI bank (QSPI_SS, QSPI_SCLK and QSPI_SD0 to QSPI_SD3) are used to execute code from an external flash device, leaving the User bank (GPIO0 to GPIO29) for the programmer to use. All GPIOs support digital input and output, but GPIO26 to GPIO29 can also be used as inputs to the chip's Analogue to Digital Converter (ADC). Each GPIO can be controlled directly by software running on the processors, or by a number of other functional blocks.

The function allocated to each GPIO is selected by calling the * gpio_funcsel function. Note that not all functions are available on all pins. Please refer to the datsheet for more information on GPIO function select.

3.23.4. Function Documentation

3.23.4.1. gpio_clr_mask

`static void gpio_clr_mask (uint32_t mask)`

Drive low every GPIO appearing in mask.

Parameters

- `mask` Bitmask of GPIO values to clear, as bits 0-29

3.23.4.2. gpio_dir

```
static void gpio_dir (uint gpio,
      int dir)
```

Set a single GPIO direction.

Parameters

- `gpio` GPIO number
- `dir` 1 = out, 0 = in

3.23.4.3. gpio_dir_all

```
static void gpio_dir_all (uint32_t value)
```

Set direction of all pins simultaneously.

Parameters

- `value` For each bit in value, 1 = out, 0 = in

3.23.4.4. gpio_dir_in_mask

```
static void gpio_dir_in_mask (uint32_t mask)
```

Set a number of GPIOs to input.

Parameters

- `mask` Bitmask of GPIO to set to input, as bits 0-29

3.23.4.5. gpio_dir_mask

```
static void gpio_dir_mask (uint32_t mask,
      uint32_t value)
```

Set multiple GPIO directions.

For each 1 bit in "mask", switch that pin to the direction given by corresponding bit in "value", leaving other pins unchanged. E.g. gpio_dir_mask(0x3, 0x2); → set pin 0 to input, pin 1 to output, simultaneously.

Parameters

- `mask` Bitmask of GPIO to set to input, as bits 0-29
- `value` Values to set

3.23.4.6. gpio_dir_out_mask

```
static void gpio_dir_out_mask (uint32_t mask)
```

Set a number of GPIOs to output.

Switch all GPIOs in "mask" to output

Parameters

- `mask` Bitmask of GPIO to set to output, as bits 0-29

3.23.4.7. gpio_disable_pulls

```
void gpio_disable_pulls (uint i)
```

Disable pulls on specified GPIO.

Parameters

- `i` GPIO number

3.23.4.8. gpio_dormant_irq_enable

```
void gpio_dormant_irq_enable (uint gpio,
      uint32_t events,
      bool enable)
```

Enable dormant wake up interrupt for specified GPIO.

This configures IRQs to restart the XOSC or ROSC when they are disabled in dormant mode

Parameters

- `gpio` GPIO number
- `events`
- `enable`

3.23.4.9. gpio_funcsel

```
void gpio_funcsel (uint i,
      uint fn)
```

Select GPIO function.

Parameters

- `i` GPIO number
- `fn` Which GPIO function select to use from list GPIO Selectors

3.23.4.10. gpio_get

```
static int gpio_get (uint gpio)
```

Get state of a single specified GPIO.

Parameters

- `gpio` GPIO number

Returns

- Current state of the GPIO. 0 for low, non-zero for high

3.23.4.11. gpio_get_all

```
static uint32_t gpio_get_all ()
```

Get raw value of all GPIOs.

Returns

- Bitmask of raw GPIO values, as bits 0-29

3.23.4.12. gpio_init

```
static void gpio_init (uint gpio)
```

Configure a GPIO.

Configure a GPIO for direct input/output from this processor TO DO: not entirely sure what this is for

Parameters

- `gpio` GPIO number

3.23.4.13. gpio_inover

```
void gpio_inover (uint i,
      int value)
```

Select GPIO input override.

Parameters

- `i` GPIO number
- `value` See GPIO Overrides

3.23.4.14. gpio_input_enable

```
void gpio_input_enable (uint i,
      bool enable)
```

Enable GPIO input.

Parameters

- `i` GPIO number
- `enable` true to enable input on specified GPIO

3.23.4.15. gpio_irq_acknowledge

```
void gpio_irq_acknowledge (uint gpio,
      uint32_t events)
```

Acknowldege a GPIO interrupt.

bit	interrupt
0	Low level
1	high level
2	edge low
3	edge high

Parameters

- `gpio` GPIO number
- `events` Bitmask of events to clear. 4 bit value as follows:

3.23.4.16. gpio_irq_enable

```
void gpio_irq_enable (uint gpio,
      uint32_t events,
      bool enable)
```

Enable interrupts for specified GPIO.

Note the IO IRQs are independent per-processor. This configures IRQs for the processor that calls the function.

Parameters

- `gpio` GPIO number
- `events`
- `enable`

3.23.4.17. gpio_irq_enable_with_callback

```
void gpio_irq_enable_with_callback (uint gpio,
       uint32_t events,
       bool enable,
       gpio_irq_callback_t callback)
```

Enable interrupts for specified GPIO.

Note the IO IRQs are independent per-processor. This configures IRQs for the processor that calls the function.

TO DO: we should either move the callback from this API (as it currently doesn't apply to the gpio being set), or make it do that.

Parameters

- `gpio` GPIO number
- `events`
- `enable`
- `callback` user function to call on GPIO irq. Note only one of these can be set per processor.

3.23.4.18. gpio_oeover

```
void gpio_oeover (uint i,
       int value)
```

Select GPIO output enable override.

Parameters

- `i` GPIO number
- `value` See GPIO Overrides

3.23.4.19. gpio_outover

```
void gpio_outover (uint i,
       int value)
```

Set GPIO output override.

Parameters

- `i` GPIO number
- `value` See GPIO Overrides

3.23.4.20. gpio_pull_down

```
void gpio_pull_down (uint i)
```

Set specified GPIO to be pulled down.

Parameters

- `i` GPIO number

3.23.4.21. gpio_pull_up

```
void gpio_pull_up (uint i)
```

Set specified GPIO to be pulled up.

Parameters

- `i` GPIO number

3.23.4.22. gpio_put

```
static void gpio_put (uint gpio,
       bool value)
```

Drive a single GPIO high/low.

Parameters

- `gpio` GPIO number
- `value` If 0 clear the GPIO, if non-zero set it.

3.23.4.23. gpio_put_all

```
static void gpio_put_all (uint32_t value)
```

Drive all pins simultaneously.

Parameters

- `value` Bitmask of GPIO values to change, as bits 0-29

3.23.4.24. gpio_put_mask

```
static void gpio_put_mask (uint32_t mask,
       uint32_t value)
```

Drive GPIO high/low depending on parameters.

For each 1 bit in `mask`, drive that pin to the value given by corresponding bit in `value`, leaving other pins unchanged. Since this uses the TOGL alias, it is concurrency-safe with e.g. an IRQ bashing different pins from the same core.

Parameters

- `mask` Bitmask of GPIO values to change, as bits 0-29
- `value` Value to set

3.23.4.25. gpio_set_mask

```
static void gpio_set_mask (uint32_t mask)
```

Drive high every GPIO appearing in mask.

Parameters

- `mask` Bitmask of GPIO values to set, as bits 0-29

3.23.4.26. gpio_set_pulls

```
void gpio_set_pulls (uint i,
       bool up,
       bool down)
```

Select up and down pulls on specific GPIO.

Note that, on RP2040, setting both pulls enables a "bus keep" function, i.e. weak pull to whatever is current high/low state of GPIO. #TO DO: #

Parameters

- `i` GPIO number
- `up`
- `down`

3.23.4.27. gpio_xor_mask

```
static void gpio_xor_mask (uint32_t mask)
```

Toggle every GPIO appearing in mask.

Parameters

- `mask` Bitmask of GPIO values to toggle, as bits 0-29

3.24. GPIO Selectors

GPIO function definitions for use with function select. More...

3.24.1. Macros

- `#define GPIO_FUNC_XIP 0`
- `#define GPIO_FUNC_SPI 1`
- `#define GPIO_FUNC_UART 2`
- `#define GPIO_FUNC_I2C 3`
- `#define GPIO_FUNC_PWM 4`
- `#define GPIO_FUNC_PROC 5`
- `#define GPIO_FUNC_PIO0 6`
- `#define GPIO_FUNC_PIO1 7`
- `#define GPIO_FUNC_GPCK 8`
- `#define GPIO_FUNC_USB 9`
- `#define GPIO_FUNC_NULL 0x1f`

3.24.2. Detailed Description

GPIO function definitions for use with function select.

Each GPIO can have one function selected at a time. Likewise, each peripheral input (e.g. UART0 RX) should only be selected on one GPIO at a time. If the same peripheral input is connected to multiple GPIOs, the peripheral sees the logical OR of these GPIO inputs.

Please refer to the datsheet for more information on GPIO function selection.

3.25. GPIO Interrupt levels

GPIO Interrupt level definitions. More...

3.25.1. Macros

- `#define GPIO_IRQ_LEVEL_LOW 0x1u`
- `#define GPIO_IRQ_LEVEL_HIGH 0x2u`
- `#define GPIO_IRQ_EDGE_FALL 0x4u`
- `#define GPIO_IRQ_EDGE_RISE 0x8u`

3.25.2. Detailed Description

GPIO Interrupt level definitions.

An interrupt can be generated for every GPIO pin in 4 scenarios:

- Level High: the GPIO pin is a logical 1 • Level Low: the GPIO pin is a logical 0 • Edge High: the GPIO has transitioned from a logical 0 to a logical 1 • Edge Low: the GPIO has transitioned from a logical 1 to a logical 0

The level interrupts are not latched. This means that if the pin is a logical 1 and the level high interrupt is active, it will become inactive as soon as the pin changes to a logical 0. The edge interrupts are stored in the INTR register and can be cleared by writing to the INTR register.

3.26. GPIO Overrides

GPIO Override definitions. More...

3.26.1. Macros

- `#define GPIO_OVERRIDE_NORMAL 0`
  peripheral signal selected via gpio_funcsel
- `#define GPIO_OVERRIDE_INVERT 1`
  invert peripheral signal selected via gpio_funcsel
- `#define GPIO_OVERRIDE_LOW 2`
  drive low/disable output
- `#define GPIO_OVERRIDE_HIGH 3`
  drive high/enable output

3.26.2. Detailed Description

GPIO Override definitions.

3.27. Hardware I2C API

The I2C bus is a two-wire serial interface, consisting of a serial data line SDA and a serial clock SCL. These wires carry information between the devices connected to the bus. Each device is recognized by a unique address and can operate as either a “transmitter” or “receiver”, depending on the function of the device. Devices can also be considered as masters or

slaves when performing data transfers. A master is a device that initiates a data transfer on the bus and generates the clock signals to permit that transfer. At that time, any device addressed is considered a slave. More...

3.27.1. Functions

- `void i2c_init (i2c_inst_t *i2c, uint baudrate)`
  Initialise the I2C HW block. More...
- `void i2c_deinit (i2c_inst_t *i2c)`
  Disable the I2C HW block. More...
- `uint i2c_set_baudrate (i2c_inst_t *i2c, uint baudrate)`
  Set I2C baudrate. More...
- `void i2c_set_slave_mode (i2c_inst_t *i2c, bool slave, uint8_t addr)`
  Set I2C port to slave mode. More...
- `static uint i2c_hw_index (i2c_inst_t *i2c)`
  Convert I2c instance to hardware instance number. More...
- `int i2c_write_blocking_until (i2c_inst_t *i2c, uint8_t addr, const uint8_t *src, size_t len, bool nostop, absolute_time_t until)`
  Attempt to write specified number of bytes to address, blocking until the specified absolute time is reached. More...
- `int i2c_read_blocking_until (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop, absolute_time_t until)`
  Attempt to write specified number of bytes to address, blocking until the specified absolute time is reached. More...
- `static int i2c_write_timeout_us (i2c_inst_t *i2c, uint8_t addr, const uint8_t *src, size_t len, bool nostop, uint timeout_us)`
  Attempt to read specified number of bytes from address, with timeout. More...
- `static int i2c_read_timeout_us (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop, uint timeout_us)`
  Attempt to read specified number of bytes from address, with timeout. More...
- `static int i2c_write_blocking (i2c_inst_t *i2c, uint8_t addr, const uint8_t *src, size_t len, bool nostop)`
  Attempt to write specified number of bytes to address, blocking. More...
- `static int i2c_read_blocking (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop)`
  Attempt to read specified number of bytes from address, blocking. More...
- `static size_t i2c_writable (i2c_inst_t *i2c)`
  Determine non-blocking write space. More...
- `static size_t i2c_readable (i2c_inst_t *i2c)`
  Determine number of bytes received. More...
- `static void i2c_write_raw_blocking (i2c_inst_t *i2c, const uint8_t *src, size_t len)`
  Write direct to TX FIFO. More...
- `static void i2c_read_raw_blocking (i2c_inst_t *i2c, uint8_t *dst, size_t len)`
  Write direct to TX FIFO. More...

3.27.2. Variables

- `i2c_inst_t i2c0_inst` More...

3.27.3. Detailed Description

The I2C bus is a two-wire serial interface, consisting of a serial data line SDA and a serial clock SCL. These wires carry information between the devices connected to the bus. Each device is recognized by a unique address and can operate as

either a “transmitter” or “receiver”, depending on the function of the device. Devices can also be considered as masters or slaves when performing data transfers. A master is a device that initiates a data transfer on the bus and generates the clock signals to permit that transfer. At that time, any device addressed is considered a slave.

This API allows the controller to be set up as a master or a slave using the * i2c_set_slave_mode function.

The external pins of each controller are connected to GPIO pins as defined in the GPIO muxing table in the datasheet. The muxing options give some IO flexibility, but each controller external pin should be connected to only one GPIO.

Note that the controller does NOT support High speed mode or Ultra-fast speed mode, the fastest operation being fast mode plus at up to 1000Kb/s.

See the datasheet for more information on the I2C controller and its usage.

I2C Bus scan example code

```
// Sweep through all 7-bit I2C addresses, to see if any slaves are present on
// the I2C bus. Print out a table that looks like this:
//
// I2C Bus Scan
//   0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
// 0
// 1       @
// 2
// 3             @
// 4
// 5
// 6
// 7
//
// E.g. if slave addresses 0x12 and 0x34 were acknowledged.

#include <stdio.h>
#include "pico/stdlib.h"
#include "hardware/i2c.h"

// I2C reserves some addresses for special purposes. We exclude these from the
scan.
// These are any addresses of the form 000 0xxx or 111 1xxx
bool reserved_addr(uint8_t addr) {
    return (addr & 0x78) == 0 || (addr & 0x78) == 0x78;
}

int main()
{
    // Enable UART so we can print status output
    setup_default_uart();

    // This example will use I2C0 on GPIO4 (SDA) and GPIO5 (SCL)
    i2c_init(i2c0, 100*1000);
    gpio_funcsel(4, GPIO_FUNC_I2C);
    gpio_funcsel(5, GPIO_FUNC_I2C);
    gpio_pull_up(4);
    gpio_pull_up(5);

    printf("\nI2C Bus Scan\n");
    printf("   0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F\n");

```

```
42     for (int addr = 0; addr < (1 << 7); ++addr) {
43         if (addr % 16 == 0) {
44             printf("%02x ", addr);
45         }
46
47         // Perform a 1-byte dummy read from the probe address. If a slave
48         // acknowledges this address, the function returns the number of bytes
49         // transferred. If the address byte is ignored, the function returns
50         // -1.
51
52         // Skip over any reserved addresses.
53         int bytes_transferred;
54         uint8_t rxdata;
55         if (reserved_addr(addr))
56             bytes_transferred = -1;
57         else
58             bytes_transferred = i2c_read_blocking(i2c0, addr, &rxdata, 1,
   false);
59
60         printf(bytes_transferred == -1 ? "." : "@");
61         printf(addr % 16 == 15 ? "\n" : "  ");
62     }
63     printf("Done.\n");
64     return 0;
65 }
```

3.27.4. Function Documentation

3.27.4.1. i2c_deinit

`void i2c_deinit (i2c_inst_t *i2c)`

Disable the I2C HW block.

Disable the I2C again if it is no longer used. Must be reinitialised before being used again.

Parameters

- `i2c` Either i2c0 or i2c1

3.27.4.2. i2c_hw_index

`static uint i2c_hw_index (i2c_inst_t *i2c)`

Convert I2c instance to hardware instance number.

Parameters

- `i2c` I2C instance

Returns

- Number of UART, 0 or 1.

3.27.4.3. i2c_init

```
void i2c_init (i2c_inst_t *i2c,
       uint baudrate)
```

Initialise the I2C HW block.

Put the I2C hardware into a known state, and enable it. Must be called before other functions. By default, the I2C is configured to operate as a master.

Parameters

- `i2c` Either i2c0 or i2c1
- `baudrate` Baudrate in Hz (e.g. 100Khz is 100000)

3.27.4.4. i2c_read_blocking

```
static int i2c_read_blocking (i2c_inst_t *i2c,
       uint8_t addr,
       uint8_t *dst,
       size_t len,
       bool nostop)
```

Attempt to read specified number of bytes from address, blocking.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `dst` Pointer to buffer to receive data
- `len` Length of data in bytes to receive
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.

Returns

- Number of bytes read, or PICO_ERROR_GENERIC if address not acknowledged, no device present.

3.27.4.5. i2c_read_blocking_until

```
int i2c_read_blocking_until (i2c_inst_t *i2c,
       uint8_t addr,
       uint8_t *dst,
       size_t len,
       bool nostop,
       absolute_time_t until)
```

Attempt to write specified number of bytes to address, blocking until the specified absolute time is reached.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `src` Pointer to data to send
- `len` Length of data in bytes to send
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.

- `until` The time that the block will wait until the entire transaction is complete. Note, an individual timeout of this value divided by the length of data is applied for each byte transfer, so if the first or subsequent bytes is not received within that sub timeout, the function will return with an error.

Returns

- Number of bytes written, or PICO_ERROR_GENERIC if address not acknowledged, no device present, or PICO_ERROR_TIMEOUT if a timeout occured.

3.27.4.6. i2c_read_raw_blocking

```
static void i2c_read_raw_blocking (i2c_inst_t *i2c,
       uint8_t *dst,
       size_t len)
```

Write direct to TX FIFO.

Reads directly from the I2C RX FIFO which us mainly useful for slave-mode operation.

Parameters

- `i2c` Either i2c0 or i2c1
- `dst` Buffer to accept data
- `len` Number of bytes to send

3.27.4.7. i2c_read_timeout_us

```
static int i2c_read_timeout_us (i2c_inst_t *i2c,
       uint8_t addr,
       uint8_t *dst,
       size_t len,
       bool nostop,
       uint timeout_us)
```

Attempt to read specified number of bytes from address, with timeout.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `dst` Pointer to buffer to receive data
- `len` Length of data in bytes to receive
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.
- `timeout_us` The time that the function will wait for the entire transaction to complete

Returns

- Number of bytes read, or PICO_ERROR_GENERIC if address not acknowledged, no device present, or PICO_ERROR_TIMEOUT if a timeout occured.

3.27.4.8. i2c_readable

```
static size_t i2c_readable (i2c_inst_t *i2c)
```

Determine number of bytes received.

Parameters

- `i2c` Either i2c0 or i2c1

Returns

- 0 if no data available, if return is nonzero at least that many bytes can be read without blocking.

3.27.4.9. i2c_set_baudrate

```
uint i2c_set_baudrate (i2c_inst_t *i2c,
       uint baudrate)
```

Set I2C baudrate.

Set I2C bus frequency as close as possible to requested, and return actual rate set. Baudrate may not be as exactly requested due to clocking limitations.

Parameters

- `i2c` Either i2c0 or i2c1
- `baudrate` Baudrate in Hz (e.g. 100Khz is 100000)

Returns

- Actual set baudrate

3.27.4.10. i2c_set_slave_mode

```
void i2c_set_slave_mode (i2c_inst_t *i2c,
       bool slave,
       uint8_t addr)
```

Set I2C port to slave mode.

Parameters

- `i2c` Either i2c0 or i2c1
- `slave` true to use slave mode, false to use master mode
- `addr` If slave is true, set the slave address to this value

3.27.4.11. i2c_writable

```
static size_t i2c_writable (i2c_inst_t *i2c)
```

Determine non-blocking write space.

Parameters

- `i2c` Either i2c0 or i2c1

Returns

- 0 if no space is available in the I2C to write more data. If return is nonzero, at least that many bytes can be written without blocking.

3.27.4.12. i2c_write_blocking

```
static int i2c_write_blocking (i2c_inst_t *i2c,
       uint8_t addr,
       const uint8_t *src,
       size_t len,
       bool nostop)
```

Attempt to write specified number of bytes to address, blocking.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `src` Pointer to data to send
- `len` Length of data in bytes to send
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.

Returns

- Number of bytes written, or PICO_ERROR_GENERIC if address not acknowledged, no device present.

3.27.4.13. i2c_write_blocking_until

```
int i2c_write_blocking_until (i2c_inst_t *i2c,
       uint8_t addr,
       const uint8_t *src,
       size_t len,
       bool nostop,
       absolute_time_t until)
```

Attempt to write specified number of bytes to address, blocking until the specified absolute time is reached.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `src` Pointer to data to send
- `len` Length of data in bytes to send
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.
- `until` The absolute time that the block will wait until the entire transaction is complete. Note, an individual timeout of this value divided by the length of data is applied for each byte transfer, so if the first or subsequent bytes fails to transfer within that sub timeout, the function will return with an error.

Returns

- Number of bytes written, or PICO_ERROR_GENERIC if address not acknowledged, no device present, or PICO_ERROR_TIMEOUT if a timeout occured.

3.27.4.14. i2c_write_raw_blocking

```
static void i2c_write_raw_blocking (i2c_inst_t *i2c,
       const uint8_t *src,
       size_t len)
```

Write direct to TX FIFO.

Writes directly to the to I2C TX FIFO which us mainly useful for slave-mode operation.

Parameters

- `i2c` Either i2c0 or i2c1
- `src` Data to send

- `len` Number of bytes to send

3.27.4.15. i2c_write_timeout_us

```
static int i2c_write_timeout_us (i2c_inst_t *i2c,
       uint8_t addr,
       const uint8_t *src,
       size_t len,
       bool nostop,
       uint timeout_us)
```

Attempt to read specified number of bytes from address, with timeout.

Parameters

- `i2c` Either i2c0 or i2c1
- `addr` Address of device to write to
- `dst` Pointer to buffer to receive data
- `len` Length of data in bytes to receive
- `nostop` If true, master retains control of the bus at the end of the transfer (no Stop is issued), and the next transfer will begin with a Restart rather than a Start.
- `timeout_us` The time that the function will wait for the entire transaction to complete.

Returns

- Number of bytes written, or PICO_ERROR_GENERIC if address not acknowledged, no device present, or PICO_ERROR_TIMEOUT if a timeout occured.

3.28. Hardware interpolator API

Each core is equipped with two interpolators (INTERP0 and INTERP1) which can be used to accelerate tasks by combining certain pre-configured simple operations into a single processor cycle. Intended for cases where the pre-configured operation is repeated a large number of times, this results in code which uses both fewer CPU cycles and fewer CPU registers in the time critical sections of the code. More...

3.28.1. Functions

- `void interp_claim (INTERP interp, uint lane)`
  Claim the interpolator lane specified. More...
- `void interp_claim_mask (INTERP interp, uint lane_mask)`
  Claim the interpolator lanes specified in the mask. More...
- `void interp_unclaim (INTERP interp, uint lane)`
  Release a previously claimed interpolator lane. More...
- `static void interp_config_shift (interp_config *c, uint shift)`
  Set the interpolator shift value. More...
- `static void interp_config_mask (interp_config *c, uint mask_lsb, uint mask_msb)`
  Set the interpolator mask range. More...
- `static void interp_config_cross_input (interp_config *c, bool cross_input)`
  Enable cross input. More...
- `static void interp_config_cross_result (interp_config *c, bool cross_result)`
  Enable cross results. More...

- `static void interp_config_signed (interp_config *c, bool _signed)`
  Set sign extension. More...
- `static void interp_config_add_raw (interp_config *c, bool add_raw)`
  Set raw add option. More...
- `static void interp_config_blend (interp_config *c, bool blend)`
  Set blend mode. More...
- `static void interp_config_clamp (interp_config *c, bool clamp)`
  Set interpolator clamp mode (Interpolator 1 only) More...
- `static void interp_config_force_bits (interp_config *c, uint bits)`
  Set interpolator Force bits. More...
- `static interp_config interp_default_config ()`
  Get a default configuration. More...
- `static void interp_set_config (INTERP interp, uint lane, interp_config *config)`
  Send configuration to a lane. More...
- `static void interp_add_force_bits (INTERP interp, uint lane, uint bits)`
  Directly set the force bits on a specified lane. More...
- `void interp_save (INTERP interp, interp_hw_save_t *saver)`
  Save the specified interpolator state. More...
- `void interp_restore (INTERP interp, interp_hw_save_t *saver)`
  Restore an interpolator state. More...
- `static void interp_set_base (INTERP interp, uint lane, uint32_t val)`
  Sets the interpolator base register by lane. More...
- `static uint32_t interp_get_base (INTERP interp, uint lane)`
  Gets the content of interpolator base register by lane. More...
- `static void interp_set_base_both (INTERP interp, uint32_t val)`
  Sets the interpolator base registers simultenously. More...
- `static void interp_set_accumulator (INTERP interp, uint lane, uint32_t val)`
  Sets the interpolator accumulator register by lane. More...
- `static uint32_t interp_get_accumulator (INTERP interp, uint lane)`
  Gets the content of the interpolator accumulator register by lane. More...
- `static uint32_t interp_pop_lane_result (INTERP interp, uint lane)`
  Read lane result, and write lane results to both accumulators to update the interpolator. More...
- `static uint32_t interp_peek_lane_result (INTERP interp, uint lane)`
  Read lane result. More...
- `static uint32_t interp_pop_full_result (INTERP interp)`
  Read lane result, and write lane results to both accumulators to update the interpolator. More...
- `static uint32_t interp_peek_full_result (INTERP interp)`
  Read lane result. More...
- `static void interp_add_accumulater (INTERP interp, uint lane, uint32_t val)`
  Add to accumulator. More...
- `static uint32_t interp_get_raw (INTERP interp, uint lane)`
  Get raw lane value. More...

3.28.2. Detailed Description

Each core is equipped with two interpolators (INTERP0 and INTERP1) which can be used to accelerate tasks by combining certain pre-configured simple operations into a single processor cycle. Intended for cases where the pre-configured operation is repeated a large number of times, this results in code which uses both fewer CPU cycles and fewer CPU registers in the time critical sections of the code.

The interpolators are used heavily to accelerate audio operations within the Pico SDK, but their flexible configuration make it possible to optimise many other tasks such as quantization and dithering, table lookup address generation, affine texture mapping, decompression and linear feedback.

Please refer to the RP2040 datasheet for more information on the HW interpolators and how they work.

3.28.3. Function Documentation

3.28.3.1. interp_add_accumulater

```
static void interp_add_accumulater (INTERP interp,
       uint lane,
       uint32_t val)
```

Add to accumulator.

