Raspberry Pi Pico C/C++ SDK

Libraries and tools for C/C++ development on RP2040 microcontrollers

Colophon

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About the SDK

Throughout the text "the SDK" refers to our Raspberry Pi Pico SDK. More details about the SDK can be found throughout this book. Source code included in the documentation is Copyright © 2020 Raspberry Pi (Trading) Ltd. and licensed under the 3-Clause BSD license.

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Chapter 1. About the SDK

1.1. Introduction

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

The 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 RP2040's hardware, including DMA, IRQs, and the wide variety fixed function peripherals and PIO (Programmable IO).

Additionally the 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. These libraries should be comprehensive enough that your application code rarely, if at all, needs to access hardware registers directly. However, if you do need or prefer to access the raw hardware, you will also find complete and fully-commented register definition headers in the SDK. There's no need to look up addresses in the datasheet.

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

Looking to get started?

This book documents the SDK APIs, explains the internals and overall design of the SDK, and explores some deeper topics like using the PIO assembler to build new interfaces to external hardware. For a quick start with setting up the SDK and writing SDK programs, **Getting started with Raspberry Pi Pico** is the best place to start.

1.2. Anatomy of a SDK Application

Before going completely depth-first in our traversal of the SDK, it's worth getting a little breadth by looking at one of the SDK examples covered in **Getting started with Raspberry Pi Pico**, in more detail.

```
1 /**
2 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 4 * SPDX-License-Identifier: BSD-3-Clause
5 */
6
7 #include "pico/stdlib.h"
9 int main() {
10 #ifndef PICO DEFAULT LED PIN
11 #warning blink example requires a board with a regular LED
      const uint LED_PIN = PICO_DEFAULT_LED_PIN;
      gpio_init(LED_PIN);
      gpio_set_dir(LED_PIN, GPIO_OUT);
15
       while (true) {
16
           gpio_put(LED_PIN, 1);
17
18
           sleep_ms(250);
```

1.1. Introduction

```
gpio_put(LED_PIN, 0);
10
20
           sleep_ms(250);
21
22 #endif
23 }
```

This program consists only of a single C file, with a single function. As with almost any C programming environment, the function called main() is special, and is the point where the language runtime first hands over control to your program, after doing things like initialising static variables with their values. In the SDK the main() function does not take any arguments. It's quite common for the main() function not to return, as is shown here.

NOTF

The return code of main() is ignored by the SDK runtime, and the default behaviour is to hang the processor on exit.

At the top of the C file, we include a header called pico/stdlib.h. This is an umbrella header that pulls in some other commonly used headers. In particular, the ones needed here are hardware/gpio.h, which is used for accessing the general purpose IOs on RP2040 (the gpio_xxx functions here), and pico/time.h which contains, among other things, the sleep_ms function. Broadly speaking, a library whose name starts with pico provides high level APIs and concepts, or aggregates smaller interfaces; a name beginning with hardware indicates a thinner abstraction between your code and RP2040 onchip hardware.

So, using mainly the hardware_gpio and pico_time libraries, this C program will blink an LED connected to GPIO25 on and off, twice per second, forever (or at least until unplugged). In the directory containing the C file (you can click the link above the source listing to go there), there is one other file which lives alongside it.

Directory listing of pico-examples/blink

```
blink
├── blink.c

    CMakeLists.txt

0 directories, 2 files
```

The second file is a CMake file, which tells the SDK how to turn the C file into a binary application for an RP2040-based microcontroller board. Later sections will detail exactly what CMake is, and why it is used, but we can look at the contents of this file without getting mired in those details.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/blink/CMakeLists.txt Lines 1 - 12

```
1 add_executable(blink
          blink.c
2
3
4
5 # Pull in our pico_stdlib which pulls in commonly used features
6 target_link_libraries(blink pico_stdlib)
8 # create map/bin/hex file etc.
9 pico_add_extra_outputs(blink)
10
11 # add url via pico_set_program_url
12 example_auto_set_url(blink)
```

The add_executable function in this file declares that a program called blink should be built from the C file shown earlier. This is also the target name used to build the program: in the pico-examples repository you can say make blink in your build directory, and that name comes from this line. You can have multiple executables in a single project, and the picoexamples repository is one such project.

The target_link_libraries is pulling in the SDK functionality that our program needs. If you don't ask for a library, it doesn't appear in your program binary. Just like pico/stdlib.h is an umbrella header that includes things like pico/time.h and hardware/gpio.h, pico_stdlib is an umbrella library that makes libraries like pico_time and hardware_gpio available to your build, so that those headers can be included in the first place, and the extra C source files are compiled and linked. If you need less common functionality, like accessing the DMA hardware, you can call those libraries out here (e.g. listing hardware_dma before or after pico_stdlib).

We could end the CMake file here, and that would be enough to build the blink program. By default, the build will produce an ELF file (executable linkable format), containing all of your code and the SDK libraries it uses. You can load an ELF into RP2040's RAM or external flash through the Serial Wire Debug port, with a debugger setup like gdb and openocd. It's often easier to program your Raspberry Pi Pico or other RP2040 board directly over USB with BOOTSEL mode, and this requires a different type of file, called UF2, which serves the same purpose here as an ELF file, but is constructed to survive the rigours of USB mass storage transfer more easily. The pico_add_extra_outputs function declares that you want a UF2 file to be created, as well as some useful extra build output like disassembly and map files.

NOTE

The ELF file is converted to a UF2 with an internal SDK tool called elf2uf2, which is bootstrapped automatically as part of the build process.

The example_auto_set_url function is to do with how you are able to read this source file in this document you are reading right now, and click links to take you to the listing on GitHub. You'll see this on the pico-examples applications, but it's not necessary on your own programs. You are seeing how the sausage is made.

Finally, a brief note on the pico_stdlib library. Besides common hardware and high-level libraries like hardware_gpio and pico_time, it also pulls in components like pico_standard_link - which contains linker scripts and crt0 for SDK - and pico_runtime, which contains code running between crt0 and main(), getting the system into a state ready to run code by putting things like clocks and resets in a safe initial state. These are incredibly low-level components that most users will not need to worry about. The reason they are mentioned is to point out that they are ultimately explicit dependencies of your program, and you can choose not to use them, whilst still building against the SDK and using things like the hardware libraries.

Chapter 2. SDK Architecture

RP2040 is a powerful chip, and in particular was designed with a disproportionate amount of system RAM for its point in the microcontroller design space. However it is an embedded environment, so RAM, CPU cycles and program space are still at a premium. As a result the tradeoffs 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 next few sections try to highlight some of the design decisions behind the SDK: the how and the why, as much as the what.



NOTE

Some parts of this overview are quite technical or deal with very low-level parts of the SDK and build system. You might prefer to skim this section at first and then read it thoroughly at a later time, after writing a few SDK applications.

2.1. The Build System

The SDK uses CMake to manage the build. CMake is widely supported by IDEs (Integrated Development Environments), which can use a CMakeLists.txt file to discover source files and generate code autocomplete suggestions. The same CMakeLists.txt file provides a terse specification of how your application (or your project with many distinct applications) should be built, which CMake uses to generate a robust build system used by make, ninja or other build tools. The build system produced is customised for the platform (e.g. Windows, or a Linux distribution) and by any configuration variables the developer chooses.

Section 2.6 shows how CMake can set configuration defines for a particular program, or based on which RP2040 board you are building for, to configure things like default pin mappings and features of SDK libraries. These defines are listed in Appendix B, and Board Configuration files are covered in more detail in Appendix D. Additionally Appendix C describes CMake variables you can use to control the functionality of the build itself.

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

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/blink/CMakeLists.txt Lines 1 - 12

```
1 add_executable(blink
          blink.c
3
5 # Pull in our pico_stdlib which pulls in commonly used features
6 target_link_libraries(blink pico_stdlib)
8 # create map/bin/hex file etc.
9 pico_add_extra_outputs(blink)
11 # add url via pico_set_program_url
12 example_auto_set_url(blink)
```

Looking here at the blink example, we are defining a new executable blink with a single source file blink.c, with a single

2.1. The Build System

dependency pico_stdlib. We also are using a SDK provided function pico_add_extra_outputs to ask additional files to be produced beyond the executable itself (.uf2, .hex, .bin, .map, .dis).

The 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 RP2040).

pico_stdlib is an INTERFACE library and provides all of the rest of the code and configuration needed to compile and link the blink application. You will notice if you do a build of blink (https://github.com/raspberrypi/pico-examples/tree/master/blink/blink.c) that in addition to the single blink.c file, the inclusion of pico_stdlib causes about 40 other source files to be compiled to flesh out the blink application such that it can be run on RP2040.

2.2. Every Library is an INTERFACE

All libraries within the SDK are INTERFACE libraries. (Note this does not include the C/C++ standard libraries provided by the compiler). Conceptually, a CMake INTERFACE library is a collection of:

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

The INTERFACE libraries form a tree of dependencies, with each contributing source files, include paths, compiler definitions and compile/link options to the build. These are collected based on the libraries you have listed in your CMakeLists.txt file, and the libraries depended on by those libraries, and so on recursively. 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.

When building an executable with the SDK, all of the code for one executable, including the SDK libraries, is (re)compiled for *that* executable from source. Building in this way allows your build configuration to specify customised settings for those libraries (e.g. enabling/disabling assertions, setting the sizes of static buffers), on a *per-application* basis, at compile time. This allows for faster and smaller binaries, in addition of course to the ability to remove support for unwanted features from your executable entirely.

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 GPlOs and printing to a UART, and the linker will garbage collect any functions you don't call, so this doesn't bloat your binary. We can take a quick peek into the directory structure of the hardware_gpio library, which our blink example uses to turn the LED on and off:

Depending on the hardware_gpio INTERFACE library in your application causes gpio.c to be compiled and linked into your executable, and adds the include directory shown here to your search path, so that a #include "hardware/gpio.h" will pull in the correct header in your code.

INTERFACE libraries also make it easy to aggregate functionality into readily consumable chunks (such as pico_stdlib), which don't directly contribute any code, but depend on a handful of lower-level libraries that do. Like a metapackage, this lets you pull in a group of libraries related to a particular goal without listing them all by name.

IMPORTANT

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 through 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.

2.3. SDK Library Structure

The full API listings are given in Chapter 4; this chapter gives an overview of how SDK libraries are organised, and the relationships between them.

There are a number of layers of libraries within the SDK. This section starts with the highest-level libraries, which can be used in C or C++ applications, and navigates all the way down to the hardware_regs library, which is a comprehensive set of hardware definitions suitable for use in Arm assembly as well as C and C++, before concluding with a brief note on how the TinyUSB stack can be used from within the SDK.

2.3.1. Higher-level Libraries

These libraries (pico_xxx) provide higher-level APIs, concepts and abstractions. The APIs are listed in Section 4.2. These may be libraries that have cross-cutting concerns between multiple pieces of hardware (for example the sleep_functions in pico_time need to concern themselves both with RP2040's timer hardware and with how processors enter and exit low power states), or they may be pure software infrastructure required for your program to run smoothly. This includes libraries for things like:

- Alarms, timers and time functions
- Multi-core support and synchronization primitives
- · Utility functions and data structures

 $These \ libraries \ are \ generally \ built \ upon \ one \ or \ more \ underlying \ {\it hardware_libraries}, \ and \ often \ depend \ on \ each \ other.$



More libraries will be forthcoming in the future (e.g. - Audio support (via PIO), DPI/VGA/MIPI Video support (via PIO) file system support, SDIO support via (PIO)), most of which are available but not yet fully supported/stable/documented in the pico-extras GitHub repository.

2.3.2. Runtime Support (pico_runtime, pico_standard_link)

These are libraries that bundle functionality which is common to most RP2040-based applications. APIs are listed in Section 4.4.

pico_runtime aggregates the libraries (listed in pico_runtime) that provide a familiar C environment for executing code, including:

• Runtime startup and initialization

- Choice of language level single/double precision floating 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
- The function runtime_init() which performs minimal hardware initialisation (e.g. default PLL and clock configuration), and calls functions with constructor attributes before entering main()

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. It also includes the default crt0, which provides the initial entry point from the flash second stage bootloader, contains the initial vector table (later relocated to RAM), and initialises static data and RAM-resident code if the application is running from flash.



There is more high-level discussion of pico_runtime in Section 2.7



TIP

Both pico_runtime and pico_standard_link are included with pico_stdlib

2.3.3. Hardware Support Libraries

These are individual libraries (hardware_xxx) providing actual APIs for interacting with each piece of physical hardware/peripheral. They are lightweight and provide only thin abstractions. The APIs are listed in Section 4.1.

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) |</pre>
     (top << PIO_SM0_EXECCTRL_WRAP_TOP_LSB);</pre>
```

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. In general their only dependencies are the hardware_structs and hardware_regs libraries that contain definitions of memory-mapped register layout on RP2040. As such they can be used by low-level or other specialized applications that doesn't want to use the rest of the SDK libraries and runtime.

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/master/src/rp2_common/hardware_pio/include/hardware/pio.h directly as shown above.

Using static inline functions is common in SDK header files because such methods are often called with parameters that have fixed known values at compile time. In such cases, the compiler is often able to fold the code down to a single register write (or in this case a read, AND with a constant value, OR with a constant value, and a write) with no function call overhead. This tends to produce much smaller and faster binaries.

2.3.3.1. 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.

2.3.4. Hardware Structs Library

The hardware_structs library provides a set of C structures which represent the memory mapped layout of RP2040 registers in the system address space. This allows you to replace something like the following (which you'd write in C with the defines from the lower-level hardware_regs)

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

with something like this (where pio0 is a pointer to type pio_hw_t at address PIO0_BASE):

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

The structures and associated pointers to memory mapped register blocks hide the complexity and potential error-prone-ness of dealing with individual memory locations, pointer casts and volatile access. As a bonus, the structs tend to produce better code with older compilers, as they encourage the reuse of a base pointer with offset load/stores, instead of producing a 32 bit literal for every register accessed.

The struct headers are named consistently with both the hardware libraries and the hardware_regs register headers. For example, if you access the hardware_pio library's functionality through hardware/pio.h, the hardware_structs library (a dependee of hardware_pio) contains a header you can include as hardware/structs/pio.h if you need to access a register directly, and this itself will pull in hardware/regs/pio.h for register field definitions. The PIO header is a bit lengthy to include here. hardware/structs/pll.h is a shorter example to give a feel for what these headers actually contain:

SDK: https://github.com/raspberrypi/pico-sdk/tree/master/src/rp2040/hardware_structs/include/hardware/structs/pll.h Lines 14 - 22

```
14 typedef struct {
15     io_rw_32 cs;
16     io_rw_32 pwr;
17     io_rw_32 fbdiv_int;
18     io_rw_32 prim;
19 } pll_hw_t;
```

```
20
21 #define pll_sys_hw ((pll_hw_t *const)PLL_SYS_BASE)
22 #define pll_usb_hw ((pll_hw_t *const)PLL_USB_BASE)
```

The structure contains the layout of the hardware registers in a block, and some defines bind that layout to the base addresses of the *instances* of that peripheral in the RP2040 global address map.

Additionally, you can use one of the atomic set, clear, or xor address aliases of a piece of hardware to set, clear or toggle respectively the specified bits in a hardware register (as opposed to having the CPU perform a read/modify/write); e.g:

```
hw_set_alias(pio0)->sm[1].shiftctrl = PIO_SM1_SHIFTCTRL_AUTOPULL_BITS;
```

Or, equivalently

```
hw_set_bits(&pio0->sm[1].shiftctrl, PIO_SM1_SHIFTCTRL_AUTOPULL_BITS);
```

NOTE

The hardware atomic set/clear/XOR IO aliases are used extensively in the SDK libraries, to avoid certain classes of data race when two cores, or an IRQ and foreground code, are accessing registers concurrently.

NOTE

On RP2040 the atomic register aliases are a native part of the *peripheral*, not a CPU function, so the system DMA can also perform atomic set/clear/XOR operation on registers.

2.3.5. Hardware Registers Library

The hardware_regs library is a complete set of include files for all 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 in C/C++.

For example, here is a snippet from hardware/regs/sio.h:

```
// Description : Single-cycle IO block
      Provides core-local and inter-core hardware for the two processors, with single-cycle access.
// -----
#ifndef HARDWARE_REGS_SIO_DEFINED
#define HARDWARE_REGS_SIO_DEFINED
// Register : SIO_CPUID
// Description : Processor core identifier
            Value is 0 when read from processor core 0, and 1 when read
//
            from processor core 1.
#define SIO_CPUID_OFFSET 0x00000000
#define SIO_CPUID_RESET "-"
#define SIO_CPUID_MSB 31
#define SIO_CPUID_LSB 0
#define SIO_CPUID_ACCESS "RO"
```

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2.3. SDK Library Structure

These header files are fairly heavily commented (the same information as is present in the datasheet register listings, or the SVD files). They define the offset of every register, and the layout of the fields in those registers, as well as the access type of the field, e.g. "RO" for read-only.



TIP

The headers in hardware_regs contain only comments and #define statements. This means they can be included from assembly files (.S, so the C preprocessor can be used), as well as C and C++ files.

2.3.6. TinyUSB Port

In addition to the core SDK libraries, we provide a RP2040 port of TinyUSB as the standard device and host USB support library within the SDK, and the SDK contains some build infrastructure for easily pulling this into your application. This is done by naming either tinyusb_dev or tinyusb_host as a dependency of your application



IMPORTANT

RP2040 USB hardware supports both Host and Device modes, but the two can not be used concurrently.

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

2.4. Directory Structure

We have discussed libraries such as pico_stdlib and hardware_gpio above. Imagine you wanted to add some code using RP2040's DMA controller to the hello_world example in pico-examples. To do this you need to add a dependency on another library, hardware_dma, which is not included by default by pico_stdlib (unlike, say, hardware_uart).

You would change your CMakeLists.txt to list both pico_stdlib and hardware_dma as dependencies of the hello_world target (executable). (Note the line breaks are not required)

```
target_link_libraries(hello_world
   pico_stdlib
    hardware dma
```

And in your source code you would include the DMA hardware library header as such:

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

Trying to include this header without listing hardware_dma as a dependency will fail, and this is due to how SDK files are organised into logical functional units on disk, to make it easier to add functionality in the future.

As an aside, this correspondence of hardware_dma → hardware/dma.h is the convention for all toplevel SDK library headers. The library is called foo_bar and the associated header is foo/bar.h. Some functions may be provided inline in the headers, others may be compiled and linked from additional .c files belonging to the library. Both of these require the relevant hardware_ library to be listed as a dependency, either directly or through some higher-level bundle like pico_stdlib.

2.4. Directory Structure 15

NOTE

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

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 top-level directories. This is described in the next section.

2.4.1. Locations of Files

Whilst you may be focused on building a binary to run specifically on Raspberry Pi Pico, which uses a RP2040, the 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 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, and much of the software complexity may be non-hardware-specific.

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 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 RP2040 hardware. This is separate from /src/rp2040 as there may be future revisions of RP2040, or other chips in the RP2 family, which can use a common SDK and API whilst potentially having 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 the hardware_ abstractions.
src/host/	This is a basic set of replacement 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 Windows Subsystem for Linux). 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 building 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)
```

As a concrete example, we can list the hardware_uart directory under pico-sdk/rp2_common (you may also recall the hardware_gpio library we looked at earlier):

2.4. Directory Structure

```
hardware_uart

    CMakeLists.txt

     - include

    hardware

       └── uart.h
    - uart.c
```

uart.h contains function declarations and preprocessor defines for the hardware_uart library, as well as some inline functions that are expected to be particularly amenable to constant folding by the compiler, uart.c contains the implementations of more complex functions, such as calculating and setting up the divisors for a given UART baud rate.



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

2.5. Conventions for Library Functions

This section covers some common patterns you will see throughout the SDK libraries, such as conventions for function names, how errors are reported, and the approach used to efficiently configure hardware with many register fields without having unreadable numbers of function arguments.

2.5.1. Function Naming Conventions

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 SDK API is a C API and does not support function overloading.

2.5.1.1. Name prefix

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

2.5.1.2. 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 food_add_salt(), rather than oven_temperature() and food_salt().

2.5.1.3. Suffixes

2.5.1.3.1. Blocking/Non-Blocking Functions and Timeouts

Table 2. 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 2.5.2) 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 2.5.2) 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 2.5.2) after the specified number of microseconds

2.5.2. Return Codes and Error Handling

As mentioned earlier, there is a decision to be made as to whether/which functions return error codes that can be handled by the caller, and indeed whether the caller is likely to actually do something in response in an embedded environment. Also note that very often return codes are there to handle parameter checking, e.g. when asked to do something with the 27th DMA channel (when there are actually only 12).

In many cases checking for obviously invalid (likely program bug) parameters in (often inline) functions is prohibitively expensive in speed and code size terms, and therefore we need to be able to configure it on/off, which precludes return codes being returned for these exceptional cases.

The SDK follows two strategies:

- Methods that can legitimately fail at runtime due to runtime conditions e.g. timeouts, dynamically allocated resource, can return a status which is either a bool indicating success or not, or an integer return code from the PICO_ERROR_ family; non error returns are >= 0.
- Other items like invalid parameters, or failure to allocate resources which are deemed program bugs (e.g. two libraries trying to use the same statically assigned piece of hardware) do not affect a return code (usually the functions return void) and must cause some sort of exceptional event.

As of right now the exceptional event is a C assert, so these checks are always disabled in release builds by default. Additionally most of the calls to assert are disabled by default for code/size performance (even in debug builds); You can set PARAM_ASSERTIONS_ENABLE_ALL=1 or PARAM_ASSERTIONS_DISABLE_ALL=1 in your build to change the default across the entire SDK, or say PARAM_ASSERTIONS_ENABLED_IZC=0/1 to explicitly specify the behavior for the hardware_i2c module

In the future we expect to support calling a custom function to throw an exception in C++ or other environments where stack unwinding is possible.

3. Obviously sometimes the calling code whether it be user code or another higher level function, may not want the called function to assert on bad input, in which case it is the responsibility of the caller to check the validity (there are a good number of API functions provided that help with this) of their arguments, and the caller can then choose to provide a more flexible runtime error experience.

2.5.3. Use of Inline Functions

SDK libraries often contain a mixture of static inline functions in header files, and non-static functions in C source files. In particular, the hardware_ libraries are likely to contain a higher proportion of inline function definitions in their headers. 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 substantially larger than the function implementation. Compilers have their own metrics to decide when to inline

function implementations at their call sites, but the use of static inline definitions gives the compiler more freedom to do this.

One reason this is particularly effective in the context of hardware register access is that these functions often:

- 1. Have relatively many parameters, which
- 2. Are immediately shifted and masked to combine with some register value, and
- 3. Are often constants known at compile time

So if the implementation of a hardware access function is inlined, the compiler can propagate the constant parameters through whatever bit manipulation and arithmetic that function may do, collapsing a complex function down to "please write this constant value to this constant address". Again, we are not forcing the compiler to do this, but the SDK consistently tries to give it freedom to do so.

The result is that there is generally no overhead using the lower-level hardware_ functions as compared with using preprocessor macros with the hardware_regs definitions, and they tend to be much less error-prone.

2.5.4. Builder Pattern for Hardware Configuration APIs

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

- 1. Readability of code (avoid "death by parameters" where a configuration function takes a dozen integers and booleans)
- 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:

```
int dma_channel = 3;
dma_channel_config config = dma_get_default_channel_config(dma_channel);
channel_config_set_read_increment(&config, true);
channel_config_set_write_increment(&config, true);
channel_config_set_dreq(&config, DREQ_SPI0_RX);
channel_config_set_transfer_data_size(&config, DMA_SIZE_8);
dma_set_config(dma_channel, &config, false);
```

The value of dma_channel is known at compile time, so the compiler can replace dma_channel with 3 when generating code (constant folding). The dma_ methods are static inline methods (from https://github.com/raspberrypi/pico-sdk/tree/master/src/rp2_common/hardware_dma/include/hardware/dma.h) meaning the implementations can be folded into your code by the compiler and, consequently, your constant parameters (like DREQ_SPIO_RX) are propagated though this local copy of the function implementation. The resulting code is usually smaller, and certainly faster, than the register shuffling caused by setting up a function call.

The net effect is that the compiler actually reduces all of the above to the following code:

 ${\it Effective\ code\ produced\ by\ the\ C\ compiler\ for\ the\ DMA\ configuration}$

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

It may seem counterintuitive that building up the configuration by passing a struct around, and committing the final result to the IO register, would be so much more compact than a series of direct register modifications using register field accessors. This is because the compiler is customarily forbidden from eliminating IO accesses (illustrated here with a volatile keyword), with good reason. Consequently it's easy to unwittingly generate code that repeatedly puts a value into a register and pulls it back out again, changing a few bits at a time, when we only care about the final value of the register. The configuration pattern shown here avoids this common pitfall.

NOTE

The 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.

2.6. Customisation and Configuration Using Preprocessor variables

The 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 libraries 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.

Appendix B has a comprehensive list of the available preprocessor defines, what they do, and what their default values

Preprocessor variables may be specified in a number of ways, described in the following sections.



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 the user specifying any settings (beyond those provided by the board configuration).

2.6.1. Preprocessor Variables via Board Configuration File

Many of the common configuration settings are actually related to the particular RP2040 board being used, and include default pin settings for various 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/master/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 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.

2.6.2. Preprocessor Variables Per Binary or Library via CMake

We could modify the https://github.com/raspberrypi/pico-examples/tree/master/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
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)
```

The target_compile_definitions specifies preprocessor definitions that will be passed to the compiler for every source file in the target hello_world (which as mentioned before includes all of the sources for all dependent INTERFACE libraries). PRIVATE is required by CMake to specify the scope for the compile definitions. Note that all preprocessor definitions used by the SDK have a PICO_ prefix.

2.7. SDK Runtime

For those coming from non embedded programming, or from other devices, this section will give you an idea of how various C/C++ language level concepts are handled within the SDK

2.7.1. Standard Input/Output (stdio) Support

The SDK runtime packages a lightweight printf library by Marco Paland, linked as pico_printf. It also contains infrastructure for routing stdout and stdin to various hardware interfaces, which is documented under pico_stdio:

- A UART interface specified by a board configuration header. The default for Raspberry Pi Pico is 115200 baud on GPIO0 (TX) and GPIO1 (RX)
- A USB CDC ACM virtual serial port, using TinyUSB's CDC support. The virtual serial device can be accessed through RP2040's dedicated USB hardware interface, in Device mode.
- (Experimental) minimal semihosting support to direct stdout to an external debug host connected via the Serial Wire Debug link on RP2040

These can be accessed using standard calls like printf, puts, getchar, found in the standard <stdio.h> header. By default, stdout converts bare linefeed characters to carriage return plus linefeed, for better display in a terminal emulator. This can be disabled at runtime, at build time, or the CR-LF support can be completely removed.

stdout is broadcast to all interfaces that are enabled, and stdin is collected from all interfaces which are enabled and support input. Since some of the interfaces, particularly USB, have heavy runtime and binary size cost, only the UART interface is included by default. You can add/remove interfaces for a given program at build time with e.g.