Atomically add the specified value to the accumulator on the specified lane

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1
- `val` Value to add

Returns

- The content of the FULL register

3.28.3.2. interp_add_force_bits

```
static void interp_add_force_bits (INTERP interp,
       uint lane,
       uint bits)
```

Directly set the force bits on a specified lane.

These bits are ORed into bits 29:28 of the lane result presented to the processor on the bus. There is no effect on the internal 32-bit datapath.

Useful for using a lane to generate sequence of pointers into flash or SRAM, saving a subsequent OR or add operation.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane to set
- `bits` The bits to set (bits 0 and 1, value range 0-3)

3.28.3.3. interp_claim

```
void interp_claim (INTERP interp,
       uint lane)
```

Claim the interpolator lane specified.

Use this function to claim exclusive access to the specfied interpolator lane.

This function will panic if the lane is already claimed.

Parameters

- `interp` Interpolator on which to claim a lane. interp0 or interp1
- `lane` The lane number, 0 or 1.

3.28.3.4. interp_claim_mask

```
void interp_claim_mask (INTERP interp,
      uint lane_mask)
```

Claim the interpolator lanes specified in the mask.

Parameters

- `interp` Interpolator on which to claim lanes. interp0 or interp1
- `lane_mask` Bit pattern of lanes to claim (only bits 0 and 1 are valid)

3.28.3.5. interp_config_add_raw

```
static void interp_config_add_raw (interp_config *c,
      bool add_raw)
```

Set raw add option.

When enabled, mask + shift is bypassed for LANE0 result. This does not affect the FULL result.

Parameters

- `c` Pointer to interpolation config
- `add_raw` If true, enable raw add option.

3.28.3.6. interp_config_blend

```
static void interp_config_blend (interp_config *c,
      bool blend)
```

Set blend mode.

If enabled, LANE1 result is a linear interpolation between BASE0 and BASE1, controlled by the 8 LSBs of lane 1 shift and mask value (a fractional number between 0 and 255/256ths)

LANE0 result does not have BASE0 added (yields only the 8 LSBs of lane 1 shift+mask value)

FULL result does not have lane 1 shift+mask value added (BASE2 + lane 0 shift+mask)

LANE1 SIGNED flag controls whether the interpolation is signed or unsig

Parameters

- `c` Pointer to interpolation config
- `blend` Set true to enable blend mode.

3.28.3.7. interp_config_clamp

```
static void interp_config_clamp (interp_config *c,
      bool clamp)
```

Set interpolator clamp mode (Interpolator 1 only)

Only present on INTERP1 on each core. If CLAMP mode is enabled:

Parameters

- `c` Pointer to interpolation config
- `clamp` Set true to enable clamp mode

3.28.3.8. interp_config_cross_input

```
static void interp_config_cross_input (interp_config *c,
       bool cross_input)
```

Enable cross input.

Allows feeding of the accumulator content from the other lane back in to this lanes shift+mask hardware. This will take effect even if the interp_config_add_raw option is set as the cross input mux is before the shift+mask bypass

Parameters

- `c` Pointer to interpolation config
- `cross_input` If true, enable the cross input.

3.28.3.9. interp_config_cross_result

```
static void interp_config_cross_result (interp_config *c,
       bool cross_result)
```

Enable cross results.

Allows feeding of the other lane's result into this lane's accumulator on a POP operation.

Parameters

- `c` Pointer to interpolation config
- `cross_result` If true, enables the cross result

3.28.3.10. interp_config_force_bits

```
static void interp_config_force_bits (interp_config *c,
       uint bits)
```

Set interpolator Force bits.

ORed into bits 29:28 of the lane result presented to the processor on the bus.

No effect on the internal 32-bit datapath. Handy for using a lane to generate sequence of pointers into flash or SRAM

Parameters

- `c` Pointer to interpolation config
- `bits` Sets the force bits to that specified. Range 0-3 (two bits)

3.28.3.11. interp_config_mask

```
static void interp_config_mask (interp_config *c,
       uint mask_lsb,
       uint mask_msb)
```

Set the interpolator mask range.

Sets the range of bits (least to most) that are allowed to pass through the interpolator

Parameters

- `c` Pointer to interpolation config
- `mask_lsb` The least significant bit allowed to pass
- `mask_msb` The most significant bit allowed to pass

3.28.3.12. interp_config_shift

```
static void interp_config_shift (interp_config *c,
       uint shift)
```

Set the interpolator shift value.

Sets the number of bits the accumulator is shifted before masking, on each iteration.

Parameters

- `c` Pointer to an interpolator config
- `shift` Number of bits

3.28.3.13. interp_config_signed

```
static void interp_config_signed (interp_config *c,
       bool _signed)
```

Set sign extension.

Enables signed mode, where the shifted and masked accumulator value is sign-extended to 32 bits before adding to BASE1, and LANE1 PEEK/POP results appear extended to 32 bits when read by processor.

Parameters

- `c` Pointer to interpolation config
- `_signed` If true, enables sign extension

3.28.3.14. interp_default_config

```
static interp_config interp_default_config ()
```

Get a default configuration.

Returns

- A default interpolation configuration

3.28.3.15. interp_get_accumulator

```
static uint32_t interp_get_accumulator (INTERP interp,
       uint lane)
```

Gets the content of the interpolator accumulator register by lane.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1

Returns

- The current content of the register

3.28.3.16. interp_get_base

```
static uint32_t interp_get_base (INTERP interp,
      uint lane)
```

Gets the content of interpolator base register by lane.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1 or 2

Returns

- The current content of the lane base register

3.28.3.17. interp_get_raw

```
static uint32_t interp_get_raw (INTERP interp,
      uint lane)
```

Get raw lane value.

Returns the raw shift and mask value from the specified lane, BASE0 is NOT added

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1

Returns

- The raw shift/mask value

3.28.3.18. interp_peek_full_result

```
static uint32_t interp_peek_full_result (INTERP interp)
```

Read lane result.

Parameters

- `interp` Interpolator instance, interp0 or interp1.

Returns

- The content of the FULL register

3.28.3.19. interp_peek_lane_result

```
static uint32_t interp_peek_lane_result (INTERP interp,
      uint lane)
```

Read lane result.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1

Returns

- The content of the lane result register

3.28.3.20. interp_pop_full_result

```
static uint32_t interp_pop_full_result (INTERP interp)
```

Read lane result, and write lane results to both accumulators to update the interpolator.

Parameters

- `interp` Interpolator instance, interp0 or interp1.

Returns

- The content of the FULL register

3.28.3.21. interp_pop_lane_result

```
static uint32_t interp_pop_lane_result (INTERP interp,
       uint lane)
```

Read lane result, and write lane results to both accumulators to update the interpolator.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1

Returns

- The content of the lane result register

3.28.3.22. interp_restore

```
void interp_restore (INTERP interp,
       interp_hw_save_t *saver)
```

Restore an interpolator state.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `saver` Pointer to save structure to reapply to the specified interpolator

3.28.3.23. interp_save

```
void interp_save (INTERP interp,
       interp_hw_save_t *saver)
```

Save the specified interpolator state.

Can be used to save state if you need an interpolator for another purpose, state can then be recovered afterwards and continue from that point

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `saver` Pointer to the save structure to fill in

3.28.3.24. interp_set_accumulator

```
static void interp_set_accumulator (INTERP interp,
       uint lane,
       uint32_t val)
```

Sets the interpolator accumulator register by lane.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1
- `val` The value to apply to the register

3.28.3.25. interp_set_base

```
static void interp_set_base (INTERP interp,
       uint lane,
       uint32_t val)
```

Sets the interpolator base register by lane.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane number, 0 or 1 or 2
- `val` The value to apply to the register

3.28.3.26. interp_set_base_both

```
static void interp_set_base_both (INTERP interp,
       uint32_t val)
```

Sets the interpolator base registers simultenously.

The lower 16 bits go to BASE0, upper bits to BASE1 simultaneously. Each half is sign-extended to 32 bits if that lane's SIGNED flag is set.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `val` The value to apply to the register

3.28.3.27. interp_set_config

```
static void interp_set_config (INTERP interp,
       uint lane,
       interp_config *config)
```

Send configuration to a lane.

If an invalid configuration is specified (ie a lane specific item is set on wrong lane), depending on setup this function can panic.

Parameters

- `interp` Interpolator instance, interp0 or interp1.
- `lane` The lane to set
- `config` Pointer to interpolation config

3.28.3.28. interp_unclaim

```
void interp_unclaim (INTERP interp,
       uint lane)
```

Release a previously claimed interpolator lane.

Parameters

- `Interpolator` Interpolator on which to release a lane. interp0 or interp1
- `lane` The lane number, 0 or 1

3.29. hardware_irq: IRQ Hardware API

The RP2040 uses the standard ARM nested vectored interrupt controller (NVIC). More...

3.29.1. Typedefs

- `typedef void(* irq_handler_t )()`
  Interrupt handler function type. More...

3.29.2. Functions

- `void irq_set_priority (uint num, uint8_t hardware_priority)`
  Set specified interrupts priority. More...
- `void irq_enable (uint num, bool enable)`
  Enable or disable a specific interrupt on the executing core. More...
- `bool irq_is_enabled (uint num)`
  Determine if a specific interrupt is enabled on the executing core. More...
- `void irq_enable_mask (uint32_t mask, bool enable)`
  Enable/disable multiple interrupts on the executing core. More...
- `void irq_set_exclusive_handler (uint num, irq_handler_t handler)`
  Set an exclusive interrupt handler for an interrupt on the executing core. More...
- `void irq_add_shared_handler (uint num, irq_handler_t handler, uint8_t order_priority)`
  Add a shared interrupt handler for an interrupt on the executing core. More...
- `void irq_remove_handler (uint num, irq_handler_t handler)`
  Remove a specific interrupt handler for the given irq number on the executing core. More...
- `irq_handler_t irq_get_vtable_handler (uint num)`
  Get the current IRQ handler for the specified IRQ from the currently installed hardware vector table (VTOR) of the execution core. More...
- `static void irq_clear (uint int_num)`
  Clear a specific interrupt on the executing core. More...

3.29.3. Detailed Description

The RP2040 uses the standard ARM nested vectored interrupt controller (NVIC).

Interrupts are identified by a number from 0 to 31.

On the RP2040, only the lower 26 IRQ signals are connected on the NVIC; IRQs 26 to 31 are tied to zero (never firing).

There is one NVIC per core, and each core's NVIC has the same hardware interrupt lines routed to it, with the exception of the IO interrupts where there is one IO interrupt per bank, per core. These are completely independent, so for example, processor 0 can be interrupted by GPIO 0 in bank 0, and processor 1 by GPIO 1 in the same bank.

Note: That all IRQ APIs affect the executing core only (i.e. the core calling the function).

Note: You should not enable the same (shared) IRQ number on both cores, as this will lead to race conditions or

starvation of one of the cores. Additionally don't forget that disabling interrupts on one core does not disable interrupts on the other core.

There are three different ways to set handlers for an IRQ:

- Calling irq_add_shared_handler() at runtime to add a handler for a multiplexed interrupt (e.g. GPIO bank) on the current core. Each handler, should check and clear the relevant hardware interrupt source
- Calling irq_set_exclusive_handler() at runtime to install a single handler for the interrupt on the current core
- Defining the interrupt handler explicitly in your application (e.g. by defining void isr_dma_0 will make that function the handler for the DMA_IRQ_0 on core 0, and you will not be able to change it using the above APIs at runtime). Using this method can cause link conflicts at runtime, and offers no runtime performance benefit (i.e, it should not generally be used).

Note: If an IRQ is enabled and fires with no handler installed, a breakpoint will be hit and the IRQ number will be in r0.

Interrupt NumbersInterrupts are numbered as follows, a set of defines is available (intctrl.h) with these names to avoid using the numbers directly.

IRQ	Interrupt Source
0	TIMER_IRQ_0
1	TIMER_IRQ_1
2	TIMER_IRQ_2
3	TIMER_IRQ_3
4	PWM_IRQ_WRAP
5	USBCTRL_IRQ
6	XIP_IRQ
7	PIO0_IRQ_0
8	PIO0_IRQ_1
9	PIO1_IRQ_0
10	PIO1_IRQ_1
11	DMA_IRQ_0
12	DMA_IRQ_1
13	IO_IRQ_BANK0
14	IO_IRQ_BANK1
15	SIOB_IRQ_PROC0
16	SIOB_IRQ_PROC1
17	CLOCKS_IRQ_DEFAULT
18	SPI0_IRQ
19	SPI1_IRQ
20	UART0_IRQ
21	UART1_IRQ
22	ADC0_IRQ_FIFO
23	I2C0_IRQ
24	I2C1_IRQ

IRQ	Interrupt Source
25	RTC_IRQ

3.29.4. Function Documentation

3.29.4.1. irq_add_shared_handler

```
void irq_add_shared_handler (uint num,
       irq_handler_t handler,
       uint8_t order_priority)
```

Add a shared interrupt handler for an interrupt on the executing core.

Use this method to add a handler on an irq number shared between multiple distinct hardware sources (e.g. GPIO, DMA or PIO IRQs). Handlers added by this method will all be called in sequence from highest order_priority to lowest. The `irq_set_exclusive_handler()` method should be used instead if you know there will or should only ever be one handler for the interrupt.

This method will assert if there is an exclusive interrupt handler set for this irq number on this core, or if the (total across all IRQs on both cores) maximum (configurable via PICO_MAX_SHARED_IRQ_HANDLERS) number of shared handlers would be exceeded.

Parameters

- `num` Interrupt number
- `handler` The handler to set. See irq_handler_t
- `order_priority` The order priority controls the order that handlers for the same IRQ number on the core are called. The shared irq handlers for an interrupt are all called when an IRQ fires, however the order of the calls is based on the order_priority (higher priorities are called first, identical priorities are called in undefined order). A good rule of thumb is to use PICO_SHARED_IRQ_HANDLER_DEFAULT_ORDER_PRIORITY if you don't much care, as it is in the middle of the priority range by default.

See also

- irq_set_exclusive_handler

3.29.4.2. irq_clear

```
static void irq_clear (uint int_num)
```

Clear a specific interrupt on the executing core.

Parameters

- `int_num` Interrupt number Interrupt Numbers

3.29.4.3. irq_enable

```
void irq_enable (uint num,
       bool enable)
```

Enable or disable a specific interrupt on the executing core.

Parameters

- `num` Interrupt number Interrupt Numbers
- `enable` true to enable the interrupt, false to disable

3.29.4.4. irq_enable_mask

```
void irq_enable_mask (uint32_t mask,
      bool enable)
```

Enable/disable multiple interrupts on the executing core.

Parameters

- `mask` 32-bit mask with one bits set for the interrupts to enable/disable
- `enable` true to enable the interrupts, false to disable them.

3.29.4.5. irq_get_vtable_handler

```
irq_handler_t irq_get_vtable_handler (uint num)
```

Get the current IRQ handler for the specified IRQ from the currently installed hardware vector table (VTOR) of the execution core.

Parameters

- `num` Interrupt number Interrupt Numbers

Returns

- the address stored in the VTABLE for the given irq number

3.29.4.6. irq_is_enabled

```
bool irq_is_enabled (uint num)
```

Determine if a specific interrupt is enabled on the executing core.

Parameters

- `num` Interrupt number Interrupt Numbers
- `true` if the interrupt is enabled

3.29.4.7. irq_remove_handler

```
void irq_remove_handler (uint num,
      irq_handler_t handler)
```

Remove a specific interrupt handler for the given irq number on the executing core.

This method may be used to remove an irq set via either `irq_set_exclusive_handler()` or `irq_add_shared_handler()`, and will assert if the handler is not currently installed for the given IRQ number

Note: This method may be called from user (non IRQ code) or from within the handler itself (i.e. an IRQ handler may remove itself as part of handling the IRQ). Attempts to call from another IRQ will cause an assertion.

Parameters

- `num` Interrupt number Interrupt Numbers
- `handler` The handler to removed.

See also

- irq_set_exclusive_handler
- irq_add_shared_handler

3.29.4.8. irq_set_exclusive_handler

```
void irq_set_exclusive_handler (uint num,
      irq_handler_t handler)
```

Set an exclusive interrupt handler for an interrupt on the executing core.

Use this method to set a handler for single IRQ source interrupts, or when your code, use case or performance requirements dictate that there should no other handlers for the interrupt.

This method will assert if there is already any sort of interrupt handler installed for the specified irq number.

Parameters

- `num` Interrupt number Interrupt Numbers
- `handler` The handler to set. See irq_handler_t

See also

- irq_add_shared_handler

3.29.4.9. irq_set_priority

```
void irq_set_priority (uint num,
      uint8_t hardware_priority)
```

Set specified interrupts priority.

Parameters

- `num` Interrupt number
- `hardware_priority` Priority to set. Hardware priorities range from 0 (lowest) to 255 (highest) though only the top 2 bits are significant on ARM Cortex M0+. To make it easier to specify higher or lower priorities than the default, all IRQ priorities are initialized to PICO_DEFAULT_IRQ_PRIORITY by the SDK runtime at startup. PICO_DEFAULT_IRQ_PRIORITY defaults to 0x80

3.30. hardware_pio: Programmable (PIO) Hardware API

A programmable input/output block (PIO) is a versatile hardware interface which can support a number of different IO standards. There are two PIO blocks in the RP2040. More...

3.30.1. Modules

- `PIO Configuration`
  Functions for modifying PIO configurations.

3.30.2. Enumerations

- `enum pio_fifo_join { PIO_FIFO_JOIN_NONE = 0, PIO_FIFO_JOIN_TX = 1, PIO_FIFO_JOIN_RX = 2 }`
  FIFO join states.

3.30.3. Functions

- `static void pio_clear_fifo (PIO pio, uint sm)`
  Clear the specific PIO block's FIFO. More...
- `static void pio_set_config (PIO pio, uint sm, const pio_sm_config *config)` More...

- static uint pio_index (PIO pio) More...
- static void pio_gpio_select (PIO pio, uint pin) More...
- static uint pio_get_dreq (PIO pio, uint sm, bool tx) More...
- bool pio_can_add_program (PIO pio, const pio_program_t *program) More...
- bool pio_can_add_program_at_offset (PIO pio, const pio_program_t *program, uint offset) More...
- uint pio_add_program (PIO pio, const pio_program_t *program) More...
- void pio_add_program_at_offset (PIO pio, const pio_program_t *program, uint offset) More...
- void pio_remove_program (PIO pio, const pio_program_t *program, uint loaded_offset) More...
- void pio_sm_init (PIO pio, uint sm, uint offset, pio_sm_config *config) More...
- static void pio_sm_exec (PIO pio, uint sm, uint instr) More...
- static void pio_sm_enable (PIO pio, uint sm, bool enable) More...
- static void pio_sm_enable_mask (PIO pio, uint32_t mask, bool enable) More...
- static void pio_sm_restart (PIO pio, uint sm) More...
- static void pio_restart_mask (PIO pio, uint sm, uint32_t mask) More...
- static void pio_clkdiv_restart (PIO pio, uint sm) More...
- static void pio_clkdiv_restart_mask (PIO pio, uint32_t mask) More...
- static void pio_enable_in_sync_mask (PIO pio, uint32_t mask) More...
- static uint8_t pio_sm_getpc (PIO pio, uint sm) More...
- static bool pio_sm_exec_stalled (PIO pio, uint sm) More...
- static void pio_sm_exec_wait_blocking (PIO pio, uint sm, uint instr) More...
- static void pio_sm_set_wrap (PIO pio, uint sm, uint bottom, uint top) More...
- static void pio_put (PIO pio, uint sm, uint data) More...
- static uint32_t pio_get (PIO pio, uint sm) More...
- static int pio_rx_full (PIO pio, uint sm) More...
- static int pio_rx_empty (PIO pio, uint sm) More...
- static int pio_rx_level (PIO pio, uint sm) More...
- static int pio_tx_full (PIO pio, uint sm) More...
- static int pio_tx_empty (PIO pio, uint sm) More...
- static int pio_tx_level (PIO pio, uint sm) More...
- static void pio_put_blocking (PIO pio, uint sm, uint32_t data) More...
- static uint32_t pio_get_blocking (PIO pio, uint sm) More...
- void pio_drain_tx (PIO pio, uint sm) More...
- static void pio_set_clkdiv (PIO pio, uint sm, float div) More...
- static void pio_set_clkdiv_int_frac (PIO pio, uint sm, uint16_t div_int, uint8_t div_frac) More...

3.30.4. Macros

- #define **pio0** pio0_hw More...

3.30.5. Macros

- `#define pio1 pio1_hw` More...

3.30.6. Detailed Description

A programmable input/output block (PIO) is a versatile hardware interface which can support a number of different IO standards. There are two PIO blocks in the RP2040.

Each PIO is programmable in the same sense as a processor: the four state machines independently execute short, sequential programs, to manipulate GPIOs and transfer data. Unlike a general purpose processor, PIO state machines are highly specialised for IO, with a focus on determinism, precise timing, and close integration with fixed-function hardware. Each state machine is equipped with:

- Two 32-bit shift registers – either direction, any shift count
- Two 32-bit scratch registers
- 4×32 bit bus FIFO in each direction (TX/RX), reconfigurable as 8×32 in a single direction
- Fractional clock divider (16 integer, 8 fractional bits)
- Flexible GPIO mapping
- DMA interface, sustained throughput up to 1 word per clock from system DMA
- IRQ flag set/clear/status

Full details of the PIO can be found in the RP2040 datasheet.

3.30.7. Function Documentation

3.30.7.1. pio_add_program

```
uint pio_add_program (PIO pio,
       const pio_program_t *program)
```

these panic if unable

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `program`

3.30.7.2. pio_add_program_at_offset

```
void pio_add_program_at_offset (PIO pio,
       const pio_program_t *program,
       uint offset)
```

these panic if unable

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `program`
- `offset`

3.30.7.3. pio_can_add_program

```
bool pio_can_add_program (PIO pio,
       const pio_program_t *program)
```

TO DO: note this returns the case at the time (possibly stale after returning)

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `program`

3.30.7.4. pio_can_add_program_at_offset

```
bool pio_can_add_program_at_offset (PIO pio,
       const pio_program_t *program,
       uint offset)
```

TO DO: note this returns the case at the time (possibly stale after returning)

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `program`
- `offset`

3.30.7.5. pio_clear_fifo

```
static void pio_clear_fifo (PIO pio,
       uint sm)
```

Clear the specific PIO block's FIFO.

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.6. pio_clkdiv_restart

```
static void pio_clkdiv_restart (PIO pio,
       uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.7. pio_clkdiv_restart_mask

```
static void pio_clkdiv_restart_mask (PIO pio,
       uint32_t mask)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `mask`

3.30.7.8. pio_drain_tx

```
void pio_drain_tx (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.9. pio_enable_in_sync_mask

```
static void pio_enable_in_sync_mask (PIO pio,
      uint32_t mask)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `mask`

3.30.7.10. pio_get

```
static uint32_t pio_get (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.11. pio_get_blocking

```
static uint32_t pio_get_blocking (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.12. pio_get_dreq

```
static uint pio_get_dreq (PIO pio,
      uint sm,
      bool tx)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `tx`

3.30.7.13. pio_gpio_select

```
static void pio_gpio_select (PIO pio,
      uint pin)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `pin`

3.30.7.14. pio_index

```
static uint pio_index (PIO pio)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1

3.30.7.15. pio_put

```
static void pio_put (PIO pio,
       uint sm,
       uint data)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `data`

3.30.7.16. pio_put_blocking

```
static void pio_put_blocking (PIO pio,
       uint sm,
       uint32_t data)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `data`

3.30.7.17. pio_remove_program

```
void pio_remove_program (PIO pio,
       const pio_program_t *program,
       uint loaded_offset)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `program`
- `loaded_offset`

3.30.7.18. pio_restart_mask

```
static void pio_restart_mask (PIO pio,
       uint sm,
       uint32_t mask)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1

- `sm` State machine (0..3)
- `mask`

3.30.7.19. pio_rx_empty

```
static int pio_rx_empty (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.20. pio_rx_full

```
static int pio_rx_full (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.21. pio_rx_level

```
static int pio_rx_level (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.22. pio_set_clkdiv

```
static void pio_set_clkdiv (PIO pio,
      uint sm,
      float div)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `div`

3.30.7.23. pio_set_clkdiv_int_frac

```
static void pio_set_clkdiv_int_frac (PIO pio,
      uint sm,
      uint16_t div_int,
      uint8_t div_frac)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

- `div_int`
- `div_frac`

3.30.7.24. pio_set_config

```
static void pio_set_config (PIO pio,
       uint sm,
       const pio_sm_config *config)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `config`

3.30.7.25. pio_sm_enable

```
static void pio_sm_enable (PIO pio,
       uint sm,
       bool enable)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `enable`

3.30.7.26. pio_sm_enable_mask

```
static void pio_sm_enable_mask (PIO pio,
       uint32_t mask,
       bool enable)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `mask`
- `enable`

3.30.7.27. pio_sm_exec

```
static void pio_sm_exec (PIO pio,
       uint sm,
       uint instr)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `instr`

3.30.7.28. pio_sm_exec_stalled

```
static bool pio_sm_exec_stalled (PIO pio,
       uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.29. pio_sm_exec_wait_blocking

```
static void pio_sm_exec_wait_blocking (PIO pio,
      uint sm,
      uint instr)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `instr`

3.30.7.30. pio_sm_getpc

```
static uint8_t pio_sm_getpc (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.31. pio_sm_init

```
void pio_sm_init (PIO pio,
      uint sm,
      uint offset,
      pio_sm_config *config)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `offset`
- `config`

3.30.7.32. pio_sm_restart

```
static void pio_sm_restart (PIO pio,
      uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.33. pio_sm_set_wrap

```
static void pio_sm_set_wrap (PIO pio,
      uint sm,
      uint bottom,
```

```
    uint top)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)
- `bottom`
- `top`

3.30.7.34. pio_tx_empty

```
static int pio_tx_empty (PIO pio,
    uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.35. pio_tx_full

```
static int pio_tx_full (PIO pio,
    uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.30.7.36. pio_tx_level

```
static int pio_tx_level (PIO pio,
    uint sm)
```

Parameters

- `pio` Handle to PIO block, either pio0 or pio1
- `sm` State machine (0..3)

3.31. PIO Configuration

Functions for modifying PIO configurations. More...

3.31.1. Data Structures

- `struct pio_sm_config`
  PIO Configuration structure.

3.31.2. Functions

- `static void sm_config_out_pins (pio_sm_config *c, uint out_base, uint out_count)`
  Set state machine 'out' pins. More...
- `static void sm_config_set_pins (pio_sm_config *c, uint set_base, uint set_count)`
  Set state machine 'set' pins. More...

- `static void sm_config_in_pins (pio_sm_config *c, uint in_base)`
  Set state machine in pins. More...
- `static void sm_config_sideset (pio_sm_config *c, uint sideset_count, bool opt, bool pindirs)`
  Set the state machine 'side-set' options. More...
- `static void sm_config_sideset_pins (pio_sm_config *c, uint sideset_base)`
  Set the state machine 'side-set' pins. More...
- `static void sm_config_clkdiv (pio_sm_config *c, float div)`
  Set the state machine clock divider from a floating point value. More...
- `static void sm_config_clkdiv_int_frac (pio_sm_config *c, uint16_t div_int, uint8_t div_frac)`
  Set the state machine clock divider from integer and fractional parts (16p8) More...
- `static void sm_config_wrap (pio_sm_config *c, uint bottom, uint top)`
  Set the State machine pin wrapping points. More...
- `static void sm_config_jmp_pin (pio_sm_config *c, uint pin)`
  Set state machine jump pin. More...
- `static void sm_config_in_shift (pio_sm_config *c, bool shift_right, bool autopush, uint push_threshold)`
  Configure the state machine in shift control register. More...
- `static void sm_config_out_shift (pio_sm_config *c, bool shift_right, bool autopull, uint pull_threshold)`
  Configure the state machine out shift control register. More...
- `static void sm_config_fifo_join (pio_sm_config *c, enum pio_fifo_join join)`
  Join together a state machine FIFO. More...
- `static void sm_config_out_special (pio_sm_config *c, bool sticky, bool has_en, int en_index)` More...
- `static void sm_config_mov_status (pio_sm_config *c, uint status_sel, uint status_n)` More...

3.31.3. Detailed Description

Functions for modifying PIO configurations.

A PIO block needs to be configured, these functions provide handly helpers to set up configuration structures. See pio_sm_config

3.31.4. Function Documentation

3.31.4.1. sm_config_clkdiv

```
static void sm_config_clkdiv (pio_sm_config *c,
      float div)
```

Set the state machine clock divider from a floating point value.

The clock divider acts on the system clock to provide a clock for the state machine. See the databook for more details.

Parameters

- `c` Pointer to the configuration structure to modify
- `div` The fractional divisor to be set. 1 for full speed. An integer clock divisor of n will cause the state machine to run 1 cycle in every n. Note that for small n, the jitter introduced by a fractional divider (e.g. 2.5) may be unacceptable although it will depend on the use case.

3.31.4.2. sm_config_clkdiv_int_frac

```
static void sm_config_clkdiv_int_frac (pio_sm_config *c,
       uint16_t div_int,
       uint8_t div_frac)
```

Set the state machine clock divider from integer and fractional parts (16p8)

The clock divider acts on the system clock to provide a clock for the state machine. See the databook for more details.

Parameters

- `c` Pointer to the configuration structure to modify
- `div_int` Integer part of the divisor
- `div_frac` Fractional part in 1/256ths

See also

- sm_config_clkdiv

3.31.4.3. sm_config_fifo_join

```
static void sm_config_fifo_join (pio_sm_config *c,
       enum pio_fifo_join join)
```

Join together a state machine FIFO.

Parameters

- `c` Pointer to the configuration structure to modify
- `join` Specifies which FIFOs to join together.

3.31.4.4. sm_config_in_pins

```
static void sm_config_in_pins (pio_sm_config *c,
       uint in_base)
```

Set state machine in pins.

Can overlap with the 'set' and 'out' pins

Parameters

- `c` Pointer to the configuration structure to modify
- `in_base` 0-31 First pin to set as input

3.31.4.5. sm_config_in_shift

```
static void sm_config_in_shift (pio_sm_config *c,
       bool shift_right,
       bool autopush,
       uint push_threshold)
```

Configure the state machine in shift control register.

TO DO: no idea...

Parameters

- `c` Pointer to the configuration structure to modify
- `shift_right`

- `autopush`
- `push_threshold`

3.31.4.6. sm_config_jmp_pin

```
static void sm_config_jmp_pin (pio_sm_config *c,
       uint pin)
```

Set state machine jump pin.

TO DO: once again no idea what this is

Parameters

- `c` Pointer to the configuration structure to modify
- `pin`

3.31.4.7. sm_config_mov_status

```
static void sm_config_mov_status (pio_sm_config *c,
       uint status_sel,
       uint status_n)
```

TO DO: no idea

Parameters

- `c` Pointer to the configuration structure to modify
- `status_sel`
- `status_n`

3.31.4.8. sm_config_out_pins

```
static void sm_config_out_pins (pio_sm_config *c,
       uint out_base,
       uint out_count)
```

Set state machine 'out' pins.

Can overlap with the 'set' and 'in' pins

Parameters

- `c` Pointer to the configuration structure to modify
- `out_base` 0-31 First pin to set as output
- `out_count` 0-32 Number of pins to set.

3.31.4.9. sm_config_out_shift

```
static void sm_config_out_shift (pio_sm_config *c,
       bool shift_right,
       bool autopull,
       uint pull_threshold)
```

Configure the state machine out shift control register.

TO DO: no idea...

Parameters

- `c` Pointer to the configuration structure to modify
- `shift_right`
- `autopull`
- `pull_threshold`

3.31.4.10. sm_config_out_special

```
static void sm_config_out_special (pio_sm_config *c,
       bool sticky,
       bool has_en,
       int en_index)
```

TO DO: no idea

Parameters

- `c` Pointer to the configuration structure to modify
- `sticky`
- `has_en`
- `en_index`

3.31.4.11. sm_config_set_pins

```
static void sm_config_set_pins (pio_sm_config *c,
       uint set_base,
       uint set_count)
```

Set state machine 'set' pins.

Can overlap with the 'out' and 'in' pins

Parameters

- `c` Pointer to the configuration structure to modify
- `set_base` 0-31 First pin to set as
- `set_count` 0-32 Number of pins to set.

3.31.4.12. sm_config_sideset

```
static void sm_config_sideset (pio_sm_config *c,
       uint sideset_count,
       bool opt,
       bool pindirs)
```

Set the state machine 'side-set' options.

TO DO: loads to do here, what does sideset mean?

Parameters

- `c` Pointer to the configuration structure to modify
- `sideset_count`
- `opt`
- `pindirs`

3.31.4.13. sm_config_sideset_pins

```
static void sm_config_sideset_pins (pio_sm_config *c,
       uint sideset_base)
```

Set the state machine 'side-set' pins.

Parameters

- `c` Pointer to the configuration structure to modify
- `sideset_base` base pin for 'side set'

3.31.4.14. sm_config_wrap

```
static void sm_config_wrap (pio_sm_config *c,
       uint bottom,
       uint top)
```

Set the State machine pin wrapping points.

TO DO: no idea what this is

Parameters

- `c` Pointer to the configuration structure to modify
- `bottom`
- `top`

3.32. HW PLL API

API access to the Phase Locked Loop HW on the RP2040. More...

3.32.1. Functions

- `void pll_init (PLL pll, uint32_t refdiv, uint32_t vco_freq, uint32_t post_div1, uint8_t post_div2)`
  Initialise specified PLL. More...
- `void pll_deinit (PLL pll)`
  Release/uninitialise specified PLL. More...

3.32.2. Detailed Description

API access to the Phase Locked Loop HW on the RP2040.

There are two PLLs in RP2040. They are:

- pll_sys - Used to generate up to a 125MHz system clock
- pll_usb - Used to generate a 48MHz USB reference clock

For details on how the PLL's are calculated, please refer to the RP2040 datasheet.

3.32.3. Function Documentation

3.32.3.1. pll_deinit

```
void pll_deinit (PLL pll)
```

Release/uninitialise specified PLL.

TO DO: complete

Parameters

- `pll` pll_sys or pll_usb

3.32.3.2. pll_init

```
void pll_init (PLL pll,
       uint32_t refdiv,
       uint32_t vco_freq,
       uint32_t post_div1,
       uint8_t post_div2)
```

Initialise specified PLL.

TO DO: PLL docs?

Parameters

- `pll` pll_sys or pll_usb
- `refdiv`
- `vco_freq`
- `post_div1`
- `post_div2`

3.33. Hardware PWM API

The RP2040 PWM block has 8 identical slices. Each slice can drive two PWM output signals, or measure the frequency or duty cycle of an input signal. This gives a total of up to 16 controllable PWM outputs. All 30 GPIOs can be driven by the PWM block. More...

3.33.1. Enumerations

- `enum pwm_divider_mode { PWM_DIV_FREE_RUNNING, PWM_DIV_B_HIGH, PWM_DIV_B_RISING, PWM_DIV_B_FALLING }`
  PWM Divider mode settings.

3.33.2. Functions

- `static pwm_inst_t pwm_gpio_to_slice (uint gpio)`
  Determine the PWM slice that is attached to the specified GPIO. More...
- `static bool pwm_gpio_to_channel (uint gpio)`
  Determine the PWM channel that is attached to the specified GPIO. More...
- `static void pwm_config_phase_correct (pwm_config *c, bool phase_correct)`
  Configure PWM phase correction. More...
- `static void pwm_config_divider (pwm_config *c, float div)`
  Configure PWM clock divider. More...
- `static void pwm_config_output_polarity (pwm_config *c, bool a, bool b)`
  Configure PWM output polarity. More...
- `static void pwm_config_wrap (pwm_config *c, uint16_t wrap)`
  Configure PWM counter wrap value. More...

- `static pwm_config pwm_get_default_config ()`
  Get a set of default values for PWM configuration. More...
- `static void pwm_set_wrap (pwm_inst_t pwm, uint16_t wrap)`
  Set PWM counter wrap value. More...
- `static void pwm_set_chan_level (pwm_inst_t pwm, bool chan, uint16_t level)`
  Set PWM counter compare value for one channel. More...
- `static void pwm_set_both_levels (pwm_inst_t pwm, uint16_t level_a, uint16_t level_b)`
  Set PWM counter compare values. More...
- `static void pwm_set_gpio_level (uint gpio, uint16_t level)`
  Helper function to set the PWM level for the slice and channel associated with a GPIO. More...
- `static int16_t pwm_get_counter (pwm_inst_t pwm)`
  Get PWM counter. More...
- `static void pwm_set_counter (pwm_inst_t pwm, uint16_t c)`
  Set PWM counter. More...
- `static void pwm_advance_count (pwm_inst_t pwm)`
  Advance PWM count. More...
- `static void pwm_retard_count (pwm_inst_t pwm)`
  Retard PWM count. More...
- `static void pwm_set_divider_raw (pwm_inst_t pwm, uint8_t integer, uint8_t fract)`
  Set PWM clock divider. More...
- `static void pwm_set_divider (pwm_inst_t pwm, float divider)`
  Set PWM clock divider. More...
- `static void pwm_set_output_polarity (pwm_inst_t pwm, bool a, bool b)`
  Set PWM output polarity. More...
- `static void pwm_set_divider_mode (pwm_inst_t pwm, enum pwm_divider_mode mode)`
  Set PWM divider mode. More...
- `static void pwm_set_phase_correct (pwm_inst_t pwm, bool phase_correct)`
  Set PWM phase correct on/off. More...
- `static void pwm_enable (pwm_inst_t pwm, bool en)`
  Enable/Disable PWM. More...
- `static void pwm_enable_multiple (uint32_t mask)`
  Enable/Disable multiple PWMs simultaneously. More...
- `static void pwm_enable_irq (pwm_inst_t pwm, bool enable)`
  Enable PWM instance interrupt. More...
- `static void pwm_enable_irq_mask (uint32_t channel_mask, bool enable)`
  Enable multiple PWM instance interrupts. More...
- `static void pwm_clear_irq (pwm_inst_t pwm)`
  Clear single PWM channel interrupt. More...
- `static int32_t pwm_get_irq ()`
  Get PWM status, raw. More...
- `static void pwm_force_irq (pwm_inst_t pwm)`
  Force PWM interrupt.

3.33.3. Detailed Description

The RP2040 PWM block has 8 identical slices. Each slice can drive two PWM output signals, or measure the frequency or duty cycle of an input signal. This gives a total of up to 16 controllable PWM outputs. All 30 GPIOs can be driven by the PWM block.

The PWM hardware functions by continuously comparing the input value to a free-running counter. This produces a toggling output where the amount of time spent at the high output level is proportional to the input value. The fraction of time spent at the high signal level is known as the duty cycle of the signal.

The default behaviour of a PWM slice is to count upward until the wrap value (* pwm_config_wrap) is reached, and then immediately wrap to 0. PWM slices also offer a phase-correct mode, where the counter starts to count downward after reaching TOP, until it reaches 0 again.

3.33.4. Function Documentation

3.33.4.1. pwm_advance_count

```
static void pwm_advance_count (pwm_inst_t pwm)
```

Advance PWM count.

Advance the phase of the counter by 1 count, while it is running. Self-clearing. Write a 1, and poll until low. Counter must be running at less than full speed (div_int + div_frac / 16 > 1)

Parameters

- `pwm` PWM instance

3.33.4.2. pwm_clear_irq

```
static void pwm_clear_irq (pwm_inst_t pwm)
```

Clear single PWM channel interrupt.

Parameters

- `pwm` PWM instance

3.33.4.3. pwm_config_divider

```
static void pwm_config_divider (pwm_config *c,
      float div)
```

Configure PWM clock divider.

If the divide mode is free-running, the PWM counter runs at clk_sys / div. Otherwise, the divider reduces the rate of events seen on the B pin input (level or edge) before passing them on to the PWM counter.

Parameters

- `c` PWM configuration struct to modify
- `div` Fractional value to reduce counting rate by. Must be greater than or equal to 1.

3.33.4.4. pwm_config_output_polarity

```
static void pwm_config_output_polarity (pwm_config *c,
      bool a,
      bool b)
```

Configure PWM output polarity.

Parameters

- `c` PWM configuration struct to modify
- `a` true to invert output A
- `b` true to invert output B

3.33.4.5. pwm_config_phase_correct

```
static void pwm_config_phase_correct (pwm_config *c,
       bool phase_correct)
```

Configure PWM phase correction.

Setting phase control to true means that instead of wrapping back to zero when the wrap point is reached, the PWM starts counting back down. The output frequency is halved when phase-correct mode is enabled.

Parameters

- `c` PWM configuration struct to modify
- `phase_correct` true to set phase correct modulation, false to set trailing edge

3.33.4.6. pwm_config_wrap

```
static void pwm_config_wrap (pwm_config *c,
       uint16_t wrap)
```

Configure PWM counter wrap value.

Set the highest value the counter will reach before returning to 0. Also known as TOP.

Parameters

- `c` PWM configuration struct to modify
- `wrap` Value to set wrap to

3.33.4.7. pwm_enable

```
static void pwm_enable (pwm_inst_t pwm,
       bool en)
```

Enable/Disable PWM.

Parameters

- `pwm` PWM instance
- `en` true to enable the specified PWM, false to disable

3.33.4.8. pwm_enable_irq

```
static void pwm_enable_irq (pwm_inst_t pwm,
       bool enable)
```

Enable PWM instance interrupt.

Used to enable a single PWM instance interrupt

Parameters

- `pwm` PWM block to enable/disable
- `enable` true to enable, false to disable

3.33.4.9. pwm_enable_irq_mask

```
static void pwm_enable_irq_mask (uint32_t channel_mask,
       bool enable)
```

Enable multiple PWM instance interrupts.

Use this to enable multiple PWM interrupts at once.

Parameters

- `channel_mask` Bitmask of all the blocks to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- `enable` true to enable, false to disable

3.33.4.10. pwm_enable_multiple

```
static void pwm_enable_multiple (uint32_t mask)
```

Enable/Disable multiple PWMs simultaneously.

Parameters

- `mask` Bitmap of PWMs to enable/disable. Bits 0 to 7 enable slices 0-7 respectively

3.33.4.11. pwm_force_irq

```
static void pwm_force_irq (pwm_inst_t pwm)
```

Force PWM interrupt.

3.33.4.12. pwm_get_counter

```
static int16_t pwm_get_counter (pwm_inst_t pwm)
```

Get PWM counter.

Get current value of PWM counter

Parameters

- `pwm` PWM instance

Returns

- Current value of PWM counter

3.33.4.13. pwm_get_default_config

```
static pwm_config pwm_get_default_config ()
```

Get a set of default values for PWM configuration.

PWM config is free running at system clock speed, no phase correction, wrapping at 0xffff, with standard polarities for channels A and B.

Returns

- Set of default values.

3.33.4.14. pwm_get_irq

```
static int32_t pwm_get_irq ()
```

Get PWM status, raw.

Returns

- Bitmask of all PWM interrupts currently set

3.33.4.15. pwm_gpio_to_channel

```
static bool pwm_gpio_to_channel (uint gpio)
```

Determine the PWM channel that is attached to the specified GPIO.

Each slice 0 to 7 has two channels, A and B.

Returns

- The PWM channel that controls the specified GPIO.

3.33.4.16. pwm_gpio_to_slice

```
static pwm_inst_t pwm_gpio_to_slice (uint gpio)
```

Determine the PWM slice that is attached to the specified GPIO.

Returns

- The PWM slice that controls the specified GPIO.

3.33.4.17. pwm_retard_count

```
static void pwm_retard_count (pwm_inst_t pwm)
```

Retard PWM count.

Retard the phase of the counter by 1 count, while it is running. Self-clearing. Write a 1, and poll until low. Counter must be running.

Parameters

- `pwm` PWM instance

3.33.4.18. pwm_set_both_levels

```
static void pwm_set_both_levels (pwm_inst_t pwm,
      uint16_t level_a,
      uint16_t level_b)
```

Set PWM counter compare values.

Set the value of the PWM counter compare values, A and B

Parameters

- `pwm` PWM instance
- `level_a` Value to set compare A to. When the counter reaches this value the A output is deasserted
- `level_b` Value to set compare B to. When the counter reaches this value the B output is deasserted

3.33.4.19. pwm_set_chan_level

```
static void pwm_set_chan_level (pwm_inst_t pwm,
      bool chan,
      uint16_t level)
```

Set PWM counter compare value for one channel.

Set the value of the PWM counter compare value, for either channel A or channel B

Parameters

- `pwm` PWM instance
- `chan` Which channel to update. false for A, true for B.
- `level` new level for the selected output

3.33.4.20. pwm_set_counter

```
static void pwm_set_counter (pwm_inst_t pwm,
       uint16_t c)
```

Set PWM counter.

Set the value of the PWM counter

Parameters

- `pwm` PWM instance
- `c` Value to set the PWM counter to

3.33.4.21. pwm_set_divider

```
static void pwm_set_divider (pwm_inst_t pwm,
       float divider)
```

Set PWM clock divider.

Set the clock divider. Counter increment will be on sysclock divided by this value, taking in to account the gating.

Parameters

- `pwm` PWM instance
- `divider` Floating point clock divider, 1.f ⇐ value < 256.f

3.33.4.22. pwm_set_divider_mode

```
static void pwm_set_divider_mode (pwm_inst_t pwm,
       enum pwm_divider_mode mode)
```

Set PWM divider mode.

Parameters

- `pwm` PWM instance
- `mode` Required divider mode

3.33.4.23. pwm_set_divider_raw

```
static void pwm_set_divider_raw (pwm_inst_t pwm,
       uint8_t integer,
       uint8_t fract)
```

Set PWM clock divider.

Set the clock divider. Counter increment will be on sysclock divided by this value, taking in to account the gating.

Parameters

- `pwm` PWM instance

- `integer` 8 bit integer part of the clock divider
- `fract` 4 bit fractional part of the clock divider

3.33.4.24. pwm_set_gpio_level

```
static void pwm_set_gpio_level (uint gpio,
       uint16_t level)
```

Helper function to set the PWM level for the slice and channel associated with a GPIO.

Look up the correct slice (0 to 7) and channel (A or B) for a given GPIO, and update the corresponding counter-compare field.

This PWM slice should already have been configured and set running. Also be careful of multiple GPIOs mapping to the same slice and channel (if GPIOs have a difference of 16).

Parameters

- `gpio` GPIO to set level of
- `level` PWM level for this GPIO

3.33.4.25. pwm_set_output_polarity

```
static void pwm_set_output_polarity (pwm_inst_t pwm,
       bool a,
       bool b)
```

Set PWM output polarity.

Parameters

- `pwm` PWM instance
- `a` true to invert output A
- `b` true to invert output B

3.33.4.26. pwm_set_phase_correct

```
static void pwm_set_phase_correct (pwm_inst_t pwm,
       bool phase_correct)
```

Set PWM phase correct on/off.

Setting phase control to true means that instead of wrapping back to zero when the wrap point is reached, the PWM starts counting back down. The output frequency is halved when phase-correct mode is enabled.

Parameters

- `pwm` PWM instance
- `phase_correct` true to set phase correct modulation, false to set trailing edge

3.33.4.27. pwm_set_wrap

```
static void pwm_set_wrap (pwm_inst_t pwm,
       uint16_t wrap)
```

Set PWM counter wrap value.

Set the highest value the counter will reach before returning to 0. Also known as TOP.

Parameters

- `pwm` PWM instance
- `wrap` Value to set wrap to

3.34. Ring Oscillator (ROSC) API

API to the ROSC HW. More...

3.34.1. Functions

- `void rosc_set_freq (uint32_t code)`
  Set frequency of the Ring Oscillator. More...
- `void rosc_set_range (uint range)`
  Set range of the Ring Oscillator. More...
- `void rosc_disable (void)`
  Disable the Ring Oscillator.
- `void rosc_dormant (void)`
  Put Ring Oscillator in to dormant mode. More...

3.34.2. Detailed Description

API to the ROSC HW.

A Ring Oscillator is an on-chip oscillator that requires no external crystal. Instead, the output is generated from a series of inverters that are chained together to create a feedback loop. RP2040 boots from the ring oscillator initially, meaning the first stages of the bootrom, including booting from SPI flash, will be clocked by the ring oscillator. If your design has a crystal oscillator, you'll likely want to switch to this as your reference clock as soon as possible, because the frequency is more accurate than the ring oscillator.

3.34.3. Function Documentation

3.34.3.1. rosc_disable

```
void rosc_disable (void)
```

Disable the Ring Oscillator.

3.34.3.2. rosc_dormant

```
void rosc_dormant (void)
```

Put Ring Oscillator in to dormant mode.

The ROSC supports a dormant mode,which stops oscillation until woken up up by an asynchronous interrupt. This can either come from the RTC, being clocked by an external clock, or a GPIO pin going high or low. If no IRQ is configured before going into dormant mode the ROSC will never restart.

PLL's should be stopped before selecting dormant mode.

3.34.3.3. rosc_set_freq

```
void rosc_set_freq (uint32_t code)
```

Set frequency of the Ring Oscillator.

Parameters

- `code` The drive strengths. See the RP2040 datasheet for information on this value.

3.34.3.4. rosc_set_range

```
void rosc_set_range (uint range)
```

Set range of the Ring Oscillator.

Frequency range. Frequencies will vary with Process, Voltage & Temperature (PVT). Clock output will not glitch when changing the range up one step at a time.

Parameters

- `range` 0x01 Low, 0x02 Medium, 0x03 High, 0x04 Too High.

3.35. Sleep Mode API

The difference between sleep and dormant is that ALL clocks are stopped in dormant mode, until the source (either xosc or rosc) is started again by an external event. In sleep mode some clocks can be left running controlled by the SLEEP_EN registers in the clocks block. For example you could keep clk_rtc running. Some destinations (proc0 and proc1 wakeup logic) can't be stopped in sleep mode otherwise there wouldn't be enough logic to wake up again. More...

3.35.1. Functions

- `void sleep_run_from_dormant_source (dormant_source_t dormant_source)`
  Set all clock sources to the the dormant clock source to prepare for sleep. More...
- `static void sleep_run_from_xosc (void)`
  Set the dormant clock source to be the crystal oscillator.
- `static void sleep_run_from_rosc (void)`
  Set the dormant clock source to be the ring oscillator.
- `void sleep_goto_sleep_until (datetime_t *t, rtc_callback_t callback)`
  Send system to sleep until the specified time. More...
- `void sleep_goto_dormant_until_pin (uint gpio_pin, bool edge, bool high)`
  Send system to sleep until the specified GPIO changes. More...
- `static void sleep_goto_dormant_until_edge_high (uint gpio_pin)`
  Send system to sleep until a leading high edge is detected on GPIO. More...
- `static void sleep_goto_dormant_until_level_high (uint gpio_pin)`
  Send system to sleep until a high level is detected on GPIO. More...

3.35.2. Detailed Description

The difference between sleep and dormant is that ALL clocks are stopped in dormant mode, until the source (either xosc or rosc) is started again by an external event. In sleep mode some clocks can be left running controlled by the SLEEP_EN registers in the clocks block. For example you could keep clk_rtc running. Some destinations (proc0 and proc1 wakeup logic) can't be stopped in sleep mode otherwise there wouldn't be enough logic to wake up again.

3.35.3. Function Documentation

3.35.3.1. sleep_goto_dormant_until_edge_high

```
static void sleep_goto_dormant_until_edge_high (uint gpio_pin)
```

Send system to sleep until a leading high edge is detected on GPIO.

One of the sleep_run_* functions must be called prior to this call

Parameters

- `gpio_pin` The pin to provide the wake up

3.35.3.2. sleep_goto_dormant_until_level_high

```
static void sleep_goto_dormant_until_level_high (uint gpio_pin)
```

Send system to sleep until a high level is detected on GPIO.

One of the sleep_run_* functions must be called prior to this call

Parameters

- `gpio_pin` The pin to provide the wake up

3.35.3.3. sleep_goto_dormant_until_pin

```
void sleep_goto_dormant_until_pin (uint gpio_pin,
       bool edge,
       bool high)
```

Send system to sleep until the specified GPIO changes.

One of the sleep_run_* functions must be called prior to this call

Parameters

- `gpio_pin` The pin to provide the wake up
- `edge` true for leading edge, false for trailing edge
- `high` true for active high, false for active low

3.35.3.4. sleep_goto_sleep_until

```
void sleep_goto_sleep_until (datetime_t *t,
       rtc_callback_t callback)
```

Send system to sleep until the specified time.

One of the sleep_run_* functions must be called prior to this call

Parameters

- `t` The time to wake up
- `callback` Function to call on wakeup.

3.35.3.5. sleep_run_from_dormant_source

```
void sleep_run_from_dormant_source (dormant_source_t dormant_source)
```

Set all clock sources to the the dormant clock source to prepare for sleep.

Parameters

- `dormant_source` The dormant clock source to use

3.35.3.6. sleep_run_from_rosc

```
static void sleep_run_from_rosc (void)
```

Set the dormant clock source to be the ring oscillator.

3.35.3.7. sleep_run_from_xosc

```
static void sleep_run_from_xosc (void)
```

Set the dormant clock source to be the crystal oscillator.

3.36. Hardware SPI API

RP2040 has 2 identical instances of an Serial Peripheral Interface (SPI) controller. More...

3.36.1. Modules

- `SPI parameters enumerations`
  Enumerations for SPI functions.