```
pico_enable_stdio_usb(target_name, 1)
```

2.7.2. Floating-point Support

The SDK provides a highly optimized single and double precision floating point implementation. In addition to being fast, many of the functions are actually implemented using support provided in the RP2040 bootrom. This means the interface from your code to the ROM floating point library has very minimal impact on your program size, certainly using dramatically less flash storage than including the standard floating point routines shipped with your compiler.

The physical ROM storage on RP2040 has single-cycle access (with a dedicated arbiter on the RP2040 busfabric), and accessing code stored here does not put pressure on the flash cache or take up space in memory, so not only are the routines fast, the rest of your code will run faster due them being resident in ROM.

This implementation is used by default as it is the best choice in the majority of cases, however it is also possible to switch to using the regular compiler soft floating point support.

2.7.2.1. Functions

The SDK provides implementations for all the standard functions from math.h. Additional functions can be found in pico/float.h and pico/double.h.

2.7.2.2. Speed/Tradeoffs

The overall goal for the bootrom floating-point routines is to achieve good performance within a small footprint, the emphasis being more on improved performance for the basic operations (add, subtract, multiply, divide and square root, and all conversion functions), and more on reduced footprint for the scientific functions (trigonometric functions, logarithms and exponentials).

The IEEE single- and double-precision data formats are used throughout, but in the interests of reducing code size, input denormals are treated as zero and output denormals are flushed to zero, and output NaNs are rendered as infinities. Only the round-to-nearest, even-on-tie rounding mode is supported. Traps are not supported. Whether input NaNs are treated as infinities or propagated is configurable.

The five basic operations (add, subtract, multiply, divide, sqrt) return results that are always correctly rounded (round-tonearest).

The scientific functions always return results within 1 ULP (unit in last place) of the exact result. In many cases results are better.

The scientific functions are calculated using internal fixed-point representations so accuracy (as measured in ULP error rather than in absolute terms) is poorer in situations where converting the result back to floating point entails a large normalising shift. This occurs, for example, when calculating the sine of a value near a multiple of pi, the cosine of a value near an odd multiple of pi/2, or the logarithm of a value near 1. Accuracy of the tangent function is also poorer when the result is very large. Although covering these cases is possible, it would add considerably to the code footprint, and there are few types of program where accuracy in these situations is essential.

The following table shows the results from a benchmark



NOTE

Whilst the SDK floating point support makes use of the routines in the RP2040 bootrom, it hides some of the limitations of the raw ROM functions (e.g. limited sin/cos range), in order to be largely indistinguishable from the compiler-provided functionality. Certain smaller functions have also been re-implemented for even more speed outside of the limited bootrom space.

Table 3. SDK implementation vs GCC 9 implementation for ARM AFARI floating point functions (these unusually named

functions provide the support for basic operations on float and double types)

Function	ROM/SDK (µs)	GCC 9 (µs)	Performance Ratio
aeabi_fadd	72.4	99.8	138%
aeabi_fsub	86.7	133.6	154%

aeabi_frsub	89.8	140.6	157%
aeabi_fmul	61.5	145	236%
aeabi_fdiv	74.7	437.5	586%
aeabi_fcmplt	39	61.1	157%
aeabi_fcmple	40.5	61.1	151%
aeabi_fcmpgt	40.5	61.2	151%
aeabi_fcmpge	41	61.2	149%
aeabi_fcmpeq	40	41.5	104%
aeabi_dadd	99.4	142.5	143%
aeabi_dsub	114.2	182	159%
aeabi_drsub	108	181.2	168%
aeabi_dmul	168.2	338	201%
aeabi_ddiv	197.1	412.2	209%
aeabi_dcmplt	53	88.3	167%
aeabi_dcmple	54.6	88.3	162%
aeabi_dcmpgt	54.4	86.6	159%
aeabi_dcmpge	55	86.6	157%
aeabi_dcmpeq	54	64.3	119%
aeabi_f2iz	17	24.5	144%
aeabi_f2uiz	42.5	106.5	251%
aeabi_f2lz	63.1	1240.5	1966%
aeabi_f2ulz	46.1	1157	2510%
aeabi_i2f	43.5	63	145%
aeabi_ui2f	41.5	55.8	134%
aeabi_l2f	75.2	643.3	855%
aeabi_ul2f	71.4	531.5	744%
aeabi_d2iz	30.6	44.1	144%
aeabi_d2uiz	75.7	159.1	210%
aeabi_d2lz	81.2	1267.8	1561%
aeabi_d2ulz	65.2	1148.3	1761%
aeabi_i2d	44.4	61.9	139%
aeabi_ui2d	43.4	51.3	118%
aeabi_l2d	104.2	559.3	537%
aeabi_ul2d	102.2	458.1	448%
acabi fod			
aeabi_f2d	20	31	155%

2.7.2.3. Configuration and Alternate Implementations

There are three different floating point implementations provided

Name	Description
default	The default; equivalent to pico
pico	Use the fast/compact SDK/bootrom implementations
compiler	Use the standard compiler provided soft floating point implementations
none	Map all functions to a runtime assertion. You can use this when you know you don't want any floating point support to make sure it isn't accidentally pulled in by some library.

These settings can be set independently for both "float" and "double":

For "float" you can call pico_set_float_implementation(TARGET NAME) in your CMakeLists.txt to choose a specific implementation for a particular target, or set the CMake variable PICO_DEFAULT_FLOAT_IMPL to pico_float_NAME to set the default.

For "double" you can call pico_set_double_implementation(TARGET NAME) in your CMakeLists.txt to choose a specific implementation for a particular target, or set the CMake variable PICO_DEFAULT_DOUBLE_IMPL to pico_double_NAME to set the default.



The pico floating point library adds very little to your binary size, however it must include implementations for any used functions that are not present in V1 of the bootrom, which is present on early Raspberry Pi Pico boards. If you know that you are only using RP2040s with V2 of the bootrom, then you can specify defines PICO_FLOAT_SUPPORT_ROM_V1=0 and PICO_DOUBLE_SUPPORT_ROM_V1=0 so the extra code will not be included. Any use of those functions on a RP2040 with a V1 bootrom will cause a panic at runtime. See the RP2040 Datasheet for more specific details of the bootrom functions.

2.7.2.3.1. NaN Propagation

The SDK implementation by default treats input NaNs as infinites. If you require propagation of NaN inputs to outputs and NaN outputs for domain errors, then you can set the compile definitions PICO_FLOAT_PROPAGATE_NANS and PICO_DOUBLE_PROPAGATE_NANS to 1, at the cost of a small runtime overhead.

2.7.3. Hardware Divider

The SDK includes optimized 32- and 64-bit division functions accelerated by the RP2040 hardware divider, which are seamlessly integrated with the C / and % operators. The SDK also supplies a high level API which includes combined quotient and remainder functions for 32- and 64-bit, also accelerated by the hardware divider.

See Figure 1 and Figure 2 for 32-bit and 64-bit integer divider comparison.

Figure 1. 32-bit divides by divider size using GCC library (blue), or the SDK library (red) with the RP2040 hardware divider.

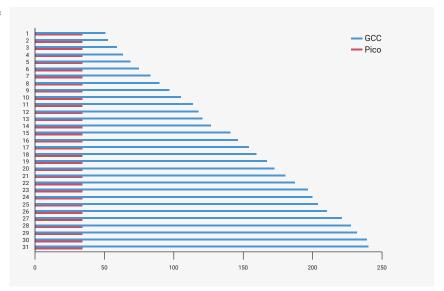
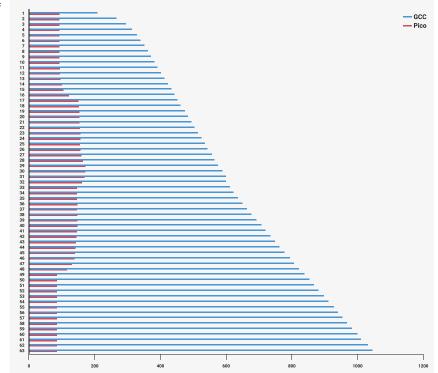


Figure 2. 64-bit divides by divider size using GCC library (blue), or the SDK library (red) with the RP2040 hardware divider.



2.8. 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.

Core 1 (the second core) is started by calling multicore_launch_core1(some_function_pointer); on core 0, which wakes the core from its low-power sleep state and provides it with its entry point — some function you have provided which hopefully with a descriptive name like void core1_main() { }. This function, as well as others such as pushing and popping data through the inter-core mailbox FIFOs, is listed under pico_multicore.

Care should be taken with calling C library functions from both cores simultaneously as they are generally not designed

2.8. Multi-core support

to be thread safe. You can use the mutex_ API provided by the SDK in the pico_sync library (
https://github.com/raspberrypi/pico-sdk/tree/master/src/common/pico_sync/include/pico/mutex.h) from within your
own code.



That the 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.

2.9. Using C++

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

C++ files are integrated into SDK projects in the same way as C files: listing them in your CMakeLists.txt file under either the add_executable() entry, or a separate target_sources() entry to append them to your target.

To save space, exception handling is disabled by default; this can be overridden with the CMake environment variable PICO_CXX_ENABLE_EXCEPTIONS=1. There are a handful of other C++ related PICO_CXX vars listed in Appendix C.

2.10. Next Steps

This has been quite a deep dive. If you've somehow made it through this chapter *without* building any software, now would be a perfect time to divert to the **Getting started with Raspberry Pi Pico** book, which has detailed instructions on connecting to your RP2040 board and loading an application built with the SDK.

Chapter 3 gives some background on RP2040's unique Programmable I/O subsystem, and walks through building some applications which use PIO to talk to external hardware.

Chapter 4 is a comprehensive listing of the SDK APIs. The APIs are listed according to groups of related functionality (e.g. low-level hardware access).

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Chapter 3. Using Programmable I/O (PIO)

3.1. What is Programmable I/O (PIO)?

Programmable I/O (PIO) is a new piece of hardware developed for RP2040. It allows you to create new types of (or additional) hardware interfaces on your RP2040-based device. If you've looked at fixed peripherals on a microcontroller, and thought "I want to add 4 more UARTs", or "I'd like to output DPI video", or even "I need to communicate with this cursed serial device I found on AliExpress, but no machine has hardware support", then you will have fun with this chapter.

PIO hardware is described extensively in chapter 3 of the RP2040 Datasheet. This is a companion to that text, focussing on how, when and why to use PIO in your software. To start, we're going to spend a while discussing why I/O is hard, what the current options are, and what PIO does differently, before diving into some software tutorials. We will also try to illuminate some of the more important parts of the hardware along the way, but will defer to the datasheet for full explanations.



You can skip to the first software tutorial if you'd prefer to dive straight in.

3.1.1. 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.

3.1.2. I/O Using dedicated hardware on your PC

Traditionally, on your desktop or laptop computer, you have one option for hardware interfacing. Your computer has high speed USB ports, HDMI outputs, PCIe 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 graphics card, hard drive 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. These interfaces are purpose-built, and if you have them, you should use them.

3.1.3. I/O 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, I2S, CAN bus and more over *general purpose I/O* pins (GPIOs). Like USB controllers (also found on some microcontrollers, including the RP2040 on Raspberry Pi Pico), I2C and SPI are general purpose buses which connect to a wide variety of external hardware, using the same piece of on-chip hardware. This includes sensors, external flash, EEPROM and SRAM memories, GPIO expanders, and more, all of them widely and cheaply available. Even HDMI uses I2C to communicate video timings between Source and Sink, and there is probably a microcontroller *embedded* in your TV to handle this.

These protocols are simpler to integrate into very low-cost devices (i.e. not the host), due to their relative simplicity and

modest speed. This is important for chips with mostly analogue or high-power circuitry: the silicon fabrication techniques used for these chips do not lend themselves to high speed or gate count, so if your switchmode power supply controller has some serial configuration interface, it is likely to be something like I2C. The number of traces routed on the circuit board, the number of pins required on the device package, and the PCB technology required to maintain signal integrity are also factors in the choice of these protocols. A microcontroller needs to communicate with these devices to be part of a larger *embedded system*.

This is all very well, but the area taken up by these individual serial peripherals, and the associated cost, often leaves you with a limited menu. You may end up paying for a bunch of stuff you don't need, and find yourself without enough of what you really want. 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).

3.1.4. I/O Using software control of GPIOs ("bit-banging")

The third option on your Raspberry Pi or microcontroller – any system with GPIOs which the processor(s) can access easily – 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, and the approximate signalling speeds involved:

Table 4. Types of hardware

Interface Speed	Interface
1-10 Hz	Push buttons, indicator LEDs
300 Hz	HDMI CEC
10-100 kHz	Temperature sensors (DHT11), one-wire serial
<100 kHz	I2C Standard mode
22-100+ kHz	PCM audio
300+ kHz	PWM audio
400-1200 kHz	WS2812 LED string
10-3000 kHz	UART serial
12 MHz	USB Full Speed
1-100 MHz	SPI
20-300 MHz	DPI/VGA video
480 MHz	USB High Speed
10-4000 MHz	Ethernet LAN
12-4000 MHz	SD card
250-20000 MHz	HDMI/DVI video

"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 back then. As processors have become faster in terms of overwhelming number-crunching brute force, the layers of software and hardware between the processor and the outside world have also grown in number and size. In response to the growing distance between processors and memory, PC-class processors keep many hundreds of instructions in-flight

on a single core at once, which has drawbacks when trying to switch rapidly between hard real time tasks. However, IRQ-based bitbanging can be an effective strategy on simpler embedded systems.

Above certain speeds — say a factor of 1000 below the processor clock speed — IRQs become impractical, in part due to the timing uncertainty of actually *entering* an interrupt handler. The alternative when "bit-banging" is to sit the processor in a carefully timed loop, often painstakingly written 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 thousands of GitHub repositories are dedicated to the task of doing such things (a large proportion of them for LED strings).

Additionally of course, your processor is now busy doing the "bit-banging", and cannot be used for other tasks. If your processor is interrupted even for a few microseconds to attend to one of the hard peripherals it is also responsible for, this can be fatal to the timing of any bit-banged protocol. The greater the ratio between protocol speed and processor speed, the more cycles your processor will spend uselessly idling in between GPIO accesses. Whilst it is eminently possible to drive a 115200 baud UART output using only software, this has a cost of >10 000 cycles per byte if the processor is running at 133 MHz, which may be poor investment of those cycles.

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 not much you can hope to do. The main case where software GPIO access is the best choice is LEDs and push buttons.

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).

3.1.5. Programmable I/O Hardware using FPGAs and CPLDs

A field-programmable gate array (FPGA), or its smaller cousin, the complex programmable logic device (CPLD), is in many ways the perfect solution for tailor-made I/O requirements, whether that entails an unusual type or unusual mixture of interfaces. FPGAs are chips with a configurable logic fabric — effectively a sea of gates and flipflops, some other special digital function blocks, and a routing fabric to connect them — which offer the same level of design flexibility available to chip designers. This brings with it all the advantages of dedicated I/O hardware:

- Absolute precision of protocol timing (within limitations of your clock source)
- Capable of very high I/O throughput
- Offload simple, repetitive calculations that are part of the I/O standard (checksums)
- Present a simpler interface to host software; abstract away details of the protocol, and handle these details internally.

The main drawback of FPGAs in embedded systems is their cost. They also present a very unfamiliar programming model to those well-versed in embedded software: you are not programming at all, but rather designing digital hardware. One you have your FPGA you will still need some other processing element in your system to run control software, unless you are using an FPGA expensive enough to either fit a soft CPU core, or contain a hardened CPU core alongside the FPGA fabric.

eFPGAs (embedded FPGAs) are available in some microcontrollers: a slice of FPGA logic fabric integrated into a more conventional microcontroller, usually with access to some GPlOs, and accessible over the system bus. These are attractive from a system integration point of view, but have a significant area overhead compared with the usual serial peripherals found on a microcontroller, so either increase the cost and power dissipation, or are very limited in size. The issue of programming complexity still remains in eFPGA-equipped systems.

3.1.6. Programmable I/O Hardware using PIO

The PIO subsystem on RP2040 allows you to write small, simple programs for what are called *PIO state machines*, of which RP2040 has eight split across two PIO *instances*. A state machine is responsible for setting and reading 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 data or attention is needed.

These programs operate with cycle accuracy at up to system clock speed (or the program clocks can be divided down to run at slower speeds for less frisky protocols).

PIO state machines are much more compact than the general-purpose Cortex-M0+ processors on RP2040. In fact, they are similar in size (and therefore cost) to a standard SPI peripheral, such as the PL022 SPI also found on RP2040, because much of their area is spent on components which are common to all serial peripherals, like FIFOs, shift registers and clock dividers. The instruction set is small and regular, so not much silicon is spent on decoding the instructions. There is no need to feel guilty about dedicating a state machine solely to a single I/O task, since you have 8 of them!

In spite of this, a PIO state machine gets a lot more done in one cycle than a Cortex-M0+ when it comes to I/O: for example, sampling a GPIO value, toggling a clock signal and pushing to a FIFO all in one cycle, every cycle. The tradeoff is that a PIO state machine is not remotely capable of running general purpose software. As we shall see though, programming a PIO state machine is quite familiar for anyone who has written assembly code before, and the small instruction set should be fairly quick to pick up for those who haven't.

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. For more involved protocols such as SDIO or DPI video you may end up using two or three.



TIP

If you are ever tempted to "bit-bang" a protocol on 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.

3.2. Getting started with PIO

It is possible to write PIO programs both within the C++ SDK and directly from MicroPython.

Additionally the future intent is to add APIs to trivially have new UARTs, PWM channels etc created for you, using a menu of pre-written PIO programs, but for now you'll have to follow along with example code and do that yourself.

3.2.1. A First PIO Application

Before getting into all of the fine details of the PIO assembly language, we should take the time to look at a small but complete application which:

- 1. Loads a program into a PIO's instruction memory
- 2. Sets up a PIO state machine to run the program
- 3. Interacts with the state machine once it is running.

The main ingredients in this recipe are:

- A PIO program
- · Some software, written in C, to run the whole show
- A CMake file describing how these two are combined into a program image to load onto a RP2040-based development board

TIP

The code listings in this section are all part of a complete application on GitHub, which you can build and run. Just click the link above each listing to go to the source. In this section we are looking at the pio/hello_pio example in pico-examples. You might choose to build this application and run it, to see what it does, before reading through this section.

NOTE

The focus here is on the main moving parts required to use a PIO program, not so much on the PIO program itself. This is a lot to take in, so we will stay high-level in this example, and dig in deeper on the next one.

3.2.1.1. PIO Program

This is our first PIO program listing. It's written in PIO assembly language.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/hello_pio/hello.pio\ Lines\ 7-15$

```
7 .program hello
9 ; Repeatedly get one word of data from the TX FIFO, stalling when the FIFO is
10 ; empty. Write the least significant bit to the OUT pin group.
11
12 loop:
    pull
13
14
      out pins. 1
15
      jmp loop
```

The pull instruction takes one data item from the transmit FIFO buffer, and places it in the output shift register (OSR). Data moves from the FIFO to the OSR one word (32 bits) at a time. The OSR is able to shift this data out, one or more bits at a time, to further destinations, using an out instruction.

FIFOs?

FIFOs are data queues, implemented in hardware. Each state machine has two FIFOs, between the state machine and the system bus, for data travelling out of (TX) and into (RX) the chip. Their name (first in, first out) comes from the fact that data appears at the FIFO's output in the same order as it was presented to the FIFO's input.

The out instruction here takes one bit from the data we just pull-ed from the FIFO, and writes that data to some pins. We will see later how to decide which pins these are.

The jmp instruction jumps back to the loop: label, so that the program repeats indefinitely. So, to sum up the function of this program: repeatedly take one data item from a FIFO, take one bit from this data item, and write it to a pin.

Our .pio file also contains a helper function to set up a PIO state machine for correct execution of this program:

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/hello_pio/hello.pio Lines 18 - 33

```
18 static inline void hello_program_init(PIO pio, uint sm, uint offset, uint pin) {
      pio_sm_config c = hello_program_get_default_config(offset);
19
20
21
      // Map the state machine's OUT pin group to one pin, namely the `pin`
22
       // parameter to this function.
       sm_config_set_out_pins(&c, pin, 1);
```

```
// Set this pin's GPIO function (connect PIO to the pad)
pio_gpio_init(pio, pin);
// Set the pin direction to output at the PIO
pio_sm_set_consecutive_pindirs(pio, sm, pin, 1, true);
// Load our configuration, and jump to the start of the program
pio_sm_init(pio, sm, offset, &c);
// Set the state machine running
pio_sm_set_enabled(pio, sm, true);
```

Here the main thing to set up is the GPIO we intend to output our data to. There are three things to consider here:

- 1. The state machine needs to be told which GPIO or GPIOs to output to. There are four different pin groups which are used by different instructions in different situations; here we are using the out pin group, because we are just using an out instruction.
- 2. The GPIO also needs to be told that PIO is in control of it (GPIO function select)
- 3. If we are using the pin for output only, we need to make sure that PIO is driving the *output enable* line high. PIO can drive this line up and down programmatically using e.g. an out pindirs instruction, but here we are setting it up before starting the program.

3.2.1.2. C Program

PIO won't do anything until it's been configured properly, so we need some software to do that. The PIO file we just looked at — hello.pio — is converted automatically (we will see later how) into a header containing our assembled PIO program binary, any helper functions we included in the file, and some useful information about the program. We include this as hello.pio.h.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/hello_pio/hello.c\ Lines\ 1-42$

```
2 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
3
 4 * SPDX-License-Identifier: BSD-3-Clause
5 */
7 #include "pico/stdlib.h"
8 #include "hardware/pio.h"
9 // Our assembled program:
10 #include "hello.pio.h"
11
12 int main() {
13 #ifndef PICO_DEFAULT_LED_PIN
14 #warning pio/hello_pio example requires a board with a regular LED
16 // Choose which PIO instance to use (there are two instances)
17
     PIO pio = pio0;
18
    // Our assembled program needs to be loaded into this PIO's instruction
19
      // memory. This SDK function will find a location (offset) in the
20
21
      // instruction memory where there is enough space for our program. We need
      // to remember this location!
      uint offset = pio_add_program(pio, &hello_program);
      // Find a free state machine on our chosen PIO (erroring if there are
25
      // none). Configure it to run our program, and start it, using the
26
27
       // helper function we included in our .pio file.
28
       uint sm = pio_claim_unused_sm(pio, true);
       hello_program_init(pio, sm, offset, PICO_DEFAULT_LED_PIN);
29
```

```
30
       // The state machine is now running. Any value we push to its TX FIFO will
31
32
      // appear on the LED pin.
33
      while (true) {
           // Blink
34
35
          pio_sm_put_blocking(pio, sm, 1);
36
          sleep_ms(500);
37
           // Blonk
           pio_sm_put_blocking(pio, sm, 0);
38
39
           sleep_ms(500);
40
41 #endif
42 }
```

You might recall that RP2040 has two PIO blocks, each of them with four state machines. Each PIO block has a 32-slot instruction memory which is visible to the four state machines in the block. We need to load our program into this instruction memory before any of our state machines can run the program. The function pio_add_program() finds free space for our program in a given PIO's instruction memory, and loads it.

32 Instructions?

This may not sound like a lot, but the PIO instruction set can be very dense once you fully explore its features. A perfectly serviceable UART transmit program can be implemented in four instructions, as shown in the pio/uart_tx example in pico-examples. There are also a couple of ways for a state machine to execute instructions from other sources — like directly from the FIFOs — which you can read all about in the RP2040 Datasheet.

Once the program is loaded, we find a free state machine and tell it to run our program. There is nothing stopping us from ordering multiple state machines to run the same program. Likewise, we could instruct each state machine to run a *different* program, provided they all fit into the instruction memory at once.

We're configuring this state machine to output its data to the LED on your Raspberry Pi Pico board. If you have already built and run the program, you probably noticed this already!

At this point, the state machine is running autonomously. The state machine will immediately *stall*, because it is waiting for data in the TX FIFO, and we haven't provided any. The processor can push data directly into the state machine's TX FIFO using the pio_sm_put_blocking() function. (_blocking because this function stalls the processor when the TX FIFO is full.) Writing a 1 will turn the LED on, and writing a 0 will turn the LED off.

3.2.1.3. CMake File

We have two lovely text files sat on our computer, with names ending with .pio and .c, but they aren't doing us much good there. A CMake file describes how these are built into a binary suitable for loading onto your Raspberry Pi Pico or other RP2040-based board.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/hello_pio/CMakeLists.txt\ Lines\ 1-15$

```
11
12 pico_add_extra_outputs(hello_pio)
13
14 # add url via pico_set_program_url
15 example_auto_set_url(hello_pio)
```

- add_executable(): Declare that we are building a program called hello_pio
- pico_generate_pio_header(): Declare that we have a PIO program, hello.pio, which we want to be built into a C header for use with our program
- target_sources(): List the source code files for our hello_pio program. In this case, just one C file.
- target_link_libraries(): Make sure that our program is built with the PIO hardware API, so we can call functions like pio_add_program() in our C file.
- pico_add_extra_outputs(): By default we just get an .elf file as the build output of our app. Here we declare we also
 want extra build formats, like a .uf2 file which can be dragged and dropped directly onto a Raspberry Pi Pico
 attached over USB.

Assuming you already have pico-examples and the SDK installed on your machine, you can run

```
mkdir build
cd build
cmake ..
make hello_pio
```

To build this program.

3.2.2. A Real Example: WS2812 LEDs

The WS2812 LED (sometimes sold as NeoPixel) is an addressable RGB LED. In other words, it's an LED where the red, green and blue components of the light can be individually controlled, and it can be connected in such a way that many WS2812 LEDs can be controlled individually, with only a single control input. Each LED has a pair of power supply terminals, a serial data input, and a serial data output.

When serial data is presented at the LED's input, it takes the first three bytes for itself (red, green, blue) and the remainder is passed along to its serial data output. Often these LEDs are connected in a single long chain, each LED connected to a common power supply, and each LED's data output connected through to the next LED's input. A long burst of serial data to the first in the chain (the one with its data input unconnected) will deposit three bytes of RGB data in each LED, so their colour and brightness can be individually programmed.

Figure 3. WS2812 line format. Wide positive pulse for 1, narrow positive pulse for 0, very long negative pulse for latch enable



Unfortunately the LEDs receive and retransmit serial data in quite an unusual format. Each bit is transferred as a positive pulse, and the width of the pulse determines whether it is a 1 or a 0 bit. There is a family of WS2812-like LEDs available, which often have slightly different timings, and demand precision. It is possible to bit-bang this protocol, or to write canned bit patterns into some generic serial peripheral like SPI or I2S to get firmer guarantees on the timing, but there is still some software complexity and cost associated with generating the bit patterns.

Ideally we would like to have all of our CPU cycles available to generate colour patterns to put on the lights, or to handle any other responsibilities the processor may have in the *embedded system* the LEDs are connected to.



TIP

Once more, this section is going to discuss a real, complete program, that you can build and run on your Raspberry Pi Pico. Follow the links above the program listings if you'd prefer to build the program yourself and run it, before going through it in detail. This section explores the pio/ws2812 example in pico-examples.

3.2.2.1. PIO Program

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.pio Lines 7 - 26

```
7 .program ws2812
8 .side_set 1
10 .define public T1 2
11 .define public T2 5
12 .define public T3 3
13
14 .lang_opt python sideset_init = pico.PIO.OUT_HIGH
15 .lang_opt python out_init = pico.PIO.OUT_HIGH
16 .lang_opt python out_shiftdir = 1
17
18 .wrap_target
19 bitloop:
   out x, 1
                   side 0 [T3 - 1]; Side-set still takes place when instruction stalls
21 jmp !x do_zero side 1 [T1 - 1]; Branch on the bit we shifted out. Positive pulse
22 do_one:
23 jmp bitloop side 1 [T2 - 1]; Continue driving high, for a long pulse
24 do zero:
25 nop
                   side 0 [T2 - 1] ; Or drive low, for a short pulse
26 .wrap
```

The previous example was a bit of a whistle-stop tour of the anatomy of a PIO-based application. This time we will dissect the code line-by-line. The first line tells the assembler that we are defining a program named ws2812:

```
.program ws2812
```

We can have multiple programs in one .pio file (and you will see this if you click the GitHub link above the main program listing), and each of these will have its own .program directive with a different name. The assembler will go through each program in turn, and all the assembled programs will appear in the output file.

Each PIO instruction is 16 bits in size. Generally, 5 of those bits in each instruction are used for the "delay" which is usually 0 to 31 cycles (after the instruction completes and before moving to the next instruction). If you have read the PIO chapter of the RP2040 Datasheet, you may have already know that these 5 bits can be used for a different purpose:

```
.side_set 1
```

This directive .side_set 1 says we're stealing one of those delay bits to use for "side set". The state machine will use this bit to drive the values of some pins, once per 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, to fit into the shared instruction memory.

Note that stealing one bit has left our delay range from 0-15 (4 bits), 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 would mean the side set is optional (at the cost of another bit to say *whether* the instruction does a side set), we have to specify a side set value for *every* instruction in the program. This is the side N you will see on each instruction in the listing.

```
.define public T1 2
.define public T2 5
.define public T3 3
```

.define lets you declare constants. The public keyword means that the assembler will also write out the value of the define in the output file for use by other software: in the context of the SDK, this is a #define. We are going to use T1, T2 and T3 in calculating the delay cycles on each instruction.

```
.lang_opt python
```

This is used to specify some PIO hardware defaults as used by the MicroPython PIO library. We don't need to worry about them in the context of SDK applications.

```
.wrap_target
```

We'll ignore this for now, and come back to it later, when we meet its friend .wrap.

```
bitloop:
```

This is a label. A label tells the assembler that this point in your code is interesting to you, and you want to refer to it later by name. Labels are mainly used with jmp instructions.

```
out x, 1 side 0 [T3 - 1] ; Side-set still takes place when instruction stalls
```

Finally we reach a line with a PIO instruction. There is a lot to see here.

- This is an out instruction. out takes some bits from the *output shift register* (OSR), and writes them somewhere else. In this case, the OSR will contain pixel data destined for our LEDs.
- [T3 1] is the number of delay cycles (T3 minus 1). T3 is a constant we defined earlier.
- x (one of two scratch registers; the other imaginatively called y) is the destination of the write data. State machines use their scratch registers to hold and compare temporary data.
- side 0: Drive low (0) the pin configured for side-set.
- Everything after the; character is a comment. Comments are ignored by the assembler: they are just notes for humans to read.

Output Shift Register

The OSR is a staging area for data entering the state machine through the TX FIFO. Data is pulled from the TX FIFO into the OSR one 32-bit chunk at a time. When an out instruction is executed, the OSR can break this data into smaller pieces by *shifting* to the left or right, and sending the bits that drop off the end to one of a handful of different destinations, such as the pins.

The amount of data to be shifted is encoded by the out instruction, and the *direction* of the shift (left or right) is configured ahead of time. For full details and diagrams, see the RP2040 Datasheet.

So, the state machine will do the following operations when it executes this instruction:

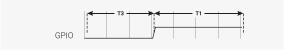
- 1. Set 0 on the side set pin (this happens even if the instruction stalls because no data is available in the OSR)
- 2. Shift one bit out of the OSR into the x register. The value of the x register will be either 0 or 1.
- 3. Wait T3 1 cycles after the instruction (I.e. the whole thing takes T3 cycles since the instruction itself took a cycle). Note that when we say cycle, we mean state machine execution cycles: a state machine can be made to execute at a slower rate than the system clock, by configuring its *clock divider*.

Let's look at the next instruction in the program.

```
jmp !x do_zero side 1 [T1 - 1] ; Branch on the bit we shifted out. Positive pulse
```

- 1. side 1 on the side set pin (this is the leading edge of our pulse)
- 2. If x == 0 then go to the instruction labelled do_zero, otherwise continue on sequentially to the next instruction
- 3. We delay T1 1 after the instruction (whether the branch is taken or not)

Let's look at what our output pin has done so far in the program.



machine drives the line low for time T1 as it shifts out one data bit from the OSR, and then high for time T2

whilst branching on

the value of the bit.

Figure 4. The state

The pin has been low for time T3, and high for time T1. If the x register is 1 (remember this contains our 1 bit of pixel data) then we will fall through to the instruction labelled do_one:

```
do_one:

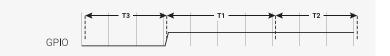
jmp bitloop side 1 [T2 - 1] ; Continue driving high, for a long pulse
```

On this side of the branch we do the following:

- 1. side 1 on the side set pin (continue the pulse)
- 2. jmp unconditionally back to bitloop (the label we defined earlier, at the top of the program); the state machine is done with this data bit, and will get another from its OSR
- 3. Delay for T2 1 cycles after the instruction

The waveform at our output pin now looks like this:

Figure 5. On a one data bit, the line is driven low for time T3, high for time T1, then high for an additional time T2



This accounts for the case where we shifted a 1 data bit into the x register. For a 0 bit, we will have jumped over the last instruction we looked at, to the instruction labelled do_zero:

```
do_zero:
nop side 0 [T2 - 1] ; Or drive low, for a short pulse
```

- 1. side 0 on the side set pin (the trailing edge of our pulse)
- 2. nop means no operation. We don't have anything else we particularly want to do, so waste a cycle
- 3. The instruction takes T2 cycles in total

For the x == 0 case, we get this on our output pin:

Figure 6. On a zero data bit, the line is driven low for time T3, high for time T1, then low again for time T1



The final line of our program is this:

.wrap

This matches with the .wrap_target directive at the top of the program. Wrapping is a hardware feature of the state machine which behaves like a wormhole: you go in through the .wrap statement and appear at the .wrap_target zero cycles later, unless the .wrap is preceded immediately by a jmp whose condition is true. This is important for getting precise timing with programs that must run quickly, and often also saves you a slot in the instruction memory.



TIP

Often an explicit .wrap_target/.wrap pair is not necessary, because the default configuration produced by pioasm has an implicit wrap from the end of the program back to the beginning, if you didn't specify one.

NOPs

NOP, or no operation, means precisely that: do nothing! You may notice there is no nop instruction defined in the instruction set reference: nop is really a synonym for mov y, y in PIO assembly.

Why did we insert a nop in this example when we could have jmp-ed? Good question! It's a dramatic device we contrived so we could discuss nop and .wrap. Writing documentation is hard. In general, though, nop is useful when you need to perform a side-set and have nothing else to do, or you need a very slightly longer delay than is available on a single instruction.

It is hopefully becoming clear why our timings T1, T2, T3 are numbered this way, because what the LED string sees really is one of these two cases:

Figure 7. The line is initially low in the idle (latch) state, and the LED is waiting for the first rising edge. It sees our pulse timings in the order T1-T2-T3, until the very last T3, where it sees a much longer negative period once the state machine runs out of data.



This should look familiar if you refer back to Figure 3.

After thoroughly dissecting our program, and hopefully being satisfied that it will repeatedly send one well-formed data bit to a string of WS2812 LEDs, we're left with a question: where is the data coming from? This is more thoroughly explained in the RP2040 Datasheet, but the data that we are shifting out from the OSR came from the state machine's TX FIFO. The TX FIFO is a data buffer between the state machine and the rest of RP2040, filled either via direct poking from the CPU, or by the system DMA, which is much faster.

The out instruction shifts data out from the OSR, and zeroes are shifted in from the other end to fill the vacuum. Because the OSR is 32 bits wide, you will start getting zeroes once you have shifted out a total of 32 bits. There is a pull instruction which explicitly takes data from the TX FIFO and put it in the OSR (stalling the state machine if the FIFO is empty).

However, in the majority of cases it is simpler to configure *autopull*, a mode where the state machine automatically refills the OSR from the TX FIFO (an automatic pull) when a configured number of bits have been shifted out. Autopull happens in the background, in parallel with whatever else the state machine may be up to (in other words it has a cost of zero cycles). We'll see how this is configured in the next section.

3.2.2.2. State Machine Configuration

When we run pioasm on the .pio file we have been looking at, and ask it to spit out 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 state machine based on user parameters, and the directives in the actual PIO program (namely the .side_set and .wrap in this case).

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 within the .pio file.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.pio Lines 31 - 47

```
31 static inline void ws2812_program_init(PIO pio, uint sm, uint offset, uint pin, float freq,
  bool rgbw) {
32
33
       pio_gpio_init(pio, pin);
34
       pio_sm_set_consecutive_pindirs(pio, sm, pin, 1, true);
35
36
       pio_sm_config c = ws2812_program_get_default_config(offset);
37
       sm_config_set_sideset_pins(&c, pin);
       sm\_config\_set\_out\_shift(\&c, \ false, \ true, \ rgbw \ ? \ 32 \ : \ 24);
38
39
       sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_TX);
40
       int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3;
41
42
       float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit);
43
       sm_config_set_clkdiv(&c, div);
44
45
       pio_sm_init(pio, sm, offset, &c);
46
       pio_sm_set_enabled(pio, sm, true);
47 }
```

In this case we are passing through code for the SDK, as requested by this line you will see if you click the link on the above listing to see the context:

```
% c-sdk {
```

We have here a function ws2812_program_init which is provided to help the user to instantiate an instance of the LED driver program, based on a handful of parameters:

pio

Which of RP2040's two PIO instances we are dealing with

SM

Which state machine on that PIO we want to configure to run the WS2812 program

offset

Where the PIO program was loaded in PIO's 5-bit program address space

pin

which GPIO pin our WS2812 LED chain is connected to

freq

The frequency (or rather baud rate) we want to output data at.

rgbw

True if we are using 4-colour LEDs (red, green, blue, white) rather than the usual 3.

Such that:

- pio_gpio_init(pio, pin); Configure a GPIO for use by PIO. (Set the GPIO function select.)
- pio_set_consecutive_pindirs(pio, sm, pin, 1, true); Sets the PIO pin direction of 1 pin starting at pin number pin to out
- pio_sm_config c = ws2812_program_default_config(offset); Get the default configuration using the generated function for this program (this includes things like the .wrap and .side_set configurations from the program). We'll modify this configuration before loading it into the state machine.
- sm_config_sideset_pins(&c, pin); Sets the side set to write to pins starting at pin pin (we 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 autopull. 32 or 24 for the number of bits for the autopull threshold, i.e. the point at which the state machine triggers a refill of the OSR, depending on whether the LEDs are RGB or RGBW.
- int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3; This is the total number of execution cycles to output a single bit. Here we see the benefit of .define public; we can use the T1 T3 values in our code.
- float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit); sm_config_clkdiv(&c, div); Slow the state machine's execution down, based on the system clock speed and the number of execution cycles required per WS2812 data bit, so that we achieve the correct bit rate.
- pio_sm_init(pio, sm, offset, &c); Load our configuration into the state machine, and go to the start address (
 offset)
- pio_sm_enable(pio, sm, true); And make it go now!

At this point the program will be stuck on the first out waiting for data. This is because we have autopull enabled, the OSR is initially empty, and there is no data to be pulled. The state machine refuses to continue until the first piece of data arrives in the FIFO.

As an aside, this last point sheds some light on the slightly cryptic comment at the start of the PIO program:

```
out x, 1 \qquad side 0 [T3 - 1] ; Side-set still takes place when instruction stalls
```

This comment is giving us an important piece of context. We stall on this instruction initially, before the first data is added, and also every time we finish sending the last piece of data at the end of a long serial burst. When a state machine stalls, it does not continue to the next instruction, rather it will reattempt the current instruction on the next divided clock cycle. However, side set still takes place. This works in our favour here, because we consequently always return the line to the idle (low) state when we stall.

3.2.2.3. C Program

The companion to the .pio file we've looked at is a .c file which drives some interesting colour patterns out onto a string of LEDs. We'll just look at the parts that are directly relevant to PIO.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.c Lines 15 - 17

```
15 static inline void put_pixel(uint32_t pixel_grb) {
16    pio_sm_put_blocking(pio0, 0, pixel_grb << 8u);
17 }</pre>
```

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.c Lines 19 - 24

Here we are writing 32-bit values into the FIFO, one at a time, directly from the CPU. pio_sm_put_blocking is a helper method that waits until there is room in the FIFO before pushing your data.

You'll notice the << 8 in put_pixel(): remember we are shifting out starting with the MSB, so we want the 24-bit colour values at the top. this works fine for WGBR too, just that the W is always 0.

This program has a handful of colour patterns, which call our put_pixel helper above to output a sequence of pixel values:

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.c\ Lines\ 40-45-100.$

```
40 void pattern_random(uint len, uint t) {
41     if (t % 8)
42         return;
43     for (int i = 0; i < len; ++i)
44         put_pixel(rand());
45 }</pre>
```

The main function loads the program onto a PIO, configures a state machine for 800 kbaud WS2812 transmission, and then starts cycling through the colour patterns randomly.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.c Lines 76 - 100

```
76 int main() {
77     //set_sys_clock_48();
78     stdio_init_all();
79     puts("WS2812 Smoke Test");
80
81     // todo get free sm
82     PIO pio = pio0;
```

```
83
        int sm = 0:
84
        uint offset = pio_add_program(pio, &ws2812_program);
85
86
        ws2812_program_init(pio, sm, offset, PIN_TX, 800000, true);
87
88
        int t = 0:
 89
        while (1) {
           int pat = rand() % count_of(pattern_table);
90
91
            int dir = (rand() >> 30) & 1 ? 1 : -1;
            puts(pattern_table[pat].name);
92
            puts(dir == 1 ? "(forward)" : "(backward)");
93
94
            for (int i = 0; i < 1000; ++i) {
95
                pattern_table[pat].pat(150, t);
96
               sleep_ms(10);
97
                t += dir:
98
            }
99
        }
100 }
```

3.2.3. PIO and DMA (A Logic Analyser)

So far we have looked at writing data to PIO directly from the processor. This often leads to the processor spinning its wheels waiting for room in a FIFO to make a data transfer, which is not a good investment of its time. It also limits the total data throughput you can achieve.

RP2040 is equipped with a powerful *direct memory access* unit (DMA), which can transfer data for you in the background. Suitably programmed, the DMA can make quite long sequences of transfers without supervision. Up to one word per system clock can be transferred to or from a PIO state machine, which is, to be quite technically precise, more bandwidth than you can shake a stick at. The bandwidth is shared across all state machines, but you can use the full amount on *one* state machine.

Let's take a look at the logic_analyser example, which uses PIO to sample some of RP2040's own pins, and capture a logic trace of what is going on there, at full system speed.

 ${\it Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/logic_analyser/logic_analyser.c\ Lines\ 40-63}$

```
40 void logic_analyser_init(PIO pio, uint sm, uint pin_base, uint pin_count, float div) {
   // Load a program to capture n pins. This is just a single `in pins, n`
42
      // instruction with a wrap.
43
   uint16_t capture_prog_instr = pio_encode_in(pio_pins, pin_count);
44
      struct pio_program capture_prog = {
45
              .instructions = &capture_prog_instr,
              .length = 1,
46
47
              .origin = -1
48
      };
49
      uint offset = pio_add_program(pio, &capture_prog);
      // Configure state machine to loop over this `in` instruction forever,
       // with autopush enabled.
      pio_sm_config c = pio_get_default_sm_config();
53
54
       sm_config_set_in_pins(&c, pin_base);
55
       sm_config_set_wrap(&c, offset, offset);
56
       sm_config_set_clkdiv(&c, div);
       // Note that we may push at a < 32 bit threshold if pin_count does not
57
58
      // divide 32. We are using shift-to-right, so the sample data ends up
59
      // left-justified in the FIFO in this case, with some zeroes at the LSBs.
      sm_config_set_in_shift(&c, true, true, bits_packed_per_word(pin_count));
60
61
       sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_RX);
62
       pio_sm_init(pio, sm, offset, &c);
63 }
```

Our program consists only of a single in pins, <pin_count> instruction, with program wrapping and autopull enabled. Because the amount of data to be shifted is only known at runtime, and because the program is so short, we are generating the program dynamically here (using the pio_encode_ functions) instead of pushing it through pioasm. The program is wrapped in a data structure stating how big the program is, and where it must be loaded — in this case origin = -1 meaning "don't care".

Input Shift Register

The *input shift register* (ISR) is the mirror image of the OSR. Generally data flows through a state machine in one of two directions: System \rightarrow TX FIFO \rightarrow OSR \rightarrow Pins, or Pins \rightarrow ISR \rightarrow RX FIFO \rightarrow System. An in instruction shifts data into the ISR.

If you don't need the ISR's shifting ability — for example, if your program is output-only — you can use the ISR as a third scratch register. It's 32 bits in size, the same as X, Y and the OSR. The full details are in the RP2040 Datasheet.

We load the program into the chosen PIO, and then configure the input pin mapping on the chosen state machine so that its in pins instruction will see the pins we care about. For an in instruction we only need to worry about configuring the base pin, i.e. the pin which is the least significant bit of the in instruction's sample. The number of pins to be sampled is determined by the bit count parameter of the in pins instruction—it will sample *n* pins starting at the base we specified, and shift them into the ISR.

Pin Groups (Mapping)

We mentioned earlier that there are four pin groups to configure, to connect a state machine's internal data buses to the GPIOs it manipulates. A state machine accesses all pins within a group at once, and pin groups can overlap. So far we have seen the *out*, *side-set* and *in* pin groups. The fourth is *set*.

The out group is the pins affected by shifting out data from the OSR, using out pins or out pindirs, up to 32 bits at a time. The set group is used with set pins and set pindirs instructions, up to 5 bits at a time, with data that is encoded directly in the instruction. It's useful for toggling control signals. The side-set group is similar to the set group, but runs simultaneously with another instruction. Note: mov pin uses the in or out group, depending on direction.

Configuring the clock divider optionally slows down the state machine's execution: a clock divisor of n means 1 instruction will be executed per n system clock cycles. The default system clock frequency for SDK is 125 MHz.

sm_config_set_in_shift sets the shift direction to rightward, enables autopush, and sets the autopush threshold to 32. The state machine keeps an eye on the total amount of data shifted into the ISR, and on the in which reaches or breaches a total shift count of 32 (or whatever number you have configured), the ISR contents, along with the new data from the in goes straight to the RX FIFO. The ISR is cleared to zero in the same operation.

sm_config_set_fifo_join is used to manipulate the FIFOs so that the DMA can get more throughput. If we want to sample every pin on every clock cycle, that's a lot of bandwidth! We've finished describing how the state machine should be configured, so we use pio_sm_init to load the configuration into the state machine, and get the state machine into a clean initial state.

FIFO Joining

Each state machine is equipped with a FIFO going in each direction: the TX FIFO buffers data on its way out of the system, and the RX FIFO does the same for data coming in. Each FIFO has four data slots, each holding 32 bits of data. Generally you want FIFOs to be as deep as possible, so there is more slack time between the timing-critical operation of a peripheral, and data transfers from system agents which may be quite busy or have high access latency. However this comes with significant hardware cost.

If you are only using one of the two FIFOs — TX or RX — a state machine can pool its resources to provide a single FIFO with double the depth. The RP2040 Datasheet goes into much more detail, including how this mechanism actually works under the hood.

Our state machine is ready to sample some pins. Let's take a look at how we hook up the DMA to our state machine, and tell the state machine to start sampling once it sees some trigger condition.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/logic_analyser/logic_analyser.c Lines 65 - 87