3.36.2. Functions

- `int spi_write_read_blocking_until (spi_inst_t *spi, const uint8_t *src, uint8_t *dst, size_t len, absolute_time_t until)`
  Write/Read to/from an SPI device. More...
- `int spi_write_blocking_until (spi_inst_t *spi, const uint8_t *src, size_t len, absolute_time_t until)`
  Write to an SPI device. More...
- `int spi_read_blocking_until (spi_inst_t *spi, uint8_t repeated_tx_data, uint8_t *dst, size_t len, absolute_time_t until)`
  Read from an SPI device. More...
- `int spi_write16_read16_blocking_until (spi_inst_t *spi, const uint16_t *src, uint16_t *dst, size_t len, absolute_time_t until)`
  Write/Read half words to/from an SPI device. More...
- `int spi_write16_blocking_until (spi_inst_t *spi, const uint16_t *src, size_t len, absolute_time_t until)`
  Write to an SPI device. More...
- `int spi_read16_blocking_until (spi_inst_t *spi, uint16_t repeated_tx_data, uint16_t *dst, size_t len, absolute_time_t until)`
  Read from an SPI device, timeout. More...
- `void spi_init (spi_inst_t *spi, uint baudrate)`
  Initialise SPI instances. More...
- `void spi_deinit (spi_inst_t *spi)`
  Deinitialise SPI instances. More...
- `uint spi_set_baudrate (spi_inst_t *spi, uint baudrate)`
  Set SPI baudrate. More...
- `static uint spi_hw_index (spi_inst_t *spi)`
  Convert I2c instance to hardware instance number. More...
- `static void spi_set_format (spi_inst_t *spi, uint data_bits, spi_cpol_t cpol, spi_cpha_t cpha, spi_order_t order)`
  Configure SPI. More...

- `static void spi_set_slave (spi_inst_t *spi, bool slave)`
  Set SPI master/slave. More...
- `static size_t spi_writable (spi_inst_t *spi)`
  Check whether a write can be done on SPI device. More...
- `static size_t spi_readable (spi_inst_t *spi)`
  Check whether a read can be done on SPI device. More...
- `static void spi_write_read_blocking (spi_inst_t *spi, const uint8_t *src, uint8_t *dst, size_t len)`
  Write/Read to/from an SPI device. More...
- `static int spi_write_read_timeout_us (spi_inst_t *spi, const uint8_t *src, uint8_t *dst, size_t len, uint timeout_us)`
  Write/Read to/from an SPI device. More...
- `static void spi_write_blocking (spi_inst_t *spi, const uint8_t *src, size_t len)`
  Write to an SPI device, blocking. More...
- `static int spi_write_timeout_us (spi_inst_t *spi, const uint8_t *src, size_t len, uint timeout_us)`
  Write to an SPI device. More...
- `static void spi_read_blocking (spi_inst_t *spi, uint8_t repeated_tx_data, uint8_t *dst, size_t len)`
  Read from an SPI device. More...
- `static int spi_read_timeout_us (spi_inst_t *spi, uint8_t repeated_tx_data, uint8_t *dst, size_t len, uint timeout_us)`
  Read from an SPI device, timeout. More...
- `static void spi_write16_read16_blocking (spi_inst_t *spi, const uint16_t *src, uint16_t *dst, size_t len)`
  Write/Read half words to/from an SPI device. More...
- `static int spi_write16_read16_timeout_us (spi_inst_t *spi, const uint16_t *src, uint16_t *dst, size_t len, uint timeout_us)`
  Write/Read half words to/from an SPI device, timeout. More...
- `static void spi_write16_blocking (spi_inst_t *spi, const uint16_t *src, size_t len)`
  Write to an SPI device. More...
- `static int spi_write16_timeout_us (spi_inst_t *spi, const uint16_t *src, size_t len, uint timeout_us)`
  Write to an SPI device, timeout. More...
- `static void spi_read16_blocking (spi_inst_t *spi, uint16_t repeated_tx_data, uint16_t *dst, size_t len)`
  Read from an SPI device. More...
- `static int spi_read16_timeout_us (spi_inst_t *spi, uint16_t repeated_tx_data, uint16_t *dst, size_t len, uint timeout_us)`
  Read from an SPI device, timeout. More...

3.36.3. Macros

- `#define spi0 ((spi_inst_t * const)spi0_hw)` More...
- `#define spi1 ((spi_inst_t * const)spi1_hw)` More...

3.36.4. Detailed Description

RP2040 has 2 identical instances of an Serial Peripheral Interface (SPI) controller.

The PrimeCell SSP is a master or slave interface for synchronous serial communication with peripheral devices that have Motorola SPI, National Semiconductor Microwire, or Texas Instruments synchronous serial interfaces.

Controller can be defined as master or slave using the * spi_set_slave function.

Each controller can be connected to a number of GPIO pins, see the datasheet GPIO function selection table for more information.

3.36.5. Function Documentation

3.36.5.1. spi_deinit

```
void spi_deinit (spi_inst_t *spi)
```

Deinitialise SPI instances.

Puts the SPI into a disabled state. Init will need to be called to reenable the device functions.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

3.36.5.2. spi_hw_index

```
static uint spi_hw_index (spi_inst_t *spi)
```

Convert I2c instance to hardware instance number.

Parameters

- `spi` SPI instance

Returns

- Number of SPI, 0 or 1.

3.36.5.3. spi_init

```
void spi_init (spi_inst_t *spi,
       uint baudrate)
```

Initialise SPI instances.

Puts the SPI into a known state, and enable it. Must be called before other functions.

Note there is no guarantee that the baudrate requested will be possible, the nearest will be chosen, and this function does not return any indication of this. You can use the `spi_set_baudrate` function which will return the actual baudrate selected if this is important.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `baudrate` Baudrate required in Hz

3.36.5.4. spi_read16_blocking

```
static void spi_read16_blocking (spi_inst_t *spi,
       uint16_t repeated_tx_data,
       uint16_t *dst,
       size_t len)
```

Read from an SPI device.

Read `len` halfwords from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst in halfwords

3.36.5.5. spi_read16_blocking_until

```
int spi_read16_blocking_until (spi_inst_t *spi,
       uint16_t repeated_tx_data,
       uint16_t *dst,
       size_t len,
       absolute_time_t until)
```

Read from an SPI device, timeout.

Read `len` halfwords from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst in halfwords
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of halfwords written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.6. spi_read16_timeout_us

```
static int spi_read16_timeout_us (spi_inst_t *spi,
       uint16_t repeated_tx_data,
       uint16_t *dst,
       size_t len,
       uint timeout_us)
```

Read from an SPI device, timeout.

Read `len` halfwords from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst in halfwords
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.36.5.7. spi_read_blocking

```
static void spi_read_blocking (spi_inst_t *spi,
       uint8_t repeated_tx_data,
       uint8_t *dst,
       size_t len)
```

Read from an SPI device.

Read `len` bytes from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst

3.36.5.8. spi_read_blocking_until

```
int spi_read_blocking_until (spi_inst_t *spi,
       uint8_t repeated_tx_data,
       uint8_t *dst,
       size_t len,
       absolute_time_t until)
```

Read from an SPI device.

Read `len` bytes from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of bytes written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.9. spi_read_timeout_us

```
static int spi_read_timeout_us (spi_inst_t *spi,
       uint8_t repeated_tx_data,
       uint8_t *dst,
       size_t len,
       uint timeout_us)
```

Read from an SPI device, timeout.

Read `len` bytes from SPI to `dst`. `repeated_tx_data` is output repeatedly on SO as data is read in from SI. Generally this can be 0, but some devices require a specific value here, e.g. SD cards expect 0xff

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

- `repeated_tx_data` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of buffer dst
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.36.5.10. spi_readable

```
static size_t spi_readable (spi_inst_t *spi)
```

Check whether a read can be done on SPI device.

Note: Although the controllers each have a 8 deep RX FIFO, the current HW implementation can only return 0 or 1 rather than the data available.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

Returns

- Non-zero if a read is possible i.e. data is present

3.36.5.11. spi_set_baudrate

```
uint spi_set_baudrate (spi_inst_t *spi,
      uint baudrate)
```

Set SPI baudrate.

Set SPI frequency as close as possible to baudrate, and return the actual achieved rate.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `baudrate` Baudrate required in Hz, should be capable of a bitrate of at least 2Mbps, or higher, depending on system clock settings.

Returns

- The actual baudrate set

3.36.5.12. spi_set_format

```
static void spi_set_format (spi_inst_t *spi,
      uint data_bits,
      spi_cpol_t cpol,
      spi_cpha_t cpha,
      spi_order_t order)
```

Configure SPI.

Configure how the SPI serialises and deserialises data on the wire

TO DO: Should this be implemented?

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

- `data_bits` Number of data bits per transfer. Valid values 4..16.
- `cpol` SSPCLKOUT polarity, applicable to Motorola SPI frame format only.
- `cpha` SSPCLKOUT phase, applicable to Motorola SPI frame format only
- `order` Not currently used.

3.36.5.13. spi_set_slave

```
static void spi_set_slave (spi_inst_t *spi,
       bool slave)
```

Set SPI master/slave.

Configure the SPI for master- or slave-mode operation. By default, `spi_init()` sets master-mode.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `slave` true to set SPI device as a slave device, false for master.

3.36.5.14. spi_writable

```
static size_t spi_writable (spi_inst_t *spi)
```

Check whether a write can be done on SPI device.

Note: Although the controllers each have a 8 deep TX FIFO, the current HW implementation can only return 0 or 1 rather than the space available.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

Returns

- 0 if no space is available to write. Non-zero if a write is possible

3.36.5.15. spi_write16_blocking

```
static void spi_write16_blocking (spi_inst_t *spi,
       const uint16_t *src,
       size_t len)
```

Write to an SPI device.

Write `len` halfwords from `src` to SPI. Discard any data received back. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `len` Length of buffers

3.36.5.16. spi_write16_blocking_until

```
int spi_write16_blocking_until (spi_inst_t *spi,
       const uint16_t *src,
       size_t len,
       absolute_time_t until)
```

Write to an SPI device.

Write `len` halfwords from `src` to SPI. Discard any data received back. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `len` Length of buffers
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of bytes written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.17. spi_write16_read16_blocking

```
static void spi_write16_read16_blocking (spi_inst_t *spi,
       const uint16_t *src,
       uint16_t *dst,
       size_t len)
```

Write/Read half words to/from an SPI device.

Write `len` halfwords from `src` to SPI. Simultaneously read `len` halfwords from SPI to `dst`. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers in halfwords

3.36.5.18. spi_write16_read16_blocking_until

```
int spi_write16_read16_blocking_until (spi_inst_t *spi,
       const uint16_t *src,
       uint16_t *dst,
       size_t len,
       absolute_time_t until)
```

Write/Read half words to/from an SPI device.

Write `len` halfwords from `src` to SPI. Simultaneously read `len` halfwords from SPI to `dst`. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers in halfwords
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of bytes written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.19. spi_write16_read16_timeout_us

```
static int spi_write16_read16_timeout_us (spi_inst_t *spi,
       const uint16_t *src,
       uint16_t *dst,
       size_t len,
       uint timeout_us)
```

Write/Read half words to/from an SPI device, timeout.

Write `len` halfwords from `src` to SPI. Simultaneously read `len` halfwords from SPI to `dst`.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers in halfwords
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.36.5.20. spi_write16_timeout_us

```
static int spi_write16_timeout_us (spi_inst_t *spi,
       const uint16_t *src,
       size_t len,
       uint timeout_us)
```

Write to an SPI device, timeout.

Write `len` halfwords from `src` to SPI. Discard any data received back.

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `len` Length of buffers
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.36.5.21. spi_write_blocking

```
static void spi_write_blocking (spi_inst_t *spi,
       const uint8_t *src,
       size_t len)
```

Write to an SPI device, blocking.

Write `len` bytes from `src` to SPI, and discard any data received back Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write

- `len` Length of src

3.36.5.22. spi_write_blocking_until

```
int spi_write_blocking_until (spi_inst_t *spi,
       const uint8_t *src,
       size_t len,
       absolute_time_t until)
```

Write to an SPI device.

Write `len` bytes from `src` to SPI, and discard any data received back Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `len` Length of src
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of bytes written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.23. spi_write_read_blocking

```
static void spi_write_read_blocking (spi_inst_t *spi,
       const uint8_t *src,
       uint8_t *dst,
       size_t len)
```

Write/Read to/from an SPI device.

Write `len` bytes from `src` to SPI. Simultaneously read `len` bytes from SPI to `dst`. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers

3.36.5.24. spi_write_read_blocking_until

```
int spi_write_read_blocking_until (spi_inst_t *spi,
       const uint8_t *src,
       uint8_t *dst,
       size_t len,
       absolute_time_t until)
```

Write/Read to/from an SPI device.

Write `len` bytes from `src` to SPI. Simultaneously read `len` bytes from SPI to `dst`. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1

- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers
- `until` Absolute time to wait until for the transation to complete before a timeout occurs.

Returns

- Number of bytes written/read or PICO_ERROR_TIMEOUT if a timeout occurred.

3.36.5.25. spi_write_read_timeout_us

```
static int spi_write_read_timeout_us (spi_inst_t *spi,
       const uint8_t *src,
       uint8_t *dst,
       size_t len,
       uint timeout_us)
```

Write/Read to/from an SPI device.

Write `len` bytes from `src` to SPI. Simultaneously read `len` bytes from SPI to `dst`. Will block until all transactions are complete

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `dst` Buffer for read data
- `len` Length of BOTH buffers
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.36.5.26. spi_write_timeout_us

```
static int spi_write_timeout_us (spi_inst_t *spi,
       const uint8_t *src,
       size_t len,
       uint timeout_us)
```

Write to an SPI device.

Write `len` bytes from `src` to SPI, and discard any data received back

Parameters

- `spi` SPI instance specifier, either spi0 or spi1
- `src` Buffer of data to write
- `len` Length of src
- `timeout_us` Timeout for the transaction

Returns

- Number of items sent, or PICO_ERROR_TIMEOUT if a timeout occurred

3.37. SPI parameters enumerations

Enumerations for SPI functions. More...

3.37.1. Enumerations

- `enum spi_cpha_t { SPI_CPHA_0 = 0, SPI_CPHA_1 = 1 }`
- `enum spi_cpol_t { SPI_CPOL_0 = 0, SPI_CPOL_1 = 1 }`
- `enum spi_order_t { SPI_LSB_FIRST = 0, SPI_MSB_FIRST = 1 }`

3.37.2. Detailed Description

Enumerations for SPI functions.

3.38. Hardware Watchdog API

Supporting functions for the Pico hardware watchdog. More...

3.38.1. Functions

- `void watchdog_reboot (uint32_t pc, uint32_t sp, uint32_t delay_ms)`
  Define actions to perform at watchdog timeout. More...
- `void watchdog_start_tick (uint cycles)`
  Start the watchdog tick. More...
- `void watchdog_update (void)`
  Reload the watchdog counter with the amount of time set in watchdog_enable.
- `void watchdog_enable (uint32_t delay_ms, bool pause_on_debug)`
  Enable the watchdog. More...
- `bool watchdog_caused_reboot (void)`
  Did the watchdog cause the last reboot? More...
- `uint32_t watchdog_get_count (void)`
  Returns the amount of microseconds before the watchdog will reboot the chip. More...

3.38.2. Detailed Description

Supporting functions for the Pico hardware watchdog.

The RP2040 has a built in HW watchdog. This is a countdown timer that can restart parts of the chip if it reaches zero. For example, this can be used to restart the processor if the software running on it gets stuck in an infinite loop or similar. The programmer has to periodically write a value to the watchdog to stop it reaching zero.

3.38.3. Function Documentation

3.38.3.1. watchdog_caused_reboot

`bool watchdog_caused_reboot (void)`

Did the watchdog cause the last reboot?

Returns

- true if the watchdog timer or a watchdog force caused the last reboot
- false there has been no watchdog reboot since run has been

3.38.3.2. watchdog_enable

```
void watchdog_enable (uint32_t delay_ms,
      bool pause_on_debug)
```

Enable the watchdog.

Note that if By default the SDK assumes a 12MHz XOSC and sets the

Parameters

- `delay_ms` Amount of milliseconds before watchdog will reboot without watchdog_update being called. Maximum of 0x7fffff, which is approximately 8.3 seconds
- `pause_on_debug` If the watchdog should be paused when the debugger is stepping through code

See also

- watchdog_start_tick value does not give a 1MHz Hardware Clock API to the watchdog system, then the
- delay_ms parameter will not be in microseconds. See the datasheet for more details.
- watchdog_start_tick appropriately.

3.38.3.3. watchdog_get_count

```
uint32_t watchdog_get_count (void)
```

Returns the amount of microseconds before the watchdog will reboot the chip.

Returns

- The number of microseconds before the watchdog will reboot the chip.

3.38.3.4. watchdog_reboot

```
void watchdog_reboot (uint32_t pc,
      uint32_t sp,
      uint32_t delay_ms)
```

Define actions to perform at watchdog timeout.

Note that if By default the SDK assumes a 12MHz XOSC and sets the

Parameters

- `pc` If Zero, a standard boot will be performed, if non-zero this is the program counter to jump to on reset.
- `sp` If pc is non-zero, this will be the stack pointer used.
- `delay_ms` Initial load value. Maximum value 0x7fffff, approximately 8.3s.

See also

- watchdog_start_tick value does not give a 1MHz Hardware Clock API to the watchdog system, then the
- delay_ms parameter will not be in microseconds. See the datasheet for more details.
- watchdog_start_tick appropriately.

3.38.3.5. watchdog_start_tick

```
void watchdog_start_tick (uint cycles)
```

Start the watchdog tick.

Parameters

- `cycles` This needs to be a divider that when applied to the XOSC input, produces a 1Mhz clock. So if the XOSC is 12MHz, this will need to be 12.

3.38.3.6. watchdog_update

```
void watchdog_update (void)
```

Reload the watchdog counter with the amount of time set in watchdog_enable.

3.39. Core specific functions

Functions for setting up, launching and communicating between cores. More...

3.39.1. Modules

- `Multicore_fifo`

3.39.2. Functions

- `void multicore_reset_core1 ()`
  Reset Core 1.
- `void multicore_launch_core1 (void(*entry)(void))`
  Run code on core 1. More...
- `void multicore_launch_core1_with_stack (void(*entry)(void), uint32_t *stack_bottom, size_t stack_size_bytes)`
  Launch code on core 1 with stack. More...
- `void multicore_sleep_core1 ()`
  Send core 1 to sleep.
- `void multicore_launch_core1_raw (void(*entry)(void), uint32_t *sp, uint32_t vector_table)`
  Launch code on core 1 with no stack protection. More...

3.39.3. Detailed Description

Functions for setting up, launching and communicating between cores.

3.39.4. Function Documentation

3.39.4.1. multicore_launch_core1

```
void multicore_launch_core1 (void(*entry)(void))
```

Run code on core 1.

Reset core1 and enter the given function on core 1 using the default core 1 stack (below core 0 stack)

Parameters

- `entry` Function entry point, this function should not return.

3.39.4.2. multicore_launch_core1_raw

```
void multicore_launch_core1_raw (void(*entry)(void),
       uint32_t *sp,
       uint32_t vector_table)
```

Launch code on core 1 with no stack protection.

Reset core1 and enter the given function using the passed sp as the initial stack pointer. This is a bare bones functions that does not provide a stack guard even if USE_STACK_GUARDS is defined

3.39.4.3. multicore_launch_core1_with_stack

```
void multicore_launch_core1_with_stack (void(*entry)(void),
       uint32_t *stack_bottom,
       size_t stack_size_bytes)
```

Launch code on core 1 with stack.

Reset core1 and enter the given function on core 1 using the passed stack for core 1

3.39.4.4. multicore_reset_core1

```
void multicore_reset_core1 ()
```

Reset Core 1.

3.39.4.5. multicore_sleep_core1

```
void multicore_sleep_core1 ()
```

Send core 1 to sleep.

3.40. Multicore_fifo

3.40.1. Functions

- `static bool multicore_fifo_rvalid ()`
  Check the read FIFO to see if there is data waiting. More...
- `static bool multicore_fifo_wready ()`
  Check the FIFO to see if the write FIFO is full. More...
- `void multicore_fifo_push_blocking (uint32_t data)`
  Push data on to the FIFO. More...
- `uint32_t multicore_fifo_pop_blocking ()`
  Pop data from the FIFO. More...
- `static void multicore_fifo_drain ()`
  Flush any data in the outgoing FIFO.
- `static void multicore_fifo_clear_irq ()`
  Clear FIFO interrupt.
- `static int32_t multicore_fifo_get_status ()`
  Get FIFO status. More...

3.40.2. Detailed Description

Intercore Mailbox/FIFO functions

The RP2040 contains two FIFOs for passing data, messages or ordered events between the two cores. Each FIFO is 32 bits wide, and 8 entries deep. One of the FIFOs can only be written by core 0, and read by core 1. The other can only be written by core 1, and read by core 0.

3.40.3. Function Documentation

3.40.3.1. multicore_fifo_clear_irq

```
static void multicore_fifo_clear_irq ()
```

Clear FIFO interrupt.

3.40.3.2. multicore_fifo_drain

```
static void multicore_fifo_drain ()
```

Flush any data in the outgoing FIFO.

3.40.3.3. multicore_fifo_get_status

```
static int32_t multicore_fifo_get_status ()
```

Get FIFO status.

Bit	Description
3	Sticky flag indicating the RX FIFO was read when empty. This read was ignored by the FIFO.
2	Sticky flag indicating the TX FIFO was written when full. This write was ignored by the FIFO.
1	Value is 1 if this core's TX FIFO is not full (i.e. if FIFO_WR is ready for more data)
0	Value is 1 if this core's RX FIFO is not empty (i.e. if FIFO_RD is valid)

Returns

- The status as a bitfield

3.40.3.4. multicore_fifo_pop_blocking

```
uint32_t multicore_fifo_pop_blocking ()
```

Pop data from the FIFO.

This function will block until there is data ready to be read Use `multicore_fifo_rvalid()` to check if data is ready to be read if you don't want to block.

Returns

- 32 bit unsigned data from the FIFO.

3.40.3.5. multicore_fifo_push_blocking

```
void multicore_fifo_push_blocking (uint32_t data)
```

Push data on to the FIFO.

This function will block until there is space for the data to be sent. Use `multicore_fifo_wready()` to check if it is possible to write to the FIFO if you don't want to block.

Parameters

- `data` A 32 bit value to push on to the FIFO

3.40.3.6. multicore_fifo_rvalid

```
static bool multicore_fifo_rvalid ()
```

Check the read FIFO to see if there is data waiting.

Returns

- true if the FIFO has data in it, false otherwise

3.40.3.7. multicore_fifo_wready

```
static bool multicore_fifo_wready ()
```

Check the FIFO to see if the write FIFO is full.

Returns

- true if the FIFO is full, false otherwise

3.41. Pico standard library helpers (stdlib)

Some basic helper functions for use in Pico applications. More...

3.41.1. Functions

- `void setup_default_uart ()`
  Initialise the UART system to default values. More...
- `void default_uart_tx_wait ()`
  Wait for the default uart to empty its TX fifo.
- `void set_sys_clock_48 ()`
  Initialise the system clock to 48Mhz. More...
- `void set_sys_clock (uint32_t vco_freq, uint post_div1, uint post_div2)`
  Initialise the system clock. More...
- `bool uart_readable_within_us (uart_inst_t *uart, uint32_t us)`
  Check for UART content within time limit. More...
- `void attempt_sys_clock (uint32_t freq_khz)`
  Attempt to set a system clock frequency. More...

3.41.2. Detailed Description

Some basic helper functions for use in Pico applications.

There are some basic default values used by these functions that will default to usable values, however, they should be

defined in a board definition header via config.h or similar

3.41.3. Function Documentation

3.41.3.1. attempt_sys_clock

```
void attempt_sys_clock (uint32_t freq_khz)
```

Attempt to set a system clock frequency.

This function will panic if the frequency could not be set exactly.

Parameters

- `freq_khz` Requested frequency

3.41.3.2. default_uart_tx_wait

```
void default_uart_tx_wait ()
```

Wait for the default uart to empty its TX fifo.

3.41.3.3. set_sys_clock

```
void set_sys_clock (uint32_t vco_freq,
       uint post_div1,
       uint post_div2)
```

Initialise the system clock.

TO DO: Fill in parameters and description

Parameters

- `vco_freq`
- `post_div1`
- `post_div2`

3.41.3.4. set_sys_clock_48

```
void set_sys_clock_48 ()
```

Initialise the system clock to 48Mhz.

Set the system clock to 48Khz, and set the peripheral clock to match.

3.41.3.5. setup_default_uart

```
void setup_default_uart ()
```

Initialise the UART system to default values.

By default this will set `uart0` as the default UART, with TX to pin GPIO 28, RX to pin GPIO 29, and the baudrate to 115200
TO DO: ^ not true

3.41.3.6. uart_readable_within_us

```
bool uart_readable_within_us (uart_inst_t *uart,
       uint32_t us)
```

Check for UART content within time limit.

loop for specified amount of time waiting to see if data has arrived on the specified UART. Will return before the timeout if data is received

Parameters

- `uart` UART instance
- `us` Timeout in microseconds

Returns

- true if data is waiting, false if timeout reached before data arrived.

3.42. Hardware ADC API

This library provides a C API to give easy access to the ADC hardware. More...

3.42.1. Detailed Description

This library provides a C API to give easy access to the ADC hardware.

The RP2040 has an internal analogue-digital converter (ADC) with the following features:

- SAR ADC
- 500 kS/s (Using an independent 48MHz clock)
- 12 bit (9.5 ENOB)
- 5 input mux:
- 4 inputs that are available on package pins shared with GPIO[29:26]
- 1 input is dedicated to the internal temperature sensor
- 4 element receive sample FIFO
- Interrupt generation
- DMA interface

Although there is only one ADC you can specify the input to it using the adc_input_select() function. In round robin mode (adc_rrobin()) will use that input and move to the next one after a read.

User ADC inputs are on 0-3 (GPIO 26-29), the temperature sensor is on input 4.

Temperature sensor values can be approximated in centigrade as:

T = 27 - (ADC_Voltage - 0.706)/0.001721

The FIFO, if used, can contain up to 4 entries.

Example

3.43. Hardware_adc

3.43.1. Functions

- `void adc_init (void)`
  Initialise the ADC HW.
- `static void adc_gpio_init (uint gpio)`

Initialise the ADC GPIO. More...

- `static void adc_input_select (uint input)`
  ADC input select. More...
- `static void adc_round_robin (uint input_mask)`
  Round Robin sampling selector. More...
- `static void adc_enable_temp_sensor (bool enable)`
  Enable the onboard temperature sensor. More...
- `static uint16_t adc_read (void)`
  Perform a single conversion. More...
- `static void adc_run (bool run)`
  Enable or disable free-running sampling mode. More...
- `static void adc_set_clkdiv (float clkdiv)`
  Set the ADC Clock divisor. More...
- `static void adc_fifo_setup (bool en, bool dreq_en, uint16_t dreq_thresh, bool err_in_fifo, bool byte_shift)`
  Setup the ADC FIFO. More...
- `static bool adc_fifo_empty (void)`
  Check FIFO empty state. More...
- `static uint8_t adc_fifo_level (void)`
  Get number of entries in the ADC FIFO. More...
- `static uint16_t adc_fifo_get (void)`
  Get ADC result from FIFO. More...
- `static uint16_t adc_fifo_get_blocking (void)`
  Wait for the ADC FIFO to have data. More...
- `static void adc_fifo_drain (void)`
  Drain the ADC FIFO. More...
- `static void adc_irq_enable (bool enable)`
  Enable/Disable ADC interrupts. More...

3.43.2. Detailed Description

```c
#include <stdio.h>
#include "pico/stdlib.h"
#include "hardware/gpio.h"
#include "hardware/adc.h"

int main() {
    setup_default_uart();
    printf("ADC Example, measuring GPIO26\n");

    adc_init();

    // Make sure GPIO is high-impedance, no pullups etc
    adc_gpio_init(26);
    // Select ADC input 0 (GPIO26)
    adc_input_select(0);

    while (1) {
        // 12-bit conversion, assume max value == ADC_VREF == 3.3 V
```

```
19          const float conversion_factor = 3.3f / (1 << 12);
20          uint16_t result = adc_read();
21          printf("Raw value: 0x%03x, voltage: %f V\n", result, result *
   conversion_factor);
22          sleep_ms(500);
23      }
24  }
```

3.43.3. Function Documentation

3.43.3.1. adc_enable_temp_sensor

`static void adc_enable_temp_sensor (bool enable)`

Enable the onboard temperature sensor.

Parameters

- `enable` Set true to power on the onboard temperature sensor, false to power off.

3.43.3.2. adc_fifo_drain

`static void adc_fifo_drain (void)`

Drain the ADC FIFO.

Will wait for any conversion to complete then drain the FIFO discarding any results.

3.43.3.3. adc_fifo_empty

`static bool adc_fifo_empty (void)`

Check FIFO empty state.

Returns

- Returns true if the fifo is empty

3.43.3.4. adc_fifo_get

`static uint16_t adc_fifo_get (void)`

Get ADC result from FIFO.

Pops the latest result from the ADC FIFO.

3.43.3.5. adc_fifo_get_blocking

`static uint16_t adc_fifo_get_blocking (void)`

Wait for the ADC FIFO to have data.

Blocks until data is present in the FIFO

3.43.3.6. adc_fifo_level

`static uint8_t adc_fifo_level (void)`

Get number of entries in the ADC FIFO.

TO DO: How many entries? More details needed on the ADC FIFO

3.43.3.7. adc_fifo_setup

```
static void adc_fifo_setup (bool en,
       bool dreq_en,
       uint16_t dreq_thresh,
       bool err_in_fifo,
       bool byte_shift)
```

Setup the ADC FIFO.

FIFO is 4 samples long, if a conversion is completed and the FIFO is full the result is dropped.

Parameters

- `en` Enables write each conversion result to the FIFO
- `dreq_en` Enable DMA requests when FIFO contains data
- `dreq_thresh` Threshold for DMA requests/FIFO IRQ if enabled.
- `err_in_fifo` If enabled, bit 15 of the FIFO contains error flag for each sample
- `byte_shift` Shift FIFO contents to be one byte in size (for byte DMA) - enables DMA to byte buffers.

3.43.3.8. adc_gpio_init

```
static void adc_gpio_init (uint gpio)
```

Initialise the ADC GPIO.

Prepare a GPIO for use with ADC, by disabling all digital functions.

Parameters

- `gpio` The GPIO number to use. Allowable GPIO numbers are 26 to 29 inclusive.

3.43.3.9. adc_init

```
void adc_init (void)
```

Initialise the ADC HW.

3.43.3.10. adc_input_select

```
static void adc_input_select (uint input)
```

ADC input select.

Select an ADC input. 0...3 are GPIOs 26...29 respectively. Input 4 is the onboard temperature sensor.

Parameters

- `input` Input to select.

3.43.3.11. adc_irq_enable

```
static void adc_irq_enable (bool enable)
```

Enable/Disable ADC interrupts.

Parameters

- `enable` Set to true to enable the ADC interrupts, false to disable

3.43.3.12. adc_read

```
static uint16_t adc_read (void)
```

Perform a single conversion.

Performs an ADC conversion, waits for the result, and then returns it.

Returns

- Result of the conversion.

3.43.3.13. adc_round_robin

```
static void adc_round_robin (uint input_mask)
```

Round Robin sampling selector.

This function sets which inputs are to be run through in round robin mode. Value between 0 and 0x1f (bit 0 to bit 4 for GPIO 26 to 29 and temperature sensor input respectively)

Parameters

- `input_mask` A bit pattern indicating which of the 5 inputs are to be sampled. Write a value of 0 to disable round robin sampling.

3.43.3.14. adc_run

```
static void adc_run (bool run)
```

Enable or disable free-running sampling mode.

Parameters

- `run` false to disable, true to enable free running conversion mode.

3.43.3.15. adc_set_clkdiv

```
static void adc_set_clkdiv (float clkdiv)
```

Set the ADC Clock divisor.

Period of samples will be (1 + div) cycles on average. Note it takes 96 cycles to perform a conversion, so any period less than that will be clamped to 96.

Parameters

- `clkdiv` If non-zero, conversion will be started at intervals rather than back to back.

3.44. Hardware Clock API

This API provices a high level interface to the clock functions. More...

3.44.1. Functions

- `void clocks_init ()`
  Initialise the clock hardware. More...
- `int clock_configure (enum clock_index clk_index, uint32_t src, uint32_t auxsrc, uint32_t src_freq, uint32_t freq)`

Configure the specified clock. More...

- `void clock_stop (enum clock_index clk_index)`
  Stop the specified clock. More...
- `uint32_t clock_get_hz (enum clock_index clk_index)`
  Get the current frequency of the specified clock. More...
- `uint32_t frequency_count_khz (uint src)` More...
- `void clock_set_reported_hz (enum clock_index clk_index, uint hz)`
  Set the "current frequency" of the clock as reported by clock_get_hz without actually changing the clock. More...

3.44.2. Detailed Description

This API provices a high level interface to the clock functions.

The clocks block provides independent clocks to on-chip and external components. It takes inputs from a variety of clock sources allowing the user to trade off performance against cost, board area and power consumption. From these sources it uses multiple clock generators to provide the required clocks. This architecture allows the user flexibility to start and stop clocks independently and to vary some clock frequencies whilst maintaining others at their optimum frequencies

Please refer to the datasheet for more details on the RP2040 clocks.

Example// hello_48MHz.c

```
#include <stdio.h>
#include "pico/stdlib.h"
#include "hardware/pll.h"
#include "hardware/clocks.h"
#include "hardware/structs/pll.h"
#include "hardware/structs/clocks.h"

void measure_freqs(void) {
    uint f_pll_sys = frequency_count_khz
(CLOCKS_FC0_SRC_VALUE_PLL_SYS_CLKSRC_PRIMARY);
    uint f_pll_usb = frequency_count_khz
(CLOCKS_FC0_SRC_VALUE_PLL_USB_CLKSRC_PRIMARY);
    uint f_rosc = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_ROSC_CLKSRC);
    uint f_clk_sys = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_SYS);
    uint f_clk_peri = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_PERI);
    uint f_clk_usb = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_USB);
    uint f_clk_adc = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_ADC);
    uint f_clk_rtc = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_RTC);

    printf("pll_sys  = %dKHz\n", f_pll_sys);
    printf("pll_usb  = %dKHz\n", f_pll_usb);
    printf("rosc     = %dKHz\n", f_rosc);
    printf("clk_sys  = %dKHz\n", f_clk_sys);
    printf("clk_peri = %dKHz\n", f_clk_peri);
    printf("clk_usb  = %dKHz\n", f_clk_usb);
    printf("clk_adc  = %dKHz\n", f_clk_adc);
    printf("clk_rtc  = %dKHz\n", f_clk_rtc);

    // Can't measure clk_ref / xosc as it is the ref
}

int main() {
```

```
31      setup_default_uart();
32
33      printf("Hello, world!\n");
34
35      measure_freqs();
36
37      // Change clk_sys to be 48MHz. The simplest way is to take this from PLL_USB
38      // which has a source frequency of 48MHz
39      clock_configure(clk_sys,
40                      CLOCKS_CLK_SYS_CTRL_SRC_VALUE_CLKSRC_CLK_SYS_AUX,
41                      CLOCKS_CLK_SYS_CTRL_AUXSRC_VALUE_CLKSRC_PLL_USB,
42                      48 * MHZ,
43                      48 * MHZ);
44
45      // Turn off PLL sys for good measure
46      pll_deinit(pll_sys);
47
48      // CLK peri is clocked from clk_sys so need to change clk_peri's freq
49      clock_configure(clk_peri,
50                      0,
51                      CLOCKS_CLK_PERI_CTRL_AUXSRC_VALUE_CLK_SYS,
52                      48 * MHZ,
53                      48 * MHZ);
54
55      // Re init uart now that clk_peri has changed
56      setup_default_uart();
57
58      measure_freqs();
59      printf("Hello, 48MHz");
60
61      return 0;
62  }
```

3.44.3. Function Documentation

3.44.3.1. clock_configure

```
int clock_configure (enum clock_index clk_index,
        uint32_t src,
        uint32_t auxsrc,
        uint32_t src_freq,
        uint32_t freq)
```

Configure the specified clock.

TO DO: Need to fill these in

Parameters

- `clk_index` The clock to configure
- `src`
- `auxsrc`
- `src_freq`

- `freq`

3.44.3.2. clock_get_hz

```
uint32_t clock_get_hz (enum clock_index clk_index)
```

Get the current frequency of the specified clock.

Parameters

- `clk_index` Clock

Returns

- Clock frequency in Hz

3.44.3.3. clock_set_reported_hz

```
void clock_set_reported_hz (enum clock_index clk_index,
      uint hz)
```

Set the "current frequency" of the clock as reported by clock_get_hz without actually changing the clock.

See also

- clock_get_hz

3.44.3.4. clock_stop

```
void clock_stop (enum clock_index clk_index)
```

Stop the specified clock.

Parameters

- `clk_index` The clock to stop

3.44.3.5. clocks_init

```
void clocks_init ()
```

Initialise the clock hardware.

Must be called before any other clock function.

3.44.3.6. frequency_count_khz

```
uint32_t frequency_count_khz (uint src)
```

TO DO: No idea what this does

3.45. Hardware Resets API

The reset controller allows software control of the resets to all of the peripherals that are not critical to boot the processor in the RP2040. More...

3.45.1. Functions

- `static void reset_block (uint32_t bits)`
  Reset the specified HW blocks. More...

- `static void unreset_block (uint32_t bits)`
  bring specified HW blocks out of reset More...
- `static void unreset_block_wait (uint32_t bits)`
  Bring specified HW blocks out of reset and wait for completion. More...

3.45.2. Detailed Description

The reset controller allows software control of the resets to all of the peripherals that are not critical to boot the processor in the RP2040.

reset_bitmaskMultiple blocks are referred to using a bitmask as follows:

Block to reset	Bit
USB	24
UART 1	23
UART 0	22
Timer	21
TB Manager	20
SysInfo	19
System Config	18
SPI 1	17
SPI 0	16
RTC	15
PWM	14
PLL USB	13
PLL System	12
PIO 1	11
PIO 0	10
Pads - QSPI	9
Pads - bank 0	8
JTAG	7
IO Bank 1	6
IO Bank 0	5
I2C 1	4
I2C 0	3
DMA	2
Bus Control	1
ADC 0	0

3.45.3. Function Documentation

3.45.3.1. reset_block

`static void reset_block (uint32_t bits)`

Reset the specified HW blocks.

Parameters

- `bits` Bit pattern indicating blocks to reset. See reset_bitmask

3.45.3.2. unreset_block

`static void unreset_block (uint32_t bits)`

bring specified HW blocks out of reset

Parameters

- `bits` Bit pattern indicating blocks to unreset. See reset_bitmask

3.45.3.3. unreset_block_wait

`static void unreset_block_wait (uint32_t bits)`

Bring specified HW blocks out of reset and wait for completion.

Parameters

- `bits` Bit pattern indicating blocks to unreset. See reset_bitmask

3.46. Hardware Real Time Clock API

The RTC keeps track of time in human readable format and generates events when the time is equal to a preset value. Think of a digital clock, not epoch time used by most computers. There are seven fields, one each for year (12 bit), month (4 bit), day (5 bit), day of the week (3 bit), hour (5 bit) minute (6 bit) and second (6 bit), storing the data in binary format. More...

3.46.1. Functions

- `int rtc_init (void)`
  Initialise the RTC system. More...
- `int rtc_set_datetime (datetime_t *t)`
  Set the RTC to the specified time. More...
- `int rtc_get_datetime (datetime_t *t)`
  Get the current time from the RTC. More...

3.46.2. Detailed Description

The RTC keeps track of time in human readable format and generates events when the time is equal to a preset value. Think of a digital clock, not epoch time used by most computers. There are seven fields, one each for year (12 bit), month (4 bit), day (5 bit), day of the week (3 bit), hour (5 bit) minute (6 bit) and second (6 bit), storing the data in binary format.

See also

- datetime_t

Example// hello_rtc.c

```
#include <stdio.h>
#include "pico/stdlib.h"
#include "pico/datetime.h"
#include "hardware/rtc.h"

int main() {
    setup_default_uart();
    printf("Hello RTC!\n");

    char datetime_buf[256];
    char *datetime_str = &datetime_buf[0];

    // Start on Friday 5th of June 2020 15:45:00
    datetime_t t = {
            .year  = 2020,
            .month = 06,
            .day   = 05,
            .dotw  = 5, // 0 is Sunday, so 5 is Friday
            .hour  = 15,
            .min   = 45,
            .sec   = 00
    };

    // Start the RTC
    rtc_init();
    rtc_set_datetime(&t);

    // Print the time
    while (true) {
        rtc_get_datetime(&t);
        datetime_to_str(datetime_str, sizeof(datetime_buf), &t);
        printf("\r%s      ", datetime_str);
        sleep_ms(100);
    }

    return 0;
}
```

3.46.3. Function Documentation

3.46.3.1. rtc_get_datetime

`int rtc_get_datetime (datetime_t *t)`

Get the current time from the RTC.

Parameters

- `t` Pointer to a datetime_t structure to receive the current RTC time

Returns

- 0 if datetime is valid, -1 if the RTC is not running.

3.46.3.2. rtc_init

```
int rtc_init (void)
```

Initialise the RTC system.

Returns

- 0 if RTC intiialised correctly, -1 if the RTC was unable to get a clock.

3.46.3.3. rtc_set_datetime

```
int rtc_set_datetime (datetime_t *t)
```

Set the RTC to the specified time.

Parameters

- `t` Pointer to a datetime_t structure contains time to set

Returns

- 0 if set, -1 if the passed in datetime was invalid.

3.47. Hardware timer API

This API provides medium level access to the timer HW. See also Time/Sleep/Alarm/Timer API which provides higher levels functionality using the hardware timer. More...

3.47.1. Typedefs

- `typedef void(* hardware_alarm_callback_t )(uint alarm_num)` More...

3.47.2. Functions

- `static uint32_t time_us_32 ()`
  Return a 32 bit timestamp value in microseconds. More...
- `uint64_t timer_us_64 ()`
  Return the current 64 bit timestamp value in microseconds. More...
- `void busy_wait_us_32 (uint32_t delay_us)`
  Busy wait wasting cycles for the given (32 bit) number of microseconds. More...
- `void busy_wait_us (uint64_t delay_us)`
  Busy wait wasting cycles for the given (64 bit) number of microseconds. More...
- `void busy_wait_until (absolute_time_t t)`
  Busy wait wasting cycles until after the specified timestamp. More...
- `static bool time_reached (absolute_time_t t)`
  Check if the specified timestamp has been reached. More...
- `void hardware_alarm_claim (uint alarm_num)`
  cooperatively claim the use of this hardware alarm_num More...
- `void hardware_alarm_unclaim (uint alarm_num)`
  cooperatively release the claim on use of this hardware alarm_num More...

- `void hardware_alarm_set_callback (uint alarm_num, hardware_alarm_callback_t callback)`
  Enable/Disable a callback for a hardware timer on this core. More...

3.47.3. Detailed Description

This API provides medium level access to the timer HW. See also Time/Sleep/Alarm/Timer API which provides higher levels functionality using the hardware timer.

The timer peripheral on RP2040 supports the following features:

- single 64-bit counter, incrementing once per microsecond
- Latching two-stage read of counter, for race-free read over 32 bit bus
- Four alarms: match on the lower 32 bits of counter, IRQ on match.

By default the timer uses a one microsecond reference that is generated in the Watchdog (see Section 4.8.2) which is derived from the clk_ref.

The timer has 4 alarms, and can output a separate interrupt for each alarm. The alarms match on the lower 32 bits of the 64 bit counter which means they can be fired a maximum of 2^32 microseconds into the future. This is equivalent to:

- 2^32 ÷ 10^6: ~4295 seconds
- 4295 ÷ 60: ~72 minutes

The timer is expected to be used for short sleeps, if you want a longer alarm see the Hardware Real Time Clock API functions.

Example

```c
#include <stdio.h>
#include "pico/stdlib.h"

// Simplest form of getting 64 bit time from the timer.
// It isn't safe when called from 2 cores because of the latching
// so isn't implemented this way in the sdk
static uint64_t get_time(void) {
    // Reading low latches the high value
    uint32_t lo = timer_hw->timelr;
    uint32_t hi = timer_hw->timehr;
    return ((uint64_t) hi << 32u) | lo;
}

volatile bool timer_fired = false;

int64_t alarm_callback(alarm_id_t id, void *user_data) {
    printf("Timer %d fired!\n", (int)id);
    timer_fired = true;
    return 0;
}

bool repeating_timer_callback(struct repeating_timer *t) {
    printf("Repeat at %lld\n", timer_us_64());
    return true;
}

int main() {
    setup_default_uart();
    printf("Hello Timer!\n");
```

```
30     add_alarm_in_ms(2000, alarm_callback, NULL, false);
31     while (!timer_fired) {
32         tight_loop_contents();
33     }
34     struct repeating_timer timer;
35
36     add_repeating_timer_ms(500, repeating_timer_callback, NULL, &timer);
37     sleep_ms(3000);
38     bool cancelled = cancel_repeating_timer(&timer);
39     printf("cancelled... %d\n", cancelled);
40     sleep_ms(2000);
41
42     // todo discuss pos / neg here - this one repeats exactly on the time, postive
   has N ms gap instead
43     add_repeating_timer_ms(-500, repeating_timer_callback, NULL, &timer);
44     sleep_ms(3000);
45     cancelled = cancel_repeating_timer(&timer);
46     printf("cancelled... %d\n", cancelled);
47     sleep_ms(2000);
48     printf("Done\n");
49     return 0;
50 }
```

3.47.4. Function Documentation

3.47.4.1. busy_wait_until

`void busy_wait_until (absolute_time_t t)`

Busy wait wasting cycles until after the specified timestamp.

Parameters

- `t` Absolute time to wait until

3.47.4.2. busy_wait_us

`void busy_wait_us (uint64_t delay_us)`

Busy wait wasting cycles for the given (64 bit) number of microseconds.

Parameters

- `delay_us` delay amount

3.47.4.3. busy_wait_us_32

`void busy_wait_us_32 (uint32_t delay_us)`

Busy wait wasting cycles for the given (32 bit) number of microseconds.

Busy wait wasting cycles for the given (32 bit) number of microseconds.

Parameters

- `delay_us` delay amount

3.47.4.4. hardware_alarm_claim

```
void hardware_alarm_claim (uint alarm_num)
```

cooperatively claim the use of this hardware alarm_num

This method hard asserts if the hardware alarm is currently claimed.

Parameters

- `alarm_num` the hardware alarm to claim

See also

- hardware_claiming

3.47.4.5. hardware_alarm_set_callback

```
void hardware_alarm_set_callback (uint alarm_num,
      hardware_alarm_callback_t callback)
```

Enable/Disable a callback for a hardware timer on this core.

This method enables/disables the alarm IRQ for the specified hardware alarm on the calling core, and set the specified callback to be associated with that alarm.

This callback will be used for the timeout set via hardware_alarm_set_target

Note: this will install the handler on the current core if the IRQ handler isn't already set. Therefore the user has the opportunity to call this up from the core of their choice

Parameters

- `alarm_num` the hardware alarm number
- `callback` the callback to install, or NULL to unset

See also

- hardware_alarm_set_target

3.47.4.6. hardware_alarm_unclaim

```
void hardware_alarm_unclaim (uint alarm_num)
```

cooperatively release the claim on use of this hardware alarm_num

Parameters

- `alarm_num` the hardware alarm to unclaim

See also

- hardware_claiming

3.47.4.7. time_reached

```
static bool time_reached (absolute_time_t t)
```

Check if the specified timestamp has been reached.

Parameters

- `t` Absolute time to compare against current time

Returns

- true if it is now after the specified timestamp

3.47.4.8. time_us_32

```
static uint32_t time_us_32 ()
```

Return a 32 bit timestamp value in microseconds.

Returns the low 32 bits of the hardware timer. Note this value wraps roughly every 1 hour 11 minutes and 35 seconds.

Returns

- the 32 bit timestamp

3.47.4.9. timer_us_64

```
uint64_t timer_us_64 ()
```

Return the current 64 bit timestamp value in microseconds.

Returns the full 64 bits of the hardware timer. The `Time/Sleep/Alarm/Timer API` and other functions rely on the fact that this value monotonically increases from power up. As such it is expected that this value counts upwards and never wraps (we apologize for introducing a potential year 5851444 bug).

Return the current 64 bit timestamp value in microseconds.

Returns

- the 64 bit timestamp

3.48. Hardware UART API

RP2040 has 2 identical instances of a UART peripheral, based on the ARM PL011. Each UART can be connected to a number of GPIO pins as defined in the GPIO muxing. More...

3.48.1. Enumerations

- `enum uart_parity_t { UART_PARITY_NONE, UART_PARITY_EVEN, UART_PARITY_ODD }`
  UART Parity enumeration.

3.48.2. Functions

- `static uint uart_hw_index (uart_inst_t *uart)`
  Convert UART instance to hardware instance number. More...
- `void uart_init (uart_inst_t *uart, uint baudrate)`
  Initialise a UART. More...
- `void uart_deinit (uart_inst_t *uart)`
  DeInitialise a UART. More...
- `uint uart_set_baudrate (uart_inst_t *uart, uint baudrate)`
  Set UART baud rate. More...
- `static void uart_set_hwflow (uart_inst_t *uart, bool cts, bool rts)`
  Set UART flow control CTS/RTS. More...
- `static void uart_set_format (uart_inst_t *uart, uint data_bits, uint stop_bits, uart_parity_t parity)`
  Set UART data format. More...
- `static void uart_set_irq_enable (uart_inst_t *uart, bool rx_has_data, bool tx_needs_data)`
  Setup UART interrupts. More...
- `static bool uart_enabled (uart_inst_t *uart)`

Test if specific UART is enabled. More...

- `static void uart_fifo_enable (uart_inst_t *uart, bool en)`
  Enable/Disable the FIFOs on specified UART. More...
- `static size_t uart_writable (uart_inst_t *uart)`
  Determine amount of space available in TX FIFO. More...
- `static void uart_tx_wait (uart_inst_t *uart)`
  Wait for the UART TX fifo to be drained. More...
- `static size_t uart_readable (uart_inst_t *uart)`
  Determine amount of data waiting in the RX FIFO. More...
- `static void uart_write_blocking (uart_inst_t *uart, const uint8_t *src, size_t len)`
  Write to the UART for transmission. More...
- `static void uart_read_blocking (uart_inst_t *uart, uint8_t *dst, size_t len)`
  Read from the UART. More...
- `static void uart_putc_raw (uart_inst_t *uart, char c)`
  Write single character to UART for transmission. More...
- `static void uart_putc (uart_inst_t *uart, char c)`
  Write single character to UART for transmission, do CR/LF conversions. More...
- `static void uart_puts (uart_inst_t *uart, const char *s)`
  Write string to UART for transmission, doing any CR/LF conversions. More...
- `static char uart_getc (uart_inst_t *uart)`
  Read a single character to UART. More...
- `static void uart_set_break (uart_inst_t *uart, bool en)`
  Assert a break condition on the UART transmission. More...
- `void uart_set_crlf (uart_inst_t *uart, bool crlf)`
  Set CR/LF conversion on UART. More...

3.48.3. Variables

- `uart_inst_t const *uart0`
  Identifier for UART instance 0. More...
- `uart_inst_t const *uart1`
  Identifier for UART instance 1.

3.48.4. Detailed Description

RP2040 has 2 identical instances of a UART peripheral, based on the ARM PL011. Each UART can be connected to a number of GPIO pins as defined in the GPIO muxing.

Only the TX, RX, RTS, and CTS signals are connected, meaning that the modem mode and IrDA mode of the PL011 are not supported.

UART Example code//

```
1  int main() {
2
3      // Initialise UART 0
4      uart_init(uart0, 115200);
5
6      // Set the GPIO pin mux to the UART - 0 is TX, 1 is RX
```

```
 7     gpio_funcsel(0, GPIO_FUNC_UART);
 8     gpio_funcsel(1, GPIO_FUNC_UART);
 9
10     uart_puts(uart0, "Hello world!");
11 }
```

3.48.5. Function Documentation

3.48.5.1. uart_deinit

```
void uart_deinit (uart_inst_t *uart)
```

DeInitialise a UART.

Disable the UART if it is no longer used. Must be reinitialised before being used again.

Parameters

- `uart` UART instance. uart0 or uart1

3.48.5.2. uart_enabled

```
static bool uart_enabled (uart_inst_t *uart)
```

Test if specific UART is enabled.

Parameters

- `uart` UART instance. uart0 or uart1

Returns

- true si the UART is enabled

3.48.5.3. uart_fifo_enable

```
static void uart_fifo_enable (uart_inst_t *uart,
      bool en)
```

Enable/Disable the FIFOs on specified UART.

Parameters

- `uart` UART instance. uart0 or uart1
- `en` true to enable FIFO (default), false to disable

3.48.5.4. uart_getc

```
static char uart_getc (uart_inst_t *uart)
```

Read a single character to UART.

This function will block until the character has been read

Parameters

- `uart` UART instance. uart0 or uart1

Returns

- The character read.

3.48.5.5. uart_hw_index

```
static uint uart_hw_index (uart_inst_t *uart)
```

Convert UART instance to hardware instance number.

Parameters

- `uart` UART instance

Returns

- Number of UART, 0 or 1.

3.48.5.6. uart_init

```
void uart_init (uart_inst_t *uart,
      uint baudrate)
```

Initialise a UART.

Put the UART into a known state, and enable it. Must be called before other functions.

Note there is no guarantee that the baudrate requested will be possible, the nearest will be chosen, and this function does not return any indication of this. You can use the `uart_set_baudrate` function which will return the actual baudrate selected if this is important.

Parameters

- `uart` UART instance. uart0 or uart1
- `baudrate` Baudrate of UART in Hz

3.48.5.7. uart_putc

```
static void uart_putc (uart_inst_t *uart,
      char c)
```

Write single character to UART for transmission, do CR/LF conversions.

This function will block until the character has been sent

Parameters

- `uart` UART instance. uart0 or uart1
- `c` The character to send

3.48.5.8. uart_putc_raw

```
static void uart_putc_raw (uart_inst_t *uart,
      char c)
```

Write single character to UART for transmission.