```
65 void logic_analyser_arm(PIO pio, uint sm, uint dma_chan, uint32_t *capture_buf, size_t
  capture_size_words,
66
                           uint trigger_pin, bool trigger_level) {
67
      pio sm set enabled(pio. sm. false):
68
      // Need to clear _input shift counter_, as well as FIFO, because there may be
69
      // partial ISR contents left over from a previous run. sm_restart does this.
70
      pio_sm_clear_fifos(pio, sm);
71
      pio_sm_restart(pio, sm);
72
73
       dma_channel_config c = dma_channel_get_default_config(dma_chan);
74
       channel_config_set_read_increment(&c, false);
75
       channel_config_set_write_increment(&c, true);
76
       channel_config_set_dreq(&c, pio_get_dreq(pio, sm, false));
77
78
       dma channel configure(dma chan. &c.
                           // Destination pointer
79
          capture buf.
80
           &pio->rxf[sm],
                              // Source pointer
81
           capture_size_words, // Number of transfers
82
                               // Start immediately
83
       ):
84
85
       pio_sm_exec(pio, sm, pio_encode_wait_gpio(trigger_level, trigger_pin));
86
       pio_sm_set_enabled(pio, sm, true);
87 }
```

We want the DMA to read from the RX FIFO on our PIO state machine, so every DMA read is from the same address. The *write* address, on the other hand, should increment after every DMA transfer so that the DMA gradually fills up our capture buffer as data comes in. We need to specify a *data request* signal (DREQ) so that the DMA transfers data at the proper rate.

Data request signals

The DMA can transfer data incredibly fast, and almost invariably this will be much faster than your PIO program actually needs. The DMA paces itself based on a data request handshake with the state machine, so there's no worry about it overflowing or underflowing a FIFO, as long as you have selected the correct DREQ signal. The state machine coordinates with the DMA to tell it when it has room available in its TX FIFO, or data available in its RX FIFO.

We need to provide the DMA channel with an initial read address, an initial write address, and the total number of reads/writes to be performed (not the total number of bytes). We start the DMA channel immediately – from this point

on, the DMA is poised, waiting for the state machine to produce data. As soon as data appears in the RX FIFO, the DMA will pounce and whisk the data away to our capture buffer in system memory.

As things stand right now, the state machine will immediately go into a 1-cycle loop of in instructions once enabled. Since the system memory available for capture is quite limited, it would be better for the state machine to wait for some trigger before it starts sampling. Specifically, we are using a wait pin instruction to stall the state machine until a certain pin goes high or low, and again we are using one of the pio_encode_ functions to encode this instruction on-the-fly.

pio_sm_exec tells the state machine to immediately execute some instruction you give it. This instruction never gets written to the instruction memory, and if the instruction stalls (as it will in this case — a wait instruction's job is to stall) then the state machine will latch the instruction until it completes. With the state machine stalled on the wait instruction, we can enable it without being immediately flooded by data.

At this point everything is armed and waiting for the trigger signal from the chosen GPIO. This will lead to the following sequence of events:

- 1. The wait instruction will clear
- 2. On the very next cycle, state machine will start to execute in instructions from the program memory
- 3. As soon as data appears in the RX FIFO, the DMA will start to transfer it.
- 4. Once the requested amount of data has been transferred by the DMA, it'll automatically stop

State Machine EXEC Functionality

So far our state machines have executed instructions from the instruction memory, but there are other options. One is the SMx_INSTR register (used by pio_sm_exec()): the state machine will immediately execute whatever you write here, momentarily interrupting the current program it's running if necessary. This is useful for poking around inside the state machine from the system side, for initial setup.

The other two options, which use the same underlying hardware, are out exec (shift out an instruction from the data being streamed through the OSR, and execute it) and mov exec (execute an instruction stashed in e.g. a scratch register). Besides making people's eyes bulge, these are really useful if you want the state machine to perform some data-defined operation at a certain point in an output stream.

The example code provides this cute function for displaying the captured logic trace as ASCII art in a terminal:

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/logic_analyser/logic_analyser.c Lines 89 - 108

```
89 void print_capture_buf(const uint32_t *buf, uint pin_base, uint pin_count, uint32_t
   n_samples) {
 90
     // Display the capture buffer in text form, like this:
       // 00: __--__-
 92
       // 01: ____-
       printf("Capture:\n");
 93
       // Each FIFO record may be only partially filled with bits, depending on
 94
95
       // whether pin_count is a factor of 32.
96
       uint record_size_bits = bits_packed_per_word(pin_count);
       for (int pin = 0; pin < pin_count; ++pin) {</pre>
97
           printf("%02d: ", pin + pin_base);
98
99
           for (int sample = 0; sample < n_samples; ++sample) {</pre>
               uint bit_index = pin + sample * pin_count;
100
101
               uint word_index = bit_index / record_size_bits;
102
               // Data is left-justified in each FIFO entry, hence the (32 - record_size_bits)
   offset
103
               uint word_mask = 1u << (bit_index % record_size_bits + 32 - record_size_bits);</pre>
104
               printf(buf[word_index] & word_mask ? "-" : "_");
105
           }
106
           printf("\n");
107
       }
108 }
```

We have everything we need now for RP2040 to capture a logic trace of its own pins, whilst running some other program. Here we're setting up a PWM slice to output at around 15 MHz on two GPIOs, and attaching our brand spanking new logic analyser to those same two GPIOs.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/logic_analyser/logic_analyser.c Lines 110 - 159

```
110 int main() {
111
       stdio_init_all();
112
        printf("PIO logic analyser example\n");
113
114
       // We're going to capture into a u32 buffer, for best DMA efficiency. Need
115
       // to be careful of rounding in case the number of pins being sampled
116
        // isn't a power of 2.
       uint total_sample_bits = CAPTURE_N_SAMPLES * CAPTURE_PIN_COUNT;
117
        total_sample_bits += bits_packed_per_word(CAPTURE_PIN_COUNT) - 1;
118
        uint buf_size_words = total_sample_bits / bits_packed_per_word(CAPTURE_PIN_COUNT);
119
120
        uint32_t *capture_buf = malloc(buf_size_words * sizeof(uint32_t));
121
        hard_assert(capture_buf);
122
123
       // Grant high bus priority to the DMA, so it can shove the processors out
124
        // of the way. This should only be needed if you are pushing things up to
125
        // >16bits/clk here, i.e. if you need to saturate the bus completely.
        bus_ctrl_hw->priority = BUSCTRL_BUS_PRIORITY_DMA_W_BITS |
126
   BUSCTRL_BUS_PRIORITY_DMA_R_BITS;
127
        PIO pio = pio0;
128
        uint sm = 0;
129
        uint dma_chan = 0;
130
131
132
        logic_analyser_init(pio, sm, CAPTURE_PIN_BASE, CAPTURE_PIN_COUNT, 1.f);
133
134
        printf("Arming trigger\n");
        logic_analyser_arm(pio, sm, dma_chan, capture_buf, buf_size_words, CAPTURE_PIN_BASE,
135
    true);
136
137
        printf("Starting PWM example\n");
138
        // PWM example: -
        gpio_set_function(CAPTURE_PIN_BASE, GPIO_FUNC_PWM);
139
140
        gpio_set_function(CAPTURE_PIN_BASE + 1, GPIO_FUNC_PWM);
141
        // Topmost value of 3: count from 0 to 3 and then wrap, so period is 4 cycles
142
        pwm_hw->slice[0].top = 3;
        // Divide frequency by two to slow things down a little
143
144
        pwm_hw->slice[0].div = 4 << PWM_CH0_DIV_INT_LSB;</pre>
145
        // Set channel A to be high for 1 cycle each period (duty cycle 1/4) and
146
        // channel B for 3 cycles (duty cycle 3/4)
147
        pwm_hw->slice[0].cc =
                (1 << PWM_CH0_CC_A_LSB) |
148
149
                (3 << PWM_CH0_CC_B_LSB);</pre>
        // Enable this PWM slice
150
151
        pwm_hw->slice[0].csr = PWM_CH0_CSR_EN_BITS;
152
153
        // The logic analyser should have started capturing as soon as it saw the
154
        // first transition. Wait until the last sample comes in from the DMA.
155
        dma_channel_wait_for_finish_blocking(dma_chan);
156
157
        print_capture_buf(capture_buf, CAPTURE_PIN_BASE, CAPTURE_PIN_COUNT, CAPTURE_N_SAMPLES);
158
159 }
```

The output of the program looks like this:

3.2.4. Further examples

Hopefully what you have seen so far has given some idea of how PIO applications can be built with the SDK. The RP2040 Datasheet contains *many* more documented examples, which highlight particular hardware features of PIO, or show how particular hardware interfaces can be implemented.

You can also browse the pio/ directory in the pico-examples repository.

3.3. Using PIOASM, the PIO Assembler

Up until now, we have glossed over the details of how the assembly program in our .pio file is translated into a binary program, ready to be loaded into our PIO state machine. Programs that handle this task — translating assembly code into binary — are generally referred to as assemblers, and PIO is no exception in this regard. The SDK includes an assembler for PIO, called pioasm. The SDK handles the details of building this tool for you behind the scenes, and then using it to build your PIO programs, for you to #include from your C or C++ program. pioasm can also be used directly, and has a few features not used by the C++ SDK, such as generating programs suitable for use with the MicroPython PIO library.

If you have built the pico-examples repository at any point, you will likely already have a pioasm binary in your build directory, located under build/tools/pioasm/pioasm, which was bootstrapped for you before building any applications that depend on it. If we want a standalone copy of pioasm, perhaps just to explore the available commandline options, we can obtain it as follows (assuming the SDK is extracted at \$PICO_SDK_PATH):

```
mkdir pioasm_build
cd pioasm_build
cmake $PICO_SDK_PATH/tools/pioasm
make
```

And then invoke as:

```
./pioasm
```

3.3.1. Usage

A description of the command line arguments can be obtained by running:

```
pioasm -?
```

giving:

```
usage: pioasm <options> <input> (<output>)
Assemble file of PIO program(s) for use in applications.
<input>
                   the input filename
<output>
                   the output filename (or filename prefix if the output
                        format produces multiple outputs).
                    if not specified, a single output will be written to stdout
options:
-o <output_format>
                    select output_format (default 'c-sdk'); available options are:
                            C header suitable for use with the Raspberry Pi Pico SDK
                        python
                            Python file suitable for use with MicroPython
                        hex
                            Raw hex output (only valid for single program inputs)
                     add a parameter to be passed to the outputter
-p <output_param>
-?, --help
                     print this help and exit
```

NOTE

Within the SDK you do not need to invoke pioasm directly, as the CMake function pico_generate_pio_header(TARGET PIO_FILE) takes care of invoking pioasm and adding the generated header to the include path of the target TARGET for you.

3.3.2. Directives

.program <name>

.origin <offset>

The following directives control the assembly of PIO programs:

Table 5. pioasm directives

.define (PUBLIC) <symbol> <value>

Define an integer symbol named <symbol> with the value <value> (see Section 3.3.3). If this .define appears before the first program in the input file, then the define is global to all programs, otherwise it is local to the program in which it occurs. If PUBLIC is specified the symbol will be emitted into the assembled output for use by user code. For the SDK this takes the form of:

#define csymbol> value for program symbols or #define <symbol> value for global symbols

Start a new program with the name < name >. Note that that name is used in code so should be alphanumeric/underscore not starting with a digit. The program lasts until another .program directive or the end of the source file. PIO

instructions are only allowed within a program

Optional directive to specify the PIO instruction memory offset at which the program must load. Most commonly this is used for programs that must load

> at offset 0, because they use data based JMPs with the (absolute) jmp target being stored in only a few bits. This directive is invalid outside of a program

If this directive is present, <count> indicates the number of side set bits to be

used. Additionally opt may be specified to indicate that a side <value> is optional for instructions (note this requires stealing an extra bit – in addition to the <count> bits - from those available for the instruction delay). Finally, pindirs may be specified to indicate that the side set values should be applied to the PINDIRs and not the PINs. This directive is only valid within a program

before the first instruction

.side_set <count> (opt) (pindirs)

.wrap_target Place prior to an instruction, this directive specifies the instruction where execution continues due to program wrapping. This directive is invalid outside of a program, may only be used once within a program, and if not specified defaults to the start of the program .wrap Placed after an instruction, this directive specifies the instruction after which, in normal control flow (i.e. jmp with false condition, or no jmp), the program wraps (to .wrap_target instruction). This directive is invalid outside of a program, may only be used once within a program, and if not specified defaults to after the last program instruction. .lang_opt <lang> <name> <option> Specifies an option for the program related to a particular language generator. (See Section 3.3.10). This directive is invalid outside of a program .word <value> Stores a raw 16-bit value as an instruction in the program. This directive is invalid outside of a program.

3.3.3. Values

The following types of values can be used to define integer numbers or branch targets

Table 6. Values in pioasm. i.e. <value>

integer	An integer value e.g. 3 or -7
hex	A hexadecimal value e.g. 0xf
binary	A binary value e.g. 0b1001
symbol	A value defined by a .define (see [pioasm_define])
<label></label>	The instruction offset of the label within the program. This makes most sense when used with a JMP instruction (see Section 3.4.2)
(<expression>)</expression>	An expression to be evaluated; see expressions. Note that the parentheses are necessary.

3.3.4. Expressions

Expressions may be freely used within pioasm values.

Table 7. Expressions in pioasm i.e. <expression>

<expression> + <expression></expression></expression>	The sum of two expressions
<expression> - <expression></expression></expression>	The difference of two expressions
<expression> * <expression></expression></expression>	The multiplication of two expressions
<expression> / <expression></expression></expression>	The integer division of two expressions
- <expression></expression>	The negation of another expression
:: <expression></expression>	The bit reverse of another expression
<value></value>	Any value (see Section 3.3.3)

3.3.5. Comments

Line comments are supported with // or ;

C-style block comments are supported via /* and */

3.3.6. Labels

Labels are of the form:

<svmbol>:

or

PUBLIC <symbol>:

at the start of a line.



TIP

A label is really just an automatic .define with a value set to the current program instruction offset. A PUBLIC label is exposed to the user code in the same way as a PUBLIC .define.

3.3.7. Instructions

All pioasm instructions follow a common pattern:

<instruction> (side <side_set_value>) ([<delay_value>])

where:

<instruction>

Is an assembly instruction detailed in the following sections. (See Section 3.4)

<side_set_value>

Is a value (see Section 3.3.3) to apply to the side_set pins at the start of the instruction. Note that the rules for a side set value via side <side_set_value> are dependent on the .side_set (see [pioasm_side_set]) directive for the program. If no .side_set is specified then the side <side_set_value> is invalid, if an optional number of sideset pins is specified then side <side_set_value> may be present, and if a non-optional number of sideset pins is specified, then side <side_set_value> is required. The <side_set_value> must fit within the number of side set bits specified in the .side_set directive.

<delay_value>

Specifies the number of cycles to delay after the instruction completes. The delay_value is specified as a value (see Section 3.3.3), and in general is between 0 and 31 inclusive (a 5-bit value), however the number of bits is reduced when sideset is enabled via the .side_set (see [pioasm_side_set]) directive. If the <delay_value> is not present, then the instruction has no delay



NOTE

pioasm instruction names, keywords and directives are case insensitive; lower case is used in the Assembly Syntax sections below as this is the style used in the SDK.



NOTE

Commas appear in some Assembly Syntax sections below, but are entirely optional, e.g. out pins, 3 may be written out pins 3, and jmp x-- label may be written as jmp x--, label. The Assembly Syntax sections below uses the first style in each case as this is the style used in the SDK.

3.3.8. Pseudoinstructions

Currently pioasm provides one pseudoinstruction, as a convenience:

nop Assembles to mov y, y. "No operation", has no particular side effect, but a useful vehicle for a side-set operation or an extra delay.

3.3.9. Output pass through

Text in the PIO file may be passed, unmodifed, to the output based on the language generator being used.

For example the following (comment and function) would be included in the generated header when the default c-sdk language generator is used.

```
% c-sdk {

// an inline function (since this is going in a header file)

static inline int some_c_code() {

   return 0;
}

%}
```

The general format is

```
% target {
pass through contents
%}
```

with targets being recognized by a particular language generator (see Section 3.3.10; note that target is usually the language generator name e.g. c-sdk, but could potentially be some_language.some_group if the language generator supports different classes of pass through with different output locations.

This facility allows you to encapsulate both the PIO program and the associated setup required in the same source file. See Section 3.3.10 for a more complete example.

3.3.10. Language generators

The following example shows a multi program source file (with multiple programs) which we will use to highlight c-sdk and python output features

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/ws2812.pio Lines 1 - 85

```
1;
2 ; Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
3;
4 ; SPDX-License-Identifier: BSD-3-Clause
5;
6
7 .program ws2812
8 .side_set 1
10 .define public T1 2
11 .define public T2 5
12 .define public T3 3
13
14 .lang_opt python sideset_init = pico.PIO.OUT_HIGH
15 .lang_opt python out_init = pico.PIO.OUT_HIGH
16 .lang_opt python out_shiftdir = 1
17
```

```
18 .wrap_target
19 bitloop:
20 out x, 1
                    side 0 [T3 - 1] ; Side-set still takes place when instruction stalls
      jmp !x do_zero side 1 [T1 - 1] ; Branch on the bit we shifted out. Positive pulse
21
22 do one:
23 jmp bitloop side 1 [T2 - 1]; Continue driving high, for a long pulse
24 do_zero:
25 nop
                    side 0 [T2 - 1] ; Or drive low, for a short pulse
26 .wrap
27
28 % c-sdk {
29 #include "hardware/clocks.h"
31 static inline void ws2812_program_init(PIO pio, uint sm, uint offset, uint pin, float freq,
  bool rgbw) {
32
33
    pio_gpio_init(pio, pin);
34
    pio_sm_set_consecutive_pindirs(pio, sm, pin, 1, true);
35
   pio_sm_config c = ws2812_program_get_default_config(offset);
37
   sm_config_set_sideset_pins(&c, pin);
38
    sm_config_set_out_shift(&c, false, true, rgbw ? 32 : 24);
     sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_TX);
39
40
      int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3;
41
      float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit);
42
43
      sm_config_set_clkdiv(&c, div);
44
45
      pio_sm_init(pio, sm, offset, &c);
46
      pio_sm_set_enabled(pio, sm, true);
47 }
48 %}
49
50 .program ws2812_parallel
51
52 .define public T1 2
53 .define public T2 5
54 .define public T3 3
55
56 .wrap_target
57 out x, 32
58 mov pins, !null [T1-1]
59 mov pins, x [T2-1]
60 mov pins, null [T3-2]
61 .wrap
62
63 % c-sdk {
64 #include "hardware/clocks.h"
65
66 static inline void ws2812_parallel_program_init(PIO pio, uint sm, uint offset, uint
  pin_base, uint pin_count, float freq) {
67
       for(uint i=pin_base; i<pin_base+pin_count; i++) {</pre>
68
          pio_gpio_init(pio, i);
69
70
      pio_sm_set_consecutive_pindirs(pio, sm, pin_base, pin_count, true);
71
72
      pio_sm_config c = ws2812_parallel_program_get_default_config(offset);
73
      sm_config_set_out_shift(&c, true, true, 32);
74
      sm_config_set_out_pins(&c, pin_base, pin_count);
75
      sm_config_set_set_pins(&c, pin_base, pin_count);
76
      sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_TX);
77
78
      int cycles_per_bit = ws2812_parallel_T1 + ws2812_parallel_T2 + ws2812_parallel_T3;
```

3.3.10.1. c-sdk

The c-sdk language generator produces a single header file with all the programs in the PIO source file:

The pass through sections (% c-sdk {) are embedded in the output, and the PUBLIC defines are available via #define



pioasm creates a function for each program (e.g. ws2812_program_get_default_config()) returning a pio_sm_config based on the .side_set, .wrap and .wrap_target settings of the program, which you can then use as a basis for configuration the PIO state machine.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/generated/ws2812.pio.h Lines 1 - 112

```
1 // ----- //
2 // This file is autogenerated by pioasm; do not edit! //
5 #if !PICO_NO_HARDWARE
6 #include "hardware/pio.h"
7 #endif
8
9 // ----- //
10 // ws2812 //
11 // ----- //
12
13 #define ws2812_wrap_target 0
14 #define ws2812_wrap 3
15
16 #define ws2812 T1 2
17 #define ws2812_T2 5
18 #define ws2812_T3 3
20 static const uint16_t ws2812_program_instructions[] = {
21
     // .wrap_target
22 0x6221, // θ: out x, 1
                                     side 0 [2]
23 0x1123, // 1: jmp !x, 3
                                    side 1 [1]
24 0x1400, // 2: jmp 0
                                     side 1 [4]
25 0xa442, // 3: nop
                                     side 0 [4]
       // .wrap
26
27 };
28
29 #if !PICO_NO_HARDWARE
30 static const struct pio_program ws2812_program = {
     .instructions = ws2812_program_instructions,
31
32
      .length = 4,
33
     .origin = -1,
34 };
35
36 static inline pio_sm_config ws2812_program_get_default_config(uint offset) {
      pio_sm_config c = pio_get_default_sm_config();
```

```
sm_config_set_wrap(&c, offset + ws2812_wrap_target, offset + ws2812_wrap);
39
      sm_config_set_sideset(&c, 1, false, false);
40
      return c:
41 }
42
43 #include "hardware/clocks.h"
44 static inline void ws2812_program_init(PIO pio, uint sm, uint offset, uint pin, float freq,
  bool rgbw) {
45
      pio_gpio_init(pio, pin);
46
      pio_sm_set_consecutive_pindirs(pio, sm, pin, 1, true);
47
      pio_sm_config c = ws2812_program_get_default_config(offset);
48
      sm_config_set_sideset_pins(&c, pin);
49
      sm_config_set_out_shift(&c, false, true, rgbw ? 32 : 24);
      sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_TX);
50
51
      int cycles_per_bit = ws2812_T1 + ws2812_T2 + ws2812_T3;
52
      float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit);
53
      sm_config_set_clkdiv(&c, div);
      pio_sm_init(pio, sm, offset, &c);
55
      pio_sm_set_enabled(pio, sm, true);
56 }
57
58 #endif
59
60 // ----- //
61 // ws2812_parallel //
62 // ----- //
64 #define ws2812_parallel_wrap_target 0
65 #define ws2812_parallel_wrap 3
67 #define ws2812_parallel_T1 2
68 #define ws2812_parallel_T2 5
69 #define ws2812_parallel_T3 3
71 static const uint16_t ws2812_parallel_program_instructions[] = {
          // .wrap_target
72
      0x6020, // 0: out x, 32
73
     0xa10b, // 1: mov pins, !null
74
                                                [1]
      0xa401, // 2: mov pins, x
75
                                                [4]
      0xa103, // 3: mov pins, null
76
                                                [1]
77
            // .wrap
78 };
79
80 #if !PICO_NO_HARDWARE
81 static const struct pio_program ws2812_parallel_program = {
.instructions = ws2812_parallel_program_instructions,
83
      .length = 4,
      .origin = -1,
84
85 };
86
87 static inline pio_sm_config ws2812_parallel_program_get_default_config(uint offset) {
      pio_sm_config c = pio_get_default_sm_config();
89
      sm_config_set_wrap(&c, offset + ws2812_parallel_wrap_target, offset +
  ws2812_parallel_wrap);
90
      return c;
91 }
92
93 #include "hardware/clocks.h"
94 static inline void ws2812_parallel_program_init(PIO pio, uint sm, uint offset, uint
  pin_base, uint pin_count, float freq) {
    for(uint i=pin_base; i<pin_base+pin_count; i++) {</pre>
96
          pio_gpio_init(pio, i);
97
```

```
pio_sm_set_consecutive_pindirs(pio, sm, pin_base, pin_count, true);
99
       pio_sm_config c = ws2812_parallel_program_get_default_config(offset);
100
       sm_config_set_out_shift(&c, true, true, 32);
       sm_config_set_out_pins(&c, pin_base, pin_count);
101
102
       sm_config_set_set_pins(&c, pin_base, pin_count);
103
       sm_config_set_fifo_join(&c, PIO_FIFO_JOIN_TX);
104
       int cycles_per_bit = ws2812_parallel_T1 + ws2812_parallel_T2 + ws2812_parallel_T3;
105
       float div = clock_get_hz(clk_sys) / (freq * cycles_per_bit);
106
       sm_config_set_clkdiv(&c, div);
107
       pio_sm_init(pio, sm, offset, &c);
108
       pio_sm_set_enabled(pio, sm, true);
109 }
110
111 #endif
```

3.3.10.2. python

The python language generator produces a single python file with all the programs in the PIO source file:

The pass through sections (% python {) would be embedded in the output, and the PUBLIC defines are available as python variables.

Also note the use of .lang_opt python to pass initializers for the <code>@pico.asm_pio</code> decorator



The python language output is provided as a utility. MicroPython supports programming with the PIO natively, so you may only want to use pioasm when sharing PIO code between the SDK and MicroPython. No effort is currently made to preserve label names, symbols or comments, as it is assumed you are either using the PIO file as a source or python; not both. The python language output can of course be used to bootstrap your MicroPython PIO development based on an existing PIO file.

 ${\it Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/ws2812/generated/ws2812.py\ Lines\ 1-46}$

```
2 # This file is autogenerated by pioasm; do not edit! #
5 import rp2
6 from machine import Pin
7 # ----- #
8 # ws2812 #
11 \text{ ws} 2812\_T1 = 2
12 \text{ ws} 2812\_T2 = 5
13 \text{ ws} 2812\_T3 = 3
14
15 @rp2.asm_pio(sideset_init=pico.PI0.0UT_HIGH, out_init=pico.PI0.0UT_HIGH, out_shiftdir=1)
16 def ws2812():
17 wrap_target()
    label("0")
18
                              .side(\theta) [2] # \theta
    out(x, 1)
19
                              .side(1) [1] # 1
    jmp(not_x, "3")
20
    jmp("0")
                               .side(1) [4] # 2
21
22
      label("3")
23
      nop()
                               .side(0) [4] # 3
24
       wrap()
25
```

3.3.10.3. hex

The hex generator only supports a single input program, as it just dumps the raw instructions (one per line) as a 4-bit hexadecimal number.

Given:

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/squarewave/squarewave.pio Lines 1 - 13

```
1;
2; Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
3;
4; SPDX-License-Identifier: BSD-3-Clause
5;
6
7.program squarewave
8 set pindirs, 1; Set pin to output
9 again:
10 set pins, 1 [1]; Drive pin high and then delay for one cycle
11 set pins, 0; Drive pin low
12 jmp again; Set PC to label `again`
```

The hex output produces:

 ${\it Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/pio/squarewave/generated/squarewave.hex\ Lines\ 1-4-2000. The pico-examples is a constraint of the pico-examples is a constraint of the pico-example is a constraint of$