This function will block until all the character has been sent

Parameters

- `uart` UART instance. uart0 or uart1
- `c` The character to send

3.48.5.9. uart_puts

```
static void uart_puts (uart_inst_t *uart,
       const char *s)
```

Write string to UART for transmission, doing any CR/LF conversions.

This function will block until the entire string has been sent

Parameters

- `uart` UART instance. uart0 or uart1
- `s` The null terminated string to send

3.48.5.10. uart_read_blocking

```
static void uart_read_blocking (uart_inst_t *uart,
       uint8_t *dst,
       size_t len)
```

Read from the UART.

This function will block until all the data has been received from the UART

Parameters

- `uart` UART instance. uart0 or uart1
- `dst` Buffer to accept received bytes
- `len` The number of bytes to receive.

3.48.5.11. uart_readable

```
static size_t uart_readable (uart_inst_t *uart)
```

Determine amount of data waiting in the RX FIFO.

NOTE

HW limitations mean this function will return either 0 or 1.

Parameters

- `uart` UART instance. uart0 or uart1

Returns

- 0 if no data available, otherwise the number of bytes, at least, that can be read

3.48.5.12. uart_set_baudrate

```
uint uart_set_baudrate (uart_inst_t *uart,
       uint baudrate)
```

Set UART baud rate.

Set baud rate as close as possible to requested, and return actual rate selected.

Parameters

- `uart` UART instance. uart0 or uart1
- `baudrate` Baudrate in Hz

3.48.5.13. uart_set_break

```
static void uart_set_break (uart_inst_t *uart,
       bool en)
```

Assert a break condition on the UART transmission.

Parameters

- `uart` UART instance. uart0 or uart1
- `en` Assert break condition (TX held low) if true. Clear break condition if false.

3.48.5.14. uart_set_crlf

```
void uart_set_crlf (uart_inst_t *uart,
       bool crlf)
```

Set CR/LF conversion on UART.

Parameters

- `uart` UART instance. uart0 or uart1
- `crlf` If true, convert line feeds to carriage return on transmissions

3.48.5.15. uart_set_format

```
static void uart_set_format (uart_inst_t *uart,
       uint data_bits,
       uint stop_bits,
       uart_parity_t parity)
```

Set UART data format.

Configure the data format (bits etc() for the UART

Parameters

- `uart` UART instance. uart0 or uart1
- `data_bits` Number of bits of data. 5..8
- `stop_bits` Number of stop bits 1..2
- `parity` Parity option.

3.48.5.16. uart_set_hwflow

```
static void uart_set_hwflow (uart_inst_t *uart,
       bool cts,
       bool rts)
```

Set UART flow control CTS/RTS.

Parameters

- `uart` UART instance. uart0 or uart1
- `cts` If true enable flow control of TX by clear-to-send input
- `rts` If true enable assertion of request-to-send output by RX flow control

3.48.5.17. uart_set_irq_enable

```
static void uart_set_irq_enable (uart_inst_t *uart,
       bool rx_has_data,
       bool tx_needs_data)
```

Setup UART interrupts.

Enable the UART's interrupt output. An interrupt handler first will need to be install prior to calling this function

Parameters

- `uart` UART instance. uart0 or uart1
- `rx_has_data` If true an interrupt will be fired when the RX FIFO contain data.
- `tx_needs_data` If true an interrupt will be fired when the TX FIFO needs data.

See also

- irq.

3.48.5.18. uart_tx_wait

```
static void uart_tx_wait (uart_inst_t *uart)
```

Wait for the UART TX fifo to be drained.

Parameters

- `uart` UART instance. uart0 or uart1

3.48.5.19. uart_writable

```
static size_t uart_writable (uart_inst_t *uart)
```

Determine amount of space available in TX FIFO.

Parameters

- `uart` UART instance. uart0 or uart1

Returns

- 0 if no space available, otherwise the number of bytes, at least, that can be written

3.48.5.20. uart_write_blocking

```
static void uart_write_blocking (uart_inst_t *uart,
       const uint8_t *src,
       size_t len)
```

Write to the UART for transmission.

This function will block until all the data has been sent to the UART

Parameters

- `uart` UART instance. uart0 or uart1
- `src` The bytes to send
- `len` The number of bytes to send

Chapter 4. Using the PIO (Programmable IO)

4.1. What is Programmable IO (PIO)?

Programmable IO (PIO) is a unique todo:? feature of the RP2040. It allows you to create new types of (or additional) hardware interfaces on your RP2040 based device. (e.g. I want to add 4 more UARTs, or I'd like to output DPI video)

4.1.1. Background

Interfacing with other digital hardware components is hard. It often happens at very high frequencies (due to amounts of data that need to be transferred), and has very exact timing requirements.

Traditionally on your desktop computer you have one option for hardware interfacing:

4.1.2. IO Using Dedicated Hardware on your PC

This is a no brainer; your computer has high speed USB ports, HDMI outputs SD card slots, SATA drive controllers etc. to take care of the tricky and time sensitive business of sending and receiving ones and zeros and responding with minimal latency or interruption to the device, SD card, hard driver etc. on the other end of the hardware interface.

The custom hardware components take care of specific tasks that the more general multi-tasking CPU is not designed for. The operating system drivers perform higher level management of what the hardware components do, and coordinate data transfers via DMA to/from memory from the controller and receive IRQs when high level tasks need attention.

4.1.3. IO Using Dedicated hardware on your Raspberry Pi or microcontroller

Not so common on PCs, your Raspberry Pi or microcontroller is likely to have dedicated hardware on chip for managing UART, I2C, SPI, PWM todo more over GPIO pins. Like USB controllers (which many microcontroller including the Raspberry Pi Pico have), I2C and SPI are general purpose connection protocols allowing connection to a wide variety of different types of external hardware using the same piece of on chip hardware.

This is all very well, but the area taken up by these individual components and the associate cost, often leaves you with a limited menu, or you end up paying for a bunch of stuff you don't need, and find yourself without enough of what you really want, and of course you are out of luck if your microcontroller does not have dedicated hardware for the type of hardware device you want to attach (although in some cases you may be able to bridge over USB, I2C or SPI at the cost of buying external hardware).

4.1.4. IO Using Software Control of GPIOs (*"bit-banging"*)

The third option on your Raspberry Pi or microcontroller - i.e. something with GPIOs - is to use the CPU to wiggle (and listen to) the GPIOs at dizzyingly high speeds, and hope to do so with sufficiently correct timing that the external hardware still understands the signals.

As a bit of background it is worth thinking about types of hardware that you might want to interface:

todo if this is a useful table, then verify and flesh it out a bit

Table 6. Types of hardware

Interface Speed	Interface
1-1000Hz	Push buttons, temperature sensors

Interface Speed	Interface
?-?	UART
22-100+ Khz	PCM audio
300+ Khz	PWM audio
400-1200 Khz	WS2812 LED string
10-4000 Mhz	LAN
20-1000 Mhz	DPI/VGA/HDMI/DVI video
12-4000 Mhz	SD card
48-40000 Mhz	USB

"Bit-Banging" (i.e using the processor to hammer out the protocol via the GPIOs) is very hard. The processor isn't really designed for this. It has other work to do.... for slower protocols you might be able to use an IRQ to wake up the processor from what it was doing fast enough (though latency here is a concern) to send the next bit(s). Indeed back in the early days of PC sound it was not uncommon to set a hardware timer interrupt at 11kHz and write out one 8 bit PCM sample every interrupt for some rather primitive sounding audio!

Doing that on a PC nowadays is laughed at, even though they are many order of magnitudes faster than they were pack then.

The alternative when *"bit-banging"* is to sit the processor in a carefully timed loop, written exactly in assembly, trying to make sure the GPIO reading and writing happens on the exact cycle required. This is really really hard work if indeed possible at all. Many heroic hours and likely hundreds of github repositories are dedicated to the task of doing such things (perhaps for LED strings). Additionally of course, your processor is now busy doing the *"bit-banging"*, and cannot be used for other tasks.

Whilst dealing with something like an LED string is possible using *"bit-banging"*, once your hardware protocol gets faster to the point that it is of similar order of magnitude to your system clock speed, there is really nothing you can hope to do.

Therefore you're back to custom hardware for the protocols you know up front you are going to want (or more accurately, the chip designer thinks you might need).

4.1.5. Programmable IO Hardware using PIO

The unique PIO subsystem of the RP2040 allows you to write small simple programs for what are called *PIO state machines* (of which the RP2040 has eight split across two PIO *instances*) which are each responsible for setting and reading bits of on one or more GPIOs, buffering data to or from the processor (or RP2040's ultra-fast DMA subsystem), and notifying the processor (via IRQ or polling) when more data or attention is needed.

These programs can perform operations with cycle accuracy at up to system clock speed (or the program clock's can be divided down to run at slower speeds for less frisky protocols).

For simple hardware protocols - such as PWM or duplex SPI - a single PIO state machine can handle the task of implementing the hardware interface all on its own, or for more involved protocols such as SDIO or DPI video you may end up using two or three.

NOTE

If you are ever tempted to *"bit-bang"* a protocol on the RP2040, don't! Use the PIO instead. Frankly this is true for anything that repeatedly reads or writes from GPIOs, but certainly anything which aims to transfer data.

4.2. Getting Started with PIO

It is possible to write PIO programs with both within the C/C++ SDK and directly from MicroPython.

Additionally the intention is for both to have simple APIs to trivially have new UARTs, PWM channels etc created for you, picking from a menu of pre-written PIO programs, but for now you'll have to follow along with example code and do that yourself.

TO DO: a mini handbook for the PIO assembly language. talk through the language constructs, show a couple of simple examples

4.3. Something simpler than WS2812 TO DO: Working title!

TO DO: Whilst WS2812 is actually only a few instructions in PIO assembly, it is probably not the simplest first program, so pre-amble with something else first

4.4. Using PIOASM the PIO Assembler

4.5. Managing WS2812 LEDs

The WS2812 LED, or NeoPixel, is…

TO DO: Write introduction to this, and tidy it all up. Direct dump from Graham's email at this time

TO DO: This is an example "app note" for PIO but probably not the **first** app note we want to show

```
1 .program ws2812
2 .side_set 1
3
4 .define public T1 2
5 .define public T2 5
6 .define public T3 3
7
8 .wrap_target
9 bitloop:
10     out x, 1       [T3 - 1] set 0 ; Side-set still takes place when instruction
  stalls
11     jmp !x do_zero [T1 - 1] set 1 ; Branch on the bit we shifted out. Positive
  pulse
12 do_one:
13     jmp  bitloop   [T2 - 1] set 1 ; Continue driving high, for a long pulse
14 do_zero:
15     nop            [T2 - 1] set 0 ; Or drive low, for a short pulse
16 .wrap
17
18 % c-sdk {
```

```
19 #include "hardware/clocks.h"
20
21 static inline void ws2812_program_init(PIO pio, uint sm, uint offset, uint pin,
   float freq, bool rgbw) {
22
23     pio_gpio_select(pio, pin);
24     pio_set_consecutive_pindirs(pio, sm, pin, 1, true);
25
26     pio_sm_config c = ws2812_program_default_config(offset);
27     sm_config_sideset_pins(&c, pin);
28     sm_config_out_shift(&c, false, true, rgbw ? 32 : 24);
29
30     int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3;
31     float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit);
32     sm_config_clkdiv(&c, div);
33
34     pio_sm_init(pio, sm, offset, &c);
35     pio_sm_enable(pio, sm, true);
36 }
37 %}
```

Starting to disect this snippet. We are defining a program named ws2812

```
.program ws2812
```

Each instruction in the PIO is 16 bits wide. 5 of those are used for the “delay” which is usually 0 to 31 cycles (after the instruction completes before moving to the next up instruction).. (FYI the instruction delay appears as the value in [] to the right of the instruction in the assembly)

```
.side_set 1
```

This directive `.side_set 1` says we’re stealing one of those bits to use for "side set" which allows us to assert pin values with each instruction (in addition to what the instructions are themselves doing).This is very useful for high frequency use cases (e.g. pixel clocks for DPI panels), but also for. Shrinking program size (each PIO only has a 32 instruction memory - shared between 4 SMs).

Note that stealing one bit has left our delay range from 0-15, but that is quite natural because you rarely want to mix side set with lower frequency stuff. Because we didn’t say `.side_set 1` opt which mens the side set is optional (at the cost of another delay bit to say whether the instruction does a side set) we now have to specify a side set value for each instruction in the program (this is the `set N` after the delay)

```
.define public T1 2
.define public T2 5
.define public T3 3
```

`.define` lets you declare constants. The public modifier means that the code generator will spit out a `#define` for it, in the Pico SDK generator case.

```
.wrap_target
```

We'll ignore this for now, and come back to it later.

```
bitloop:
```

This is a label, while,

```
    out x, 1       [T3 - 1] set 0 ; Side-set still takes place when instruction
stalls
```

- `out` takes bits from the OSR (output shift register) which contains data coming from the the CPU (or DMA) side. Basically this is the data we are trying to write to the LED string. We are dealing with 1 bit (the ", 1")... this takes a 1 bit value from the OSR and shifts the remainder. Whether it takes the top bit(s) SHIFT_TO_LEFT or the bottom bits SHIFT_TO_RIGHT is configurable on the PIO state machine (SM).
- `x` (one of two scratch registers; the other imaginatively called y) is the target
- `[T3-1]` is the delay we talked about (T3 minus 1 cycles), set 0 its the side set

So, we can read the instruction as:

1. Set 0 on the side set pin (since side set happens from the beginning of the instruction)
2. Shift one bit out of the OSR into the x register. Result is that x register is 0 or 1
3. Wait `T3 - 1` cycles after the instruction (I.e. the whole thing takes `T3` cycles since the instruction itself took a cycle). Note also here we're talking bout cycles from the point of view of the state machine. That is confutable to a user defined frequency by (fractional) clk divider from the system clock.

```
    jmp !x do_zero [T1 - 1] set 1 ; Branch on the bit we shifted out. Positive
pulse
```

1. `set 1` on the side set pin (this is the leading edge of our pulse)
2. if `x == 0` then the next instruction will be at table do_zero, otherwise it will be the next instruction
3. we delay `T1 - 1` after the instruction (whether the branch is taken or not)

Ok, at this point we have output

```
      ----------
_____|
  T3      T1
```

```
do_one:
    jmp  bitloop   [T2 - 1] set 1 ; Continue driving high, for a long pulse
```

In this branch we do

1. `set 1` on the side set pin (this is the leading edge of our pulse)
2. `jmp` unconditionally to bitloop
3. we delay `T1 - 1` after the instruction, so we have

```
      ----------.------
-----|
  T3     T1        T2
```

4. we end up back where we started

```
do_zero:
    nop            [T2 - 1] set 0 ; Or drive low, for a short pulse
```

1. `set 0` on the side set pin (this is the leading edge of our pulse)
2. twiddle our thumbs for a cycle.
3. we delay `T1 - 1` after the instruction, so we have

```
      ----------
-----|          |------
  T3     T1        T2
```

Why did we twiddle our thumbs when we could have `jmp`-ed, good question, actually in this case there is no good reason, however it does show you .wrap and .wrap_target

`.wrap` -> `.wrap_target` is basically a free jmp (which often is important to either save the instruction space of the jump, or the 1 cycle cost)). In this case we just fall off the end of the program and start back at the beginning.

Anway, now it should be clear why our timings are numbered this way, because what the LED string sees really is

```
 ----------.------
|                |-----
    T1        T2    T3
```

For a one, and

```
 ----------
|          |------.-----
    T1        T2.   T3
```

For a zero

I say sees as it is looking for the start of a pulse and the wire is at 0 until we start sending bits (which are encoded as long pulses for 1 and short pulses for zero

So it looks like we just do this indefinitely, but where is the data coming from

This is more fully explained in the **RP2040 Datasheet**, but the data that goes into the OSR comes from the SM's write FIFO (which is filled by directly by poking from the CPU, or via DMA)

The `OUT` instruction by default will shift zeros into the other end of the (32 bit) OSR as it shifts data out, so you'll end up getting zeros for sure after 32 bits. There is a `PULL` instruction to explicitly take data from the FIFO and put it in the OSR (it also blocks if the FIFO is empty)

However, in the majority of cases it is simpler to configured the SM for auto-pull (in which case the OSR is automatically refilled (PULLed) when a configured number of bits have been shifted out of the ISR) You'll see this configured number of bits in the switch I had between 24 and 32 for (BGR or WGBR for number of data bits in 3 color or 4 color LEDs)

When we run `pioasm` and ask it to spit out Pico SDK code (which is the default), it will create some static variables describing the program, and a method ws2812_default_program_config which configures a PIO SM based on the information in the actual .pio file (namely the .side_set in this case).

```
% c-sdk {
```

Of course how you configure the PIO SM when using the program is very much related to the program you have written. Rather than try to store a data representation off all that information, and parse it at runtime, for the use cases where you'd like to encapsulate setup or other API functions with your Pio program, you can embed code withing the .PIO file

In this case we are passing thru code for the Pico SDK (it will end up in the generated header file)

We have here a function `ws2812_program_init` which is provided to help the user to instantiate an instance of the LED driver program

PIO

(which of the two PIOs we are dealing with)

SM

which state machine on that pio

Offset

where the PIO program was loaded in the 5 bit address space

Pin

which GPIO pin we'd like to output on

Freq

the bit frequency to output at

Rgbw

true if we have 4 color not 3

Such that,

- `pio_gpio_select(pio, pin);` Configures the func sea for the pin to the right PIO
- `pio_sm_config c = ws2812_program_default_config(offset);` Get the default configuration using the generated function for this program
- `pio_set_consecutive_pindirs(pio, sm, pin, 1, true);` Sets the PIO pin direction of 1 pin starting at pin number "pin" to out
- `sm_config_sideset_pins(&c, pin);` Sets the side set to set values starting at pin "pin" (I say starting at because if you had .side_set 3, then it would be outputting values on numbers pin, pin+1, pin+2)
- `sm_config_out_shift(&c, false, true, rgbw ? 32 : 24);` False for shift_to_right (i.e. we want to shift out MSB first) True for auto-pull 32 or 24 for the number of bits to shift before we refill the OSR
- `int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3;` Here we see the benefit of .define public; we can use the T1 - T3 values in our code

This is the total number of PIO SM. Cycles to output a single bit

- `float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit); sm_config_clkdiv(&c, div);` Using that we can configure how much to divide the system clock by
- `pio_sm_init(pio, sm, offset, &c);` Now initialize the SM using the configuration we have built
- `pio_sm_enable(pio, sm, true);`

And make it go now!

At this point the program will be stuck on OUT waiting for data (the OUT becomes blocking because the OSR was empty, and with auto-pull it effectively did a PULL which blocked because the FIFO is empty)… note I misspoke slightly earlier when I said you are configuring how many bits are shifted out before re-filling. You are configuring what to set the "count of valid bits" value for the OSR to when it is PULLed. i.e. the OSR is empty when the count of valid bits decrements to zero

NOTE

If you pokes 32 bit values one at time (one per pixel) directly to the SM FIFO

`pio_put_blocking(pio0, 0, pixel_grb << 8);` You'll notice the << 8 remember we were shifting out starting with the MSB, so we want the 24 bit color values at the top… this works fine for WGBR too, just that the W is always 0)

`pio_put_blocking` is a helper method that waits until there is room in the FIFO before trying to write another value

Alternative you can make a DMA transfer that reads sequential words from memory and writes each of them to the same address (the SM FIFO address). Fortunately the PIO SM provides a DREQ signal that can be configured onto your transfer, so that data flows at the correct rate

This is all very snazzy and efficient, and the PIO SM can actually consume data thru the FIFO via DMA at up to 32 bits every 2 system clocks cycles (although we don't have anything - including video- that goes quite that fast, although of course this is shared bandwidth).

TODO: show code to send to start the PIO transferring a whole string of pixels without further CPU intervention via DMA

Appendix A: App Notes

Attaching a 7 segment LED via GPIO

This example code shows how to interface the Raspberry Pi Pico to a generic 7 segment LED device. It uses the LED to count from 0 to 9 and then repeat. If the button is pressed, then the numbers will count down instead of up.

Wiring information

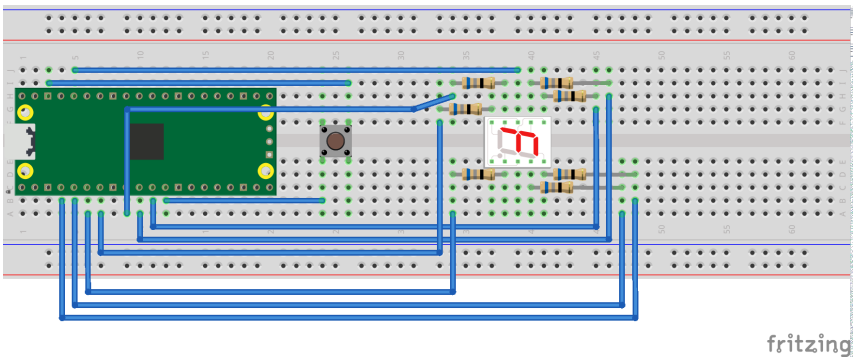
Our 7 Segment display has pins as follows.

```
--A--
F   B
--G--
E   C
--D--
```

By default we are allocating GPIO 2 to A, 3 to B etc. So, connect GPIO 2 to pin A on the 7 segment LED display and so on. You will need the appropriate resistors (68 ohm should be fine) for each segment. The LED device used here is common anode, so the anode pin is connected to the 3.3v supply, and the GPIO's need to pull low (to ground) to complete the circuit. The pull direction of the GPIO's is specified in the code itself.

Connect the switch to connect on pressing. One side should be connected to ground, the other to GPIO 9.

Figure 1. Wiring Diagram for 7 segment LED.



List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/gpio/hello_7segment/CMakeLists.txt Lines 1 - 9

```
1 add_executable(hello_7segment
2     hello_7segment.c
3 )
4
5 # Pull in our pico_stdlib which pulls in commonly used features
6 target_link_libraries(hello_7segment pico_stdlib)
7
```

```
# create map/bin/hex file etc.
pico_add_extra_outputs(hello_7segment)
```

hello_7segment.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/gpio/hello_7segment/hello_7segment.c *Lines 1 - 95*

```
/**
 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 *
 * SPDX-License-Identifier: BSD-3-Clause
 */

#include <stdio.h>
#include "pico/stdlib.h"
#include "hardware/gpio.h"

/*
  Our 7 Segment display has pins as follows:

  --A--
  F   B
  --G--
  E   C
  --D--

  By default we are allocating GPIO 2 to A, 3 to B etc.
  So, connect GOIP 2 to pin A on the 7 segment LED display etc. Don't forget
  the appropriate resistors, best to use one for each segment!

  Connect button so that pressing the switch connects the GPIO 9 (default) to
  ground (pull down)
*/

#define FIRST_GPIO 2
#define BUTTON_GPIO (FIRST_GPIO+7)

// This array converts a number 0-9 to a bit pattern to send to the GPIO's
int bits[10] = {
        0x3f,  // 0
        0x06,  // 1
        0x5b,  // 2
        0x4f,  // 3
        0x66,  // 4
        0x6d,  // 5
        0x7d,  // 6
        0x07,  // 7
        0x7f,  // 8
        0x67   // 9
};

// tag::hello_gpio[]
int main() {
```

```
47      setup_default_uart();
48      printf("Hello, 7segment - press button to count down!\n");
49
50      // We could use gpio_dir_out_mask() here
51      for (int gpio = FIRST_GPIO; gpio < FIRST_GPIO + 7; gpio++) {
52          gpio_init(gpio);
53          gpio_dir(gpio, GPIO_OUT);
54          // Our bitmap above has a bit set where we need an LED on, BUT, we are
    pulling low to light
55          // so invert our output
56          gpio_outover(gpio, GPIO_OVERRIDE_INVERT);
57      }
58
59      gpio_init(BUTTON_GPIO);
60      gpio_dir(BUTTON_GPIO, GPIO_IN);
61      // We are using the button to pull down to 0v when pressed, so ensure that
    when
62      // unpressed, it uses internal pull ups. Otherwise when unpressed, the input
    will
63      // be floating.
64      gpio_pull_up(BUTTON_GPIO);
65
66      int val = 0;
67      while (true) {
68          // Count upwards or downwards depending on button input
69          // We are pulling down on switch active, so invert the get to make
70          // a press count downwards
71          if (!gpio_get(BUTTON_GPIO)) {
72              if (val == 9) {
73                  val = 0;
74              } else {
75                  val++;
76              }
77          } else if (val == 0) {
78              val = 9;
79          } else {
80              val--;
81          }
82
83          // We are starting with GPIO 2, our bitmap starts at bit 0 so shift to
    start at 2.
84          int32_t mask = bits[val] << FIRST_GPIO;
85
86          // Set all our GPIO's in one go!
87          // If something else is using GPIO, we might want to use gpio_put_mask()
88          gpio_set_mask(mask);
89          sleep_ms(250);
90          gpio_clr_mask(mask);
91      }
92
93      return 0;
94  }
95  // end::hello_gpio[]
```

Bill of Materials

Table 7. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
7 segment LED module	1	generic part
68 ohm resistor	7	generic part
DIL push to make switch	1	generic switch
M/M Jumper wires	10	generic part

DHT-11, DHT-22, and AM2302 Sensors

The DHT sensors are fairly well known hobbyist sensors for measuring relative humidity and temperature using a capacitive humidity sensor, and a thermistor. While they are slow, one reading every ~2 seconds, they are reliable and good for basic data logging. Communication is based on a custom protocol which uses a single wire for data.

NOTE

The DHT-11 and DHT-22 sensors are the most common. They use the same protocol but have different characteristics, the DHT-22 has better accuracy, and has a larger sensor range than the DHT-11.

Wiring information

See Figure 2 for wiring instructions.

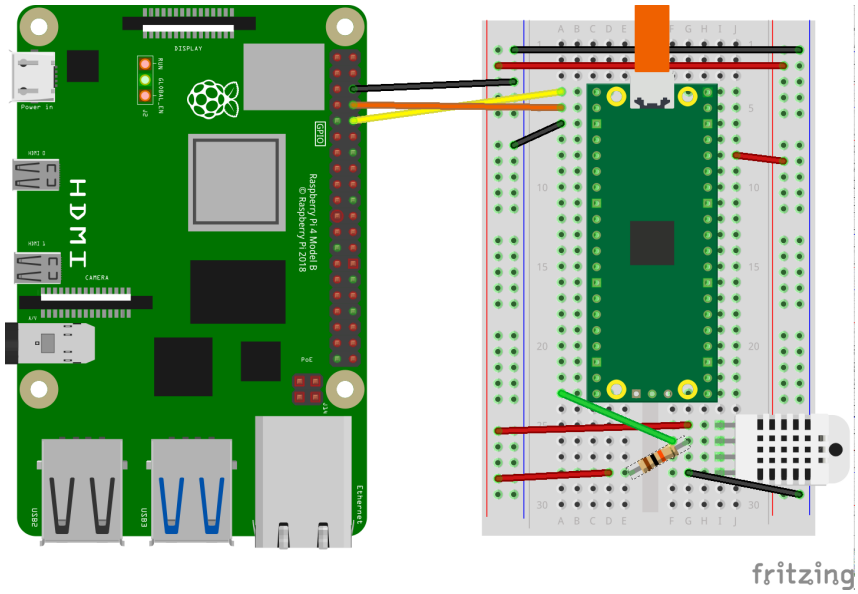


Figure 2. Wiring the DHT-22 temperature sensor to Raspberry Pi Pico, and connecting Pico's UART0 to the Raspberry Pi 4.

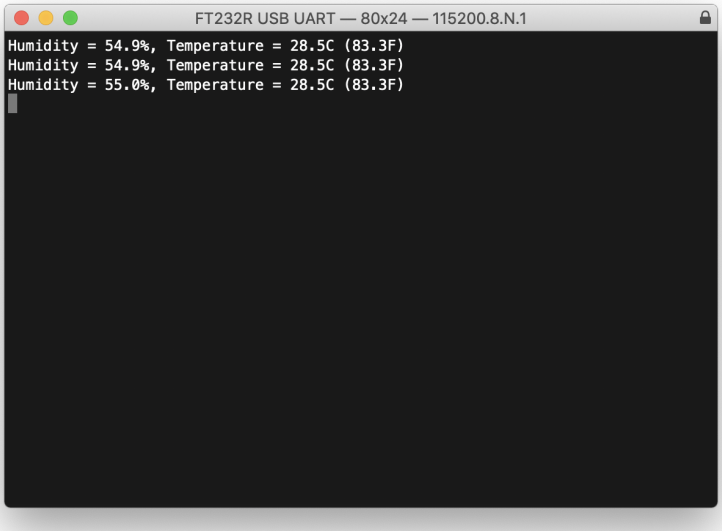
NOTE

One of the pins (pin 3) on the DHT sensor will not be connected, it is not used.

You will want to place a 10 kΩ resistor between VCC and the data pin, to act as a medium-strength pull up on the data line.

Connecting UART0 of Pico to Raspberry Pi as in Figure 2 and you should see something similar to Figure 3 in `minicom` when connected to `/dev/serial0` on the Raspberry Pi.

Figure 3. Serial output over Pico's UART0 in a terminal window.



Connect to `/dev/serial0` by typing,

```
$ minicom -b 115200 -o -D /dev/serial0
```

at the command line.

List of Files

A list of files with descriptions of their function;

CMakeLists.txt

Make file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/dht_sensor/CMakeLists.txt Lines 1 - 7

```
1 add_executable(dht
2     dht.c
3 )
4
5 target_link_libraries(dht pico_stdlib)
6
7 pico_add_extra_outputs(dht)
```

dht.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/dht_sensor/dht.c Lines 1 - 83

```c
/**
 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 *
 * SPDX-License-Identifier: BSD-3-Clause
 **/

#include <stdio.h>
#include <math.h>
#include "pico/stdlib.h"
#include "hardware/gpio.h"

const uint LED_PIN = PICO_DEFAULT_LED_PIN;
const uint DHT_PIN = 15;
const uint MAX_TIMINGS = 85;

typedef struct {
    float humidity;
    float temp_celsius;
} dht_reading;

void read_from_dht(dht_reading *result);

int main() {
    setup_default_uart();
    gpio_init(LED_PIN);
    gpio_init(DHT_PIN);
    gpio_dir(LED_PIN, GPIO_OUT);
    while (1) {
        dht_reading reading;
        read_from_dht(&reading);
        float fahrenheit = (reading.temp_celsius * 9 / 5) + 32;
        printf("Humidity = %.1f%%, Temperature = %.1fC (%.1fF)\n",
            reading.humidity, reading.temp_celsius, fahrenheit);

        sleep_ms(2000);
    }
}

void read_from_dht(dht_reading *result) {
    int data[5] = { 0, 0, 0, 0, 0 };
    uint last = 1;
    uint j = 0;

    gpio_dir(DHT_PIN, GPIO_OUT);
    gpio_put(DHT_PIN, 0);
    sleep_ms(20);
    gpio_dir(DHT_PIN, GPIO_IN);

    gpio_put(LED_PIN, 1);
    for ( uint i = 0; i < MAX_TIMINGS; i++ ) {
```

```
51          uint count = 0;
52          while ( gpio_get(DHT_PIN) == last ) {
53              count++;
54              sleep_us(1);
55              if (count == 255) break;
56          }
57          last = gpio_get(DHT_PIN);
58          if (count == 255) break;
59
60          if ((i >= 4) && (i % 2 == 0)) {
61              data[j / 8] <<= 1;
62              if (count > 16) data[j / 8] |= 1;
63              j++;
64          }
65      }
66      gpio_put(LED_PIN, 0);
67
68      if ((j >= 40) && (data[4] == ((data[0] + data[1] + data[2] + data[3]) &
    0xFF))) {
69          result->humidity = (float)((data[0] << 8) + data[1]) / 10;
70          if ( result->humidity > 100 ) {
71              result->humidity = data[0];
72          }
73          result->temp_celsius = (float)(((data[2] & 0x7F) << 8) + data[3]) / 10;
74          if (result->temp_celsius > 125) {
75              result->temp_celsius = data[2];
76          }
77          if (data[2] & 0x80) {
78              result->temp_celsius = -result->temp_celsius;
79          }
80      } else  {
81          printf("Bad data\n");
82      }
83  }
```

Bill of Materials

Table 8. A list of materials required for the example

Item	**Quantity**	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
10 kΩ resistor	1	generic part
M/M Jumper wires	4	generic part
DHT-22 sensor	1	https://www.adafruit.com/product/385

Attaching a BME280 temperature/humidity/pressure sensor via SPI

This example code shows how to interface the Raspberry Pi Pico to a BME280 temperature/humidity/pressure. The particular device used can be interfaced via I2C or SPI, we are using SPI, and interfacing at 3.3v.

This examples reads the data from the sensor, and runs it through the appropraite conpensation routines (see the chip datasheet for details https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bme280-ds002.pdf). At startup the compensation parameters required by the compensation routines are read from the chip.)

Wiring information

Wiring up the device requires 6 jumpers as follows:

- GPIO 16 (pin 21) MISO/spi0_rx→ SDO/SDO on bme280 board
- GPIO 17 (pin 22) Chip select → CSB/!CS on bme280 board
- GPIO 18 (pin 24) SCK/spi0_sclk → SCL/SCK on bme280 board
- GPIO 19 (pin 25) MOSI/spi0_tx → SDA/SDI on bme280 board
- 3.3v (pin 3;6) → VCC on bme280 board
- GND (pin 38) → GND on bme280 board

The example here uses SPI port 0. Power is supplied from the 3.3V pin.

NOTE

There are many different manufacturers who sell boards with the BME280. Whilst they all appear slightly different, they all have, at least, the same 6 pins required to power and communicate. When wiring up a board that is different to the one in the diagram, ensure you connect up as described in the previous paragraph.

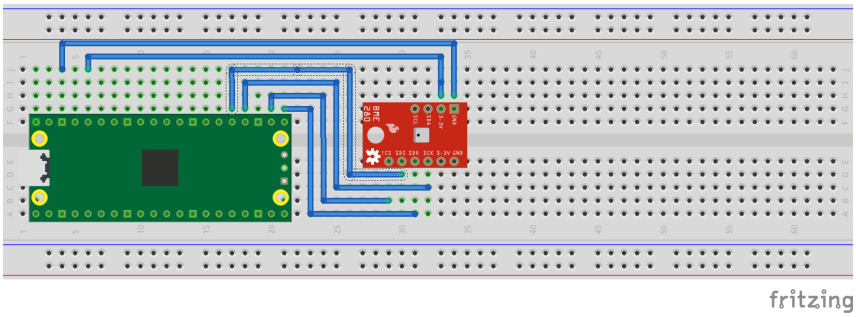


Figure 4. Wiring Diagram for bme280.

List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/spi/bme280_spi/CMakeLists.txt Lines 1 - 9

```
1 add_executable(bme280_spi
2     bme280_spi.c
3 )
4
5 # Pull in our (to be renamed) simple get you started dependencies
6 target_link_libraries(bme280_spi pico_stdlib hardware_spi)
7
8 # create map/bin/hex file etc.
9 pico_add_extra_outputs(bme280_spi)
```

bme280_spi.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/spi/bme280_spi/bme280_spi.c Lines 1 - 229

```
/**
 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 *
 * SPDX-License-Identifier: BSD-3-Clause
 */

#include <stdio.h>
#include <string.h>
#include "pico/stdlib.h"
#include "hardware/spi.h"

/* Example code to talk to a bme280 humidity/temperature/pressure sensor.

   NOTE: Ensure the device is capable of being driven at 3.3v NOT 5v. The Pico
   GPIO (and therefor SPI) cannot be used at 5v.

   You will need to use a level shifter on the SPI lines if you want to run the
   board at 5v.

   Connections on Raspberry Pi Pico board and a generic bme280 board, other
   boards may vary.

   GPIO 16 (pin 21) MISO/spi0_rx-> SDO/SDO on bme280 board
   GPIO 17 (pin 22) Chip select -> CSB/!CS on bme280 board
   GPIO 18 (pin 24) SCK/spi0_sclk -> SCL/SCK on bme280 board
   GPIO 19 (pin 25) MOSI/spi0_tx -> SDA/SDI on bme280 board
   3.3v (pin 3;6) -> VCC on bme280 board
   GND (pin 38)  -> GND on bme280 board

   Note: SPI devices can have a number of different naming schemes for pins. See
   the Wikipedia page at
https://en.wikipedia.org/wiki/Serial_Peripheral_Interface
   for variations.

   This code uses a bunch of register definitions, and some compensation code
derived
   from the Bosch datasheet which can be found here.
   https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-
bme280-ds002.pdf
*/

#define PIN_MISO 16
#define PIN_CS   17
#define PIN_SCK  18
#define PIN_MOSI 19

#define SPI_PORT spi0
#define READ_BIT 0x80

int32_t t_fine;
```

```
48
49 uint16_t dig_T1;
50 int16_t dig_T2, dig_T3;
51 uint16_t dig_P1;
52 int16_t dig_P2, dig_P3, dig_P4, dig_P5, dig_P6, dig_P7, dig_P8, dig_P9;
53 uint8_t dig_H1, dig_H3;
54 int8_t dig_H6;
55 int16_t dig_H2, dig_H4, dig_H5;
56
57 /* The following compensation functions are required to convert from the raw ADC
58 data from the chip to something usable. Each chip has a different set of
59 compensation parameters stored on the chip at point of manufacture, which are
60 read from the chip at startup and used inthese routines.
61 */
62 int32_t compensate_temp(int32_t adc_T) {
63     int32_t var1, var2, T;
64     var1 = ((((adc_T>>3) - ((int32_t)dig_T1<<1))) * ((int32_t)dig_T2)) >> 11;
65     var2 = (((((adc_T>>4) - ((int32_t)dig_T1)) * ((adc_T>>4) - ((int32_t)
   dig_T1))) >> 12) * ((int32_t)dig_T3)) >> 14;
66
67     t_fine = var1 + var2;
68     T =(t_fine*5+128)>>8;
69     return T;
70 }
71
72 uint32_t compensate_pressure(int32_t adc_P) {
73     int32_t var1, var2;
74     uint32_t p;
75     var1 = (((int32_t)t_fine)>>1) - (int32_t)64000;
76     var2 = (((var1>>2) * (var1>>2)) >> 11 ) * ((int32_t)dig_P6);
77     var2 = var2 + ((var1*((int32_t)dig_P5))<<1);
78     var2 = (var2>>2)+(((int32_t)dig_P4)<<16);
79     var1 = (((dig_P3 * (((var1>>2) * (var1>>2)) >> 13 )) >> 3) + ((((int32_t
   )dig_P2) * var1)>>1))>>18; var1 =((((32768+var1))*((int32_t)dig_P1))>>15);
80     if (var1 == 0)
81         return 0;
82
83     p = (((uint32_t)(((int32_t)1048576)-adc_P)-(var2>>12)))*3125;
84     if (p < 0x80000000)
85         p = (p << 1) / ((uint32_t)var1);
86     else
87         p = (p / (uint32_t)var1) * 2;
88
89     var1 = (((int32_t)dig_P9) * ((int32_t)(((p>>3) * (p>>3))>>13)))>>12; var2 =
   (((int32_t)(p>>2)) * ((int32_t)dig_P8))>>13;
90     p = (uint32_t)((int32_t)p + ((var1 + var2 + dig_P7) >> 4));
91
92     return p;
93 }
94
95 uint32_t compensate_humidity(int32_t adc_H) {
96     int32_t v_x1_u32r;
97     v_x1_u32r = (t_fine - ((int32_t)76800));
98     v_x1_u32r = (((((adc_H << 14) - (((int32_t)dig_H4) << 20) - (((int32_t
   )dig_H5) * v_x1_u32r)) +
```

```
 99                 ((int32_t)16384)) >> 15) * (((((((v_x1_u32r * ((int32_t)
    dig_H6)) >> 10) * (((v_x1_u32r *
100                 ((int32_t)dig_H3)) >> 11) + ((int32_t)32768))) >> 10) +
    ((int32_t)2097152)) *
101                 ((int32_t)dig_H2) + 8192) >> 14));
102     v_x1_u32r = (v_x1_u32r - (((((v_x1_u32r >> 15) * (v_x1_u32r >> 15)) >> 7) *
    ((int32_t)dig_H1)) >> 4));
103     v_x1_u32r = (v_x1_u32r < 0 ? 0 : v_x1_u32r);
104     v_x1_u32r = (v_x1_u32r > 419430400 ? 419430400 : v_x1_u32r);
105
106     return (uint32_t)(v_x1_u32r >> 12);
107 }
108
109 static inline void cs_select() {
110     asm volatile("nop \n nop \n nop");
111     gpio_put(PIN_CS, 0);  // Active low
112     asm volatile("nop \n nop \n nop");
113 }
114
115 static inline void cs_deselect() {
116     asm volatile("nop \n nop \n nop");
117     gpio_put(PIN_CS, 1);
118     asm volatile("nop \n nop \n nop");
119 }
120
121 static void write_register(uint8_t reg, uint8_t data) {
122     uint8_t buf[2];
123     buf[0] = reg & 0x7f;  // remove read bit as this is a write
124     buf[1] = data;
125     cs_select();
126     spi_write_blocking(SPI_PORT, buf, 2);
127     cs_deselect();
128     sleep_ms(10);
129 }
130
131 static void read_registers(uint8_t reg, uint8_t *buf, uint16_t len) {
132     // For this particular device, we send the device the register we want to
    read
133     // first, then subsequently read from the device. The register is auto
    incrementing
134     // so we don't need to keep sending the register we want, just the first.
135     reg |= READ_BIT;
136     cs_select();
137     spi_write_blocking(SPI_PORT, &reg, 1);
138     sleep_ms(10);
139     spi_read_blocking(SPI_PORT, 0, buf, len);
140     cs_deselect();
141     sleep_ms(10);
142 }
143
144 /* This function reads the manufacturing assigned compensation parameters from
    the device */
145 void read_compensation_parameters() {
146     uint8_t buffer[26];
147
```

```
148     read_registers(0x88, buffer, 24);
149
150     dig_T1 = buffer[0] | (buffer[1] << 8);
151     dig_T2 = buffer[2] | (buffer[3] << 8);
152     dig_T3 = buffer[4] | (buffer[5] << 8);
153
154     dig_P1 = buffer[6] | (buffer[7] << 8);
155     dig_P2 = buffer[8] | (buffer[9] << 8);
156     dig_P3 = buffer[10] | (buffer[11] << 8);
157     dig_P4 = buffer[12] | (buffer[13] << 8);
158     dig_P5 = buffer[14] | (buffer[15] << 8);
159     dig_P6 = buffer[16] | (buffer[17] << 8);
160     dig_P7 = buffer[18] | (buffer[19] << 8);
161     dig_P8 = buffer[20] | (buffer[21] << 8);
162     dig_P9 = buffer[22] | (buffer[23] << 8);
163
164     dig_H1 = buffer[25];
165
166     read_registers(0xE1, buffer, 8);
167
168     dig_H2 = buffer[0] | (buffer[1] << 8);
169     dig_H3 = (int8_t)buffer[2];
170     dig_H4 = buffer[3] << 4 | (buffer[4] & 0xf);
171     dig_H5 = (buffer[5] >> 4) | (buffer[6] << 4);
172     dig_H6 = (int8_t)buffer[7];
173 }
174
175 static void bme280_read_raw(int32_t *humidity, int32_t *pressure, int32_t
    *temperature) {
176     uint8_t buffer[8];
177
178     read_registers(0xF7, buffer, 8);
179     *pressure = ((uint32_t)buffer[0] << 12) | ((uint32_t)buffer[1] << 4) |
    (buffer[2] >> 4);
180     *temperature = ((uint32_t)buffer[3] << 12) | ((uint32_t)buffer[4] << 4) |
    (buffer[5] >> 4);
181     *humidity = (uint32_t)buffer[6] << 8 | buffer[7];
182 }
183
184 int main() {
185     setup_default_uart();
186
187     printf("Hello, bme280! Reading raw data from registers via SPI...\n");
188
189     // This example will use SPI0 at 0.5MHz.
190     spi_init(SPI_PORT, 500*1000);
191     gpio_funcsel(PIN_MISO, GPIO_FUNC_SPI);
192     gpio_funcsel(PIN_CS,   GPIO_FUNC_PROC);
193     gpio_funcsel(PIN_SCK,  GPIO_FUNC_SPI);
194     gpio_funcsel(PIN_MOSI, GPIO_FUNC_SPI);
195
196     // Chip select is active-low, so we'll initialise it to a driven-high state
197     gpio_dir(PIN_CS, GPIO_OUT);
198     gpio_put(PIN_CS, 1);
199
```

```
200     // See if SPI is working - interrograte the device for its I2C ID number,
    should be 0x60
201     uint8_t id;
202     read_registers(0xD0, &id, 1);
203     printf("Chip ID is 0x%x\n", id);
204
205     read_compensation_parameters();
206
207     write_register(0xF2, 0x1); // Humidity oversampling register - going for x1
208     write_register(0xF4, 0x27);// Set rest of oversampling modes and run mode to
    normal
209
210     int32_t humidity, pressure, temperature;
211
212     while (1) {
213         bme280_read_raw(&humidity, &pressure, &temperature);
214
215         // These are the raw numbers from the chip, so we need to run through the
216         // compensations to get human understandable numbers
217         pressure = compensate_pressure(pressure);
218         temperature = compensate_temp(temperature);
219         humidity = compensate_humidity(humidity);
220
221         printf("Humidity = %.2f%%\n",humidity / 1024.0);
222         printf("Pressure = %dPa\n", pressure);
223         printf("Temp. = %.2fC\n", temperature/100.0);
224
225         sleep_ms(1000);
226     }
227
228     return 0;
229 }
```

Bill of Materials

Table 9. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
BME280 board	1	generic part
M/M Jumper wires	6	generic part

Attaching a MPU9250 acceleromter/gyoscope via SPI

This example code shows how to interface the Raspberry Pi Pico to the MPU9250 accelerometer/gyroscope board. The particular device used can be interfaced via I2C or SPI, we are using SPI, and interfacing at 3.3v.

NOTE

This is a very basic example, and only recovers raw data from the sensor. There are various calibration options available that should be used to ensure that the final results are accurate. It is also possible to wire up the interrupt pin to a GPIO and read data only when it is ready, rather than using the polling approach in the example.

Wiring information

Wiring up the device requires 6 jumpers as follows:

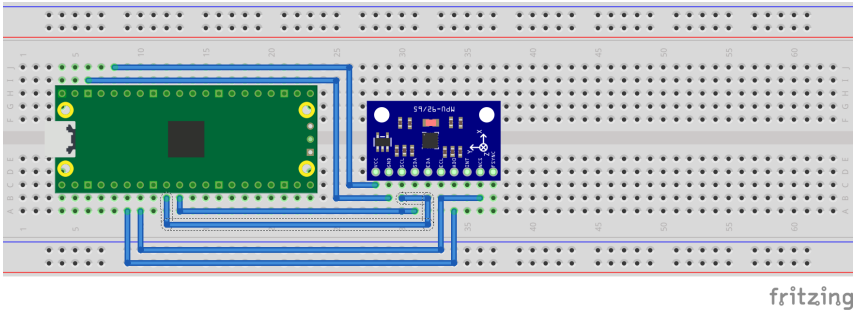
- GPIO 4 (pin 6) MISO/spi0_rx→ ADO on MPU9250 board
- GPIO 5 (pin 7) Chip select → NCS on MPU9250 board
- GPIO 6 (pin 9) SCK/spi0_sclk → SCL on MPU9250 board
- GPIO 7 (pin 10) MOSI/spi0_tx → SDA on MPU9250 board
- 3.3v (pin 36) → VCC on MPU9250 board
- GND (pin 38) → GND on MPU9250 board

The example here uses SPI port 0. Power is supplied from the 3.3V pin.

NOTE

There are many different manufacturers who sell boards with the MPU9250. Whilst they all appear slightly different, they all have, at least, the same 6 pins required to power and communicate. When wiring up a board that is different to the one in the diagram, ensure you connect up as described in the previous paragraph.

Figure 5. Wiring Diagram for MPU9250.



List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/spi/mpu9250_spi/CMakeLists.txt Lines 1 - 9

```
1 add_executable(mpu9250_spi
2     mpu9250_spi.c
3 )
4
5 # Pull in our (to be renamed) simple get you started dependencies
6 target_link_libraries(mpu9250_spi pico_stdlib hardware_spi)
7
8 # create map/bin/hex file etc.
9 pico_add_extra_outputs(mpu9250_spi)
```

mpu9250_spi.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/spi/mpu9250_spi/mpu9250_spi.c Lines 1 - 150

```
 1 /**
 2  * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 3  *
 4  * SPDX-License-Identifier: BSD-3-Clause
 5  */
 6
 7 #include <stdio.h>
 8 #include <string.h>
 9 #include "pico/stdlib.h"
10 #include "hardware/spi.h"
11
12 /* Example code to talk to a MPU9250 MEMS accelerometer and gyroscope.
13    Ignores the magnetometer, that is left as a exercise for the reader.
14
15    This is taking to simple approach of simply reading registers. It's perfectly
16    possible to link up an interrupt line and set things up to read from the
17    inbuilt FIFO to make it more useful.
18
19    NOTE: Ensure the device is capable of being driven at 3.3v NOT 5v. The Pico
20    GPIO (and therefor SPI) cannot be used at 5v.
21
22    You will need to use a level shifter on the I2C lines if you want to run the
23    board at 5v.
24
25    Connections on Raspberry Pi Pico board and a generic MPU9250 board, other
26    boards may vary.
27
28    GPIO 4 (pin 6) MISO/spi0_rx-> ADO on MPU9250 board
29    GPIO 5 (pin 7) Chip select -> NCS on MPU9250 board
30    GPIO 6 (pin 9) SCK/spi0_sclk -> SCL on MPU9250 board
31    GPIO 7 (pin 10) MOSI/spi0_tx -> SDA on MPU9250 board
32    3.3v (pin 36) -> VCC on MPU9250 board
33    GND (pin 38)  -> GND on MPU9250 board
34
35    Note: SPI devices can have a number of different naming schemes for pins. See
36    the Wikipedia page at
   https://en.wikipedia.org/wiki/Serial_Peripheral_Interface
37    for variations.
38    The particular device used here uses the same pins for I2C and SPI, hence the
39    using of I2C names
40 */
41
42 #define PIN_MISO 4
43 #define PIN_CS   5
44 #define PIN_SCK  6
45 #define PIN_MOSI 7
46
47 #define SPI_PORT spi0
48 #define READ_BIT 0x80
49
```

```
 50 static inline void cs_select() {
 51     asm volatile("nop \n nop \n nop");
 52     gpio_put(PIN_CS, 0);  // Active low
 53     asm volatile("nop \n nop \n nop");
 54 }
 55
 56 static inline void cs_deselect() {
 57     asm volatile("nop \n nop \n nop");
 58     gpio_put(PIN_CS, 1);
 59     asm volatile("nop \n nop \n nop");
 60 }
 61
 62 static void mpu9250_reset() {
 63         // Two byte reset. First byte register, second byte data
 64         // There are a load more options to set up the device in different ways
    that could be added here
 65         uint8_t buf[] = {0x6B, 0x00};
 66         cs_select();
 67         spi_write_blocking(SPI_PORT, buf, 2);
 68         cs_deselect();
 69 }
 70
 71
 72 static void read_registers(uint8_t reg, uint8_t *buf, uint16_t len) {
 73     // For this particular device, we send the device the register we want to
    read
 74     // first, then subsequently read from the device. The register is auto
    incrementing
 75     // so we don't need to keep sending the register we want, just the first.
 76
 77     reg |= READ_BIT;
 78     cs_select();
 79     spi_write_blocking(SPI_PORT, &reg, 1);
 80     sleep_ms(10);
 81     spi_read_blocking(SPI_PORT, 0, buf, len);
 82     cs_deselect();
 83     sleep_ms(10);
 84 }
 85
 86
 87 static void mpu9250_read_raw(int16_t accel[3], int16_t gyro[3], int16_t *temp)
    {
 88     uint8_t buffer[6];
 89
 90     // Start reading acceleration registers from register 0x3B for 6 bytes
 91     read_registers(0x3B, buffer, 6);
 92
 93     for (int i=0;i<3;i++) {
 94         accel[i] = (buffer[i*2] << 8 | buffer[(i*2)+1]);
 95     }
 96
 97     // Now gyro data from reg 0x43 for 6 bytes
 98     read_registers(0x43, buffer, 6);
 99
100     for (int i=0;i<3;i++) {
```

```
101         gyro[i] = (buffer[i*2] << 8 | buffer[(i*2)+1]);;
102     }
103
104     // Now temperature from reg 0x41 for 2 bytes
105     read_registers(0x41, buffer, 2);
106
107     *temp = buffer[0] << 8 | buffer[1];
108 }
109
110 int main() {
111     setup_default_uart();
112
113     printf("Hello, MPU9250! Reading raw data from registers via SPI...\n");
114
115     // This example will use SPI0 at 0.5MHz.
116     spi_init(SPI_PORT, 500*1000);
117     gpio_funcsel(PIN_MISO, GPIO_FUNC_SPI);
118     gpio_funcsel(PIN_CS,   GPIO_FUNC_PROC);
119     gpio_funcsel(PIN_SCK,  GPIO_FUNC_SPI);
120     gpio_funcsel(PIN_MOSI, GPIO_FUNC_SPI);
121
122     // Chip select is active-low, so we'll initialise it to a driven-high state
123     gpio_dir(PIN_CS, GPIO_OUT);
124     gpio_put(PIN_CS, 1);
125
126     mpu9250_reset();
127
128     // See if SPI is working - interrograte the device for its I2C ID number,
    should be 0x71
129     uint8_t id;
130     read_registers(0x75, &id, 1);
131     printf("I2C address is 0x%x\n", id);
132
133     int16_t acceleration[3], gyro[3], temp;
134
135     while (1) {
136       mpu9250_read_raw(acceleration, gyro, &temp);
137
138       // These are the raw numbers from the chip, so will need tweaking to be
    really useful.
139       // See the datasheet for more information
140       printf("Acc. X = %d, Y = %d, Z = %d\n", acceleration[0], acceleration[1],
    acceleration[2]);
141       printf("Gyro. X = %d, Y = %d, Z = %d\n", gyro[0], gyro[1], gyro[2]);
142       // Temperature is simple so use the datasheet calculation to get deg C.
143       // Note this is chip temperature.
144       printf("Temp. = %f\n", (temp/340.0) + 36.53);
145
146       sleep_ms(100);
147     }
148
149     return 0;
150 }
```

Bill of Materials

Table 10. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
MPU9250 board	1	generic part
M/M Jumper wires	6	generic part

Attaching a MPU6050 acceleromter/gyoscope via I2C

This example code shows how to interface the Raspberry Pi Pico to the MPU6050 accelerometer/gyroscope board. This device uses I2C for communications, and most MPU6050 parts are happy running at either 3.3 or 5v. The Raspberry Pi RP2040 GPIO's work at 3.3v so that is what the example uses.