```
1 e081
2 e101
3 e000
4 0001
```

3.4. PIO Instruction Set Reference

NOTE

This section refers in places to concepts and pieces of hardware discussed in the RP2040 Datasheet. You are encouraged to read the PIO chapter of the datasheet to get the full context for what these instructions do.

3.4.1. Summary

PIO instructions are 16 bits long, and have the following encoding:

Table 8. PIO instruction encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JMP	0	0	0		Del	ay/side	-set		С	Conditio	n			Addres	S	
WAIT	0	0	1		Del	ay/side	-set		Pol	Sou	ırce			Index		
IN	0	1	0		Del	ay/side	-set			Source	;		E	Bit cour	nt	
OUT	0	1	1		Del	ay/side	-set		De	estinati	on		E	Bit cour	nt	
PUSH	1	0	0		Del	ay/side	-set		0	IfF	Blk	0	0	0	0	0
PULL	1	0	0		Del	ay/side	-set		1	IfE	Blk	0	0	0	0	0
MOV	1	0	1		Del	ay/side	-set		De	estinati	on	С)p		Source	
IRQ	1	1	0		Del	ay/side	-set		0	Clr	Wait			Index		
SET	1	1	1		Del	ay/side	-set		De	estinati	on			Data		

All PIO instructions execute in one clock cycle.

The Delay/side-set field is present in all instructions. Its exact use is configured for each state machine by PINCTRL_SIDESET_COUNT:

- Up to 5 MSBs encode a side-set operation, which optionally asserts a constant value onto some GPIOs, concurrently with main instruction execution logic
- Remaining LSBs (up to 5) encode the number of idle cycles inserted between this instruction and the next

3.4.2. JMP

3.4.2.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JMP	0	0	0		Del	ay/side	-set		С	conditio	n		,	Addres	S	

3.4.2.2. Operation

Set program counter to Address if Condition is true, otherwise no operation.

Delay cycles on a JMP always take effect, whether Condition is true or false, and they take place after Condition is evaluated and the program counter is updated.

- Condition:
 - o 000: (no condition): Always
 - o 001: !X: scratch X zero

o 010: X--: scratch X non-zero, post-decrement

o 011: !Y: scratch Y zero

o 100: Y--: scratch Y non-zero, post-decrement

o 101: X!=Y: scratch X not equal scratch Y

o 110: PIN: branch on input pin

o 111: !OSRE: output shift register not empty

 Address: Instruction address to jump to. In the instruction encoding this is an absolute address within the PIO instruction memory.

JMP PIN branches on the GPIO selected by EXECCTRL_JMP_PIN, a configuration field which selects one out of the maximum of 32 GPIO inputs visible to a state machine, independently of the state machine's other input mapping. The branch is taken if the GPIO is high.

!OSRE compares the bits shifted out since the last PULL with the shift count threshold configured by SHIFTCTRL_PULL_THRESH. This is the same threshold used by autopull.

JMP X-- and JMP Y-- always decrement scratch register X or Y, respectively. The decrement is not conditional on the current value of the scratch register. The branch is conditioned on the *initial* value of the register, i.e. before the decrement took place: if the register is initially nonzero, the branch is taken.

3.4.2.3. Assembler Syntax

jmp (<cond>) <target>

where:

<cond>

Is an optional condition listed above (e.g. !x for scratch X zero). If a condition code is not specified, the branch is always taken

<target>

Is a program label or value (see Section 3.3.3) representing instruction offset within the program (the first instruction being offset 0). Note that because the PIO JMP instruction uses absolute addresses in the PIO instruction memory, JMPs need to be adjusted based on the program load offset at runtime. This is handled for you when loading a program with the SDK, but care should be taken when encoding JMP instructions for use by OUT EXEC

3.4.3. WAIT

3.4.3.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WAIT	0	0	1		Del	ay/side	e-set		Pol	Sou	ırce			Index		

3.4.3.2. Operation

Stall until some condition is met.

Like all stalling instructions, delay cycles begin after the instruction *completes*. That is, if any delay cycles are present, they do not begin counting until *after* the wait condition is met.

Polarity:

- o 1: wait for a 1.
- o 0: wait for a 0.
- · Source: what to wait on. Values are:
 - 00: 6PIO: System GPIO input selected by Index. This is an absolute GPIO index, and is not affected by the state machine's input IO mapping.
 - 01: PIN: Input pin selected by Index. This state machine's input IO mapping is applied first, and then Index selects which of the mapped bits to wait on. In other words, the pin is selected by adding Index to the PINCTRL_IN_BASE configuration, modulo 32.
 - o 10: IRQ: PIO IRQ flag selected by Index
 - o 11: Reserved
- · Index: which pin or bit to check.

WAIT x IRQ behaves slightly differently from other WAIT sources:

- If Polarity is 1, the selected IRQ flag is cleared by the state machine upon the wait condition being met.
- The flag index is decoded in the same way as the IRQ index field: if the MSB is set, the state machine ID (0...3) is added to the IRQ index, by way of modulo-4 addition on the two LSBs. For example, state machine 2 with a flag value of '0x11' will wait on flag 3, and a flag value of '0x13' will wait on flag 1. This allows multiple state machines running the same program to synchronise with each other.

A CAUTION

WAIT 1 IRQ x should not be used with IRQ flags presented to the interrupt controller, to avoid a race condition with a system interrupt handler

3.4.3.3. Assembler Syntax

actual irq number used is calculating by replacing the low two bits of the irq number (irq_num_{10}) with the low two bits of the sum ($irq_num_{10} + sm_num_{10}$) where sm_num_{10} is the state machine

3.4.4. IN

3.4.4.1. Encoding

number

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IN	0	1	0		Del	ay/side	-set			Source	!		E	Bit cour	nt	

3.4.4.2. Operation

Shift Bit count bits from Source into the Input Shift Register (ISR). Shift direction is configured for each state machine by SHIFTCTRL_IN_SHIFTDIR. Additionally, increase the input shift count by Bit count, saturating at 32.

- · Source:
 - o 000: PINS
 - o 001: X (scratch register X)
 - o 010: Y (scratch register Y)
 - o 011: NULL (all zeroes)
 - o 100: Reserved
 - o 101: Reserved
 - o 110: ISR
 - o 111: OSR
- Bit count: How many bits to shift into the ISR. 1...32 bits, 32 is encoded as 00000.

If automatic push is enabled, IN will also push the ISR contents to the RX FIFO if the push threshold is reached (SHIFTCTRL_PUSH_THRESH). IN still executes in one cycle, whether an automatic push takes place or not. The state machine will stall if the RX FIFO is full when an automatic push occurs. An automatic push clears the ISR contents to all-zeroes, and clears the input shift count.

IN always uses the least significant Bit count bits of the source data. For example, if PINCTRL_IN_BASE is set to 5, the instruction IN PINS, 3 will take the values of pins 5, 6 and 7, and shift these into the ISR. First the ISR is shifted to the left or right to make room for the new input data, then the input data is copied into the gap this leaves. The bit order of the input data is not dependent on the shift direction.

NULL can be used for shifting the ISR's contents. For example, UARTs receive the LSB first, so must shift to the right. After 8 IN PINS, 1 instructions, the input serial data will occupy bits 31...24 of the ISR. An IN NULL, 24 instruction will shift in 24 zero bits, aligning the input data at ISR bits 7...0. Alternatively, the processor or DMA could perform a byte read from FIFO address + 3, which would take bits 31...24 of the FIFO contents.

3.4.4.3. Assembler Syntax

in <source>, <bit_count>

where:

<source> Is one of the sources specified above.

<bit_count>
Is a value (see Section 3.3.3) specifying the number of bits to shift (valid range 1-32)

3.4.5. OUT

3.4.5.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OUT	0	1	1		Del	ay/side	-set		De	estinati	on		E	Bit cour	nt	

3.4.5.2. Operation

Shift Bit count bits out of the Output Shift Register (OSR), and write those bits to Destination. Additionally, increase the output shift count by Bit count, saturating at 32.

- Destination:
 - o 000: PINS
 - o 001: X (scratch register X)
 - o 010: Y (scratch register Y)
 - o 011: NULL (discard data)
 - o 100: PINDIRS
 - o 101: PC
 - o 110: ISR (also sets ISR shift counter to Bit count)
 - o 111: EXEC (Execute OSR shift data as instruction)
- Bit count: how many bits to shift out of the OSR. 1...32 bits, 32 is encoded as 00000.

A 32-bit value is written to Destination: the lower Bit count bits come from the OSR, and the remainder are zeroes. This value is the least significant Bit count bits of the OSR if SHIFTCTRL_OUT_SHIFTDIR is to the right, otherwise it is the most significant bits.

PINS and PINDIRS use the OUT pin mapping.

If automatic pull is enabled, the OSR is automatically refilled from the TX FIFO if the pull threshold, SHIFTCTRL_PULL_THRESH, is reached. The output shift count is simultaneously cleared to 0. In this case, the OUT will stall if the TX FIFO is empty, but otherwise still executes in one cycle.

OUT EXEC allows instructions to be included inline in the FIFO datastream. The OUT itself executes on one cycle, and the instruction from the OSR is executed on the next cycle. There are no restrictions on the types of instructions which can be executed by this mechanism. Delay cycles on the initial OUT are ignored, but the executee may insert delay cycles as normal

OUT PC behaves as an unconditional jump to an address shifted out from the OSR.

3.4.5.3. Assembler Syntax

out <destination>, <bit_count>

where:

<destination> Is one of the destinations specified above.

<bit_count> Is a value (see Section 3.3.3) specifying the number of bits to shift (valid range 1-32)

3.4.6. PUSH

3.4.6.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PUSH	1	0	0		Del	ay/side	-set		0	IfF	Blk	0	0	0	0	0

3.4.6.2. Operation

Push the contents of the ISR into the RX FIFO, as a single 32-bit word. Clear ISR to all-zeroes.

- IfFull: If 1, do nothing unless the total input shift count has reached its threshold, SHIFTCTRL_PUSH_THRESH (the same as for autopush).
- Block: If 1, stall execution if RX FIFO is full.

PUSH IFFULL helps to make programs more compact, like autopush. It is useful in cases where the IN would stall at an inappropriate time if autopush were enabled, e.g. if the state machine is asserting some external control signal at this point.

The PIO assembler sets the Block bit by default. If the Block bit is not set, the PUSH does not stall on a full RX FIFO, instead continuing immediately to the next instruction. The FIFO state and contents are unchanged when this happens. The ISR is still cleared to all-zeroes, and the FDEBUG_RXSTALL flag is set (the same as a blocking PUSH or autopush to a full RX FIFO) to indicate data was lost.

3.4.6.3. Assembler Syntax

push (iffull)

push (iffull) block

push (iffull) noblock

where:

iffull Is equivalent to Iffull == 1 above. i.e. the default if this is not specified is Iffull == 0

block Is equivalent to Block == 1 above. This is the default if neither block nor noblock are specified

noblock Is equivalent to Block == 0 above.

3.4.7. PULL

3.4.7.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PULL	1	0	0		Del	ay/side	-set		1	IfE	Blk	0	0	0	0	0

3.4.7.2. Operation

Load a 32-bit word from the TX FIFO into the OSR.

- IfEmpty: If 1, do nothing unless the total output shift count has reached its threshold, SHIFTCTRL_PULL_THRESH (the same as for autopull).
- Block: If 1, stall if TX FIFO is empty. If 0, pulling from an empty FIFO copies scratch X to OSR.

Some peripherals (UART, SPI...) should halt when no data is available, and pick it up as it comes in; others (I2S) should clock continuously, and it is better to output placeholder or repeated data than to stop clocking. This can be achieved with the Block parameter.

A nonblocking PULL on an empty FIFO has the same effect as MOV OSR, X. The program can either preload scratch register X with a suitable default, or execute a MOV X, OSR after each PULL NOBLOCK, so that the last valid FIFO word will be recycled until new data is available.

PULL IFEMPTY is useful if an OUT with autopull would stall in an inappropriate location when the TX FIFO is empty. For example, a UART transmitter should not stall immediately after asserting the start bit. If Empty permits some of the same program simplifications as autopull, but the stall occurs at a controlled point in the program.



NOTE

When autopull is enabled, any PULL instruction is a no-op when the OSR is full, so that the PULL instruction behaves as a barrier. OUT NULL, 32 can be used to explicitly discard the OSR contents. See the RP2040 Datasheet for more detail on autopull.

3.4.7.3. Assembler Syntax

pull (ifempty) pull (ifempty) block pull (ifempty) noblock where:

Is equivalent to IfEmpty == 1 above. i.e. the default if this is not specified is IfEmpty == 0ifempty

block Is equivalent to Block == 1 above. This is the default if neither block nor noblock are specified

noblock Is equivalent to Block == 0 above.

3.4.8. MOV

3.4.8.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOV	1	0	1		Del	ay/side	-set		De	estinati	on	С)p		Source	

3.4.8.2. Operation

Copy data from Source to Destination.

- Destination:
 - o 000: PINS (Uses same pin mapping as OUT)
 - o 001: X (Scratch register X)
 - o 010: Y (Scratch register Y)
 - o 011: Reserved
 - o 100: EXEC (Execute data as instruction)

- o 101: PC
- 110: ISR (Input shift counter is reset to 0 by this operation, i.e. empty)
- o 111: OSR (Output shift counter is reset to 0 by this operation, i.e. full)
- Operation:
 - o 00: None
 - o 01: Invert (bitwise complement)
 - o 10: Bit-reverse
 - o 11: Reserved
- Source:
 - o 000: PINS (Uses same pin mapping as IN)
 - 。 001: X
 - o 010: Y
 - o 011: NULL
 - o 100: Reserved
 - 101: STATUS
 - o 110: ISR
 - o 111: OSR

MOV PC causes an unconditional jump. MOV EXEC has the same behaviour as OUT EXEC (Section 3.4.5), and allows register contents to be executed as an instruction. The MOV itself executes in 1 cycle, and the instruction in Source on the next cycle. Delay cycles on MOV EXEC are ignored, but the executee may insert delay cycles as normal.

The STATUS source has a value of all-ones or all-zeroes, depending on some state machine status such as FIFO full/empty, configured by EXECCTRL_STATUS_SEL.

MOV can manipulate the transferred data in limited ways, specified by the Operation argument. Invert sets each bit in Destination to the logical NOT of the corresponding bit in Source, i.e. 1 bits become 0 bits, and vice versa. Bit reverse sets each bit *n* in Destination to bit 31 - *n* in Source, assuming the bits are numbered 0 to 31.

3.4.8.3. Assembler Syntax

mov <destination>, (op) <source>

where:

<destination> Is one of the destinations specified above.

<op> If present, is:

! or ~ for NOT (Note: this is always a bitwise NOT)

:: for bit reverse

<source> Is one of the sources specified above.

3.4.9. IRQ

3.4.9.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IRQ	1	1	0		Del	ay/side	-set		0	Clr	Wait			Index		

3.4.9.2. Operation

Set or clear the IRQ flag selected by Index argument.

- Clear: if 1, clear the flag selected by Index, instead of raising it. If Clear is set, the Wait bit has no effect.
- · Wait: if 1, halt until the raised flag is lowered again, e.g. if a system interrupt handler has acknowledged the flag.
- Index:
 - o The 3 LSBs specify an IRQ index from 0-7. This IRQ flag will be set/cleared depending on the Clear bit.
 - If the MSB is set, the state machine ID (0...3) is added to the IRQ index, by way of modulo-4 addition on the two LSBs. For example, state machine 2 with a flag value of 0x11 will raise flag 3, and a flag value of 0x13 will raise flag 1.

IRQ flags 4-7 are visible only to the state machines; IRQ flags 0-3 can be routed out to system level interrupts, on either of the PIO's two external interrupt request lines, configured by IRQ0_INTE and IRQ1_INTE.

The modulo addition bit allows relative addressing of 'IRQ' and 'WAIT' instructions, for synchronising state machines which are running the same program. Bit 2 (the third LSB) is unaffected by this addition.

If Wait is set, Delay cycles do not begin until after the wait period elapses.

3.4.9.3. Assembler Syntax

irq <irq_num> (_rel)

irq set <irq_num> (_rel)

irq nowait <irq_num> (_rel)

irq wait <irq_num> (_rel)

irq clear <irq_num> (_rel)

where:

<irq_num> (rel)

Is a value (see Section 3.3.3) specifying The irq number to wait on (0-7). If rel is present, then the actual irq number used is calculating by replacing the low two bits of the irq number (irq_num_{10}) with the low two bits of the sum ($irq_num_{10} + sm_num_{10}$) where sm_num_{10} is the state machine

number

irq Means set the IRQ without waiting

irq set Also means set the IRQ without waiting

irq nowait Again, means set the IRQ without waiting

irq wait Means set the IRQ and wait for it to be cleared before proceeding

irq clear Means clear the IRQ

3.4.10. SET

3.4.10.1. Encoding

Bit:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SET	1	1	1		Del	ay/side	e-set		De	estinati	on			Data		

3.4.10.2. Operation

Write immediate value Data to Destination.

- Destination:
- 000: PINS
- 001: X (scratch register X) 5 LSBs are set to Data, all others cleared to 0.
- 010: Y (scratch register Y) 5 LSBs are set to Data, all others cleared to 0.
- 011: Reserved
- 100: PINDIRS
- 101: Reserved
- 110: Reserved
- 111: Reserved
- Data: 5-bit immediate value to drive to pins or register.

This can be used to assert control signals such as a clock or chip select, or to initialise loop counters. As Data is 5 bits in size, scratch registers can be SET to values from 0-31, which is sufficient for a 32-iteration loop.

The mapping of SET and OUT onto pins is configured independently. They may be mapped to distinct locations, for example if one pin is to be used as a clock signal, and another for data. They may also be overlapping ranges of pins: a UART transmitter might use SET to assert start and stop bits, and OUT instructions to shift out FIFO data to the same pins.

3.4.10.3. Assembler Syntax

set <destination>, <value>

where:

<destination> Is one of the destinations specified above.

<value> The value (see Section 3.3.3) to set (valid range 0-31)

Chapter 4. Library Documentation

4.1. Hardware APIs

hardware_adc	
hardware_base	
hardware_claim	
hardware_clocks	
hardware_divider	
hardware_dma	
channel_config	DMA channel configuration.
hardware_exception	
hardware_flash	
hardware_gpio	
hardware_i2c	
hardware_interp	
interp_config	Interpolator configuration.
hardware_irq	
hardware_pio	
sm_config	PIO state machine configuration.
hardware_pll	
hardware_pwm	
hardware_resets	
hardware_rtc	
hardware_spi	
hardware_sync	
hardware_timer	
hardware_uart	
hardware_vreg	
hardware_watchdog	
hardware_xosc	

4.1.1. hardware_adc

Analog to Digital Converter (ADC) API

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_select_input() 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

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
3 #include "hardware/gpio.h"
4 #include "hardware/adc.h"
6 int main() {
7
    stdio_init_all();
    printf("ADC Example, measuring GPI026\n");
8
9
10
    adc_init();
11
12 // Make sure GPIO is high-impedance, no pullups etc
13 adc_gpio_init(26);
   // Select ADC input 0 (GPI026)
14
    adc_select_input(0);
15
16
17
    while (1) {
        // 12-bit conversion, assume max value == ADC_VREF == 3.3 V
18
19
          const float conversion_factor = 3.3f / (1 << 12);</pre>
20
          uint16_t result = adc_read();
          printf("Raw value: 0x%03x, voltage: %f V\n", result, result * conversion_factor);
21
22
          sleep_ms(500);
23
      }
24 }
```

4.1.1.1. Function List

- void adc_init (void)
- static void adc_gpio_init (uint gpio)
- static void adc_select_input (uint input)

```
static uint adc_get_selected_input (void)
static void adc_set_round_robin (uint input_mask)
static void adc_set_temp_sensor_enabled (bool enable)
static uint16_t adc_read (void)
static void adc_run (bool run)
static void adc_set_clkdiv (float clkdiv)
static void adc_fifo_setup (bool en, bool dreq_en, uint16_t dreq_thresh, bool err_in_fifo, bool byte_shift)
static bool adc_fifo_is_empty (void)
static uint8_t adc_fifo_get_level (void)
static uint16_t adc_fifo_get_blocking (void)
static void adc_fifo_drain (void)
```

4.1.1.2. Function Documentation

• static void adc_irq_set_enabled (bool enabled)

4.1.1.2.1. 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.

4.1.1.2.2. adc_fifo_get

```
static uint16_t adc_fifo_get (void)
```

Get ADC result from FIFO.

Pops the latest result from the ADC FIFO.

4.1.1.2.3. 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

4.1.1.2.4. adc_fifo_get_level

```
static uint8_t adc_fifo_get_level (void)
```

Get number of entries in the ADC FIFO.

The ADC FIFO is 4 entries long. This function will return how many samples are currently present.

4.1.1.2.5. adc_fifo_is_empty

```
static bool adc_fifo_is_empty (void)
```

Check FIFO empty state.

Returns

· Returns true if the fifo is empty

4.1.1.2.6. 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.

4.1.1.2.7. adc_get_selected_input

```
static uint adc_get_selected_input (void)
```

Get the currently selected ADC input channel.

Returns

• The currently selected input channel. 0...3 are GPIOs 26...29 respectively. Input 4 is the onboard temperature sensor.

4.1.1.2.8. adc_gpio_init

```
static void adc_gpio_init (uint gpio)
```

Initialise the gpio for use as an ADC pin.

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.

4.1.1.2.9. adc_init

```
void adc_init (void)
```

Initialise the ADC HW.

4.1.1.2.10. adc_irq_set_enabled

```
static void adc_irq_set_enabled (bool enabled)
```

Enable/Disable ADC interrupts.

Parameters

• enabled Set to true to enable the ADC interrupts, false to disable

4.1.1.2.11. 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.

4.1.1.2.12. 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.

4.1.1.2.13. adc_select_input

```
static void adc_select_input (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.

4.1.1.2.14. 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.

4.1.1.2.15. adc_set_round_robin

```
static void adc_set_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.

4.1.1.2.16. adc_set_temp_sensor_enabled

static void adc_set_temp_sensor_enabled (bool enable)

Enable the onboard temperature sensor.

Parameters

• enable Set true to power on the onboard temperature sensor, false to power off.

4.1.2. hardware_base

Low-level types and (atomic) accessors for memory-mapped hardware registers

hardware_base defines the low level types and access functions for memory mapped hardware registers. It is included by default by all other hardware libraries.

The following 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	В	С	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 use 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.

4.1.2.1. Function List

- static __force_inline void hw_set_bits (io_rw_32 *addr, uint32_t mask)
- static __force_inline void hw_clear_bits (io_rw_32 *addr, uint32_t mask)
- static __force_inline void hw_xor_bits (io_rw_32 *addr, uint32_t mask)
- static __force_inline void hw_write_masked (io_rw_32 *addr, uint32_t values, uint32_t write_mask)

4.1.2.2. Function Documentation

4.1.2.2.1. hw_clear_bits

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

Parameters

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

4.1.2.2.2. hw_set_bits

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

Parameters

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

4.1.2.2.3. hw_write_masked

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

4.1.2.2.4. hw_xor_bits

Atomically flip the specified bits in a HW register.

Parameters

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

4.1.3. hardware_claim

Lightweight hardware resource management

hardware_claim provides a simple API for management of hardware resources at runtime.

This API is usually called by other hardware specific *claiming* APIs and provides simple multi-core safe methods to manipulate compact bit-sets representing hardware resources.

This API allows any other library to cooperatively participate in a scheme by which both compile time and runtime allocation of resources can co-exist, and conflicts can be avoided or detected (depending on the use case) without the libraries having any other knowledge of each other.

Facilities are providing for:

- · Claiming resources (and asserting if they are already claimed)
- Freeing (unclaiming) resources
- Finding unused resources

4.1.3.1. Function List

```
    void hw_claim_or_assert (uint8_t *bits, uint bit_index, const char *message)
    int hw_claim_unused_from_range (uint8_t *bits, bool required, uint bit_lsb, uint bit_msb, const char *message)
    bool hw_is_claimed (const uint8_t *bits, uint bit_index)
    void hw_claim_clear (uint8_t *bits, uint bit_index)
    uint32_t hw_claim_lock (void)
    void hw_claim_unlock (uint32_t token)
```

4.1.3.2. Function Documentation

4.1.3.2.1. hw_claim_clear

Atomically unclaim a resource.

The resource ownership is indicated by the bit_index bit in an array of bits.

Parameters

- bits pointer to an array of bits (8 bits per byte)
- bit_index resource to unclaim (bit index into array of bits)

4.1.3.2.2. hw_claim_lock

```
uint32_t hw_claim_lock (void)
```

Acquire the runtime mutual exclusion lock provided by the hardware_claim library.

This method is called automatically by the other hw_claim_ methods, however it is provided as a convenience to code that might want to protect other hardware initialization code from concurrent use.

Returns

• a token to pass to hw_claim_unlock()

4.1.3.2.3. hw_claim_or_assert

Atomically claim a resource, panicking if it is already in use.

The resource ownership is indicated by the bit_index bit in an array of bits.

Parameters

- bits pointer to an array of bits (8 bits per byte)
- bit_index resource to claim (bit index into array of bits)
- message string to display if the bit cannot be claimed; note this may have a single printf format "%d" for the bit

4.1.3.2.4. hw_claim_unlock

```
void hw_claim_unlock (uint32_t token)
```

Release the runtime mutual exclusion lock provided by the hardware_claim library.

Parameters

• token the token returned by the corresponding call to hw_claim_lock()

4.1.3.2.5. hw_claim_unused_from_range

Atomically claim one resource out of a range of resources, optionally asserting if none are free.

Parameters

- bits pointer to an array of bits (8 bits per byte)
- required true if this method should panic if the resource is not free
- bit_lsb the lower bound (inclusive) of the resource range to claim from
- bit_msb the upper bound (inclusive) of the resource range to claim from
- message string to display if the bit cannot be claimed

Returns

• the bit index representing the claimed or -1 if none are available in the range, and required = false

4.1.3.2.6. hw_is_claimed

Determine if a resource is claimed at the time of the call.

The resource ownership is indicated by the bit_index bit in an array of bits.

Parameters

• bits pointer to an array of bits (8 bits per byte)

bit_index resource to check (bit index into array of bits)

Returns

• true if the resource is claimed

4.1.4. hardware_clocks

Clock Management API

This API provides 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.

The clock source depends on which clock you are attempting to configure. The first table below shows main clock sources. If you are not setting the Reference clock or the System clock, or you are specifying that one of those two will be using an auxiliary clock source, then you will need to use one of the entries from the subsequent tables.

Main Clock Sources

Source	Reference Clock	System Clock
ROSC	CLOCKS_CLK_REF_CTRL_SRC_VALUE _ROSC_CLKSRC_PH	
Auxiliary	CLOCKS_CLK_REF_CTRL_SRC_VALUE _CLKSRC_CLK_REF_AUX	CLOCKS_CLK_SYS_CTRL_SRC_VALUE _CLKSRC_CLK_SYS_AUX
XOSC	CLOCKS_CLK_REF_CTRL_SRC_VALUE _XOSC_CLKSRC	
Reference		CLOCKS_CLK_SYS_CTRL_SRC_VALUE _CLK_REF

Auxiliary Clock Sources

The auxiliary clock sources available for use in the configure function depend on which clock is being configured. The following table describes the available values that can be used. Note that for clk_gpout[x], x can be 0-3.

Aux Source	clk_gpout[x]	clk_ref	clk_sys
System PLL	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLKSRC _PLL_SYS		CLOCKS_CLK_SYS_CTRL_A UXSRC_VALUE_CLKSRC_PL L_SYS
GPIO in 0	CLOCKS_CLK_GPOUTx_CTR	CLOCKS_CLK_REF_CTRL_A	CLOCKS_CLK_SYS_CTRL_A
	L_AUXSRC_VALUE_CLKSRC	UXSRC_VALUE_CLKSRC_GP	UXSRC_VALUE_CLKSRC_GP
	_GPIN0	IN0	IN0
GPIO in 1	CLOCKS_CLK_GPOUTx_CTR	CLOCKS_CLK_REF_CTRL_A	CLOCKS_CLK_SYS_CTRL_A
	L_AUXSRC_VALUE_CLKSRC	UXSRC_VALUE_CLKSRC_GP	UXSRC_VALUE_CLKSRC_GP
	_GPIN1	IN1	IN1
USB PLL	CLOCKS_CLK_GPOUTx_CTR	CLOCKS_CLK_REF_CTRL_A	CLOCKS_CLK_SYS_CTRL_A
	L_AUXSRC_VALUE_CLKSRC	UXSRC_VALUE_CLKSRC_PL	UXSRC_VALUE_CLKSRC_PL
	_PLL_USB	L_USB	L_USB

Aux Source	clk_gpout[x]	clk_ref	clk_sys
ROSC	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_ROSC_C LKSRC		CLOCKS_CLK_SYS_CTRL_A UXSRC_VALUE_ROSC_CLKS RC
XOSC	CLOCKS_CLK_GPOUTX_CTR L_AUXSRC_VALUE_XOSC_C LKSRC		CLOCKS_CLK_SYS_CTRL_A UXSRC_VALUE_ROSC_CLKS RC
System clock	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLK_SY S		
USB Clock	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLK_US B		
ADC clock	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLK_AD C		
RTC Clock	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLK_RT C		
Ref clock	CLOCKS_CLK_GPOUTx_CTR L_AUXSRC_VALUE_CLK_RE F		

Aux Source	clk_peri	clk_usb	clk_adc
System PLL	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_CLKSRC_PL L_SYS	CLOCKS_CLK_USB_CTRL_A UXSRC_VALUE_CLKSRC_PL L_SYS	CLOCKS_CLK_ADC_CTRL_A UXSRC_VALUE_CLKSRC_PL L_SYS
GPIO in 0	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_CLKSRC_GP IN0	CLOCKS_CLK_USB_CTRL_A UXSRC_VALUE_CLKSRC_GP IN0	CLOCKS_CLK_ADC_CTRL_A UXSRC_VALUE_CLKSRC_GP IN0
GPIO in 1	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_CLKSRC_GP IN1	CLOCKS_CLK_USB_CTRL_A UXSRC_VALUE_CLKSRC_GP IN1	CLOCKS_CLK_ADC_CTRL_A UXSRC_VALUE_CLKSRC_GP IN1
USB PLL	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_CLKSRC_PL L_USB	CLOCKS_CLK_USB_CTRL_A UXSRC_VALUE_CLKSRC_PL L_USB	CLOCKS_CLK_ADC_CTRL_A UXSRC_VALUE_CLKSRC_PL L_USB
ROSC	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_ROSC_CLKS RC_PH		CLOCKS_CLK_ADC_CTRL_A UXSRC_VALUE_ROSC_CLKS RC_PH
XOSC	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_XOSC_CLKS RC	CLOCKS_CLK_USB_CTRL_A UXSRC_VALUE_XOSC_CLKS RC	
System clock	CLOCKS_CLK_PERI_CTRL_A UXSRC_VALUE_CLK_SYS		

Aux Source	clk_rtc
System PLL	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_CLKSRC_PLL_ SYS
GPIO in 0	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_CLKSRC_GPIN 0
GPIO in 1	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_CLKSRC_GPIN 1
USB PLL	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_CLKSRC_PLL_ USB
ROSC	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_ROSC_CLKSR C_PH
XOSC	CLOCKS_CLK_RTC_CTRL_AUXSRC_VALUE_XOSC_CLKSR C

Example// hello_48MHz.c

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
 3 #include "hardware/pll.h"
4 #include "hardware/clocks.h"
 5 #include "hardware/structs/pll.h"
 6 #include "hardware/structs/clocks.h"
 8 void measure_freqs(void) {
       uint f_pll_sys = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_PLL_SYS_CLKSRC_PRIMARY);
10
       uint f_pll_usb = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_PLL_USB_CLKSRC_PRIMARY);
11
       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);
12
       uint f_clk_peri = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_PERI);
13
       uint f_clk_usb = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_USB);
14
       uint f_clk_adc = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_ADC);
15
16
      uint f_clk_rtc = frequency_count_khz(CLOCKS_FC0_SRC_VALUE_CLK_RTC);
17
      printf("pll_sys = %dkHz\n", f_pll_sys);
18
19
    printf("pll_usb = %dkHz\n", f_pll_usb);
20
    printf("rosc = %dkHz\n", f_rosc);
21
   printf("clk_sys = %dkHz\n", f_clk_sys);
22
    printf("clk_peri = %dkHz\n", f_clk_peri);
23
    printf("clk_usb = %dkHz\n", f_clk_usb);
24
    printf("clk_adc = %dkHz\n", f_clk_adc);
25
      printf("clk_rtc = %dkHz\n", f_clk_rtc);
26
27
       // Can't measure clk_ref / xosc as it is the ref
28 }
29
30 int main() {
31
      stdio_init_all();
32
33
     printf("Hello, world!\n");
34
35
     measure_freqs();
36
37
      // Change clk_sys to be 48 MHz. 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,
                       48 * MHZ);
43
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
                       CLOCKS_CLK_PERI_CTRL_AUXSRC_VALUE_CLK_SYS,
51
52
                       48 * MHZ,
                       48 * MHZ);
53
54
55
      // Re init uart now that clk_peri has changed
56
      stdio_init_all();
57
    measure_freqs();
58
59
     printf("Hello, 48MHz");
60
61
       return 0;
62 }
```

4.1.4.1. Enumerations

enum clock_index { clk_gpout0 = 0, clk_gpout1, clk_gpout2, clk_gpout3, clk_ref, clk_sys, clk_peri, clk_usb, clk_adc, clk_rtc, CLK_COUNT }
 Enumeration identifying a hardware clock.

4.1.4.2. Typedefs

typedef void(* resus_callback_t)(void)
 Resus callback function type.

4.1.4.3. Function List

```
    void clocks_init (void)
    bool clock_configure (enum clock_index clk_index, uint32_t src, uint32_t auxsrc, uint32_t src_freq, uint32_t freq)
    void clock_stop (enum clock_index clk_index)
    uint32_t clock_get_hz (enum clock_index clk_index)
    uint32_t frequency_count_khz (uint src)
    void clock_set_reported_hz (enum clock_index clk_index, uint hz)
    void clocks_enable_resus (resus_callback_t resus_callback)
    void clock_gpio_init (uint gpio, uint src, uint div)
    bool clock_configure_gpin (enum clock_index clk_index, uint gpio, uint32_t src_freq, uint32_t freq)
```

4.1.4.4. Function Documentation

4.1.4.4.1. clock_configure

Configure the specified clock.

See the tables in the description for details on the possible values for clock sources.

Parameters

- clk_index The clock to configure
- src The main clock source, can be 0.
- auxsrc The auxiliary clock source, which depends on which clock is being set. Can be 0
- src_freq Frequency of the input clock source
- freq Requested frequency

4.1.4.4.2. clock_configure_gpin

Configure a clock to come from a gpio input.

Parameters

- clk_index The clock to configure
- gpio The GPIO pin to run the clock from. Valid GPIOs are: 20 and 22.
- src_freq Frequency of the input clock source
- freq Requested frequency

4.1.4.4.3. 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

4.1.4.4.4. clock_gpio_init

```
void clock_gpio_init (uint gpio,
     uint src,
     uint div)
```

Output an optionally divided clock to the specified gpio pin.

Parameters

- gpio The GPIO pin to output the clock to. Valid GPIOs are: 21, 23, 24, 25. These GPIOs are connected to the GPOUT0-3 clock generators.
- src The source clock. See the register field CLOCKS_CLK_GPOUTO_CTRL_AUXSRC for a full list. The list is the same for each GPOUT clock generator.
- · div The amount to divide the source clock by. This is useful to not overwhelm the GPIO pin with a fast clock.

4.1.4.4.5. clock_set_reported_hz

Set the "current frequency" of the clock as reported by clock_get_hz without actually changing the clock.

See also

• clock_get_hz()

4.1.4.4.6. clock_stop

```
void clock_stop (enum clock_index clk_index)
```

Stop the specified clock.

Parameters

• clk_index The clock to stop

4.1.4.4.7. clocks_enable_resus

```
void clocks_enable_resus (resus_callback_t resus_callback)
```

Enable the resus function. Restarts clk_sys if it is accidentally stopped.

The resuscitate function will restart the system clock if it falls below a certain speed (or stops). This could happen if the clock source the system clock is running from stops. For example if a PLL is stopped.

Parameters

• resus_callback a function pointer provided by the user to call if a resus event happens.

4.1.4.4.8. clocks_init

```
void clocks_init (void)
```

Initialise the clock hardware.

Must be called before any other clock function.

4.1.4.4.9. frequency_count_khz

```
uint32_t frequency_count_khz (uint src)
```

Measure a clocks frequency using the Frequency counter.

Uses the inbuilt frequency counter to measure the specified clocks frequency. Currently, this function is accurate to +-1KHz. See the datasheet for more details.

4.1.5. hardware_divider

Low-level hardware-divider access

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 performing asynchronous divides. These functions however do not follow the regular SDK conventions for saving/restoring the divider state, so are not generally safe to call from interrupt handlers

The pico_divider library provides 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 through that library, meaning you can just use C level / and % operators and gain the benefits of the fast hardware divider.

See also

• pico_divider

Example

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
3 #include "hardware/divider.h"
5 int main() {
6
     stdio_init_all();
      printf("Hello, divider!\n");
7
8
      // This is the basic hardware divider function
10
      int32_t dividend = 123456;
11
       int32_t divisor = -321;
12
       divmod_result_t result = hw_divider_divmod_s32(dividend, divisor);
13
       printf("%d/%d = %d remainder %d\n", dividend, divisor, to_quotient_s32(result),
   to_remainder_s32(result));
15
      // Is it right?
16
17
       printf("Working backwards! Result %d should equal %d!\n\n",
18
19
              to_quotient_s32(result) * divisor + to_remainder_s32(result), dividend);
20
21
      // This is the recommended unsigned fast divider for general use.
22
      int32 t udividend = 123456:
      int32_t udivisor = 321;
23
24
       divmod_result_t uresult = hw_divider_divmod_u32(udividend, udivisor);
25
26
       printf("%d/%d = %d remainder %d\n", udividend, udivisor, to_quotient_u32(uresult),
   to_remainder_u32(uresult));
27
28
      // Is it right?
29
30
       printf("Working backwards! Result %d should equal %d!\n\n",
31
              to_quotient_u32(result) * divisor + to_remainder_u32(result), dividend);
32
       // You can also do divides asynchronously. Divides will be complete after 8 cyles.
33
34
35
       hw_divider_divmod_s32_start(dividend, divisor);
36
37
       // Do something for 8 cycles!
38
39
       // In this example, our results function will wait for completion.
      // Use hw_divider_result_nowait() if you don't want to wait, but are sure you have delayed
  at least 8 cycles
```

```
41
42
      result = hw_divider_result_wait();
43
      printf("Async result %d/%d = %d remainder %d\n", dividend, divisor, to_quotient_s32
44
   (result),
45
             to_remainder_s32(result));
46
      // For a really fast divide, you can use the inlined versions... the / involves a function
  call as / always does
    // when using the ARM AEABI, so if you really want the best performance use the inlined
    // Note that the / operator function DOES use the hardware divider by default, although
  you can change
    // that behavior by calling pico_set_divider_implementation in the cmake build for your
  target.
51
     printf("%d / %d = (by operator %d) (inlined %d)\n", dividend, divisor,
52
             dividend / divisor, hw_divider_s32_quotient_inlined(dividend, divisor));
53
      // Note however you must manually save/restore the divider state if you call the inlined
  methods from within an IRQ
55
    // handler.
56
    hw_divider_state_t state;
     hw_divider_divmod_s32_start(dividend, divisor);
57
58
    hw_divider_save_state(&state);
59
60
     hw_divider_divmod_s32_start(123, 7);
     printf("inner %d / %d = %d\n", 123, 7, hw_divider_s32_quotient_wait());
61
62
63
      hw_divider_restore_state(&state);
64
      int32_t tmp = hw_divider_s32_quotient_wait();
65
      printf("outer divide %d / %d = %d\n", dividend, divisor, tmp);
66
      return 0;
67 }
```

4.1.5.1. Function List

```
static void hw_divider_divmod_s32_start (int32_t a, int32_t b)
static void hw_divider_divmod_u32_start (uint32_t a, uint32_t b)
static void hw_divider_wait_ready (void)
static divmod_result_t hw_divider_result_nowait (void)
static divmod_result_t hw_divider_result_wait (void)
static uint32_t hw_divider_u32_quotient_wait (void)
static int32_t hw_divider_u32_remainder_wait (void)
static uint32_t hw_divider_u32_remainder_wait (void)
static int32_t hw_divider_s32_remainder_wait (void)
divmod_result_t hw_divider_divmod_s32 (int32_t a, int32_t b)
divmod_result_t hw_divider_divmod_u32 (uint32_t a, uint32_t b)
static uint32_t to_quotient_u32 (divmod_result_t r)
static uint32_t to_remainder_u32 (divmod_result_t r)
static uint32_t to_remainder_u32 (divmod_result_t r)
```

```
• static int32_t to_remainder_s32 (divmod_result_t r)
• static uint32_t hw_divider_u32_quotient (uint32_t a, uint32_t b)
• static uint32_t hw_divider_u32_remainder (uint32_t a, uint32_t b)
• static int32_t hw_divider_quotient_s32 (int32_t a, int32_t b)
• static int32_t hw_divider_remainder_s32 (int32_t a, int32_t b)
• static void hw_divider_pause (void)
• static uint32_t hw_divider_u32_quotient_inlined (uint32_t a, uint32_t b)
• static uint32_t hw_divider_u32_remainder_inlined (uint32_t a, uint32_t b)
• static int32_t hw_divider_s32_quotient_inlined (int32_t a, int32_t b)
• static int32_t hw_divider_s32_remainder_inlined (int32_t a, int32_t b)
• void hw_divider_save_state (hw_divider_state_t *dest)
• void hw_divider_restore_state (hw_divider_state_t *src)
```

4.1.5.2. Function Documentation

4.1.5.2.1. hw_divider_divmod_s32

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.

4.1.5.2.2. hw_divider_divmod_s32_start

```
static void hw_divider_divmod_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_divider_wait_ready()) prior to reading the results.

Parameters

- a The dividend
- b The divisor

4.1.5.2.3. hw_divider_divmod_u32

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.

4.1.5.2.4. hw_divider_divmod_u32_start

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_divider_wait_ready()) prior to reading the results.

Parameters

- a The dividend
- b The divisor

4.1.5.2.5. hw_divider_pause

```
static void hw_divider_pause (void)
```

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

4.1.5.2.6. hw_divider_quotient_s32

```
static int32_t hw_divider_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

4.1.5.2.7. hw_divider_remainder_s32

```
static int32_t hw_divider_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

4.1.5.2.8. hw_divider_restore_state

```
void hw_divider_restore_state (hw_divider_state_t *src)
```

Load a saved hardware divider state into the current core's hardware divider.

Copy the passed hardware divider state into the hardware divider.

Parameters

src the location to load the divider state from

4.1.5.2.9. hw_divider_result_nowait

```
static divmod_result_t hw_divider_result_nowait (void)
```

Return result of HW divide, nowait.

Returns

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

4.1.5.2.10. hw_divider_result_wait

```
static divmod_result_t hw_divider_result_wait (void)
```

Return result of last asynchronous HW divide.

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

Returns

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

4.1.5.2.11. hw_divider_s32_quotient_inlined

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

4.1.5.2.12. hw_divider_s32_quotient_wait

```
static int32_t hw_divider_s32_quotient_wait (void)
```

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

This function waits for the result to be ready by calling $hw_divider_wait_ready()$.

Returns

• Current signed quotient result.

4.1.5.2.13. hw_divider_s32_remainder_inlined

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

4.1.5.2.14. hw_divider_s32_remainder_wait

```
static int32_t hw_divider_s32_remainder_wait (void)
```

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

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

Returns

· Current remainder results.

4.1.5.2.15. hw_divider_save_state

```
void hw_divider_save_state (hw_divider_state_t *dest)
```

Save the calling cores hardware divider state.

Copy the current core's hardware divider state into the provided structure. This method waits for the divider results to be stable, then copies them to memory. They can be restored via hw_divider_restore_state()

Parameters

• dest the location to store the divider state

4.1.5.2.16. hw_divider_u32_quotient

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

4.1.5.2.17. hw_divider_u32_quotient_inlined

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

4.1.5.2.18. hw_divider_u32_quotient_wait

```
static uint32_t hw_divider_u32_quotient_wait (void)
```

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

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

Returns

· Current unsigned quotient result.

4.1.5.2.19. hw_divider_u32_remainder

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

4.1.5.2.20. hw_divider_u32_remainder_inlined

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

Divide ${\bf a}$ by ${\bf b}$, wait for calculation to complete, return remainder.

Parameters

- a The dividend
- b The divisor

Returns

Remainder result of the divide

4.1.5.2.21. hw_divider_u32_remainder_wait

```
static uint32_t hw_divider_u32_remainder_wait (void)
```

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

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

Returns

Current unsigned remainder result.

4.1.5.2.22. hw_divider_wait_ready

```
static void hw_divider_wait_ready (void)
```

Wait for a divide to complete.

Wait for a divide to complete

4.1.5.2.23. to_quotient_s32

```
static int32_t to_quotient_s32 (divmod_result_t r)
```

Efficient extraction of signed quotient from 32p32 fixed point.

Parameters

• r 32p32 fixed point value.

Returns

Unsigned quotient

4.1.5.2.24. to_quotient_u32

```
static uint32_t to_quotient_u32 (divmod_result_t r)
```

Efficient extraction of unsigned quotient from 32p32 fixed point.

Parameters

• r 32p32 fixed point value.

Returns

Unsigned quotient

4.1.5.2.25. to_remainder_s32

```
static int32_t to_remainder_s32 (divmod_result_t r)
```

Efficient extraction of signed remainder from 32p32 fixed point.

Parameters

r 32p32 fixed point value.

Returns

Signed remainder

4.1.5.2.26. to_remainder_u32

```
static uint32_t to_remainder_u32 (divmod_result_t r)
```

Efficient extraction of unsigned remainder from 32p32 fixed point.

Parameters

• r 32p32 fixed point value.

Returns

Unsigned remainder

4.1.6. hardware_dma

DMA Controller 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.

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

4.1.6.1. Modules

channel_config
 DMA channel configuration.

4.1.6.2. 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.

4.1.6.3. Function List

- void dma_channel_claim (uint channel)
- void dma_claim_mask (uint32_t channel_mask)
- void dma_channel_unclaim (uint channel)
- int dma_claim_unused_channel (bool required)
- bool dma_channel_is_claimed (uint channel)
- static void dma_channel_set_config (uint channel, const dma_channel_config *config, bool trigger)
- static void dma_channel_set_read_addr (uint channel, const volatile void *read_addr, bool trigger)
- static void dma_channel_set_write_addr (uint channel, volatile void *write_addr, bool trigger)
- static void dma_channel_set_trans_count (uint channel, uint32_t trans_count, bool trigger)
- static void dma_channel_configure (uint channel, const dma_channel_config *config, volatile void *write_addr, const volatile void *read_addr, uint transfer_count, bool trigger)
- static void dma_channel_transfer_from_buffer_now (uint channel, const volatile void *read_addr, uint32_t
 transfer_count)
- static void dma_channel_transfer_to_buffer_now (uint channel, volatile void *write_addr, uint32_t transfer_count)

```
• static void dma_start_channel_mask (uint32_t chan_mask)
• static void dma_channel_start (uint channel)
• static void dma_channel_abort (uint channel)

    static void dma_channel_set_irq0_enabled (uint channel, bool enabled)

• static void dma_set_irq0_channel_mask_enabled (uint32_t channel_mask, bool enabled)
• static void dma_channel_set_irq1_enabled (uint channel, bool enabled)
• static void dma_set_irq1_channel_mask_enabled (uint32_t channel_mask, bool enabled)
• static void dma_irqn_set_channel_enabled (uint irq_index, uint channel, bool enabled)
• static void dma_irqn_set_channel_mask_enabled (uint irq_index, uint32_t channel_mask, bool enabled)
static bool dma_channel_get_irq0_status (uint channel)
• static bool dma_channel_get_irq1_status (uint channel)
• static bool dma_irqn_get_channel_status (uint irq_index, uint channel)
• static void dma_channel_acknowledge_irq0 (uint channel)
• static void dma_channel_acknowledge_irq1 (uint channel)
• static void dma_irqn_acknowledge_channel (uint irq_index, uint channel)
• static bool dma_channel_is_busy (uint channel)
• static void dma_channel_wait_for_finish_blocking (uint channel)
• static void dma_sniffer_enable (uint channel, uint mode, bool force_channel_enable)
• static void dma_sniffer_set_byte_swap_enabled (bool swap)
• static void dma_sniffer_disable (void)
```

4.1.6.4. Function Documentation

4.1.6.4.1. dma_channel_abort

```
static void dma_channel_abort (uint channel)
```

Stop a DMA transfer.

Function will only return once the DMA has stopped.

Parameters

channel DMA channel

4.1.6.4.2. dma_channel_acknowledge_irq0

```
static void dma_channel_acknowledge_irq0 (uint channel)
```

Acknowledge a channel IRQ, resetting it as the cause of DMA_IRQ_0.

Parameters

channel DMA channel

4.1.6.4.3. dma_channel_acknowledge_irq1

```
static void dma_channel_acknowledge_irq1 (uint channel)
```

Acknowledge a channel IRQ, resetting it as the cause of DMA_IRQ_1.

Parameters

• channel DMA channel

4.1.6.4.4. 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 4 8 1

• channel the dma channel

4.1.6.4.5. dma_channel_configure

Configure all DMA parameters and optionally 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

4.1.6.4.6. dma_channel_get_irq0_status

```
static bool dma_channel_get_irq0_status (uint channel)
```

Determine if a particular channel is a cause of DMA_IRQ_0.

Parameters

channel DMA channel

Returns

true if the channel is a cause of DMA_IRQ_0, false otherwise

4.1.6.4.7. dma_channel_get_irq1_status

```
static bool dma_channel_get_irq1_status (uint channel)
```

Determine if a particular channel is a cause of DMA_IRQ_1.

Parameters

• channel DMA channel

Returns

• true if the channel is a cause of DMA_IRQ_1, false otherwise

4.1.6.4.8. dma_channel_is_busy

```
static bool dma_channel_is_busy (uint channel)
```

Check if DMA channel is busy.

Parameters

channel DMA channel

Returns

• true if the channel is currently busy

4.1.6.4.9. dma_channel_is_claimed

```
bool dma_channel_is_claimed (uint channel)
```

Determine if a dma channel is claimed.

Parameters

• channel the dma channel

Returns

• true if the channel is claimed, false otherwise

See also

- dma_channel_claim
- dma_channel_claim_mask

4.1.6.4.10. dma_channel_set_config

Set a channel configuration.

Parameters

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

4.1.6.4.11. dma_channel_set_irq0_enabled

Enable single DMA channel's interrupt via DMA_IRQ_0.

Parameters

channel DMA channel

• enabled true to enable interrupt 0 on specified channel, false to disable.

4.1.6.4.12. dma_channel_set_irq1_enabled

Enable single DMA channel's interrupt via DMA_IRQ_1.

Parameters

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

4.1.6.4.13. dma_channel_set_read_addr

Set the DMA initial read address.

Parameters

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

4.1.6.4.14. dma_channel_set_trans_count

Set the number of bus transfers the channel will do.

Parameters

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

4.1.6.4.15. dma_channel_set_write_addr

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

Set the DMA initial write address.

Parameters

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

4.1.6.4.16. dma_channel_start

```
static void dma_channel_start (uint channel)
```

Start a single DMA channel.

Parameters

channel DMA channel

4.1.6.4.17. dma_channel_transfer_from_buffer_now

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 channel_config_set_transfer_data_size() to be sent.

4.1.6.4.18. dma_channel_transfer_to_buffer_now

```
static void dma_channel_transfer_to_buffer_now (uint channel,
    volatile 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 channel_config_set_transfer_data_size() to be sent.

4.1.6.4.19. 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

4.1.6.4.20. dma_channel_wait_for_finish_blocking

```
static void dma_channel_wait_for_finish_blocking (uint channel)
```

Wait for a DMA channel transfer to complete.

Parameters

channel DMA channel

4.1.6.4.21. 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)

4.1.6.4.22. dma_claim_unused_channel

```
int dma_claim_unused_channel (bool required)
```

Claim a free dma channel.

Parameters

• required if true the function will panic if none are available

Returns

• the dma channel number or -1 if required was false, and none were free

4.1.6.4.23. dma_irqn_acknowledge_channel

Acknowledge a channel IRQ, resetting it as the cause of DMA_IRQ_N.

Parameters

- irq_index the IRQ index; either 0 or 1 for DMA_IRQ_0 or DMA_IRQ_1
- channel DMA channel

4.1.6.4.24. dma_irqn_get_channel_status

Determine if a particular channel is a cause of DMA_IRQ_N.

Parameters

- irq_index the IRQ index; either 0 or 1 for DMA_IRQ_0 or DMA_IRQ_1
- channel DMA channel

Returns

• true if the channel is a cause of the DMA_IRQ_N, false otherwise

4.1.6.4.25. dma_irqn_set_channel_enabled

Enable single DMA channel interrupt on either DMA_IRQ_0 or DMA_IRQ_1.

Parameters

- irq_index the IRQ index; either 0 or 1 for DMA_IRQ_0 or DMA_IRQ_1
- channel DMA channel
- enabled true to enable interrupt via irq_index for specified channel, false to disable.

4.1.6.4.26. dma_irqn_set_channel_mask_enabled

Enable multiple DMA channels' interrupt via either DMA_IRQ_0 or DMA_IRQ_1.

Parameters

- irq_index the IRQ index; either 0 or 1 for DMA_IRQ_0 or DMA_IRQ_1
- channel_mask Bitmask of all the channels to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- enabled true to enable all the interrupts specified in the mask, false to disable all the interrupts specified in the mask

4.1.6.4.27. dma_set_irq0_channel_mask_enabled

Enable multiple DMA channels' interrupts via DMA_IRQ_0.

Parameters

- channel_mask Bitmask of all the channels to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- enabled true to enable all the interrupts specified in the mask, false to disable all the interrupts specified in the mask.

4.1.6.4.28. dma_set_irq1_channel_mask_enabled

Enable multiple DMA channels' interrupts via DMA_IRQ_1.

Parameters

- channel_mask Bitmask of all the channels to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- enabled true to enable all the interrupts specified in the mask, false to disable all the interrupts specified in the mask.

4.1.6.4.29. dma_sniffer_disable

```
static void dma_sniffer_disable (void)
```

Disable the DMA sniffer.

4.1.6.4.30. dma_sniffer_enable

Enable the DMA sniffing targeting the specified channel.

The mode can be one of the following:

Mode	Function
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)

Parameters

- channel DMA channel
- mode See description
- force_channel_enable Set true to also turn on sniffing in the channel configuration (this is usually what you want, but sometimes you might have a chain DMA with only certain segments of the chain sniffed, in which case you might pass false).

4.1.6.4.31. dma_sniffer_set_byte_swap_enabled

static void dma_sniffer_set_byte_swap_enabled (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 channel_config_set_bswap() and dma_sniffer_set_byte_swap_enabled() are both enabled, their effects cancel from the sniffer's point of view.

Parameters

• swap Set true to enable byte swapping

4.1.6.4.32. dma_start_channel_mask

static void dma_start_channel_mask (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.

4.1.7. channel_config

DMA channel configuration.

A DMA channel needs to be configured, these functions provide handy helpers to set up configuration structures. See <a href="mailto:dm

4.1.7.1. Function List

```
static void channel_config_set_read_increment (dma_channel_config *c, bool incr)
static void channel_config_set_write_increment (dma_channel_config *c, bool incr)
static void channel_config_set_dreq (dma_channel_config *c, uint dreq)
static void channel_config_set_chain_to (dma_channel_config *c, uint chain_to)
static void channel_config_set_transfer_data_size (dma_channel_config *c, enum dma_channel_transfer_size size)
static void channel_config_set_ring (dma_channel_config *c, bool write, uint size_bits)
static void channel_config_set_bswap (dma_channel_config *c, bool bswap)
static void channel_config_set_irq_quiet (dma_channel_config *c, bool irq_quiet)
static void channel_config_set_enable (dma_channel_config *c, bool enable)
static void channel_config_set_sniff_enable (dma_channel_config *c, bool sniff_enable)
static dma_channel_config dma_channel_get_default_config (uint channel)
static dma_channel_config_get_ctrl_value (const dma_channel_config *config)
```

4.1.7.2. Function Documentation

4.1.7.2.1. channel_config_get_ctrl_value

```
static uint32_t channel_config_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

4.1.7.2.2. channel_config_set_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

4.1.7.2.3. channel_config_set_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.

4.1.7.2.4. channel_config_set_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 $0x3a \rightarrow select$ DREQ n as TREQ $0x3b \rightarrow Select$ Timer 0 as TREQ $0x3c \rightarrow Select$ Timer 1 as TREQ $0x3d \rightarrow Select$ Timer 2 as TREQ (Optional) $0x3e \rightarrow Select$ Timer 3 as TREQ (Optional) $0x3f \rightarrow Select$

Parameters

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

4.1.7.2.5. channel_config_set_enable

```
static void channel_config_set_enable (dma_channel_config *c,
    bool enable)
```

Enable/Disable the 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
- enable True to enable the DMA channel. When enabled, the channel will respond to triggering events, and start transferring data.

4.1.7.2.6. channel_config_set_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.

4.1.7.2.7. channel_config_set_read_increment

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

4.1.7.2.8. channel_config_set_ring

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)

 $0x0 \rightarrow No wrapping.$

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.

4.1.7.2.9. channel_config_set_sniff_enable

```
static void channel_config_set_sniff_enable (dma_channel_config *c,
    bool sniff_enable)
```

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_enable True to enable the Sniff HW access to this DMA channel.

4.1.7.2.10. channel_config_set_transfer_data_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.

4.1.7.2.11. channel_config_set_write_increment

```
static void channel_config_set_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

4.1.7.2.12. dma_channel_get_default_config

static dma_channel_config dma_channel_get_default_config (uint channel)

Get the default channel configuration for a given channel.

Setting	Default
Read Increment	true
Write Increment	false
DReq	DREQ_FORCE
Chain to	self
Data size	DMA_SIZE_32
Ring	write=false, size=0 (i.e. off)
Byte Swap	false
Quiet IRQs	false
Channel Enable	true
Sniff Enable	false

Parameters

channel DMA channel

Returns

the default configuration which can then be modified.

4.1.7.2.13. dma_get_channel_config

static dma_channel_config dma_get_channel_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)

4.1.8. hardware_exception

Methods for setting processor exception handlers

Exceptions are identified by a exception_num which is a number from -15 to -1; these are the numbers relative to the index of the first IRQ vector in the vector table. (i.e. vector table index is exception_num plus 16)

There is one set of exception handlers per core, so the exception handlers for each core as set by these methods are independent.

That all exception APIs affect the executing core only (i.e. the core calling the function).

4.1.8.1. Enumerations

```
    enum exception_number { NMI_EXCEPTION = -14, HARDFAULT_EXCEPTION = -13, SVCALL_EXCEPTION = -5, PENDSV_EXCEPTION = -2, SYSTICK_EXCEPTION = -1 }
    Exception number definitions.
```

4.1.8.2. Typedefs

typedef void(* exception_handler_t)(void)
 Exception handler function type.

4.1.8.3. Function List

- exception_handler_t exception_set_exclusive_handler (enum exception_number num, exception_handler_t handler)
- void exception_restore_handler (enum exception_number, exception_handler_t original_handler)
- exception_handler_t exception_get_vtable_handler (enum exception_number num)

4.1.8.4. Function Documentation

4.1.8.4.1. exception_get_vtable_handler

```
exception_handler_t exception_get_vtable_handler (enum exception_number num)
```

Get the current exception handler for the specified exception from the currently installed vector table of the execution core.

Parameters

num Exception number

Returns

• the address stored in the VTABLE for the given exception number

4.1.8.4.2. exception_restore_handler

Restore the original exception handler for an exception on this core.

This method may be used to restore the exception handler for an exception on this core to the state prior to the call to exception_set_exclusive_handler(), so that exception_set_exclusive_handler() may be called again in the future.

Parameters

- num Exception number exception_nums
- original_handler The original handler returned from exception_set_exclusive_handler

See also

exception_set_exclusive_handler()

4.1.8.4.3. exception_set_exclusive_handler

Set the exception handler for an exception on the executing core.

This method will assert if an exception handler has been set for this exception number on this core via this method, without an intervening restore via exception_restore_handler.

Parameters

- num Exception number
- handler The handler to set

See also

exception_number

4.1.9. hardware_flash

Low level flash programming and erase API

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.

Likewise they are *unsafe* if you have interrupt handlers or an interrupt vector table in flash, so you must disable interrupts before calling in this case.

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

```
1 #include <stdio.h>
2 #include <stdlib.h>
4 #include "pico/stdlib.h"
5 #include "hardware/flash.h"
7 // We're going to erase and reprogram a region 256k from the start of flash.
8 // Once done, we can access this at XIP_BASE + 256k.
9 #define FLASH_TARGET_OFFSET (256 * 1024)
10
11 const uint8_t *flash_target_contents = (const uint8_t *) (XIP_BASE + FLASH_TARGET_OFFSET);
12
13 void print_buf(const uint8_t *buf, size_t len) {
      for (size_t i = 0; i < len; ++i) {
14
           printf("%02x", buf[i]);
15
           if (i % 16 == 15)
16
17
               printf("\n");
18
19
               printf(" ");
20
```

```
21 }
22
23 int main() {
       stdio_init_all();
24
25
       uint8_t random_data[FLASH_PAGE_SIZE];
26
       for (int i = 0; i < FLASH_PAGE_SIZE; ++i)</pre>
27
           random_data[i] = rand() >> 16;
28
29
       printf("Generated random data:\n");
30
       print_buf(random_data, FLASH_PAGE_SIZE);
31
       // Note that a whole number of sectors must be erased at a time.
32
33
       printf("\nErasing target region...\n");
       {\tt flash\_range\_erase(FLASH\_TARGET\_OFFSET,\ FLASH\_SECTOR\_SIZE);}
34
       printf("Done. Read back target region:\n");
35
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
       bool mismatch = false;
43
       for (int i = 0; i < FLASH_PAGE_SIZE; ++i) {</pre>
44
45
           if (random_data[i] != flash_target_contents[i])
46
               mismatch = true;
47
48
      if (mismatch)
49
           printf("Programming failed!\n");
50
51
           printf("Programming successful!\n");
52 }
```

4.1.9.1. Function List

```
    void flash_range_erase (uint32_t flash_offs, size_t count)
    void flash_range_program (uint32_t flash_offs, const uint8_t *data, size_t count)
    void flash_get_unique_id (uint8_t *id_out)
    void flash_do_cmd (const uint8_t *txbuf, uint8_t *rxbuf, size_t count)
```

4.1.9.2. Function Documentation

4.1.9.2.1. flash_do_cmd

Execute bidirectional flash command.

Low-level function to execute a serial command on a flash device attached to the QSPI interface. Bytes are simultaneously transmitted and received from txbuf and to rxbuf. Therefore, both buffers must be the same length, count, which is the length of the overall transaction. This is useful for reading metadata from the flash chip, such as device ID or SFDP parameters.

The XIP cache is flushed following each command, in case flash state has been modified. Like other hardware_flash functions, the flash is not accessible for execute-in-place transfers whilst the command is in progress, so entering a

flash-resident interrupt handler or executing flash code on the second core concurrently will be fatal. To avoid these pitfalls it is recommended that this function only be used to extract flash metadata during startup, before the main application begins to run: see the implementation of pico_get_unique_id() for an example of this.

Parameters

- txbuf Pointer to a byte buffer which will be transmitted to the flash
- rxbuf Pointer to a byte buffer where data received from the flash will be written. txbuf and rxbuf may be the same buffer.
- · count Length in bytes of txbuf and of rxbuf

4.1.9.2.2. flash_get_unique_id

```
void flash_get_unique_id (uint8_t *id_out)
```

Get flash unique 64 bit identifier.

Use a standard 4Bh RUID instruction to retrieve the 64 bit unique identifier from a flash device attached to the QSPI interface. Since there is a 1:1 association between the MCU and this flash, this also serves as a unique identifier for the board.

Parameters

• id_out Pointer to an 8-byte buffer to which the ID will be written

4.1.9.2.3. flash_range_erase

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).

4.1.9.2.4. flash_range_program

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).

4.1.10. hardware_gpio

General Purpose Input/Output (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.

The function allocated to each GPIO is selected by calling the gpio_set_function function. Not all functions are available on all pins.

Each GPIO can have one function selected at a time. Likewise, each peripheral input (e.g. UARTO 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 datasheet for more information on GPIO function select.

Table 9. Function Select Table

GPIO	F1	F2	F3	F4	F5	F6	F7	F8	F9
0	SPI0 RX	UARTO TX	12C0 SDA	PWM0 A	SIO	PIO0	PIO1		USB OVCUR DET
1	SPI0 CSn	UARTO RX	I2C0 SCL	PWM0 B	SIO	PIO0	PIO1		USB VBUS DET
2	SPI0 SCK	UARTO CTS	I2C1 SDA	PWM1 A	SIO	PIO0	PIO1		USB VBUS EN
3	SPI0 TX	UARTO RTS	I2C1 SCL	PWM1 B	SIO	PIO0	PIO1		USB OVCUR DET
4	SPI0 RX	UART1 TX	I2C0 SDA	PWM2 A	SIO	PIO0	PIO1		USB VBUS DET
5	SPI0 CSn	UART1 RX	I2C0 SCL	PWM2 B	SIO	PIO0	PIO1		USB VBUS EN
6	SPI0 SCK	UART1 CTS	I2C1 SDA	PWM3 A	SIO	PIO0	PIO1		USB OVCUR DET
7	SPI0 TX	UART1 RTS	I2C1 SCL	PWM3 B	SIO	PIO0	PIO1		USB VBUS DET
8	SPI1 RX	UART1 TX	I2C0 SDA	PWM4 A	SIO	PIO0	PIO1		USB VBUS EN
9	SPI1 CSn	UART1 RX	12C0 SCL	PWM4 B	SIO	PIO0	PIO1		USB OVCUR DET
10	SPI1 SCK	UART1 CTS	I2C1 SDA	PWM5 A	SIO	PIO0	PIO1		USB VBUS DET
11	SPI1 TX	UART1 RTS	I2C1 SCL	PWM5 B	SIO	PIO0	PIO1		USB VBUS EN
12	SPI1 RX	UARTO TX	12C0 SDA	PWM6 A	SIO	PIO0	PIO1		USB OVCUR DET
13	SPI1 CSn	UARTO RX	I2C0 SCL	PWM6 B	SIO	PIO0	PIO1		USB VBUS DET
14	SPI1 SCK	UARTO CTS	I2C1 SDA	PWM7 A	SIO	PIO0	PIO1		USB VBUS EN
15	SPI1 TX	UARTO RTS	I2C1 SCL	PWM7 B	SIO	PIO0	PIO1		USB OVCUR DET

GPIO	F1	F2	F3	F4	F5	F6	F7	F8	F9
16	SPI0 RX	UARTO TX	I2C0 SDA	PWM0 A	SIO	PIO0	PI01		USB VBUS DET
17	SPI0 CSn	UARTO RX	I2C0 SCL	PWM0 B	SIO	PIO0	PIO1		USB VBUS EN
18	SPI0 SCK	UARTO CTS	I2C1 SDA	PWM1 A	SIO	PIO0	PIO1		USB OVCUR DET
19	SPI0 TX	UARTO RTS	I2C1 SCL	PWM1 B	SIO	PIO0	PIO1		USB VBUS DET
20	SPI0 RX	UART1 TX	I2C0 SDA	PWM2 A	SIO	PIO0	PI01	CLOCK GPIN0	USB VBUS EN
21	SPI0 CSn	UART1 RX	12C0 SCL	PWM2 B	SIO	PIO0	PIO1	CLOCK GPOUT0	USB OVCUR DET
22	SPI0 SCK	UART1 CTS	I2C1 SDA	PWM3 A	SIO	PIO0	PIO1	CLOCK GPIN1	USB VBUS DET
23	SPI0 TX	UART1 RTS	I2C1 SCL	PWM3 B	SIO	PIO0	PIO1	CLOCK GPOUT1	USB VBUS EN
24	SPI1 RX	UART1 TX	12C0 SDA	PWM4 A	SIO	PIO0	PIO1	CLOCK GPOUT2	USB OVCUR DET
25	SPI1 CSn	UART1 RX	I2C0 SCL	PWM4 B	SIO	PIO0	PIO1	CLOCK GPOUT3	USB VBUS DET
26	SPI1 SCK	UART1 CTS	I2C1 SDA	PWM5 A	SIO	PIO0	PIO1		USB VBUS EN
27	SPI1 TX	UART1 RTS	I2C1 SCL	PWM5 B	SIO	PIO0	PIO1		USB OVCUR DET
28	SPI1 RX	UARTO TX	I2C0 SDA	PWM6 A	SIO	PI00	PIO1		USB VBUS DET
29	SPI1 CSn	UARTO RX	I2C0 SCL	PWM6 B	SIO	PIO0	PIO1		USB VBUS EN

4.1.10.1. Enumerations

```
• enum gpio_function { GPIO_FUNC_XIP = 0, GPIO_FUNC_SPI = 1, GPIO_FUNC_UART = 2, GPIO_FUNC_I2C = 3, GPIO_FUNC_PWM = 4, GPIO_FUNC_SIO = 5, GPIO_FUNC_PIO0 = 6, GPIO_FUNC_PIO1 = 7, GPIO_FUNC_GPCK = 8, GPIO_FUNC_USB = 9, GPIO_FUNC_NULL = 0x1f }
```

GPIO function definitions for use with function select.

• enum gpio_irq_level { GPIO_IRQ_LEVEL_LOW = 0x1u, GPIO_IRQ_LEVEL_HIGH = 0x2u, GPIO_IRQ_EDGE_FALL = 0x4u,
 GPIO_IRQ_EDGE_RISE = 0x8u }
GPIO Interrupt level definitions.

• enum gpio_slew_rate { GPIO_SLEW_RATE_SLOW = 0, GPIO_SLEW_RATE_FAST = 1 }
Slew rate limiting levels for GPIO outputs.

enum gpio_drive_strength { GPIO_DRIVE_STRENGTH_2MA = 0, GPIO_DRIVE_STRENGTH_4MA = 1, GPIO_DRIVE_STRENGTH_8MA = 2, GPIO_DRIVE_STRENGTH_12MA = 3 }
 Drive strength levels for GPIO outputs.

4.1.10.2. Typedefs

• typedef void(* gpio_irq_callback_t)(uint gpio, uint32_t events)

4.1.10.3. Function List

```
• void gpio_set_function (uint gpio, enum gpio_function fn)
```

- void gpio_set_pulls (uint gpio, bool up, bool down)
- static void gpio_pull_up (uint gpio)
- static bool gpio_is_pulled_up (uint gpio)
- static void gpio_pull_down (uint gpio)
- static bool gpio_is_pulled_down (uint gpio)
- static void gpio_disable_pulls (uint gpio)
- void gpio_set_irqover (uint gpio, uint value)
- void gpio_set_outover (uint gpio, uint value)
- void gpio_set_inover (uint gpio, uint value)
- void gpio_set_oeover (uint gpio, uint value)
- void gpio_set_input_enabled (uint gpio, bool enabled)
- void gpio_set_input_hysteresis_enabled (uint gpio, bool enabled)
- bool gpio_is_input_hysteresis_enabled (uint gpio)
- void gpio_set_slew_rate (uint gpio, enum gpio_slew_rate slew)
- enum gpio_slew_rate gpio_get_slew_rate (uint gpio)
- void gpio_set_drive_strength (uint gpio, enum gpio_drive_strength drive)
- enum gpio_drive_strength gpio_get_drive_strength (uint gpio)
- void gpio_set_irq_enabled (uint gpio, uint32_t events, bool enabled)
- void gpio_set_irq_enabled_with_callback (uint gpio, uint32_t events, bool enabled, gpio_irq_callback_t callback)
- void gpio_set_dormant_irq_enabled (uint gpio, uint32_t events, bool enabled)
- void gpio_acknowledge_irq (uint gpio, uint32_t events)
- void gpio_init (uint gpio)
- void gpio_init_mask (uint gpio_mask)
- static bool gpio_get (uint gpio)
- static uint32_t gpio_get_all (void)
- static void gpio_set_mask (uint32_t mask)
- static void gpio_clr_mask (uint32_t mask)
- static void qpio_xor_mask</pr>(uint32_t mask)
- static void gpio_put_masked (uint32_t mask, uint32_t value)

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

- static void gpio_put (uint gpio, bool value)
- static bool gpio_get_out_level (uint gpio)
- static void gpio_set_dir_out_masked (uint32_t mask)
- static void gpio_set_dir_in_masked (uint32_t mask)
- static void gpio_set_dir_masked (uint32_t mask, uint32_t value)
- static void gpio_set_dir_all_bits (uint32_t values)
- static void gpio_set_dir (uint gpio, bool out)
- static bool gpio_is_dir_out (uint gpio)
- static uint gpio_get_dir (uint gpio)

4.1.10.4. Function Documentation

4.1.10.4.1. gpio_acknowledge_irq

Acknowledge a GPIO interrupt.

Parameters

- gpio GPIO number
- events Bitmask of events to clear. See gpio_set_irq_enabled for details.

4.1.10.4.2. 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

4.1.10.4.3. gpio_disable_pulls

```
static void gpio_disable_pulls (uint gpio)
```

Disable pulls on specified GPIO.

Parameters

• gpio GPIO number

4.1.10.4.4. gpio_get

```
static bool 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

4.1.10.4.5. gpio_get_all

```
static uint32_t gpio_get_all (void)
```

Get raw value of all GPIOs.

Returns

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

4.1.10.4.6. gpio_get_dir

```
static uint gpio_get_dir (uint gpio)
```

Get a specific GPIO direction.

Parameters

• gpio GPIO number

Returns

• 1 for out, 0 for in

4.1.10.4.7. gpio_get_drive_strength

```
enum gpio_drive_strength gpio_get_drive_strength (uint gpio)
```

Determine current slew rate for a specified GPIO.

Parameters

• gpio GPIO number

Returns

• Current drive strength of that GPIO

See also

• gpio_set_drive_strength

4.1.10.4.8. gpio_get_out_level

```
static bool gpio_get_out_level (uint gpio)
```

Determine whether a GPIO is currently driven high or low.

This function returns the high/low output level most recently assigned to a GPIO via <code>gpio_put()</code> or similar. This is the value that is presented outward to the IO muxing, the input level back from the pad (which can be read using <code>gpio_get()</code>).

To avoid races, this function must not be used for read-modify-write sequences when driving GPIOs instead functions like gpio_put() should be used to atomically update GPIOs. This accessor is intended for debug use only.

Parameters

• gpio GPIO number

Returns

• true if the GPIO output level is high, false if low.

4.1.10.4.9. gpio_get_slew_rate

```
enum gpio_slew_rate gpio_get_slew_rate (uint gpio)
```

Determine current slew rate for a specified GPIO.

Parameters

• gpio GPIO number

Returns

· Current slew rate of that GPIO

See also

• gpio_set_slew_rate

4.1.10.4.10. gpio_init

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

Initialise a GPIO for (enabled I/O and set func to GPIO_FUNC_SIO)

Clear the output enable (i.e. set to input) Clear any output value.

Parameters

• gpio GPIO number

4.1.10.4.11. gpio_init_mask

```
void gpio_init_mask (uint gpio_mask)
```

Initialise multiple GPIOs (enabled I/O and set func to GPIO_FUNC_SIO)

Clear the output enable (i.e. set to input) Clear any output value.

Parameters

• gpio_mask Mask with 1 bit per GPIO number to initialize

4.1.10.4.12. gpio_is_dir_out

```
static bool gpio_is_dir_out (uint gpio)
```

Check if a specific GPIO direction is OUT.

Parameters

• gpio GPIO number

Returns

• true if the direction for the pin is OUT

4.1.10.4.13. gpio_is_input_hysteresis_enabled

```
bool gpio_is_input_hysteresis_enabled (uint gpio)
```

Determine whether input hysteresis is enabled on a specified GPIO.

Parameters

• gpio GPIO number

See also

• gpio_set_input_hysteresis_enabled

4.1.10.4.14. gpio_is_pulled_down

```
static bool gpio_is_pulled_down (uint gpio)
```

Determine if the specified GPIO is pulled down.

Parameters

• gpio GPIO number

Returns

• true if the GPIO is pulled down

4.1.10.4.15. gpio_is_pulled_up

```
static bool gpio_is_pulled_up (uint gpio)
```

Determine if the specified GPIO is pulled up.

Parameters

• gpio GPIO number

Returns

• true if the GPIO is pulled up

4.1.10.4.16. gpio_pull_down

```
static void gpio_pull_down (uint gpio)
```

Set specified GPIO to be pulled down.

Parameters

• gpio GPIO number

4.1.10.4.17. gpio_pull_up

```
static void gpio_pull_up (uint gpio)
```

Set specified GPIO to be pulled up.

Parameters

• gpio GPIO number

4.1.10.4.18. gpio_put

Drive a single GPIO high/low.

Parameters

- gpio GPIO number
- value If false clear the GPIO, otherwise set it.

4.1.10.4.19. 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

4.1.10.4.20. gpio_put_masked

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

4.1.10.4.21. gpio_set_dir

Set a single GPIO direction.

Parameters

- gpio GPIO number
- out true for out, false for in

4.1.10.4.22. gpio_set_dir_all_bits

```
static void gpio_set_dir_all_bits (uint32_t values)
```

Set direction of all pins simultaneously.

Parameters

• values individual settings for each gpio; for GPIO N, bit N is 1 for out, 0 for in

4.1.10.4.23. gpio_set_dir_in_masked

```
static void gpio_set_dir_in_masked (uint32_t mask)
```

Set a number of GPIOs to input.

Parameters

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

4.1.10.4.24. gpio_set_dir_masked

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_set_dir_masked(0x3, 0x2); \rightarrow 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

4.1.10.4.25. gpio_set_dir_out_masked

```
static void gpio_set_dir_out_masked (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

4.1.10.4.26. gpio_set_dormant_irq_enabled

```
void gpio_set_dormant_irq_enabled (uint gpio,
            uint32_t events,
            bool enabled)
```

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 Which events will cause an interrupt. See gpio_set_irq_enabled for details.
- enabled Enable/disable flag

4.1.10.4.27. gpio_set_drive_strength

Set drive strength for a specified GPIO.

Parameters

- gpio GPIO number
- drive GPIO output drive strength

See also

gpio_get_drive_strength

4.1.10.4.28. gpio_set_function

Select GPIO function.

Parameters

• gpio GPIO number

• fn Which GPIO function select to use from list gpio_function

4.1.10.4.29. gpio_set_inover

Select GPIO input override.

Parameters

- gpio GPIO number
- value See gpio_override

4.1.10.4.30. gpio_set_input_enabled

Enable GPIO input.

Parameters

- gpio GPIO number
- enabled true to enable input on specified GPIO

4.1.10.4.31. gpio_set_input_hysteresis_enabled

Enable/disable GPIO input hysteresis (Schmitt trigger)

Enable or disable the Schmitt trigger hysteresis on a given GPIO. This is enabled on all GPIOs by default. Disabling input hysteresis can lead to inconsistent readings when the input signal has very long rise or fall times, but slightly reduces the GPIO's input delay.

Parameters

- gpio GPIO number
- enabled true to enable input hysteresis on specified GPIO

See also

• gpio_is_input_hysteresis_enabled

4.1.10.4.32. gpio_set_irq_enabled

```
void gpio_set_irq_enabled (uint gpio,
     uint32_t events,
     bool enabled)
```

Enable or disable interrupts for specified GPIO.