NOTE

This is a very basic example, and only recovers raw data from the sensor. There are various calibration options available that should be used to ensure that the final results are accurate. It is also possible to wire up the interrupt pin to a GPIO and read data only when it is ready, rather than using the polling approach in the example.

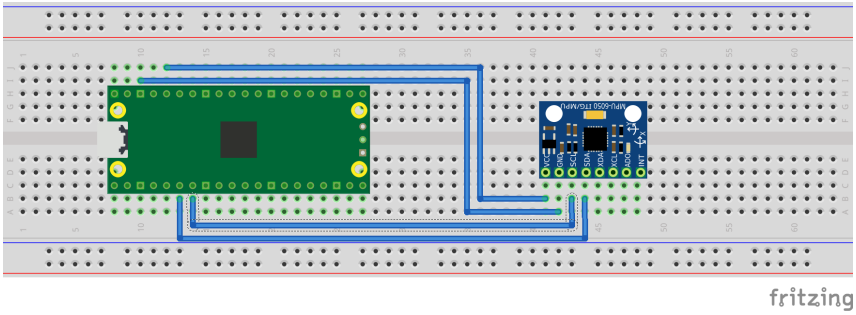
Wiring information

Wiring up the device requires 4 jumpers, to connect VCC (3.3v), GND, SDA and SCL. The example here uses I2C port 0, which is assigned to GPIO 4 (SDA) and 5 (SCL) in software. Power is supplied from the 3.3V pin.

NOTE

There are many different manufacturers who sell boards with the MPU6050. Whilst they all appear slightly different, they all have, at least, the same 4 pins required to power and communicate. When wiring up a board that is different to the one in the diagram, ensure you connect up as described in the previous paragraph.

Figure 6. Wiring Diagram for MPU6050.



List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/i2c/mpu6050_i2c/CMakeLists.txt Lines 1 - 9

```
1 add_executable(mpu6050_i2c
2     mpu6050_i2c.c
```

```
)

# Pull in our (to be renamed) simple get you started dependencies
target_link_libraries(mpu6050_i2c pico_stdlib hardware_i2c)

# create map/bin/hex file etc.
pico_add_extra_outputs(mpu6050_i2c)
```

mpu6050_i2c.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/i2c/mpu6050_i2c/mpu6050_i2c.c Lines 1 - 110

```
/**
 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 *
 * SPDX-License-Identifier: BSD-3-Clause
 */

#include <stdio.h>
#include <string.h>
#include "pico/stdlib.h"
#include "hardware/i2c.h"

/* Example code to talk to a MPU6050 MEMS acceleromter and gyroscope

   This is taking to simple approach of simply reading registers. It's perfectly
   possible to link up an interrupt line and set things up to read from the
   inbuilt FIFO to make it more useful.

   NOTE: Ensure the device is capable of being driven at 3.3v NOT 5v. The Pico
   GPIO (and therefor I2C) cannot be used at 5v.

   You will need to use a level shifter on the I2C lines if you want to run the
   board at 5v.

   Connections on Raspberry Pi Pico board, other boards may vary.

   GPIO 4 (pin 6)-> SDA on MPU6050 board
   GPIO 5 (pin 7)-> SCL on MPU6050 board
   3.3v (pin 36) -> VCC on MPU6050 board
   GND (pin 38)  -> GND on MPU6050 board
*/

// By default these devices  are on bus address 0x68
static int addr = 0x68;

#define I2C_PORT i2c0

static void mpu6050_reset() {
      // Two byte reset. First byte register, second byte data
      // There are a load more options to set up the device in different ways
   that could be added here
      uint8_t buf[] = {0x6B, 0x00};
```

```
41        i2c_write_blocking(I2C_PORT, addr, buf, 2, false);
42  }
43
44  static void mpu6050_read_raw(int16_t accel[3], int16_t gyro[3], int16_t *temp)
    {
45      // For this particular device, we send the device the register we want to
    read
46      // first, then subsequently read from the device. The register is auto
    incrementing
47      // so we dont need to keep sending the register we want, just the first.
48
49      uint8_t buffer[6];
50
51      // Start reading acceleration registers from register 0x3B for 6 bytes
52      uint8_t val= 0x3B;
53      i2c_write_blocking(I2C_PORT, addr, &val, 1, true); // true to keep master
    control of bus
54      i2c_read_blocking(I2C_PORT, addr, buffer, 6, false);
55
56      for (int i=0;i<3;i++) {
57          accel[i] = (buffer[i*2] << 8 | buffer[(i*2)+1]);
58      }
59
60      // Now gyro data from reg 0x43 for 6 bytes
61      // The register is auto incrementing on each read
62      val=0x43;
63      i2c_write_blocking(I2C_PORT, addr, &val, 1, true);
64      i2c_read_blocking(I2C_PORT, addr, buffer, 6, false);  // False - finished
    with bus
65
66      for (int i=0;i<3;i++) {
67          gyro[i] = (buffer[i*2] << 8 | buffer[(i*2)+1]);;
68      }
69
70      // Now temperature from reg 0x41 for 2 bytes
71      // The register is auto incrementing on each read
72      val=0x41;
73      i2c_write_blocking(I2C_PORT, addr, &val, 1, true);
74      i2c_read_blocking(I2C_PORT, addr, buffer, 2, false);  // False - finished
    with bus
75
76      *temp = buffer[0] << 8 | buffer[1];
77  }
78
79  int main() {
80      setup_default_uart();
81
82      printf("Hello, MPU6050! Reading raw data from registers...\n");
83
84      // This example will use I2C0 on GPIO4 (SDA) and GPIO5 (SCL) running at
    400KHz.
85      i2c_init(I2C_PORT, 400*1000);
86      gpio_funcsel(4, GPIO_FUNC_I2C);
87      gpio_funcsel(5, GPIO_FUNC_I2C);
88      gpio_pull_up(4);
```

```
 89     gpio_pull_up(5);
 90
 91     mpu6050_reset();
 92
 93     int16_t acceleration[3], gyro[3], temp;
 94
 95     while (1) {
 96       mpu6050_read_raw(acceleration, gyro, &temp);
 97
 98       // These are the raw numbers from the chip, so will need tweaking to be
    really useful.
 99       // See the datasheet for more information
100       printf("Acc. X = %d, Y = %d, Z = %d\n", acceleration[0], acceleration[1],
    acceleration[2]);
101       printf("Gyro. X = %d, Y = %d, Z = %d\n", gyro[0], gyro[1], gyro[2]);
102       // Temperature is simple so use the datasheet calculation to get deg C.
103       // Note this is chip temperature.
104       printf("Temp. = %f\n", (temp/340.0) + 36.53);
105
106       sleep_ms(100);
107     }
108
109     return 0;
110 }
```

Bill of Materials

Table 11. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
MPU6050 board	1	generic part
M/M Jumper wires	4	generic part

Attaching a 16x2 LCD via I2C

This example code shows how to interface the Raspberry Pi Pico to one of the very common 16x2 LCD character displays. The display will need a 3.3V I2C adapter board as this example uses I2C for communications.

NOTE

These LCD displays can also be driven directly using GPIO without the use of an adapter board. That is beyond the scope of this example.

Wiring information

Wiring up the device requires 4 jumpers, to connect VCC (3.3v), GND, SDA and SCL. The example here uses I2C port 0, which is assigned to GPIO 4 (SDA) and 5 (SCL) in software. Power is supplied from the 3.3V pin.

WARNING

Many displays of this type are 5v. If you wish to use a 5v display you will need to use level shifters on the SDA and SCL lines to convert from the 3.3V used by the RP2040. Whilst a 5v display will just about work at 3.3v, the display will be dim.

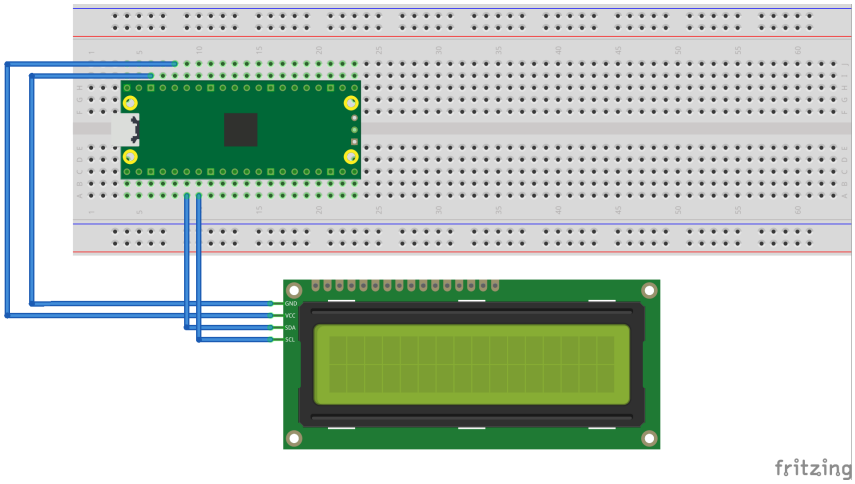


Figure 7. Wiring Diagram for LCD1602A LCD with I2C bridge.

List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/i2c/lcd_1602_i2c/CMakeLists.txt Lines 1 - 9

```
1 add_executable(lcd_1602_i2c
2     lcd_1602_i2c.c
3 )
4
5 # Pull in our (to be renamed) simple get you started dependencies
6 target_link_libraries(lcd_1602_i2c pico_stdlib hardware_i2c)
7
8 # create map/bin/hex file etc.
9 pico_add_extra_outputs(lcd_1602_i2c)
```

lcd_1602_i2c.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/pre_release/i2c/lcd_1602_i2c/lcd_1602_i2c.c Lines 1 - 160

```
 1 /**
 2  * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 3  *
 4  * SPDX-License-Identifier: BSD-3-Clause
 5  */
 6
 7 #include <stdio.h>
 8 #include <string.h>
 9 #include "pico/stdlib.h"
10 #include "hardware/i2c.h"
```

```
11
12 /* Example code to drive a 16x2 LCD panel via a I2C bridge chip (e.g. PCF8574)
13
14    NOTE: The panel must be capable of being driven  at 3.3v NOT 5v. The Pico
15    GPIO (and therefor I2C) cannot be used at 5v.
16
17    You will need to use a level shifter on the I2C lines if you want to run the
18    board at 5v.
19
20    Connections on Raspberry Pi Pico board, other boards may vary.
21
22    GPIO 4 (pin 6)-> SDA on LCD bridge board
23    GPIO 5 (pin 7)-> SCL on LCD bridge board
24    3.3v (pin 36) -> VCC on LCD bridge board
25    GND (pin 38)  -> GND on LCD bridge board
26 */
27 // commands
28 const int LCD_CLEARDISPLAY   = 0x01;
29 const int LCD_RETURNHOME     = 0x02;
30 const int LCD_ENTRYMODESET   = 0x04;
31 const int LCD_DISPLAYCONTROL = 0x08;
32 const int LCD_CURSORSHIFT    = 0x10;
33 const int LCD_FUNCTIONSET    = 0x20;
34 const int LCD_SETCGRAMADDR   = 0x40;
35 const int LCD_SETDDRAMADDR   = 0x80;
36
37 // flags for display entry mode
38 const int LCD_ENTRYSHIFTINCREMENT = 0x01;
39 const int LCD_ENTRYLEFT           = 0x02;
40
41 // flags for display and cursor control
42 const int LCD_BLINKON    = 0x01;
43 const int LCD_CURSORON   = 0x02;
44 const int LCD_DISPLAYON  = 0x04;
45
46 // flags for display and cursor shift
47 const int LCD_MOVERIGHT   = 0x04;
48 const int LCD_DISPLAYMOVE = 0x08;
49
50 // flags for function set
51 const int LCD_5x10DOTS = 0x04;
52 const int LCD_2LINE    = 0x08;
53 const int LCD_8BITMODE = 0x10;
54
55 // flag for backlight control
56 const int LCD_BACKLIGHT   = 0x08;
57
58 const int LCD_ENABLE_BIT = 0x04;
59
60 #define I2C_PORT i2c0
61 // By default these LCD display drivers are on bus address 0x27
62 static int addr = 0x27;
63
64 // Modes for lcd_send_byte
65 #define LCD_CHARACTER  1
```

```
#define LCD_COMMAND    0

#define MAX_LINES      2
#define MAX_CHARS      16

/* Quick helper fucntion for single byte transfers */
void i2c_write_byte(uint8_t val) {
    i2c_write_blocking(I2C_PORT, addr, &val, 1, false);
}

void lcd_toggle_enable(uint8_t val) {
  // Toggle enable pin on LCD display
  // We cannot do this too quickly or things dont work
#define DELAY_US 600
  sleep_us(DELAY_US);
  i2c_write_byte(val | LCD_ENABLE_BIT);
  sleep_us(DELAY_US);
  i2c_write_byte(val & ~LCD_ENABLE_BIT);
  sleep_us(DELAY_US);
}

// The display is sent a byte as two separate nibble transfers
void lcd_send_byte(uint8_t val, int mode)   {
  uint8_t high = mode | (val & 0xF0) | LCD_BACKLIGHT ;
  uint8_t low = mode | ((val << 4) & 0xF0) | LCD_BACKLIGHT ;

  i2c_write_byte(high);
  lcd_toggle_enable(high);
  i2c_write_byte(low);
  lcd_toggle_enable(low);
}

void lcd_clear(void)   {
  lcd_send_byte(LCD_CLEARDISPLAY, LCD_COMMAND);
}

// go to location on LCD
void lcd_set_cursor(int line, int position) {
    int val = (line == 0) ? 0x80 + position : 0xC0 + position;
    lcd_send_byte(val, LCD_COMMAND);
}

void inline lcd_char(char val)   {
  lcd_send_byte(val, LCD_CHARACTER);
}

void lcd_string(const char *s) {
    while (*s)
        lcd_char(*s++);
}

void lcd_init() {
    lcd_send_byte(0x03, LCD_COMMAND);
    lcd_send_byte(0x03, LCD_COMMAND);
    lcd_send_byte(0x03, LCD_COMMAND);
```

```
121     lcd_send_byte(0x02, LCD_COMMAND);
122
123     lcd_send_byte(LCD_ENTRYMODESET | LCD_ENTRYLEFT, LCD_COMMAND);
124     lcd_send_byte(LCD_FUNCTIONSET | LCD_2LINE, LCD_COMMAND);
125     lcd_send_byte(LCD_DISPLAYCONTROL | LCD_DISPLAYON,  LCD_COMMAND);
126     lcd_clear();
127 }
128
129 int main() {
130     // This example will use I2C0 on GPIO4 (SDA) and GPIO5 (SCL)
131     i2c_init(I2C_PORT, 100*1000);
132     gpio_funcsel(4, GPIO_FUNC_I2C);
133     gpio_funcsel(5, GPIO_FUNC_I2C);
134     gpio_pull_up(4);
135     gpio_pull_up(5);
136
137     lcd_init();
138
139     static uint8_t *message[] =
140     {
141       "RP2040 by", "Raspberry Pi",
142       "A brand new", "microcontroller",
143       "Twin core M0", "Full C SDK",
144       "More power in", "your product",
145       "More beans", "than Heinz!"
146     };
147
148     while (1) {
149         for (int m = 0;m < sizeof(message)/sizeof(message[0]); m+=MAX_LINES) {
150             for (int line = 0; line < MAX_LINES; line++) {
151               lcd_set_cursor(line, (MAX_CHARS/2) - strlen(message[m+line])/2);
152               lcd_string(message[m+line]);
153             }
154             sleep_ms(2000);
155             lcd_clear();
156         }
157     }
158
159     return 0;
160 }
```

Bill of Materials

Table 12. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	https://adafruit.com/product/64
Raspberry Pi Pico	1	http://raspberrypi.org/
1602A based LCD panel 3.3v	1	generic part
1602A to I2C bridge device 3.3v	1	generic part
M/M Jumper wires	4	generic part

Appendix B: SDK Configuration

SDK configuration is the process of customising the SDK differently to the defaults. In cases where you do need to make changes for specific circumstances, this chapter will show how that can be done, and what parameters can be changed.

Configuration is done by setting various predefined values in header files in your code. These will override the default values from the SDK itself.

So for example, if you wish to change the ID of the mutex used to protect access to spinlocks from its default value (8) to 9, you would add the following to your project header files, before any SDK includes.

```
#define PICO_SPINLOCK_ID_MUTEX 9`
```

Configuration Parameters

TO DO : this needs to be updated/corrected

Table 13. SDK Configuration Parameters

Parameter name	Used by	Default	Purpose
PICO_SPINLOCK_ID_MUTEX	sync.h	8	Mutex used when accessing Spinlocks
PICO_SPINLOCK_ID_IRQ	sync.h	9	
PICO_SPINLOCK_ID_TIMER	sync.h	10	
PICO_SPINLOCK_ID_HARDWARE_CLAIM	sync.h	11	Spinlock used when using `hw_claim_lock()`
PICO_SPINLOCK_ID_STRIPED_FIRST	sync.h	16	
PICO_SPINLOCK_ID_STRIPED_LAST	sync.h	23	
PICO_SPINLOCK_ID_USER0	sync.h	16	
PICO_STACK_SIZE			
PICO_NO_RAM_VECTOR_TABLE		0	
PICO_PHEAP_MAX_ENTRIES	pheap.h		
PICO_USBDEV_ENABLE_DEBUG_TRACE	usbdevice.h	0	
PICO_USBDEV_ASSUME_ZERO_INIT	usbdevice.h	0	
PICO_USBDEV_MAX_ENDPOINTS	usbdevice.h	USB_NUM_ENDPOINTS	
PICO_USBDEV_MAX_DESCRIPTOR_SIZE	usbdevice.h	64	
PICO_USBDEV_NO_DEVICE_SETUP_HANDLER	usbdevice.h	0	

Parameter name	Used by	Default	Purpose
PICO_USBDEV_NO_ENDPOINT_SETUP_HANDLER	usbdevice.h	0	
PICO_USBDEV_BULK_ONLY_EP1_THRU_16	usbdevice.h	0	
PICO_USBDEV_USE_ZERO_BASED_INTERFACES	usbdevice.h	0	
PICO_USBDEV_NO_TRANSFER_ON_INIT_METHOD	usbdevice.h	0	
PICO_USBDEV_NO_TRANSFER_ON_CANCEL_METHOD	usbdevice.h	0	
PICO_USBDEV_NO_INTERFACE_ALTERNATES	usbdevice.h	0	Disable alternative interfaces
PICO_USBDEV_ISOCHRONOUS_BUFFER_STRIDE_TYPE	usbdevice.h	0	Stride Type

Appendix C: Board Configuration

Board Configuration

Board configuration is the process of customising the SDK to run on a specific board design. The SDK comes some predefined configurations for boards produced by Raspberry Pi, the main (and default) example being the Raspberry Pi Pico.

Configurations specify a number of parameters that could vary between hardware designs. For example, default UART ports, on board LED locations and flash capacities etc.

This chapter will go though where these configurations files are, how to make changes and set parameters, and how to build your SDK using CMake with your customisations.

The Configuration files

Board specfic configuration files are stored in the SDK source tree, at `⋯/src/boards/include/boards/<boardname>.h`. The default configuration file is that for the Raspberry Pi Pico, and at the time of writing is:

`<sdk_path>/src/boards/include/boards/pico.h`

This relatively short file contains overrides from default of a small number of parameters used by the SDK when building code.

Pico SDK: https://github.com/raspberrypi/pico-sdk/tree/pre_release/src/boards/include/boards/pico.h Lines 1 - 49

```
1  /*
2   * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
3   *
4   * SPDX-License-Identifier: BSD-3-Clause
5   */
6
7  // ------------------------------------------------
8  // NOTE: THIS HEADER IS ALSO INCLUDED BY ASSEMBLER SO
9  //       SHOULD ONLY CONSIST OF PREPROCESSOR DIRECTIVES
10 // ------------------------------------------------
11
12 // This header may be included by other board headers as "boards/pico.h"
13
14 #ifndef _BOARDS_PICO_H
15 #define _BOARDS_PICO_H
16
17 #ifndef PICO_DEFAULT_UART
18 #define PICO_DEFAULT_UART 0
19 #endif
20
21 #ifndef PICO_DEFAULT_UART_TX_PIN
22 #define PICO_DEFAULT_UART_TX_PIN 0
23 #endif
24
25 #ifndef PICO_DEFAULT_UART_RX_PIN
26 #define PICO_DEFAULT_UART_RX_PIN 1
27 #endif
```

```
28
29 #ifndef PICO_DEFAULT_LED_PIN
30 #define PICO_DEFAULT_LED_PIN 25
31 #endif
32
33 // This is true for the W25Q40 on first-run picoboards:
34 #ifndef PICO_FLASH_SIZE_BYTES
35 #define PICO_FLASH_SIZE_BYTES (512 * 1024)
36 #endif
37
38 // Drive high to force power supply into PWM mode (lower ripple on 3V3 at light
   loads)
39 #define PICO_SMPS_MODE_PIN 23
40
41 #ifndef PICO_FLOAT_SUPPORT_ROM_V1
42 #define PICO_FLOAT_SUPPORT_ROM_V1 1
43 #endif
44
45 #ifndef PICO_DOUBLE_SUPPORT_ROM_V1
46 #define PICO_DOUBLE_SUPPORT_ROM_V1 1
47 #endif
48
49 #endif
```

As can be seen, it sets up the default UART to `uart0`, the GPIO pins to be used for that UART, the GPIO pin used for the onboard LED, and the flash size.

To create your own configuration file, create a file in the board `../source/folder` withthe name of your board, for example, `myboard.h`. Enter your board specific parameters in this file.

Building applications with a custom board configuration

The CMake system is what specifies which board configuration is going to be used.

To create a new build based on a new board configuration (we will use the `myboard` example from the previous section) first create a new build folder under your project folder. For our example we will use the pico-examples folder.

```
$ cd pico-examples
$ mkdir myboard_build
$ cd myboard_build
```

then run cmake as follows:

`cmake -D"PICO_BOARD=myboard" ..`

This will set up the system ready to build so you can simply type `make` in the `myboard_build` folder and the examples will be built for your new board configuration.

Available configuration parameters

TO DO : this needs to be updated/corrected

Table 14. Board Configuration Parameters

Parameter name	Used by	Default	Purpose
PICO_DEFAULT_UART	uart.h	0	Define which uart is the default. i.e. `0`, `1`
PICO_DEFAULT_UART_TX_PIN	uart.h	0	Define which GPIO pin is used for TX
PICO_DEFAULT_UART_RX_PIN	uart.h	1	Define which GPIO pin is used for RX
PICO_UART_ENABLE_CRLF_SUPPORT	uart.h	1	Enable/disable CRLF translation
PICO_DEFAULT_UART_BAUD_RATE	uart.h	115200	Set the baud rate of the default uart
PICO_DEFAULT_LED_PIN	user	25	Defines a default LED pin
PICO_FLASH_SIZE_BYTES	flash.c	None	Specify the flash memory size (in bytes)
PICO_SMPS_MODE_PIN			
PICO_FLASH_SPI_CLKDIV		None	Set the SPI Flash clock divider
PICO_SD_CLK_PIN	sdcard.h	23	
PICO_SD_CMD_PIN	sdcard.h	24	
PICO_SD_DAT0_PIN	sdcard.h	19	

Appendix D: Tuning for size and performance

TODO: wnyip

Appendix E: Building the Pico SDK API documentation

The Pico SDK documentation can also be found as part of Pico SDK itself and can be built directly from the command line. If you haven't already checked out the Pico SDK repository you should do so,

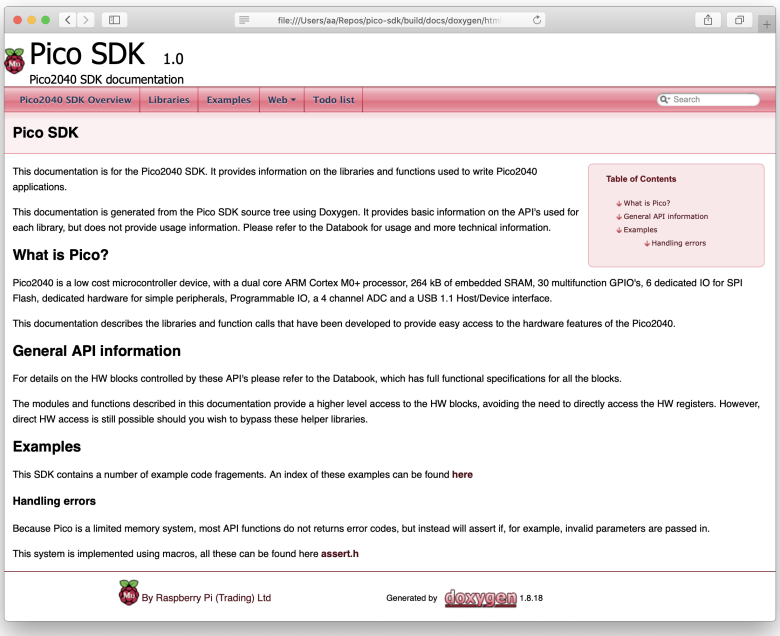
```
$ cd ~/
$ mkdir pico
$ cd pico
$ git clone -b pre_release git@github.com:raspberrypi/pico-sdk.git
$ cd pico-sdk
$ git submodule update --init --recursive
$ cd ..
$ git clone -b pre_release git@github.com:raspberrypi/pico-examples.git
```

and then afterwards you can go ahead and build the documentation.

```
$ cd pico-sdk
$ mkdir build
$ cd build
$ cmake ..
$ make docs
```

The API documentation will be build and can be found in the `pico-sdk/build/docs/doxygen/html` directory, see Figure 8.

Figure 8. The Pico SDK API documentation



When building the documentation `cmake` will go ahead and clone the `pico-examples` repo into the `build` directory directly from Github. This can be over ridden if you have a local copy on the command line,

```
$ cmake -DPICO_EXAMPLES_PATH=../../pico-examples ..
```

or by using an environment variable.

```
$ export PICO_EXAMPLES_PATH=../../pico-examples
$ cmake ..
```

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