Events is a bitmask of the following:

bit	interrupt
0	Low level
1	High level

bit	interrupt
2	Edge low
3	Edge high

Parameters

- gpio GPIO number
- events Which events will cause an interrupt
- enabled Enable or disable flag

4.1.10.4.33. gpio_set_irq_enabled_with_callback

Enable interrupts for specified GPIO.

Parameters

- gpio GPIO number
- events Which events will cause an interrupt. See gpio_set_irq_enabled for details.
- enabled Enable or disable flag
- callback user function to call on GPIO irq. Note only one of these can be set per processor.

4.1.10.4.34. gpio_set_irqover

```
void gpio_set_irqover (uint gpio,
      uint value)
```

Set GPIO IRQ override.

Optionally invert a GPIO IRQ signal, or drive it high or low

Parameters

- gpio GPIO number
- value See gpio_override

4.1.10.4.35. 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

4.1.10.4.36. gpio_set_oeover

```
void gpio_set_oeover (uint gpio,
      uint value)
```

Select GPIO output enable override.

Parameters

- gpio GPIO number
- value See gpio_override

4.1.10.4.37. gpio_set_outover

```
void gpio_set_outover (uint gpio,
      uint value)
```

Set GPIO output override.

Parameters

- gpio GPIO number
- value See gpio_override

4.1.10.4.38. gpio_set_pulls

Select up and down pulls on specific GPIO.

Parameters

- gpio GPIO number
- up If true set a pull up on the GPIO
- down If true set a pull down on the GPIO

4.1.10.4.39. gpio_set_slew_rate

Set slew rate for a specified GPIO.

Parameters

- gpio GPIO number
- slew GPIO output slew rate

See also

• gpio_get_slew_rate

4.1.10.4.40. 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

4.1.11. hardware_i2c

I2C Controller 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.

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.

Example

```
1 // Sweep through all 7-bit I2C addresses, to see if any slaves are present on
 2 // the I2C bus. Print out a table that looks like this:
3 //
 4 // I2C Bus Scan
 5 // 0 1 2 3 4 5 6 7 8 9 A B C D E F
 6 // 0
 7 // 1
             @
8 // 2
9 // 3
                   @
10 // 4
11 // 5
12 // 6
13 // 7
14 //
15 // E.g. if slave addresses 0x12 and 0x34 were acknowledged.
16
17 #include <stdio.h>
18 #include "pico/stdlib.h"
19 #include "pico/binary_info.h"
20 #include "hardware/i2c.h"
22 // I2C reserves some addresses for special purposes. We exclude these from the scan.
23 // These are any addresses of the form 000 0xxx or 111 1xxx
24 bool reserved_addr(uint8_t addr) {
25
       return (addr & 0x78) == 0 || (addr & 0x78) == 0x78;
26 }
27
28 int main() {
    // Enable UART so we can print status output
      stdio_init_all();
31 #if !defined(i2c_default) || !defined(PICO_DEFAULT_I2C_SDA_PIN) ||
  !defined(PICO_DEFAULT_I2C_SCL_PIN)
32 #warning i2c/bus_scan example requires a board with I2C pins
puts("Default I2C pins were not defined");
34 #else
    // This example will use I2C0 on the default SDA and SCL pins (4, 5 on a Pico)
35
    i2c_init(i2c_default, 100 * 1000);
36
    gpio_set_function(PICO_DEFAULT_I2C_SDA_PIN, GPIO_FUNC_I2C);
37
38
     gpio_set_function(PICO_DEFAULT_I2C_SCL_PIN, GPIO_FUNC_I2C);
39
      gpio_pull_up(PICO_DEFAULT_I2C_SDA_PIN);
40
      gpio_pull_up(PICO_DEFAULT_I2C_SCL_PIN);
       // Make the I2C pins available to picotool
41
       bi_decl(bi_2pins_with_func(PICO_DEFAULT_I2C_SDA_PIN, PICO_DEFAULT_I2C_SCL_PIN,
42
  GPIO_FUNC_I2C));
43
       printf("\nI2C Bus Scan\n");
44
       printf(" 0 1 2 3 4 5 6 7 8 9 A B C D E F\n");
45
```

```
46
47
       for (int addr = 0; addr < (1 << 7); ++addr) {
48
           if (addr % 16 == 0) {
49
               printf("%02x ", addr);
50
51
           // Perform a 1-byte dummy read from the probe address. If a slave
53
           // acknowledges this address, the function returns the number of bytes
54
           // transferred. If the address byte is ignored, the function returns
55
           // -1.
56
57
           // Skip over any reserved addresses.
58
           int ret;
59
           uint8_t rxdata;
60
           if (reserved_addr(addr))
61
               ret = PICO_ERROR_GENERIC;
62
           else
               ret = i2c_read_blocking(i2c_default, addr, &rxdata, 1, false);
63
64
65
           printf(ret < 0 ? "." : "@");</pre>
66
           printf(addr % 16 == 15 ? "\n" : " ");
67
       printf("Done.\n");
68
69
       return 0;
70 #endif
71 }
```

4.1.11.1. Variables

• i2c_inst_t i2c0_inst

4.1.11.2. Function List

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

```
• void i2c_deinit (i2c_inst_t *i2c)
```

- uint i2c_set_baudrate (i2c_inst_t *i2c, uint baudrate)
- void i2c_set_slave_mode (i2c_inst_t *i2c, bool slave, uint8_t addr)
- static uint i2c_hw_index (i2c_inst_t *i2c)
- 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)
- int i2c_read_blocking_until (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop, absolute_time_t
 until)
- 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)
- static int i2c_read_timeout_us (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop, uint timeout_us)
- int i2c_write_blocking (i2c_inst_t *i2c, uint8_t addr, const uint8_t *src, size_t len, bool nostop)
- int i2c_read_blocking (i2c_inst_t *i2c, uint8_t addr, uint8_t *dst, size_t len, bool nostop)
- static size_t i2c_get_write_available (i2c_inst_t *i2c)
- static size_t i2c_get_read_available (i2c_inst_t *i2c)

- static void i2c_write_raw_blocking (i2c_inst_t *i2c, const uint8_t *src, size_t len)
- static void i2c_read_raw_blocking (i2c_inst_t *i2c, uint8_t *dst, size_t len)

4.1.11.3. Function Documentation

4.1.11.3.1. 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

4.1.11.3.2. i2c_get_read_available

```
static size_t i2c_get_read_available (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.

4.1.11.3.3. i2c_get_write_available

```
static size_t i2c_get_write_available (i2c_inst_t *i2c)
```

Determine non-blocking write space available.

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.

4.1.11.3.4. 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 I2C, 0 or 1.

4.1.11.3.5. i2c_init

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.

The I2C bus frequency is set as close as possible to requested, and the return actual rate set is returned

Parameters

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

Returns

· Actual set baudrate

4.1.11.3.6. i2c_read_blocking

```
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 read from
- 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.

4.1.11.3.7. i2c_read_blocking_until

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

Parameters

- i2c Either i2c0 or i2c1
- addr Address of device to read from
- 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.
- until The absolute time that the block will wait until the entire transaction is complete.

Returns

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

4.1.11.3.8. i2c_read_raw_blocking

Read direct from RX FIFO.

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

Parameters

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

4.1.11.3.9. i2c_read_timeout_us

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

Parameters

- i2c Either i2c0 or i2c1
- addr Address of device to read from
- 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 occurred.

4.1.11.3.10. i2c_set_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

4.1.11.3.11. i2c_set_slave_mode

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

4.1.11.3.12. i2c_write_blocking

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.

4.1.11.3.13. i2c_write_blocking_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 occurred.

4.1.11.3.14. i2c_write_raw_blocking

Write direct to TX FIFO.

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

Parameters

- i2c Either i2c0 or i2c1
- src Data to send
- len Number of bytes to send

4.1.11.3.15. i2c_write_timeout_us

Attempt to write specified number of bytes to address, with timeout.

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.
- timeout_us The time that the function will wait for the entire transaction to 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 occurred.

4.1.12. hardware_interp

Hardware Interpolator API

Each core is equipped with two interpolators (INTERPO 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 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.

4.1.12.1. Modules

• interp_config Interpolator configuration.

4.1.12.2. Function List

```
• void interp_claim_lane (interp_hw_t *interp, uint lane)
• void interp_claim_lane_mask (interp_hw_t *interp, uint lane_mask)
• void interp_unclaim_lane (interp_hw_t *interp, uint lane)
• bool interp_lane_is_claimed (interp_hw_t *interp, uint lane)
• void interp_unclaim_lane_mask (interp_hw_t *interp, uint lane_mask)
• static void interp_set_force_bits (interp_hw_t *interp, uint lane, uint bits)
void interp_save (interp_hw_t *interp, interp_hw_save_t *saver)
• void interp_restore (interp_hw_t *interp, interp_hw_save_t *saver)
• static void interp_set_base (interp_hw_t *interp, uint lane, uint32_t val)
• static uint32_t interp_get_base (interp_hw_t *interp, uint lane)
• static void interp_set_base_both (interp_hw_t *interp, uint32_t val)
• static void interp_set_accumulator (interp_hw_t *interp, uint lane, uint32_t val)
• static uint32_t interp_get_accumulator (interp_hw_t *interp, uint lane)
• static uint32_t interp_pop_lane_result (interp_hw_t *interp, uint lane)
• static uint32_t interp_peek_lane_result (interp_hw_t *interp, uint lane)
• static uint32_t interp_pop_full_result (interp_hw_t *interp)
• static uint32_t interp_peek_full_result (interp_hw_t *interp)
• static void interp_add_accumulater (interp_hw_t *interp, uint lane, uint32_t val)
```

• static uint32_t interp_get_raw (interp_hw_t *interp, uint lane)

4.1.12.3. Function Documentation

4.1.12.3.1. interp_add_accumulater

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

4.1.12.3.2. interp_claim_lane

Claim the interpolator lane specified.

Use this function to claim exclusive access to the specified 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.

4.1.12.3.3. interp_claim_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)

4.1.12.3.4. interp_get_accumulator

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

4.1.12.3.5. interp_get_base

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

4.1.12.3.6. interp_get_raw

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

4.1.12.3.7. interp_lane_is_claimed

Determine if an interpolator lane is claimed.

Parameters

- interp Interpolator whose lane to check
- lane The lane number, 0 or 1

Returns

· true if claimed, false otherwise

See also

- interp_claim_lane
- interp_claim_lane_mask

4.1.12.3.8. interp_peek_full_result

```
static uint32_t interp_peek_full_result (interp_hw_t *interp)
```

Read lane result.

Parameters

• interp Interpolator instance, interp0 or interp1.

Returns

• The content of the FULL register

4.1.12.3.9. interp_peek_lane_result

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

4.1.12.3.10. interp_pop_full_result

```
static uint32_t interp_pop_full_result (interp_hw_t *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

4.1.12.3.11. interp_pop_lane_result

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

4.1.12.3.12. interp_restore

Restore an interpolator state.

Parameters

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

4.1.12.3.13. interp_save

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

4.1.12.3.14. interp_set_accumulator

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

4.1.12.3.15. interp_set_base

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

4.1.12.3.16. interp_set_base_both

Sets the interpolator base registers simultaneously.

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

4.1.12.3.17. interp_set_force_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)

4.1.12.3.18. interp_unclaim_lane

Release a previously claimed interpolator lane.

Parameters

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

4.1.12.3.19. interp_unclaim_lane_mask

Release previously claimed interpolator lanes.

Parameters

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

See also

• interp_claim_lane_mask

4.1.13. interp_config

Interpolator configuration.

Each interpolator needs to be configured, these functions provide handy helpers to set up configuration structures.

4.1.13.1. Function List

```
static void interp_config_set_shift (interp_config *c, uint shift)
static void interp_config_set_mask (interp_config *c, uint mask_lsb, uint mask_msb)
static void interp_config_set_cross_input (interp_config *c, bool cross_input)
static void interp_config_set_cross_result (interp_config *c, bool cross_result)
static void interp_config_set_signed (interp_config *c, bool _signed)
static void interp_config_set_add_raw (interp_config *c, bool add_raw)
static void interp_config_set_blend (interp_config *c, bool blend)
static void interp_config_set_clamp (interp_config *c, bool clamp)
static void interp_config_set_force_bits (interp_config *c, uint bits)
static interp_config interp_default_config (void)
static void interp_set_config (interp_hw_t *interp, uint lane, interp_config *config)
```

4.1.13.2. Function Documentation

4.1.13.2.1. interp_config_set_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.

4.1.13.2.2. interp_config_set_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.

4.1.13.2.3. interp_config_set_clamp

```
static void interp_config_set_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

4.1.13.2.4. interp_config_set_cross_input

```
static void interp_config_set_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_set_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.

4.1.13.2.5. interp_config_set_cross_result

```
static void interp_config_set_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

4.1.13.2.6. interp_config_set_force_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)

4.1.13.2.7. interp_config_set_mask

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

4.1.13.2.8. interp_config_set_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

4.1.13.2.9. interp_config_set_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

4.1.13.2.10. interp_default_config

```
static interp_config interp_default_config (void)
```

Get a default configuration.

Returns

• A default interpolation configuration

4.1.13.2.11. interp_set_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

4.1.14. hardware_irq

Hardware interrupt handling

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.

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

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).

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	PI00_IRQ_0
8	PI00_IRQ_1
9	PIO1_IRQ_0
10	PIO1_IRQ_1
11	DMA_IRQ_0
12	DMA_IRQ_1

IRQ	Interrupt Source
13	IO_IRQ_BANK0
14	IO_IRQ_QSPI
15	SIO_IRQ_PROC0
16	SIO_IRQ_PROC1
17	CLOCKS_IRQ
18	SPI0_IRQ
19	SPI1_IRQ
20	UART0_IRQ
21	UART1_IRQ
22	ADC0_IRQ_FIFO
23	I2C0_IRQ
24	I2C1_IRQ
25	RTC_IRQ

4.1.14.1. Typedefs

• typedef void(* irq_handler_t)(void) Interrupt handler function type.

4.1.14.2. Function List

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

```
• void irq_set_enabled (uint num, bool enabled)
```

- bool irq_is_enabled (uint num)
- void irq_set_mask_enabled (uint32_t mask, bool enabled)
- void irq_set_exclusive_handler (uint num, irq_handler_t handler)
- irq_handler_t irq_get_exclusive_handler (uint num)
- void irq_add_shared_handler (uint num, irq_handler_t handler, uint8_t order_priority)
- void irq_remove_handler (uint num, irq_handler_t handler)
- irq_handler_t irq_get_vtable_handler (uint num)
- static void irq_clear (uint int_num)
- void irq_set_pending (uint num)

4.1.14.3. Function Documentation

4.1.14.3.1. 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()

4.1.14.3.2. irq_clear

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

Clear a specific interrupt on the executing core.

Parameters

int_num Interrupt number Interrupt Numbers

4.1.14.3.3. irq_get_exclusive_handler

```
irq_handler_t irq_get_exclusive_handler (uint num)
```

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

This method will return an exclusive IRQ handler set on this core by irq_set_exclusive_handler if there is one.

Parameters

• num Interrupt number Interrupt Numbers

Returns

 handler The handler if an exclusive handler is set for the IRQ, NULL if no handler is set or shared/shareable handlers are installed

See also

• irq_set_exclusive_handler()

4.1.14.3.4. 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

4.1.14.3.5. 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

Returns

• true if the interrupt is enabled

4.1.14.3.6. irq_remove_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

Parameters

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

See also

- irq_set_exclusive_handler()
- irq_add_shared_handler()

4.1.14.3.7. irq_set_enabled

Enable or disable a specific interrupt on the executing core.

Parameters

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

4.1.14.3.8. irq_set_exclusive_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 irg_handler_t

See also

irg_add_shared_handler()

4.1.14.3.9. irq_set_mask_enabled

Enable/disable multiple interrupts on the executing core.

Parameters

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

4.1.14.3.10. irq_set_pending

```
void irq_set_pending (uint num)
```

Force an interrupt to pending on the executing core.

This should generally not be used for IRQs connected to hardware.

Parameters

• num Interrupt number Interrupt Numbers

4.1.14.3.11. irq_set_priority

Set specified interrupts priority.

Parameters

- num Interrupt number
- hardware_priority Priority to set. Numerically-lower values indicate a higher priority. Hardware priorities range from
 0 (highest priority) to 255 (lowest priority) 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

4.1.15. hardware_pio

Programmable I/O (PIO) 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

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.

4.1.15.1. Modules

sm_config

PIO state machine configuration.

4.1.15.2. Enumerations

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

```
• enum pio_mov_status_type { STATUS_TX_LESSTHAN = 0, STATUS_RX_LESSTHAN = 1 } MOV status types.
```

```
    enum pio_interrupt_source { pis_interrupt0 = PIO_INTR_SM0_LSB, pis_interrupt1 = PIO_INTR_SM1_LSB, pis_interrupt2 = PIO_INTR_SM2_LSB, pis_interrupt3 = PIO_INTR_SM3_LSB, pis_sm0_tx_fifo_not_ful1 = PIO_INTR_SM0_TXNFULL_LSB, pis_sm1_tx_fifo_not_ful1 = PIO_INTR_SM1_TXNFULL_LSB, pis_sm2_tx_fifo_not_ful1 = PIO_INTR_SM2_TXNFULL_LSB, pis_sm3_tx_fifo_not_ful1 = PIO_INTR_SM3_TXNFULL_LSB, pis_sm0_rx_fifo_not_empty = PIO_INTR_SM0_RXNEMPTY_LSB, pis_sm1_rx_fifo_not_empty = PIO_INTR_SM1_RXNEMPTY_LSB, pis_sm3_rx_fifo_not_empty = PIO_INTR_SM3_RXNEMPTY_LSB, pis_sm3_rx_fifo_not_empty = PIO_INTR_SM3_RXNEMPTY_LSB, PI
```

4.1.15.3. Macros

• #define pio0 pio0_hw

4.1.15.4. Macros

• #define pio1 pio1_hw

4.1.15.5. Function List

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

- static uint pio_get_index (PIO pio)
- static void pio_gpio_init (PIO pio, uint pin)
- static uint pio_get_dreq (PIO pio, uint sm, bool is_tx)
- bool pio_can_add_program (PIO pio, const pio_program_t *program)
- bool pio_can_add_program_at_offset (PIO pio, const pio_program_t *program, uint offset)
- uint pio_add_program (PIO pio, const pio_program_t *program)
- void pio_add_program_at_offset (PIO pio, const pio_program_t *program, uint offset)

```
• void pio_remove_program (PIO pio, const pio_program_t *program, uint loaded_offset)
void pio_clear_instruction_memory (PIO pio)
• void pio_sm_init (PIO pio, uint sm, uint initial_pc, const pio_sm_config *config)
• static void pio_sm_set_enabled (PIO pio, uint sm, bool enabled)
• static void pio set sm mask enabled (PIO pio, uint32 t mask, bool enabled)
• static void pio_sm_restart (PIO pio, uint sm)
static void pio_restart_sm_mask (PIO pio, uint32_t mask)
• static void pio_sm_clkdiv_restart (PIO pio, uint sm)
• static void pio_clkdiv_restart_sm_mask (PIO pio, uint32_t mask)
• static void pio_enable_sm_mask_in_sync (PIO pio, uint32_t mask)

    static void pio_set_irq0_source_enabled (PIO pio, enum pio_interrupt_source source, bool enabled)

• static void pio_set_irq1_source_enabled (PIO pio, enum pio_interrupt_source source, bool enabled)
• static void pio_set_irq0_source_mask_enabled (PIO pio, uint32_t source_mask, bool enabled)
• static void pio_set_irq1_source_mask_enabled (PIO pio, uint32_t source_mask, bool enabled)
• static void pio_set_irqn_source_enabled (PIO pio, uint irq_index, enum pio_interrupt_source source, bool enabled)
• static void pio_set_irqn_source_mask_enabled (PIO pio, uint irq_index, uint32_t source_mask, bool enabled)
• static bool pio_interrupt_get (PIO pio, uint pio_interrupt_num)
• static void pio_interrupt_clear (PIO pio, uint pio_interrupt_num)
• static uint8_t pio_sm_get_pc (PIO pio, uint sm)
• static void pio_sm_exec (PIO pio, uint sm, uint instr)
• static bool pio_sm_is_exec_stalled (PIO pio, uint sm)
• static void pio_sm_exec_wait_blocking (PIO pio, uint sm, uint instr)
• static void pio_sm_set_wrap (PIO pio, uint sm, uint wrap_target, uint wrap)
• static void pio_sm_put (PIO pio, uint sm, uint32_t data)
• static uint32_t pio_sm_get (PIO pio, uint sm)
• static bool pio_sm_is_rx_fifo_full (PIO pio, uint sm)
• static bool pio_sm_is_rx_fifo_empty (PIO pio, uint sm)
• static uint pio_sm_get_rx_fifo_level (PIO pio, uint sm)
• static bool pio_sm_is_tx_fifo_full (PIO pio, uint sm)
static bool pio_sm_is_tx_fifo_empty (PIO pio, uint sm)
• static uint pio_sm_get_tx_fifo_level (PIO pio, uint sm)
• static void pio_sm_put_blocking (PIO pio, uint sm, uint32_t data)
• static uint32_t pio_sm_get_blocking (PIO pio, uint sm)
• void pio_sm_drain_tx_fifo (PIO pio, uint sm)
static void pio_sm_set_clkdiv_int_frac (PIO pio, uint sm, uint16_t div_int, uint8_t div_frac)
• static void pio_sm_set_clkdiv (PIO pio, uint sm, float div)
```

4.1. Hardware APIs

• static void pio_sm_clear_fifos (PIO pio, uint sm)

```
• void pio_sm_set_pins (PIO pio, uint sm, uint32_t pin_values)
```

- void pio_sm_set_pins_with_mask (PIO pio, uint sm, uint32_t pin_values, uint32_t pin_mask)
- void pio_sm_set_pindirs_with_mask (PIO pio, uint sm, uint32_t pin_dirs, uint32_t pin_mask)
- void pio_sm_set_consecutive_pindirs (PIO pio, uint sm, uint pin_base, uint pin_count, bool is_out)
- void pio_sm_claim (PIO pio, uint sm)
- void pio_claim_sm_mask (PIO pio, uint sm_mask)
- void pio_sm_unclaim (PIO pio, uint sm)
- int pio_claim_unused_sm (PIO pio, bool required)
- bool pio_sm_is_claimed (PIO pio, uint sm)

4.1.15.6. Function Documentation

4.1.15.6.1. pio_add_program

Attempt to load the program, panicking if not possible.

Parameters

- pio The PIO instance; either pio0 or pio1
- program the program definition

Returns

• the instruction memory offset the program is loaded at

See also

• pio_can_add_program() if you need to check whether the program can be loaded

4.1.15.6.2. pio_add_program_at_offset

Attempt to load the program at the specified instruction memory offset, panicking if not possible.

Parameters

- pio The PIO instance; either pio0 or pio1
- program the program definition
- offset the instruction memory offset wanted for the start of the program

See also

• pio_can_add_program_at_offset() if you need to check whether the program can be loaded

4.1.15.6.3. pio_can_add_program

Determine whether the given program can (at the time of the call) be loaded onto the PIO instance.

Parameters

- pio The PIO instance; either pio0 or pio1
- program the program definition

Returns

• true if the program can be loaded; false if there is not suitable space in the instruction memory

4.1.15.6.4. pio_can_add_program_at_offset

Determine whether the given program can (at the time of the call) be loaded onto the PIO instance starting at a particular location.

Parameters

- pio The PIO instance; either pio0 or pio1
- program the program definition
- offset the instruction memory offset wanted for the start of the program

Returns

• true if the program can be loaded at that location; false if there is not space in the instruction memory

4.1.15.6.5. pio_claim_sm_mask

```
void pio_claim_sm_mask (PIO pio,
     uint sm_mask)
```

Mark multiple state machines as used.

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

Parameters

- pio The PIO instance; either pio0 or pio1
- sm_mask Mask of state machine indexes

4.1.15.6.6. pio_claim_unused_sm

Claim a free state machine on a PIO instance.

Parameters

- pio The PIO instance; either pio0 or pio1
- required if true the function will panic if none are available

Returns

• the state machine index or -1 if required was false, and none were free

4.1.15.6.7. pio_clear_instruction_memory

```
void pio_clear_instruction_memory (PIO pio)
```

Clears all of a PIO instance's instruction memory.

Parameters

• pio The PIO instance; either pio0 or pio1

4.1.15.6.8. pio_clkdiv_restart_sm_mask

Restart multiple state machines' clock dividers from a phase of 0.

Each state machine's clock divider is a free-running piece of hardware, that generates a pattern of clock enable pulses for the state machine, based on the configured integer/fractional divisor. The pattern of running/halted cycles slows the state machine's execution to some controlled rate.

This function simultaneously clears the integer and fractional phase accumulators of multiple state machines' clock dividers. If these state machines all have the same integer and fractional divisors configured, their clock dividers will run in precise deterministic lockstep from this point.

With their execution clocks synchronised in this way, it is then safe to e.g. have multiple state machines performing a 'wait irq' on the same flag, and all clear it on the same cycle.

Also note that this function can be called whilst state machines are running (e.g. if you have just changed the clock divisors of some state machines and wish to resynchronise them), and that disabling a state machine does not halt its clock divider: that is, if multiple state machines have their clocks synchronised, you can safely disable and reenable one of the state machines without losing synchronisation.

Parameters

- pio The PIO instance; either pio0 or pio1
- mask bit mask of state machine indexes to modify the enabled state of

4.1.15.6.9. pio_enable_sm_mask_in_sync

Enable multiple PIO state machines synchronizing their clock dividers.

This is equivalent to calling both pio_set_sm_mask_enabled() and pio_clkdiv_restart_sm_mask() on the clock cycle. All state machines specified by 'mask' are started simultaneously and, assuming they have the same clock divisors, their divided clocks will stay precisely synchronised.

Parameters

- pio The PIO instance; either pio0 or pio1
- ${}^{\bullet}$ ${}_{\mbox{\scriptsize mask}}$ bit mask of state machine indexes to modify the enabled state of

4.1.15.6.10. pio_get_dreq

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

Return the DREQ to use for pacing transfers to a particular state machine.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- · is_tx true for sending data to the state machine, false for received data from the state machine

4.1.15.6.11. pio_get_index

```
static uint pio_get_index (PIO pio)
```

Return the instance number of a PIO instance.

Parameters

• pio The PIO instance; either pio0 or pio1

Returns

• the PIO instance number (either 0 or 1)

4.1.15.6.12. pio_gpio_init

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

Setup the function select for a GPIO to use output from the given PIO instance.

PIO appears as an alternate function in the GPIO muxing, just like an SPI or UART. This function configures that multiplexing to connect a given PIO instance to a GPIO. Note that this is not necessary for a state machine to be able to read the value from a GPIO, but only for it to set the output value or output enable.

Parameters

- pio The PIO instance; either pio0 or pio1
- pin the GPIO pin whose function select to set

4.1.15.6.13. pio_interrupt_clear

Clear a particular PIO interrupt.

Parameters

- pio The PIO instance; either pio0 or pio1
- pio_interrupt_num the PIO interrupt number 0-7

4.1.15.6.14. pio_interrupt_get

Determine if a particular PIO interrupt is set.

Parameters

- pio The PIO instance; either pio0 or pio1
- pio_interrupt_num the PIO interrupt number 0-7

Returns

• true if corresponding PIO interrupt is currently set

4.1.15.6.15. pio_remove_program

Remove a program from a PIO instance's instruction memory.

Parameters

- pio The PIO instance; either pio0 or pio1
- program the program definition
- loaded_offset the loaded offset returned when the program was added

4.1.15.6.16. pio_restart_sm_mask

Restart multiple state machine with a known state.

This method clears the ISR, shift counters, clock divider counter pin write flags, delay counter, latched EXEC instruction, and IRQ wait condition.

Parameters

- pio The PIO instance; either pio0 or pio1
- mask bit mask of state machine indexes to modify the enabled state of

4.1.15.6.17. pio_set_irq0_source_enabled

Enable/Disable a single source on a PIO's IRQ 0.

Parameters

- pio The PIO instance; either pio0 or pio1
- source the source number (see pio_interrupt_source)
- enabled true to enable IRQ 0 for the source, false to disable.

4.1.15.6.18. pio_set_irq0_source_mask_enabled

Enable/Disable multiple sources on a PIO's IRQ 0.

Parameters

- pio The PIO instance; either pio0 or pio1
- source_mask Mask of bits, one for each source number (see pio_interrupt_source) to affect
- enabled true to enable all the sources specified in the mask on IRQ 0, false to disable all the sources specified in the mask on IRQ 0

4.1.15.6.19. pio_set_irq1_source_enabled

Enable/Disable a single source on a PIO's IRQ 1.

Parameters

- pio The PIO instance; either pio0 or pio1
- source the source number (see pio_interrupt_source)
- enabled true to enable IRQ 0 for the source, false to disable.

4.1.15.6.20. pio_set_irq1_source_mask_enabled

Enable/Disable multiple sources on a PIO's IRQ 1.

Parameters

- pio The PIO instance; either pio0 or pio1
- source_mask Mask of bits, one for each source number (see pio_interrupt_source) to affect
- enabled true to enable all the sources specified in the mask on IRQ 1, false to disable all the source specified in the mask on IRQ 1

4.1.15.6.21. pio_set_irqn_source_enabled

```
static void pio_set_irqn_source_enabled (PIO pio,
    uint irq_index,
    enum pio_interrupt_source source,
    bool enabled)
```

Enable/Disable a single source on a PIO's specified (0/1) IRQ index.

Parameters

- pio The PIO instance; either pio0 or pio1
- irq_index the IRQ index; either 0 or 1
- source the source number (see pio_interrupt_source)
- enabled true to enable the source on the specified IRQ, false to disable.

4.1.15.6.22. pio_set_irqn_source_mask_enabled

Enable/Disable multiple sources on a PIO's specified (0/1) IRQ index.

Parameters

- pio The PIO instance; either pio0 or pio1
- irq_index the IRQ index; either 0 or 1

- source_mask Mask of bits, one for each source number (see pio_interrupt_source) to affect
- enabled true to enable all the sources specified in the mask on the specified IRQ, false to disable all the sources specified in the mask on the specified IRQ

4.1.15.6.23. pio_set_sm_mask_enabled

Enable or disable multiple PIO state machines.

Note that this method just sets the enabled state of the state machine; if now enabled they continue exactly from where they left off.

Parameters

- pio The PIO instance; either pio0 or pio1
- mask bit mask of state machine indexes to modify the enabled state of
- enabled true to enable the state machines; false to disable

See also

 pio_enable_sm_mask_in_sync() if you wish to enable multiple state machines and ensure their clock dividers are in sync.

4.1.15.6.24. pio_sm_claim

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

Mark a state machine as used.

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

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.15.6.25. pio_sm_clear_fifos

Clear a state machine's TX and RX FIFOs.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.15.6.26. pio_sm_clkdiv_restart

Restart a state machine's clock divider from a phase of 0.

Each state machine's clock divider is a free-running piece of hardware, that generates a pattern of clock enable pulses

for the state machine, based on the configured integer/fractional divisor. The pattern of running/halted cycles slows the state machine's execution to some controlled rate.

This function clears the divider's integer and fractional phase accumulators so that it restarts this pattern from the beginning. It is called automatically by pio_sm_init() but can also be called at a later time, when you enable the state machine, to ensure precisely consistent timing each time you load and run a given PIO program.

More commonly this hardware mechanism is used to synchronise the execution clocks of multiple state machines see pio_clkdiv_restart_sm_mask().

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.15.6.27. pio_sm_drain_tx_fifo

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

Empty out a state machine's TX FIFO.

This method executes pull instructions on the state machine until the TX FIFO is empty. This disturbs the contents of the OSR, so see also pio_sm_clear_fifos() which clears both FIFOs but leaves the state machine's internal state undisturbed.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

See also

pio_sm_clear_fifos()

4.1.15.6.28. pio_sm_exec

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

Immediately execute an instruction on a state machine.

This instruction is executed instead of the next instruction in the normal control flow on the state machine. Subsequent calls to this method replace the previous executed instruction if it is still running.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- instr the encoded PIO instruction

See also

• pio_sm_is_exec_stalled() to see if an executed instruction is still running (i.e. it is stalled on some condition)

4.1.15.6.29. pio_sm_exec_wait_blocking

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

Immediately execute an instruction on a state machine and wait for it to complete.

This instruction is executed instead of the next instruction in the normal control flow on the state machine. Subsequent calls to this method replace the previous executed instruction if it is still running.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- instr the encoded PIO instruction

See also

pio_sm_is_exec_stalled() to see if an executed instruction is still running (i.e. it is stalled on some condition)

4.1.15.6.30. pio_sm_get

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

Read a word of data from a state machine's RX FIFO.

This is a raw FIFO access that does not check for emptiness. If the FIFO is empty, the hardware ignores the attempt to read from the FIFO (the FIFO remains in an empty state following the read) and the sticky RXUNDER flag for this FIFO is set in FDEBUG to indicate that the system tried to read from this FIFO when empty. The data returned by this function is undefined when the FIFO is empty.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

See also

pio_sm_get_blocking()

4.1.15.6.31. pio_sm_get_blocking

Read a word of data from a state machine's RX FIFO, blocking if the FIFO is empty.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.15.6.32. pio_sm_get_pc

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

Return the current program counter for a state machine.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

the program counter

4.1.15.6.33. pio_sm_get_rx_fifo_level

Return the number of elements currently in a state machine's RX FIFO.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• the number of elements in the RX FIFO

4.1.15.6.34. pio_sm_get_tx_fifo_level

Return the number of elements currently in a state machine's TX FIFO.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• the number of elements in the TX FIFO

4.1.15.6.35. pio_sm_init

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

Resets the state machine to a consistent state, and configures it.

This method:

The state machine is left disabled on return from this call.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- initial_pc the initial program memory offset to run from
- config the configuration to apply (or NULL to apply defaults)

4.1.15.6.36. pio_sm_is_claimed

```
bool pio_sm_is_claimed (PIO pio,
            uint sm)
```

Determine if a PIO state machine is claimed.

Parameters

• pio The PIO instance; either pio0 or pio1

• sm State machine index (0..3)

Returns

• true if claimed, false otherwise

See also

- pio_sm_claim
- pio_claim_sm_mask

4.1.15.6.37. pio_sm_is_exec_stalled

Determine if an instruction set by pio_sm_exec() is stalled executing.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• true if the executed instruction is still running (stalled)

4.1.15.6.38. pio_sm_is_rx_fifo_empty

Determine if a state machine's RX FIFO is empty.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• true if the RX FIFO is empty

4.1.15.6.39. pio_sm_is_rx_fifo_full

Determine if a state machine's RX FIFO is full.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• true if the RX FIFO is full

4.1.15.6.40. pio_sm_is_tx_fifo_empty

Determine if a state machine's TX FIFO is empty.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• true if the TX FIFO is empty

4.1.15.6.41. pio_sm_is_tx_fifo_full

Determine if a state machine's TX FIFO is full.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

Returns

• true if the TX FIFO is full

4.1.15.6.42. pio_sm_put

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

Write a word of data to a state machine's TX FIFO.

This is a raw FIFO access that does not check for fullness. If the FIFO is full, the FIFO contents and state are not affected by the write attempt. Hardware sets the TXOVER sticky flag for this FIFO in FDEBUG, to indicate that the system attempted to write to a full FIFO.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- data the 32 bit data value

See also

• pio_sm_put_blocking()

4.1.15.6.43. pio_sm_put_blocking

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

Write a word of data to a state machine's TX FIFO, blocking if the FIFO is full.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

• data the 32 bit data value

4.1.15.6.44. pio_sm_restart

Restart a state machine with a known state.

This method clears the ISR, shift counters, clock divider counter pin write flags, delay counter, latched EXEC instruction, and IRQ wait condition.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.15.6.45. pio_sm_set_clkdiv

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

set the current clock divider for a state machine

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- div the floating point clock divider

4.1.15.6.46. pio_sm_set_clkdiv_int_frac

set the current clock divider for a state machine using a 16:8 fraction

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- div_int the integer part of the clock divider
- div_frac the fractional part of the clock divider in 1/256s

4.1.15.6.47. pio_sm_set_config

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

Apply a state machine configuration to a state machine.

Parameters

• pio Handle to PIO instance; either pio0 or pio1

- sm State machine index (0..3)
- config the configuration to apply

4.1.15.6.48. pio_sm_set_consecutive_pindirs

```
void pio_sm_set_consecutive_pindirs (PIO pio,
     uint sm,
     uint pin_base,
     uint pin_count,
     bool is out)
```

Use a state machine to set the same pin direction for multiple consecutive pins for the PIO instance.

This method repeatedly reconfigures the target state machine's pin configuration and executes 'set' instructions to set the pin direction on consecutive pins, before restoring the state machine's pin configuration to what it was.

This method is provided as a convenience to set initial pin directions, and should not be used against a state machine that is enabled.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3) to use
- pin_base the first pin to set a direction for
- pin_count the count of consecutive pins to set the direction for
- is_out the direction to set; true = out, false = in

4.1.15.6.49. pio_sm_set_enabled

Enable or disable a PIO state machine.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- enabled true to enable the state machine; false to disable

4.1.15.6.50. pio_sm_set_pindirs_with_mask

```
void pio_sm_set_pindirs_with_mask (PIO pio,
     uint sm,
     uint32_t pin_dirs,
     uint32_t pin_mask)
```

Use a state machine to set the pin directions for multiple pins for the PIO instance.

This method repeatedly reconfigures the target state machine's pin configuration and executes 'set' instructions to set pin directions on up to 32 pins, before restoring the state machine's pin configuration to what it was.

This method is provided as a convenience to set initial pin directions, and should not be used against a state machine that is enabled.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3) to use
- pin_dirs the pin directions to set 1 = out, 0 = in (if the corresponding bit in pin_mask is set)
- pin_mask a bit for each pin to indicate whether the corresponding pin_value for that pin should be applied.

4.1.15.6.51. pio_sm_set_pins

```
void pio_sm_set_pins (PIO pio,
     uint sm,
     uint32_t pin_values)
```

Use a state machine to set a value on all pins for the PIO instance.

This method repeatedly reconfigures the target state machine's pin configuration and executes 'set' instructions to set values on all 32 pins, before restoring the state machine's pin configuration to what it was.

This method is provided as a convenience to set initial pin states, and should not be used against a state machine that is enabled.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3) to use
- pin_values the pin values to set

4.1.15.6.52. pio_sm_set_pins_with_mask

```
void pio_sm_set_pins_with_mask (PIO pio,
     uint sm,
     uint32_t pin_values,
     uint32_t pin_mask)
```

Use a state machine to set a value on multiple pins for the PIO instance.

This method repeatedly reconfigures the target state machine's pin configuration and executes 'set' instructions to set values on up to 32 pins, before restoring the state machine's pin configuration to what it was.

This method is provided as a convenience to set initial pin states, and should not be used against a state machine that is enabled.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3) to use
- pin_values the pin values to set (if the corresponding bit in pin_mask is set)
- pin_mask a bit for each pin to indicate whether the corresponding pin_value for that pin should be applied.

4.1.15.6.53. pio_sm_set_wrap

```
static void pio_sm_set_wrap (PIO pio,
     uint sm,
     uint wrap_target,
     uint wrap)
```

Set the current wrap configuration for a state machine.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- wrap_target the instruction memory address to wrap to
- wrap the instruction memory address after which to set the program counter to wrap_target if the instruction does not itself update the program_counter

4.1.15.6.54. pio_sm_unclaim

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

Mark a state machine as no longer used.

Method for cooperative claiming of hardware.

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)

4.1.16. sm_config

PIO state machine configuration.

A PIO block needs to be configured, these functions provide helpers to set up configuration structures. See pio_sm_set_config

4.1.16.1. Data Structures

struct pio_sm_config
 PIO Configuration structure.

4.1.16.2. Function List

```
• static void sm_config_set_out_pins (pio_sm_config *c, uint out_base, uint out_count)
```

- static void sm_config_set_set_pins (pio_sm_config *c, uint set_base, uint set_count)
- static void sm_config_set_in_pins (pio_sm_config *c, uint in_base)
- static void sm_config_set_sideset_pins (pio_sm_config *c, uint sideset_base)
- static void sm_config_set_sideset (pio_sm_config *c, uint bit_count, bool optional, bool pindirs)
- static void sm_config_set_clkdiv_int_frac (pio_sm_config *c, uint16_t div_int, uint8_t div_frac)
- static void sm_config_set_clkdiv (pio_sm_config *c, float div)
- static void sm_config_set_wrap (pio_sm_config *c, uint wrap_target, uint wrap)
- static void sm_config_set_jmp_pin (pio_sm_config *c, uint pin)
- static void sm_config_set_in_shift (pio_sm_config *c, bool shift_right, bool autopush, uint push_threshold)
- static void sm_config_set_out_shift (pio_sm_config *c, bool shift_right, bool autopull, uint pull_threshold)
- static void sm_config_set_fifo_join (pio_sm_config *c, enum pio_fifo_join join)
- static void sm_config_set_out_special (pio_sm_config *c, bool sticky, bool has_enable_pin, uint enable_pin_index)
- static void sm_config_set_mov_status (pio_sm_config *c, enum pio_mov_status_type status_sel, uint status_n)

- static pio_sm_config pio_get_default_sm_config (void)
- static void pio_sm_set_out_pins (PIO pio, uint sm, uint out_base, uint out_count)
- static void pio_sm_set_set_pins (PIO pio, uint sm, uint set_base, uint set_count)
- static void pio_sm_set_in_pins (PIO pio, uint sm, uint in_base)
- static void pio_sm_set_sideset_pins (PIO pio, uint sm, uint sideset_base)

4.1.16.3. Function Documentation

4.1.16.3.1. pio_get_default_sm_config

static pio_sm_config pio_get_default_sm_config (void)

Get the default state machine configuration.

Setting	Default
Out Pins	32 starting at 0
Set Pins	0 starting at 0
In Pins (base)	0
Side Set Pins (base)	0
Side Set	disabled
Wrap	wrap=31, wrap_to=0
In Shift	shift_direction=right, autopush=false, push_thrshold=32
Out Shift	shift_direction=right, autopull=false, pull_thrshold=32
Jmp Pin	0
Out Special	sticky=false, has_enable_pin=false, enable_pin_index=0
Mov Status	status_sel=STATUS_TX_LESSTHAN, n=0

Returns

• the default state machine configuration which can then be modified.

4.1.16.3.2. pio_sm_set_in_pins

```
static void pio_sm_set_in_pins (PIO pio,
    uint sm,
    uint in_base)
```

Set the current 'in' pins for a state machine.

Can overlap with the 'out', "set' and 'sideset' pins

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- in_base 0-31 First pin to use as input

4.1.16.3.3. pio_sm_set_out_pins

```
static void pio_sm_set_out_pins (PIO pio,
     uint sm,
     uint out_base,
     uint out_count)
```

Set the current 'out' pins for a state machine.

Can overlap with the 'in', 'set' and 'sideset' pins

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- out_base 0-31 First pin to set as output
- out_count 0-32 Number of pins to set.

4.1.16.3.4. pio_sm_set_set_pins

```
static void pio_sm_set_set_pins (PIO pio,
     uint sm,
     uint set_base,
     uint set_count)
```

Set the current 'set' pins for a state machine.

Can overlap with the 'in', 'out' and 'sideset' pins

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- set_base 0-31 First pin to set as
- set_count 0-5 Number of pins to set.

4.1.16.3.5. pio_sm_set_sideset_pins

```
static void pio_sm_set_sideset_pins (PIO pio,
     uint sm,
     uint sideset_base)
```

Set the current 'sideset' pins for a state machine.

Can overlap with the 'in', 'out' and 'set' pins

Parameters

- pio The PIO instance; either pio0 or pio1
- sm State machine index (0..3)
- sideset_base 0-31 base pin for 'side set'

4.1.16.3.6. sm_config_set_clkdiv

Set the state machine clock divider (from a floating point value) in a state machine configuration.

The clock divider slows the state machine's execution by masking the system clock on some cycles, in a repeating

pattern, so that the state machine does not advance. Effectively this produces a slower clock for the state machine to run from, which can be used to generate e.g. a particular UART baud rate. See the datasheet for further detail.

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.

4.1.16.3.7. sm_config_set_clkdiv_int_frac

Set the state machine clock divider (from integer and fractional parts - 16:8) in a state machine configuration.

The clock divider can slow the state machine's execution to some rate below the system clock frequency, by enabling the state machine on some cycles but not on others, in a regular pattern. This can be used to generate e.g. a given UART baud rate. See the datasheet for further detail.

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_set_clkdiv()

4.1.16.3.8. sm_config_set_fifo_join

Setup the FIFO joining in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- join Specifies the join type.

See also

• enum pio_fifo_join

4.1.16.3.9. sm_config_set_in_pins

Set the 'in' pins in a state machine configuration.

Can overlap with the 'out', "set' and 'sideset' pins

Parameters

- c Pointer to the configuration structure to modify
- in_base 0-31 First pin to use as input

4.1.16.3.10. sm_config_set_in_shift

Setup 'in' shifting parameters in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- shift_right true to shift ISR to right, false to shift ISR to left
- autopush whether autopush is enabled
- push_threshold threshold in bits to shift in before auto/conditional re-pushing of the ISR

4.1.16.3.11. sm_config_set_jmp_pin

Set the 'jmp' pin in a state machine configuration.

Parameters

- · c Pointer to the configuration structure to modify
- pin The raw GPIO pin number to use as the source for a jmp pin instruction

4.1.16.3.12. sm_config_set_mov_status

Set source for 'mov status' in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- status_sel the status operation selector.
- status_n parameter for the mov status operation (currently a bit count)

See also

• enum pio_mov_status_type

4.1.16.3.13. sm_config_set_out_pins

```
static void sm_config_set_out_pins (pio_sm_config *c,
          uint out_base,
          uint out_count)
```

Set the 'out' pins in a state machine configuration.

Can overlap with the 'in', 'set' and 'sideset' 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.

4.1.16.3.14. sm_config_set_out_shift

Setup 'out' shifting parameters in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- shift_right true to shift OSR to right, false to shift OSR to left
- autopull whether autopull is enabled
- pull_threshold threshold in bits to shift out before auto/conditional re-pulling of the OSR

4.1.16.3.15. sm_config_set_out_special

Set special 'out' operations in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- sticky to enable 'sticky' output (i.e. re-asserting most recent OUT/SET pin values on subsequent cycles)
- has_enable_pin true to enable auxiliary OUT enable pin
- enable_pin_index pin index for auxiliary OUT enable

4.1.16.3.16. sm_config_set_set_pins

```
static void sm_config_set_set_pins (pio_sm_config *c,
     uint set_base,
     uint set_count)
```

Set the 'set' pins in a state machine configuration.

Can overlap with the 'in', 'out' and 'sideset' pins

Parameters

- c Pointer to the configuration structure to modify
- set_base 0-31 First pin to set as
- set_count 0-5 Number of pins to set.

4.1.16.3.17. sm_config_set_sideset

Set the 'sideset' options in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- bit_count Number of bits to steal from delay field in the instruction for use of side set (max 5)
- optional True if the topmost side set bit is used as a flag for whether to apply side set on that instruction
- pindirs True if the side set affects pin directions rather than values

4.1.16.3.18. sm_config_set_sideset_pins

Set the 'sideset' pins in a state machine configuration.

Can overlap with the 'in', 'out' and 'set' pins

Parameters

- c Pointer to the configuration structure to modify
- sideset_base 0-31 base pin for 'side set'

4.1.16.3.19. sm_config_set_wrap

```
static void sm_config_set_wrap (pio_sm_config *c,
     uint wrap_target,
     uint wrap)
```

Set the wrap addresses in a state machine configuration.

Parameters

- c Pointer to the configuration structure to modify
- wrap_target the instruction memory address to wrap to
- wrap the instruction memory address after which to set the program counter to wrap_target if the instruction does
 not itself update the program_counter

4.1.17. hardware_pll

Phase Locked Loop control APIs

There are two PLLs in RP2040. They are:

- pll_sys Used to generate up to a 133MHz 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.

4.1.17.1. Function List

- void pll_init (PLL pll, uint ref_div, uint vco_freq, uint post_div1, uint post_div2)
- void pll_deinit (PLL pll)

4.1.17.2. Function Documentation

4.1.17.2.1. pll_deinit

```
void pll_deinit (PLL pll)
```

Release/uninitialise specified PLL.

This will turn off the power to the specified PLL. Note this function does not currently check if the PLL is in use before powering it off so should be used with care.

Parameters

• pll pll_sys or pll_usb

4.1.17.2.2. pll_init

```
void pll_init (PLL pll,
     uint ref_div,
     uint vco_freq,
     uint post_div1,
     uint post_div2)
```

Initialise specified PLL.

Parameters

- pll pll_sys or pll_usb
- ref_div Input clock divider.
- vco_freq Requested output from the VCO (voltage controlled oscillator)
- post_div1 Post Divider 1 range 1-7. Must be >= post_div2
- post_div2 Post Divider 2 range 1-7

4.1.18. hardware_pwm

Hardware Pulse Width Modulation (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

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_set_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.

Example

```
1 // Output PWM signals on pins 0 and 1
2
3 #include "pico/stdlib.h"
4 #include "hardware/pwm.h"
5
6 int main() {
7
8 // Tell GPIO 0 and 1 they are allocated to the PWM
```

```
gpio_set_function(0, GPIO_FUNC_PWM);
a
       gpio_set_function(1, GPIO_FUNC_PWM);
10
11
      // Find out which PWM slice is connected to GPIO 0 (it's slice 0)
12
13
      uint slice_num = pwm_gpio_to_slice_num(0);
14
      // Set period of 4 cycles (0 to 3 inclusive)
15
      pwm_set_wrap(slice_num, 3);
17
      // Set channel A output high for one cycle before dropping
18
      pwm_set_chan_level(slice_num, PWM_CHAN_A, 1);
19
      // Set initial B output high for three cycles before dropping
20
      pwm_set_chan_level(slice_num, PWM_CHAN_B, 3);
      // Set the PWM running
21
22
      pwm_set_enabled(slice_num, true);
23
24
     // Note we could also use pwm_set_gpio_level(gpio, x) which looks up the
25
      // correct slice and channel for a given GPIO.
26 }
```

4.1.18.1. Enumerations

• enum pwm_clkdiv_mode { PWM_DIV_FREE_RUNNING = 0, PWM_DIV_B_HIGH = 1, PWM_DIV_B_RISING = 2, PWM_DIV_B_FALLING = 3 } PWM Divider mode settings.

4.1.18.2. Function List

```
• static uint pwm_gpio_to_slice_num (uint gpio)
• static uint pwm_gpio_to_channel (uint gpio)

    static void pwm_config_set_phase_correct (pwm_config *c, bool phase_correct)

• static void pwm_config_set_clkdiv (pwm_config *c, float div)
• static void pwm_config_set_clkdiv_int (pwm_config *c, uint div)
• static void pwm_config_set_clkdiv_mode (pwm_config *c, enum pwm_clkdiv_mode mode)
• static void pwm_config_set_output_polarity (pwm_config *c, bool a, bool b)
• static void pwm_config_set_wrap (pwm_config *c, uint16_t wrap)
• static void pwm_init (uint slice_num, pwm_config *c, bool start)
static pwm_config pwm_get_default_config (void)
static void pwm_set_wrap (uint slice_num, uint16_t wrap)
• static void pwm_set_chan_level (uint slice_num, uint chan, uint16_t level)
• static void pwm_set_both_levels (uint slice_num, uint16_t level_a, uint16_t level_b)
• static void pwm_set_gpio_level (uint gpio, uint16_t level)
• static uint16_t pwm_get_counter (uint slice_num)
• static void pwm_set_counter (uint slice_num, uint16_t c)
static void pwm_advance_count (uint slice_num)
• static void pwm_retard_count (uint slice_num)
static void pwm_set_clkdiv_int_frac (uint slice_num, uint8_t integer, uint8_t fract)
• static void pwm_set_clkdiv (uint slice_num, float divider)
```

```
• static void pwm_set_output_polarity (uint slice_num, bool a, bool b)
```

- static void pwm_set_clkdiv_mode (uint slice_num, enum pwm_clkdiv_mode mode)
- static void pwm_set_phase_correct (uint slice_num, bool phase_correct)
- static void pwm_set_enabled (uint slice_num, bool enabled)
- static void pwm_set_mask_enabled (uint32_t mask)
- static void pwm_set_irq_enabled (uint slice_num, bool enabled)
- static void pwm_set_irq_mask_enabled (uint32_t slice_mask, bool enabled)
- static void pwm_clear_irq (uint slice_num)
- static uint32_t pwm_get_irq_status_mask (void)
- static void pwm_force_irq (uint slice_num)

4.1.18.3. Function Documentation

4.1.18.3.1. pwm_advance_count

```
static void pwm_advance_count (uint slice_num)
```

Advance PWM count.

Advance the phase of a running the counter by 1 count.

This function will return once the increment is complete.

Parameters

• slice_num PWM slice number

4.1.18.3.2. pwm_clear_irg

```
static void pwm_clear_irq (uint slice_num)
```

Clear single PWM channel interrupt.

Parameters

• slice_num PWM slice number

4.1.18.3.3. pwm_config_set_clkdiv

Set clock divider in a PWM configuration.

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 Value to divide counting rate by. Must be greater than or equal to 1.

4.1.18.3.4. pwm_config_set_clkdiv_int

```
static void pwm_config_set_clkdiv_int (pwm_config *c,
```

```
uint div)
```

Set PWM clock divider in a PWM configuration.

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 integer value to reduce counting rate by. Must be greater than or equal to 1.

4.1.18.3.5. pwm_config_set_clkdiv_mode

Set PWM counting mode in a PWM configuration.

Configure which event gates the operation of the fractional divider. The default is always-on (free-running PWM). Can also be configured to count on high level, rising edge or falling edge of the B pin input.

Parameters

- c PWM configuration struct to modify
- mode PWM divide/count mode

4.1.18.3.6. pwm_config_set_output_polarity

```
static void pwm_config_set_output_polarity (pwm_config *c,
    bool a,
    bool b)
```

Set output polarity in a PWM configuration.

Parameters

- c PWM configuration struct to modify
- a true to invert output A
- b true to invert output B

4.1.18.3.7. pwm_config_set_phase_correct

Set phase correction in a PWM configuration.

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

4.1.18.3.8. pwm_config_set_wrap

Set PWM counter wrap value in a PWM configuration.

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

4.1.18.3.9. pwm_force_irq

```
static void pwm_force_irq (uint slice_num)
```

Force PWM interrupt.

Parameters

• slice_num PWM slice number

4.1.18.3.10. pwm_get_counter

```
static uint16_t pwm_get_counter (uint slice_num)
```

Get PWM counter.

Get current value of PWM counter

Parameters

• slice_num PWM slice number

Returns

• Current value of PWM counter

4.1.18.3.11. pwm_get_default_config

```
static pwm_config pwm_get_default_config (void)
```

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.

4.1.18.3.12. pwm_get_irq_status_mask

```
static uint32_t pwm_get_irq_status_mask (void)
```

Get PWM interrupt status, raw.

Returns

• Bitmask of all PWM interrupts currently set

4.1.18.3.13. pwm_gpio_to_channel

```
static uint 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.

4.1.18.3.14. pwm_gpio_to_slice_num

```
static uint pwm_gpio_to_slice_num (uint gpio)
```

Determine the PWM slice that is attached to the specified GPIO.

Returns

• The PWM slice number that controls the specified GPIO.

4.1.18.3.15. pwm_init

```
static void pwm_init (uint slice_num,
    pwm_config *c,
    bool start)
```

Initialise a PWM with settings from a configuration object.

Use the pwm_get_default_config() function to initialise a config structure, make changes as needed using the pwm_config_* functions, then call this function to set up the PWM.

Parameters

- slice_num PWM slice number
- c The configuration to use
- start If true the PWM will be started running once configured. If false you will need to start manually using pwm_set_enabled() or pwm_set_mask_enabled()

4.1.18.3.16. pwm_retard_count

```
static void pwm_retard_count (uint slice_num)
```

Retard PWM count.

Retard the phase of a running counter by 1 count

This function will return once the retardation is complete.

Parameters

• slice_num PWM slice number

4.1.18.3.17. pwm_set_both_levels

Set PWM counter compare values.

Set the value of the PWM counter compare values, \boldsymbol{A} and \boldsymbol{B}

The counter compare register is double-buffered in hardware. This means that, when the PWM is running, a write to the counter compare values does not take effect until the next time the PWM slice wraps (or, in phase-correct mode, the next time the slice reaches 0). If the PWM is not running, the write is latched in immediately.

Parameters

• slice_num PWM slice number

- 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

4.1.18.3.18. pwm_set_chan_level

Set the current PWM counter compare value for one channel.

Set the value of the PWM counter compare value, for either channel A or channel B

The counter compare register is double-buffered in hardware. This means that, when the PWM is running, a write to the counter compare values does not take effect until the next time the PWM slice wraps (or, in phase-correct mode, the next time the slice reaches 0). If the PWM is not running, the write is latched in immediately.

Parameters

- slice_num PWM slice number
- chan Which channel to update. 0 for A, 1 for B.
- level new level for the selected output

4.1.18.3.19. pwm_set_clkdiv

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

- slice_num PWM slice number
- divider Floating point clock divider, 1.f \leftarrow value < 256.f

4.1.18.3.20. pwm_set_clkdiv_int_frac

Set PWM clock divider using an 8:4 fractional value.

Set the clock divider. Counter increment will be on sysclock divided by this value, taking in to account the gating.

Parameters

- slice_num PWM slice number
- integer 8 bit integer part of the clock divider
- fract 4 bit fractional part of the clock divider

4.1.18.3.21. pwm_set_clkdiv_mode

Set PWM divider mode.

Parameters

- slice_num PWM slice number
- mode Required divider mode

4.1.18.3.22. pwm_set_counter

Set PWM counter.

Set the value of the PWM counter

Parameters

- slice num PWM slice number
- c Value to set the PWM counter to

4.1.18.3.23. pwm_set_enabled

Enable/Disable PWM.

Parameters

- slice_num PWM slice number
- enabled true to enable the specified PWM, false to disable

4.1.18.3.24. pwm_set_gpio_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).

The counter compare register is double-buffered in hardware. This means that, when the PWM is running, a write to the counter compare values does not take effect until the next time the PWM slice wraps (or, in phase-correct mode, the next time the slice reaches 0). If the PWM is not running, the write is latched in immediately.

Parameters

- gpio GPIO to set level of
- level PWM level for this GPIO

4.1.18.3.25. pwm_set_irq_enabled

Enable PWM instance interrupt.

Used to enable a single PWM instance interrupt

Parameters

- slice_num PWM block to enable/disable
- enabled true to enable, false to disable

4.1.18.3.26. pwm_set_irq_mask_enabled

Enable multiple PWM instance interrupts.

Use this to enable multiple PWM interrupts at once.

Parameters

- slice_mask Bitmask of all the blocks to enable/disable. Channel 0 = bit 0, channel 1 = bit 1 etc.
- enabled true to enable, false to disable

4.1.18.3.27. pwm_set_mask_enabled

```
static void pwm_set_mask_enabled (uint32_t mask)
```

Enable/Disable multiple PWM slices simultaneously.

Parameters

• mask Bitmap of PWMs to enable/disable. Bits 0 to 7 enable slices 0-7 respectively

4.1.18.3.28. pwm_set_output_polarity

Set PWM output polarity.

Parameters

- slice_num PWM slice number
- a true to invert output A
- b true to invert output B

4.1.18.3.29. pwm_set_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

- slice_num PWM slice number
- phase_correct true to set phase correct modulation, false to set trailing edge

4.1.18.3.30. pwm_set_wrap

Set the current PWM counter wrap value.

Set the highest value the counter will reach before returning to 0. Also known as TOP.

The counter wrap value is double-buffered in hardware. This means that, when the PWM is running, a write to the counter wrap value does not take effect until after the next time the PWM slice wraps (or, in phase-correct mode, the next time the slice reaches 0). If the PWM is not running, the write is latched in immediately.

Parameters

- slice_num PWM slice number
- wrap Value to set wrap to

4.1.19. hardware_resets

Hardware Reset 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.

reset_bitmask

Multiple 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

Block to reset	Bit
IO Bank 0	5
I2C 1	4
I2C 0	3
DMA	2
Bus Control	1
ADC 0	0

Example

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
3 #include "hardware/resets.h"
5 int main() {
 6
     stdio_init_all();
     printf("Hello, reset!\n");
8
9
    // Put the PWM block into reset
10
    reset_block(RESETS_RESET_PWM_BITS);
11
12
13
    // And bring it out
14
    unreset_block_wait(RESETS_RESET_PWM_BITS);
15
16
   // Put the PWM and RTC block into reset
17
    reset_block(RESETS_RESET_PWM_BITS | RESETS_RESET_RTC_BITS);
18
19
    // Wait for both to come out of reset
    unreset_block_wait(RESETS_RESET_PWM_BITS | RESETS_RESET_RTC_BITS);
20
21
22
      return 0;
23 }
```

4.1.19.1. Function List

```
• static void reset_block (uint32_t bits)
```

- static void unreset_block (uint32_t bits)
- static void unreset_block_wait (uint32_t bits)

4.1.19.2. Function Documentation

4.1.19.2.1. 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

4.1.19.2.2. 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

4.1.19.2.3. 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

4.1.20. hardware_rtc

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.

See also

datetime_t

Example

```
1 #include <stdio.h>
2 #include "hardware/rtc.h"
3 #include "pico/stdlib.h"
4 #include "pico/util/datetime.h"
6 int main() {
     stdio_init_all();
 7
     printf("Hello RTC!\n");
 8
    char datetime_buf[256];
10
11
      char *datetime_str = &datetime_buf[0];
12
13
      // Start on Friday 5th of June 2020 15:45:00
14
       datetime_t t = {
              .year = 2020,
15
16
              .month = 06,
              .day = 05,
17
              .dotw = 5, // 0 is Sunday, so 5 is Friday
18
              .hour = 15,
19
20
              .min = 45,
21
              .sec = 00
22
      };
23
24
    // Start the RTC
25
    rtc_init();
26
     rtc_set_datetime(&t);
27
28
       // Print the time
```

```
while (true) {
29
30
       rtc_get_datetime(&t);
          datetime_to_str(datetime_str, sizeof(datetime_buf), &t);
31
32
          printf("\r%s
                          ", datetime_str);
33
          sleep_ms(100);
34
35
36
      return 0;
37 }
```

4.1.20.1. Typedefs

• typedef void(* rtc_callback_t)(void)

4.1.20.2. Function List

```
    void rtc_init (void)
    bool rtc_set_datetime (datetime_t *t)
    bool rtc_get_datetime (datetime_t *t)
    bool rtc_running (void)
    void rtc_set_alarm (datetime_t *t, rtc_callback_t user_callback)
    void rtc_enable_alarm (void)
    void rtc_disable_alarm (void)
```

4.1.20.3. Function Documentation

4.1.20.3.1. rtc_disable_alarm

```
void rtc_disable_alarm (void)
Disable the RTC alarm (if active)
```

4.1.20.3.2. rtc_enable_alarm

```
void rtc_enable_alarm (void)
Enable the RTC alarm (if inactive)
```

4.1.20.3.3. rtc_get_datetime

```
bool 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

• true if datetime is valid, false if the RTC is not running.

4.1.20.3.4. rtc_init

```
void rtc_init (void)
```

Initialise the RTC system.

4.1.20.3.5. rtc_running

```
bool rtc_running (void)
```

Is the RTC running?

4.1.20.3.6. rtc_set_alarm

Set a time in the future for the RTC to call a user provided callback.

Parameters

- t Pointer to a datetime_t structure containing a time in the future to fire the alarm. Any values set to -1 will not be matched on.
- user_callback pointer to a rtc_callback_t to call when the alarm fires

4.1.20.3.7. rtc_set_datetime

```
bool 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

• true if set, false if the passed in datetime was invalid.

4.1.21. hardware_spi

Hardware SPI API

RP2040 has 2 identical instances of the 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.

4.1.21.1. Macros

```
• #define spi0 ((spi_inst_t * const)spi0_hw)
```

```
• #define spi1 ((spi_inst_t * const)spi1_hw)
```

4.1.21.2. Enumerations

```
    enum spi_cpha_t { SPI_CPHA_0 = 0, SPI_CPHA_1 = 1 }
        Enumeration of SPI CPHA (clock phase) values.
    enum spi_cpol_t { SPI_CPOL_0 = 0, SPI_CPOL_1 = 1 }
```

Enumeration of SPI CPOL (clock polarity) values.

• enum spi_order_t { SPI_LSB_FIRST = 0, SPI_MSB_FIRST = 1 } Enumeration of SPI bit-order values.

4.1.21.3. Function List

```
• uint spi_init (spi_inst_t *spi, uint baudrate)
• void spi_deinit (spi_inst_t *spi)
• uint spi_set_baudrate (spi_inst_t *spi, uint baudrate)
• uint spi_get_baudrate (const spi_inst_t *spi)
• static uint spi_get_index (const spi_inst_t *spi)
• static void spi_set_format (spi_inst_t *spi, uint data_bits, spi_cpol_t cpol, spi_cpha_t cpha, __unused spi_order_t
 order)
• static void spi_set_slave (spi_inst_t *spi, bool slave)
• static bool spi_is_writable (const spi_inst_t *spi)
• static bool spi_is_readable (const spi_inst_t *spi)
• static bool spi_is_busy (const spi_inst_t *spi)
• int spi_write_read_blocking (spi_inst_t *spi, const uint8_t *src, uint8_t *dst, size_t len)
• int spi_write_blocking (spi_inst_t *spi, const uint8_t *src, size_t len)
• int spi_read_blocking (spi_inst_t *spi, uint8_t repeated_tx_data, uint8_t *dst, size_t len)
• int spi_write16_read16_blocking (spi_inst_t *spi, const uint16_t *src, uint16_t *dst, size_t len)
• int spi_write16_blocking (spi_inst_t *spi, const uint16_t *src, size_t len)
• int spi_read16_blocking (spi_inst_t *spi, uint16_t repeated_tx_data, uint16_t *dst, size_t len)
```

4.1.21.4. Function Documentation

4.1.21.4.1. spi_deinit

Deinitialise SPI instances

```
void spi_deinit (spi_inst_t *spi)
```

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

4.1.21.4.2. spi_get_baudrate

```
uint spi_get_baudrate (const spi_inst_t *spi)
Get SPI baudrate.
```

Get SPI baudrate which was set by

Parameters

• spi SPI instance specifier, either spi0 or spi1

Returns

· The actual baudrate set

See also

• spi_set_baudrate

4.1.21.4.3. spi_get_index

```
static uint spi_get_index (const spi_inst_t *spi)
```

Convert SPI instance to hardware instance number.

Parameters

• spi SPI instance

Returns

• Number of SPI, 0 or 1.

4.1.21.4.4. spi_init

Initialise SPI instances

Puts the SPI into a known state, and enable it. Must be called before other functions.

Parameters

- spi SPI instance specifier, either spi0 or spi1
- baudrate Baudrate requested in Hz

Returns

• the actual baud rate set

4.1.21.4.5. spi_is_busy

```
static bool spi_is_busy (const spi_inst_t *spi)
```

Check whether SPI is busy.

Parameters

• spi SPI instance specifier, either spi0 or spi1

Returns

• true if SPI is busy

4.1.21.4.6. spi_is_readable

```
static bool spi_is_readable (const spi_inst_t *spi)
```

Check whether a read can be done on SPI device.

Parameters

• spi SPI instance specifier, either spi0 or spi1

Returns

• true if a read is possible i.e. data is present

4.1.21.4.7. spi_is_writable

```
static bool spi_is_writable (const spi_inst_t *spi)
```

Check whether a write can be done on SPI device.

Parameters

• spi SPI instance specifier, either spi0 or spi1

Returns

• false if no space is available to write. True if a write is possible

4.1.21.4.8. spi_read16_blocking

```
int 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. Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate. repeated_tx_data is output repeatedly on TX as data is read in from RX. 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

Returns

· Number of halfwords written/read

4.1.21.4.9. spi_read_blocking

```
int 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. Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate. repeated_tx_data is output repeatedly on TX as data is read in from RX. 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

Returns

• Number of bytes written/read

4.1.21.4.10. spi_set_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

4.1.21.4.11. spi_set_format

```
static void spi_set_format (spi_inst_t *spi,
        uint data_bits,
        spi_cpol_t cpol,
        spi_cpha_t cpha,
        __unused spi_order_t order)
```

Configure SPI.

Configure how the SPI serialises and deserialises data on the wire

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 Must be SPI_MSB_FIRST, no other values supported on the PL022

4.1.21.4.12. spi_set_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.

4.1.21.4.13. spi_write16_blocking

Write to an SPI device.

Write len halfwords from src to SPI. Discard any data received back. Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate.

Parameters

- spi SPI instance specifier, either spi0 or spi1
- src Buffer of data to write
- len Length of buffers

Returns

• Number of halfwords written/read

4.1.21.4.14. spi_write16_read16_blocking

Write/Read half words to/from an SPI device.

Write len halfwords from src to SPI. Simultaneously read len halfwords from SPI to dst. Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate.

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

Returns

• Number of halfwords written/read

4.1.21.4.15. spi_write_blocking

Write to an SPI device, blocking.

Write len bytes from src to SPI, and discard any data received back Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate.

Parameters

- spi SPI instance specifier, either spi0 or spi1
- src Buffer of data to write
- len Length of src

Returns

· Number of bytes written/read

4.1.21.4.16. spi_write_read_blocking

Write/Read to/from an SPI device.

Write len bytes from src to SPI. Simultaneously read len bytes from SPI to dst. Blocks until all data is transferred. No timeout, as SPI hardware always transfers at a known data rate.

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

Returns

• Number of bytes written/read

4.1.22. hardware_sync

Low level hardware spin locks, barrier and processor event APIs

Spin Locks

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

Generally each spin lock itself is a shared resource, i.e. the same hardware spin lock can be used by multiple higher level primitives (as long as the spin locks are neither held for long periods, nor held concurrently with other spin locks by the same core - which could lead to deadlock). A hardware spin lock that is exclusively owned can be used individually without more flexibility and without regard to other software. Note that no hardware spin lock may be acquired reentrantly (i.e. hardware spin locks are not on their own safe for use by both thread code and IRQs) however the default spinlock related methods here (e.g. spin_lock_blocking) always disable interrupts while the lock is held as use by IRQ handlers and user code is common/desirable, and spin locks are only expected to be held for brief periods.

The SDK uses the following default spin lock assignments, classifying which spin locks are reserved for exclusive/special purposes vs those suitable for more general shared use:

Number (ID)	Description
0-13	Currently reserved for exclusive use by the SDK and other libraries. If you use these spin locks, you risk breaking SDK or other library functionality. Each reserved spin lock used individually has its own PICO_SPINLOCK_ID so you can search for those.
14,15	(PICO_SPINLOCK_ID_OS1 and PICO_SPINLOCK_ID_OS2). Currently reserved for exclusive use by an operating system (or other system level software) co-existing with the SDK.

Number (ID)	Description
16-23	(PICO_SPINLOCK_ID_STRIPED_FIRST - PICO_SPINLOCK_ID_STRIPED_LAST). Spin locks from this range are assigned in a round-robin fashion via next_striped_spin_lock_num(). These spin locks are shared, but assigning numbers from a range reduces the probability that two higher level locking primitives using striped spin locks will actually be using the same spin lock.
24-31	(PICO_SPINLOCK_ID_CLAIM_FREE_FIRST - PICO_SPINLOCK_ID_CLAIM_FREE_LAST). These are reserved for exclusive use and are allocated on a first come first served basis at runtime via spin_lock_claim_unused()

4.1.22.1. Typedefs

typedef uint32_t spin_lock_t
 A spin lock identifier.

4.1.22.2. Function List

```
• static force_inline void sev (void)
```

- static force_inline void wfe (void)
- static force_inline void wfi (void)
- static force_inline void dmb (void)
- static force_inline void dsb (void)
- static force_inline void isb (void)
- static force_inline void mem_fence_acquire (void)
- static force_inline void mem_fence_release (void)
- static __force_inline uint32_t save_and_disable_interrupts (void)
- static __force_inline void restore_interrupts (uint32_t status)
- static __force_inline spin_lock_t * spin_lock_instance (uint lock_num)
- static __force_inline uint spin_lock_get_num (spin_lock_t *lock)
- static __force_inline void spin_lock_unsafe_blocking (spin_lock_t *lock)
- static __force_inline void spin_unlock_unsafe (spin_lock_t *lock)
- static __force_inline uint32_t spin_lock_blocking (spin_lock_t *lock)
- static bool is_spin_locked (spin_lock_t *lock)
- static __force_inline void spin_unlock (spin_lock_t *lock, uint32_t saved_irq)
- static __force_inline uint get_core_num (void)
- spin_lock_t * spin_lock_init (uint lock_num)
- void spin_locks_reset (void)
- uint next_striped_spin_lock_num (void)

- void spin_lock_claim (uint lock_num)
- void spin_lock_claim_mask (uint32_t lock_num_mask)
- void spin_lock_unclaim (uint lock_num)
- int spin_lock_claim_unused (bool required)
- bool spin_lock_is_claimed (uint lock_num)

4.1.22.3. Function Documentation

4.1.22.3.1. __dmb

```
static force_inline void dmb (void)
```

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.

4.1.22.3.2. __dsb

```
static force_inline void dsb (void)
```

Insert a DSB instruction in to the code path.

The DSB (data synchronization barrier) acts as a special kind of data memory barrier (DMB). The DSB operation completes when all explicit memory accesses before this instruction complete.

4.1.22.3.3. __isb

```
static force_inline void isb (void)
```

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.

4.1.22.3.4. __mem_fence_acquire

```
static force_inline void mem_fence_acquire (void)
```

Acquire a memory fence.

4.1.22.3.5. __mem_fence_release

```
static force_inline void mem_fence_release (void)
```

Release a memory fence.

4.1.22.3.6. __sev

```
static force_inline void sev (void)
```

Insert a SEV instruction in to the code path.

The SEV (send event) instruction sends an event to both cores.

4.1.22.3.7. __wfe

```
static force_inline void wfe (void)
```

Insert a WFE instruction in to the code path.

The WFE (wait for event) instruction waits until one of a number of events occurs, including events signalled by the SEV instruction on either core.

4.1.22.3.8. __wfi

```
static force_inline void wfi (void)
```

Insert a WFI instruction in to the code path.

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

4.1.22.3.9. get_core_num

```
static __force_inline uint get_core_num (void)
```

Get the current core number.

Returns

• The core number the call was made from

4.1.22.3.10. is_spin_locked

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

Check to see if a spinlock is currently acquired elsewhere.

Parameters

• lock Spinlock instance

4.1.22.3.11. next_striped_spin_lock_num

```
uint next_striped_spin_lock_num (void)
```

Return a spin lock number from the striped range.

Returns a spin lock number in the range PICO_SPINLOCK_ID_STRIPED_FIRST to PICO_SPINLOCK_ID_STRIPED_LAST in a round robin fashion. This does not grant the caller exclusive access to the spin lock, so the caller must:

Returns

• lock_num a spin lock number the caller may use (non exclusively)

See also

- PICO_SPINLOCK_ID_STRIPED_FIRST
- PICO_SPINLOCK_ID_STRIPED_LAST

4.1.22.3.12. restore_interrupts

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

Restore interrupts to a specified state.

Parameters

• status Previous interrupt status from save_and_disable_interrupts()

4.1.22.3.13. save_and_disable_interrupts

```
static __force_inline uint32_t save_and_disable_interrupts (void)
```

Save and disable interrupts.

Returns

• The prior interrupt enable status for restoration later via restore_interrupts()

4.1.22.3.14. spin_lock_blocking

```
static __force_inline uint32_t spin_lock_blocking (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

4.1.22.3.15. spin_lock_claim

```
void spin_lock_claim (uint lock_num)
```

Mark a spin lock as used.

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

Parameters

lock_num the spin lock number

4.1.22.3.16. spin_lock_claim_mask

```
void spin_lock_claim_mask (uint32_t lock_num_mask)
```

Mark multiple spin locks as used.

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

Parameters

• lock_num_mask Bitfield of all required spin locks to claim (bit 0 == spin lock 0, bit 1 == spin lock 1 etc)

4.1.22.3.17. 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 available

Returns

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

4.1.22.3.18. spin_lock_get_num

```
static __force_inline uint spin_lock_get_num (spin_lock_t *lock)
```

Get HW Spinlock number from instance.

Parameters

• lock The Spinlock instance

Returns

• The Spinlock ID

4.1.22.3.19. spin_lock_init

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

Initialise a spin lock.

The spin lock is initially unlocked

Parameters

• lock_num The spin lock number

Returns

• The spin lock instance

4.1.22.3.20. spin_lock_instance

```
static __force_inline spin_lock_t* spin_lock_instance (uint lock_num)
```

Get HW Spinlock instance from number.

Parameters

• lock_num Spinlock ID

Returns

• The spinlock instance

4.1.22.3.21. spin_lock_is_claimed

```
bool spin_lock_is_claimed (uint lock_num)
```

Determine if a spin lock is claimed.

Parameters

• lock_num the spin lock number

Returns

• true if claimed, false otherwise

See also

- spin_lock_claim
- spin_lock_claim_mask

4.1.22.3.22. spin_lock_unclaim

void spin_lock_unclaim (uint lock_num)

Mark a spin lock as no longer used.

Method for cooperative claiming of hardware.

Parameters

• lock_num the spin lock number to release

4.1.22.3.23. spin_lock_unsafe_blocking

```
static __force_inline void spin_lock_unsafe_blocking (spin_lock_t *lock)
```

Acquire a spin lock without disabling interrupts (hence unsafe)

Parameters

• lock Spinlock instance

4.1.22.3.24. spin_locks_reset

```
void spin_locks_reset (void)
```

Release all spin locks.

4.1.22.3.25. spin_unlock

Release a spin lock safely.

This function will re-enable interrupts according to the parameters.

Parameters

- lock Spinlock instance
- saved_irq Return value from the spin_lock_blocking() function.

Returns

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

See also

• spin_lock_blocking()

4.1.22.3.26. spin_unlock_unsafe

```
static __force_inline void spin_unlock_unsafe (spin_lock_t *lock)
```

Release a spin lock without re-enabling interrupts.

Parameters

• lock Spinlock instance

4.1.23. hardware_timer

Low-level hardware timer API

This API provides medium level access to the timer HW. See also pico_time 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_rtc functions.

Example

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
4 volatile bool timer_fired = false;
6 int64_t alarm_callback(alarm_id_t id, void *user_data) {
     printf("Timer %d fired!\n", (int) id);
7
8
      timer_fired = true;
9
    // Can return a value here in us to fire in the future
10
      return 0;
11 }
12
13 bool repeating_timer_callback(struct repeating_timer *t) {
      printf("Repeat at %lld\n", time_us_64());
14
15
       return true;
16 }
17
18 int main() {
19
       stdio_init_all();
20
       printf("Hello Timer!\n");
21
22
      // Call alarm_callback in 2 seconds
23
     add_alarm_in_ms(2000, alarm_callback, NULL, false);
24
25
    // Wait for alarm callback to set timer_fired
26
     while (!timer_fired) {
27
          tight_loop_contents();
28
29
30
     // Create a repeating timer that calls repeating_timer_callback.
      // If the delay is > 0 then this is the delay between the previous callback ending and the
31
  next starting.
     // If the delay is negative (see below) then the next call to the callback will be exactly
32
  500ms after the
33
      // start of the call to the last callback
      struct repeating_timer timer;
34
35
      add_repeating_timer_ms(500, repeating_timer_callback, NULL, &timer);
36
      sleep_ms(3000);
      bool cancelled = cancel_repeating_timer(&timer);
38
      printf("cancelled... %d\n", cancelled);
39
       sleep_ms(2000);
40
       // Negative delay so means we will call repeating_timer_callback, and call it again
41
       // 500ms later regardless of how long the callback took to execute
42
```

```
add_repeating_timer_ms(-500, repeating_timer_callback, NULL, &timer);
sleep_ms(3000);
cancelled = cancel_repeating_timer(&timer);
printf("cancelled... %d\n", cancelled);
sleep_ms(2000);
printf("Done\n");
return 0;
```

See also

• pico_time

4.1.23.1. Typedefs

• typedef void(* hardware_alarm_callback_t)(uint alarm_num)

4.1.23.2. Function List

```
static uint32_t time_us_32 (void)
uint64_t time_us_64 (void)
void busy_wait_us_32 (uint32_t delay_us)
void busy_wait_us (uint64_t delay_us)
void busy_wait_ms (uint32_t delay_ms)
void busy_wait_until (absolute_time_t t)
static bool time_reached (absolute_time_t t)
void hardware_alarm_claim (uint alarm_num)
void hardware_alarm_is_claimed (uint alarm_num)
bool hardware_alarm_set_callback (uint alarm_num, hardware_alarm_callback_t callback)
bool hardware_alarm_set_target (uint alarm_num, absolute_time_t t)
void hardware_alarm_set_target (uint alarm_num, absolute_time_t t)
void hardware_alarm_cancel (uint alarm_num)
```

4.1.23.3. Function Documentation

4.1.23.3.1. busy_wait_ms

```
void busy_wait_ms (uint32_t delay_ms)
```

Busy wait wasting cycles for the given number of milliseconds.

Parameters

delay_ms delay amount in milliseconds

4.1.23.3.2. 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

4.1.23.3.3. 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 in microseconds

4.1.23.3.4. 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 in microseconds

4.1.23.3.5. hardware_alarm_cancel

```
void hardware_alarm_cancel (uint alarm_num)
```

Cancel an existing target (if any) for a given hardware_alarm.

Parameters

• alarm_num

4.1.23.3.6. 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

4.1.23.3.7. hardware_alarm_is_claimed

bool hardware_alarm_is_claimed (uint alarm_num)

Determine if a hardware alarm has been claimed.

Parameters

• alarm_num the hardware alarm number

Returns

• true if claimed, false otherwise

See also

• hardware_alarm_claim

4.1.23.3.8. hardware_alarm_set_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

Parameters

- alarm_num the hardware alarm number
- · callback the callback to install, or NULL to unset

See also

• hardware_alarm_set_target()

4.1.23.3.9. hardware_alarm_set_target

Set the current target for the specified hardware alarm.

This will replace any existing target

Parameters

- alarm_num the hardware alarm number
- t the target timestamp

Returns

• true if the target was "missed"; i.e. it was in the past, or occurred before a future hardware timeout could be set

4.1.23.3.10. 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

4.1.23.3.11. 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

4.1.23.3.12. time_us_32

```
static uint32_t time_us_32 (void)
```

Return a 32 bit timestamp value in microseconds.

Returns the low 32 bits of the hardware timer.

Returns

• the 32 bit timestamp

4.1.23.3.13. time_us_64

```
uint64_t time_us_64 (void)
```

Return the current 64 bit timestamp value in microseconds.

Returns the full 64 bits of the hardware timer. The pico_time 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

4.1.24. hardware_uart

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.

Only the TX, RX, RTS, and CTS signals are connected, meaning that the modem mode and IrDA mode of the PL011 are not supported.

Example

```
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_set_function(0, GPIO_FUNC_UART);
8     gpio_set_function(1, GPIO_FUNC_UART);
9
10     uart_puts(uart0, "Hello world!");
11 }
```

4.1.24.1. Enumerations

• enum uart_parity_t { UART_PARITY_NONE, UART_PARITY_EVEN, UART_PARITY_ODD } UART Parity enumeration.

4.1.24.2. Macros

```
    #define uart0 ((uart_inst_t * const)uart0_hw)
    Identifier for UART instance 0.
```

```
    #define uart1 ((uart_inst_t * const)uart1_hw)
    Identifier for UART instance 1.
```

4.1.24.3. Function List

```
static uint uart_get_index (uart_inst_t *uart)
• uint uart init (uart inst t *uart, uint baudrate)
• void uart_deinit (uart_inst_t *uart)
• uint uart_set_baudrate (uart_inst_t *uart, uint baudrate)
• static void uart_set_hw_flow (uart_inst_t *uart, bool cts, bool rts)
• static void uart_set_format (uart_inst_t *uart, uint data_bits, uint stop_bits, uart_parity_t parity)

    static void uart_set_irq_enables (uart_inst_t *uart, bool rx_has_data, bool tx_needs_data)

• static bool uart_is_enabled (uart_inst_t *uart)
• static void uart_set_fifo_enabled (uart_inst_t *uart, bool enabled)
• static bool uart_is_writable (uart_inst_t *uart)
static void uart_tx_wait_blocking (uart_inst_t *uart)
• static bool uart_is_readable (uart_inst_t *uart)
• static void uart_write_blocking (uart_inst_t *uart, const uint8_t *src, size_t len)
• static void uart_read_blocking (uart_inst_t *uart, uint8_t *dst, size_t len)
• static void uart_putc_raw (uart_inst_t *uart, char c)
• static void uart_putc (uart_inst_t *uart, char c)
• static void uart_puts (uart_inst_t *uart, const char *s)
• static char uart_getc (uart_inst_t *uart)
• static void uart_set_break (uart_inst_t *uart, bool en)
• void uart_set_translate_crlf (uart_inst_t *uart, bool translate)
• static void uart_default_tx_wait_blocking (void)
• bool uart_is_readable_within_us (uart_inst_t *uart, uint32_t us)
```

4.1.24.4. Function Documentation

4.1.24.4.1. uart_default_tx_wait_blocking

```
static void uart_default_tx_wait_blocking (void)
Wait for the default UART'S TX fifo to be drained.
```

4.1.24.4.2. uart_deinit

```
void uart_deinit (uart_inst_t *uart)
```

Delnitialise 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

4.1.24.4.3. uart_get_index

```
static uint uart_get_index (uart_inst_t *uart)
```

Convert UART instance to hardware instance number.

Parameters

• uart UART instance

Returns

• Number of UART, 0 or 1.

4.1.24.4.4. 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.

4.1.24.4.5. uart_init

Initialise a UART.

Put the UART into a known state, and enable it. Must be called before other functions.

Parameters

- uart UART instance. uart0 or uart1
- baudrate Baudrate of UART in Hz

Returns

Actual set baudrate

4.1.24.4.6. uart_is_enabled

```
static bool uart_is_enabled (uart_inst_t *uart)
```

Test if specific UART is enabled.

Parameters

• uart UART instance. uart0 or uart1

Returns

• true if the UART is enabled

4.1.24.4.7. uart_is_readable

```
static bool uart_is_readable (uart_inst_t *uart)
```

Determine whether data is waiting in the RX FIFO.

Parameters

• uart UART instance. uart0 or uart1

Returns

• 0 if no data available, otherwise the number of bytes, at least, that can be read

4.1.24.4.8. uart_is_readable_within_us

Wait for up to a certain number of microseconds for the RX FIFO to be non empty.

Parameters

- uart UART instance. uart0 or uart1
- us the number of microseconds to wait at most (may be 0 for an instantaneous check)

Returns

• true if the RX FIFO became non empty before the timeout, false otherwise

4.1.24.4.9. uart_is_writable

```
static bool uart_is_writable (uart_inst_t *uart)
```

Determine if space is available in the TX FIFO.

Parameters

• uart UART instance, uart0 or uart1

Returns

false if no space available, true otherwise

4.1.24.4.10. uart_putc

Write single character to UART for transmission, with optional 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

4.1.24.4.11. uart_putc_raw

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

4.1.24.4.12. uart_puts

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

4.1.24.4.13. uart_read_blocking

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.

4.1.24.4.14. uart_set_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

Returns

Actual set baudrate

4.1.24.4.15. uart_set_break

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.

4.1.24.4.16. uart_set_fifo_enabled

Enable/Disable the FIFOs on specified UART.

Parameters

- uart UART instance. uart0 or uart1
- enabled true to enable FIFO (default), false to disable

4.1.24.4.17. uart_set_format

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.

4.1.24.4.18. uart_set_hw_flow

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

4.1.24.4.19. uart_set_irq_enables

Setup UART interrupts.

Enable the UART's interrupt output. An interrupt handler will need to be installed 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.

4.1.24.4.20. uart_set_translate_crlf

Set CR/LF conversion on UART.

Parameters

- uart UART instance. uart0 or uart1
- translate If true, convert line feeds to carriage return on transmissions

4.1.24.4.21. uart_tx_wait_blocking

```
static void uart_tx_wait_blocking (uart_inst_t *uart)
```

Wait for the UART TX fifo to be drained.

Parameters

• uart UART instance. uart0 or uart1

4.1.24.4.22. uart_write_blocking

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

4.1.25. hardware_vreg

Voltage Regulation API

4.1.25.1. Function List

• void vreg_set_voltage (enum vreg_voltage voltage)

4.1.25.2. Function Documentation

4.1.25.2.1. vreg_set_voltage

```
void vreg_set_voltage (enum vreg_voltage voltage)
```

Set voltage. Parameters

• voltage The voltage (from enumeration vreg_voltage) to apply to the voltage regulator

4.1.26. hardware_watchdog

Hardware Watchdog Timer API

Supporting functions for the Pico hardware watchdog timer.

The RP2040 has a built in HW watchdog Timer. 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.

Example

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
3 #include "hardware/watchdog.h"
5 int main() {
     stdio_init_all();
7
 8
    if (watchdog_caused_reboot()) {
9
          printf("Rebooted by Watchdog!\n");
10
           return 0;
    } else {
11
          printf("Clean boot\n");
12
13
14
15
      // Enable the watchdog, requiring the watchdog to be updated every 100ms or the chip will
  reboot
16
      // second arg is pause on debug which means the watchdog will pause when stepping through
17
       watchdog_enable(100, 1);
18
       for (uint i = 0; i < 5; i++) {
19
          printf("Updating watchdog %d\n", i);
20
21
          watchdog_update();
22
23
      // Wait in an infinite loop and don't update the watchdog so it reboots us
25
       printf("Waiting to be rebooted by watchdog\n");
       while(1);
27 }
```

4.1.26.1. Function List

```
• void watchdog_reboot (uint32_t pc, uint32_t sp, uint32_t delay_ms)
```

- void watchdog_start_tick (uint cycles)
- void watchdog_update (void)
- void watchdog_enable (uint32_t delay_ms, bool pause_on_debug)

- bool watchdog_caused_reboot (void)
- uint32_t watchdog_get_count (void)

4.1.26.2. Function Documentation

4.1.26.2.1. 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

4.1.26.2.2. watchdog_enable

Enable the watchdog.

By default the SDK assumes a 12MHz XOSC and sets the watchdog_start_tick appropriately.

Parameters

- delay_ms Number of milliseconds before watchdog will reboot without watchdog_update being called. Maximum of 0x7ffffff, which is approximately 8.3 seconds
- pause_on_debug If the watchdog should be paused when the debugger is stepping through code

4.1.26.2.3. watchdog_get_count

```
uint32_t watchdog_get_count (void)
```

Returns the number of microseconds before the watchdog will reboot the chip.

Returns

• The number of microseconds before the watchdog will reboot the chip.

4.1.26.2.4. watchdog_reboot

```
void watchdog_reboot (uint32_t pc,
            uint32_t sp,
            uint32_t delay_ms)
```

Define actions to perform at watchdog timeout.

By default the SDK assumes a 12MHz XOSC and sets the $watchdog_start_tick$ appropriately.

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.

4.1.26.2.5. 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.

4.1.26.2.6. watchdog_update

```
void watchdog_update (void)
```

Reload the watchdog counter with the amount of time set in watchdog_enable.

4.1.27. hardware_xosc

Crystal Oscillator (XOSC) API

4.1.27.1. Function List

- void xosc_init (void)
- void xosc_disable (void)
- void xosc_dormant (void)

4.1.27.2. Function Documentation

4.1.27.2.1. xosc_disable

```
void xosc_disable (void)
```

Disable the Crystal oscillator.

Turns off the crystal oscillator source, and waits for it to become unstable

4.1.27.2.2. xosc_dormant

```
void xosc_dormant (void)
```

Set the crystal oscillator system to dormant.

Turns off the crystal oscillator until it is woken by an interrupt. This will block and hence the entire system will stop, until an interrupt wakes it up. This function will continue to block until the oscillator becomes stable after its wakeup.

4.1.27.2.3. xosc_init

```
void xosc_init (void)
```

Initialise the crystal oscillator system.

This function will block until the crystal oscillator has stabilised.

4.2. High Level APIs

pico_multicore	
fifo	Functions for inter-core FIFO.
pico_stdlib	
pico_sync	
critical_section	Critical Section API for short-lived mutual exclusion safe for IRQ and multi-core.
lock_core	base synchronization/lock primitive support
mutex	Mutex API for non IRQ mutual exclusion between cores.
sem	Semaphore API for restricting access to a resource.
pico_time	
timestamp	Timestamp functions relating to points in time (including the current time)
sleep	Sleep functions for delaying execution in a lower power state.
alarm	Alarm functions for scheduling future execution.
repeating_timer	Repeating Timer functions for simple scheduling of repeated execution.
pico_unique_id	
pico_util	Useful data structures and utility functions.
datetime	Date/Time formatting.
pheap	
queue	

4.2.1. pico_multicore

Adds support for running code on the second processor core (core1)

Example

```
1 #include <stdio.h>
2 #include "pico/stdlib.h"
3 #include "pico/multicore.h"
5 #define FLAG_VALUE 123
7 void core1_entry() {
9
     multicore_fifo_push_blocking(FLAG_VALUE);
10
11
    uint32_t g = multicore_fifo_pop_blocking();
12
    if (g != FLAG_VALUE)
13
          printf("Hmm, that's not right on core 1!\n");
14
15
16
          printf("Its all gone well on core 1!");
17
18
     while (1)
19
         tight_loop_contents();
20 }
```

```
22 int main() {
    stdio_init_all();
       printf("Hello, multicore!\n");\\
24
25
26
27
      multicore_launch_core1(core1_entry);
29
       // Wait for it to start up
30
31
       uint32_t g = multicore_fifo_pop_blocking();
32
       if (g != FLAG_VALUE)
33
34
           printf("Hmm, that's not right on core 0!\n");
35
       else {
36
           multicore_fifo_push_blocking(FLAG_VALUE);
37
           printf("It's all gone well on core 0!");
38
39
40 }
```

4.2.1.1. Modules

• fifo

Functions for inter-core FIFO.

4.2.1.2. Function List

- void multicore_reset_core1 (void)
- void multicore_launch_core1 (void(*entry)(void))
- void multicore_launch_core1_with_stack (void(*entry)(void), uint32_t *stack_bottom, size_t stack_size_bytes)
- void multicore_launch_core1_raw (void(*entry)(void), uint32_t *sp, uint32_t vector_table)

4.2.1.3. Function Documentation

4.2.1.3.1. 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.

4.2.1.3.2. multicore_launch_core1_raw

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

4.2.1.3.3. multicore_launch_core1_with_stack

Launch code on core 1 with stack.

Reset core1 and enter the given function on core 1 using the passed stack for core 1

4.2.1.3.4. multicore_reset_core1

```
void multicore_reset_core1 (void)
Reset Core 1.
```

4.2.2. fifo

Functions for inter-core FIFO.

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.

4.2.2.1. Function List

```
• static bool multicore_fifo_rvalid (void)
```

```
• static bool multicore_fifo_wready (void)
```

- void multicore_fifo_push_blocking (uint32_t data)
- uint32_t multicore_fifo_pop_blocking (void)
- static void multicore_fifo_drain (void)
- static void multicore_fifo_clear_irq (void)
- static uint32_t multicore_fifo_get_status (void)

4.2.2.2. Function Documentation

4.2.2.2.1. multicore_fifo_clear_irq

```
static void multicore_fifo_clear_irq (void)
```

Clear FIFO interrupt.

Note that this only clears an interrupt that was caused by the ROE or WOF flags. To clear the VLD flag you need to use one of the 'pop' or 'drain' functions.

4.2.2.2. multicore_fifo_drain

```
static void multicore_fifo_drain (void)
```

Flush any data in the incoming FIFO.

4.2.2.2.3. multicore_fifo_get_status

static uint32_t multicore_fifo_get_status (void)

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

4.2.2.2.4. multicore_fifo_pop_blocking

uint32_t multicore_fifo_pop_blocking (void)

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.

4.2.2.2.5. 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

4.2.2.2.6. multicore_fifo_rvalid

static bool multicore_fifo_rvalid (void)

Check the read FIFO to see if there is data waiting.

Returns

• true if the FIFO has data in it, false otherwise

4.2.2.2.7. multicore_fifo_wready

static bool multicore_fifo_wready (void)

Check the write FIFO to see if it is ready for more data.

Returns

• true if the FIFO has room for more data, false otherwise

4.2.3. pico_stdlib

Aggregation of a core subset of Raspberry Pi Pico SDK libraries used by most executables along with some additional utility methods. Including pico_stdlib gives you everything you need to get a basic program running which prints to stdout or flashes a LED

This library aggregates:

- hardware_uart
- hardware_gpio
- pico_binary_info
- pico_runtime
- pico_platform
- pico_printf
- pico_stdio
- pico_standard_link
- pico_util

There are some basic default values used by these functions that will default to usable values, however, they can be customised in a board definition header via config.h or similar

4.2.3.1. Function List

```
void setup_default_uart (void)
```

```
• void set_sys_clock_48mhz (void)
```

- void set_sys_clock_pll (uint32_t vco_freq, uint post_div1, uint post_div2)
- bool check_sys_clock_khz (uint32_t freq_khz, uint *vco_freq_out, uint *post_div1_out, uint *post_div2_out)
- static bool set_sys_clock_khz (uint32_t freq_khz, bool required)

4.2.3.2. Function Documentation

4.2.3.2.1. check_sys_clock_khz

```
bool check_sys_clock_khz (uint32_t freq_khz,
     uint *vco_freq_out,
     uint *post_div1_out,
     uint *post_div2_out)
```

Check if a given system clock frequency is valid/attainable.

Parameters

- freq_khz Requested frequency
- vco_freq_out On success, the voltage controller oscillator frequeucny to be used by the SYS PLL
- post_div1_out On success, The first post divider for the SYS PLL

post_div2_out On success, The second post divider for the SYS PLL.

Returns

• true if the frequency is possible and the output parameters have been written.

4.2.3.2.2. set_sys_clock_48mhz

```
void set_sys_clock_48mhz (void)
```

Initialise the system clock to 48MHz.

Set the system clock to 48MHz, and set the peripheral clock to match.

4.2.3.2.3. set_sys_clock_khz

Attempt to set a system clock frequency in khz.

Note that not all clock frequencies are possible; it is preferred that you use src/rp2_common/hardware_clocks/scripts/vcocalc.py to calculate the parameters for use with set_sys_clock_pll

Parameters

- freq_khz Requested frequency
- required if true then this function will assert if the frequency is not attainable.

Returns

• true if the clock was configured

4.2.3.2.4. set_sys_clock_pll

```
void set_sys_clock_pll (uint32_t vco_freq,
            uint post_div1,
            uint post_div2)
```

Initialise the system clock.

See the PLL documentation in the datasheet for details of driving the PLLs.

Parameters

- vco_freq The voltage controller oscillator frequency to be used by the SYS PLL
- post_div1 The first post divider for the SYS PLL
- post_div2 The second post divider for the SYS PLL.

4.2.3.2.5. setup_default_uart

```
void setup_default_uart (void)
```

Set up the default UART and assign it to the default GPIO's.

By default this will use UART 0, with TX to pin GPIO 0, RX to pin GPIO 1, and the baudrate to 115200

Calling this method also initializes stdin/stdout over UART if the pico_stdio_uart library is linked.

Defaults can be changed using configuration defines, PICO_DEFAULT_UART_INSTANCE, PICO_DEFAULT_UART_BAUD_RATE PICO_DEFAULT_UART_TX_PIN PICO_DEFAULT_UART_RX_PIN

4.2.4. pico_sync

Synchronization primitives and mutual exclusion

4.2.4.1. Modules

• critical_section

Critical Section API for short-lived mutual exclusion safe for IRQ and multi-core.

lock_core

base synchronization/lock primitive support

mutex

Mutex API for non IRQ mutual exclusion between cores.

se

Semaphore API for restricting access to a resource.

4.2.5. critical_section

Critical Section API for short-lived mutual exclusion safe for IRQ and multi-core.

A critical section is non-reentrant, and provides mutual exclusion using a spin-lock to prevent access from the other core, and from (higher priority) interrupts on the same core. It does the former using a spin lock and the latter by disabling interrupts on the calling core.

Because interrupts are disabled when a critical_section is owned, uses of the critical_section should be as short as possible.

4.2.5.1. Function List

- void critical_section_init (critical_section_t *crit_sec)
- void critical_section_init_with_lock_num (critical_section_t *crit_sec, uint lock_num)
- static void critical_section_enter_blocking (critical_section_t *crit_sec)
- static void critical_section_exit (critical_section_t *crit_sec)
- void critical_section_deinit (critical_section_t *crit_sec)

4.2.5.2. Function Documentation

4.2.5.2.1. critical_section_deinit

```
void critical_section_deinit (critical_section_t *crit_sec)
```

De-Initialise a critical_section created by the critical_section_init method.

This method is only used to free the associated spin lock allocated via the critical_section_init method (it should not be used to de-initialize a spin lock created via critical_section_init_with_lock_num). After this call, the critical section is invalid

Parameters

crit_sec Pointer to critical_section structure

4.2.5.2.2. critical_section_enter_blocking

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

Enter a critical_section.

If the spin lock associated with this critical section is in use, then this method will block until it is released.

Parameters

crit_sec Pointer to critical_section structure

4.2.5.2.3. critical_section_exit

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

Release a critical_section.

Parameters

crit_sec Pointer to critical_section structure

4.2.5.2.4. critical_section_init

```
void critical_section_init (critical_section_t *crit_sec)
```

Initialise a critical_section structure allowing the system to assign a spin lock number.

The critical section is initialized ready for use, and will use a (possibly shared) spin lock number assigned by the system. Note that in general it is unlikely that you would be nesting critical sections, however if you do so you use critical_section_init_with_lock_num to ensure that the spin lock's used are different.

Parameters

crit_sec Pointer to critical_section structure

4.2.5.2.5. critical_section_init_with_lock_num

Initialise a critical_section structure assigning a specific spin lock number.

Parameters

- crit_sec Pointer to critical_section structure
- lock_num the specific spin lock number to use

4.2.6. lock_core

base synchronization/lock primitive support

Most of the pico_sync locking primitives contain a lock_core_t structure member. This currently just holds a spin lock which is used only to protect the contents of the rest of the structure as part of implementing the synchronization primitive. As such, the spin_lock member of lock core is never still held on return from any function for the primitive.

critical_section is an exceptional case in that it does not have a lock_core_t and simply wraps a spin lock, providing methods to lock and unlock said spin lock.

lock_core based structures work by locking the spin lock, checking state, and then deciding whether they additionally need to block or notify when the spin lock is released. In the blocking case, they will wake up again in the future, and try the process again.

By default the SDK just uses the processors' events via SEV and WEV for notification and blocking as these are

sufficient for cross core, and notification from interrupt handlers. However macros are defined in this file that abstract the wait and notify mechanisms to allow the SDK locking functions to effectively be used within an RTOS or other environment.

When implementing an RTOS, it is desirable for the SDK synchronization primitives that wait, to block the calling task (and immediately yield), and those that notify, to wake a blocked task which isn't on processor. At least the wait macro implementation needs to be atomic with the protecting spin_lock unlock from the callers point of view; i.e. the task should unlock the spin lock when it starts its wait. Such implementation is up to the RTOS integration, however the macros are defined such that such operations are always combined into a single call (so they can be performed atomically) even though the default implementation does not need this, as a WFE which starts following the corresponding SEV is not missed.

4.2.6.1. Macros

- #define lock_owner_id_t int8_t
 - type to use to store the 'owner' of a lock. By default this is int8_t as it only needs to store the core number or -1, however it may be overridden if a larger type is required (e.g. for an RTOS task id)
- #define LOCK_INVALID_OWNER_ID ((lock_owner_id_t)-1)
 marker value to use for a lock_owner_id_t which does not refer to any valid owner
- #define lock_get_caller_owner_id ((lock_owner_id_t)get_core_num())
 return the owner id for the caller By default this returns the calling core number, but may be overridden (e.g. to return an RTOS task id)
- #define lock_internal_spin_unlock_with_wait(lock, save) spin_unlock((lock)>spin_lock, save), __wfe()
 Atomically unlock the lock's spin lock, and wait for a notification.
- #define lock_internal_spin_unlock_with_notify(lock, save) spin_unlock((lock)*spin_lock, save), __sev()
 Atomically unlock the lock's spin lock, and send a notification.
- #define lock_internal_spin_unlock_with_best_effort_wait_or_timeout(lock, save, until) ({
 spin_unlock((lock) * spin_lock, save); \ best_effort_wfe_or_timeout(until); \ })
 Atomically unlock the lock's spin lock, and wait for a notification or a timeout.
- #define sync_internal_yield_until_before(until) ((void)0)
 yield to other processing until some time before the requested time

4.2.6.2. Function List

• void lock_init (lock_core_t *core, uint lock_num)

4.2.6.3. Function Documentation

4.2.6.3.1. lock_init

```
void lock_init (lock_core_t *core,
      uint lock_num)
```

Initialise a lock structure.

Inititalize a lock structure, providing the spin lock number to use for protecting internal state.

Parameters

- core Pointer to the lock_core to initialize
- lock_num Spin lock number to use for the lock. As the spin lock is only used internally to the locking primitive method implementations, this does not need to be globally unique, however could suffer contention

4.2.7. mutex

Mutex API for non IRQ mutual exclusion between cores.

Mutexes are application level locks usually used protecting data structures that might be used by multiple cores. Unlike critical sections, the mutex protected code is not necessarily required/expected to complete quickly, as no other sytemwide locks are held on account of a locked mutex.

Because they are not re-entrant on the same core, blocking on a mutex should never be done in an IRQ handler. It is valid to call mutex_try_enter from within an IRQ handler, if the operation that would be conducted under lock can be skipped if the mutex is locked (at least by the same core).

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

4.2.7.1. Macros

```
    #define auto_init_mutex(name) static __attribute__((section(".mutex_array"))) mutex_t name
Helper macro for static definition of mutexes.
    #define auto_init_recursive_mutex(name) static __attribute__((section(".mutex_array"))) mutex_t name = {
```

```
.recursion_state = MAX_RECURSION_STATE }
```

Helper macro for static definition of recursive mutexes.

4.2.7.2. Function List

```
    void mutex_init (mutex_t *mtx)
    void recursive_mutex_init (mutex_t *mtx)
    void mutex_enter_blocking (mutex_t *mtx)
    bool mutex_try_enter (mutex_t *mtx, uint32_t *owner_out)
    bool mutex_enter_timeout_ms (mutex_t *mtx, uint32_t timeout_ms)
    bool mutex_enter_timeout_us (mutex_t *mtx, uint32_t timeout_us)
    bool mutex_enter_block_until (mutex_t *mtx, absolute_time_t until)
    void mutex_exit (mutex_t *mtx)
    static bool mutex_is_initialzed (mutex_t *mtx)
```

4.2.7.3. Function Documentation

4.2.7.3.1. mutex_enter_block_until

Wait for mutex until a specific time.

Wait until the specific time to take ownership of the mutex. If the calling core can take ownership of the mutex before the timeout expires, then true will be returned and the calling core will own the mutex, otherwise false will be returned and the calling core will own the mutex.

Parameters

- mtx Pointer to mutex structure
- until The time after which to return if the core cannot take ownership of the mutex

Returns

· true if mutex now owned, false if timeout occurred before mutex became available

4.2.7.3.2. mutex_enter_blocking

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

Take ownership of a mutex.

This function will block until the calling core can claim ownership of the mutex. On return the caller core owns the mutex

Parameters

• mtx Pointer to mutex structure

4.2.7.3.3. mutex_enter_timeout_ms

Wait for mutex with timeout.

Wait for up to the specific time to take ownership of the mutex. If the calling core can take ownership of the mutex before the timeout expires, then true will be returned and the calling core will own the mutex, otherwise false will be returned and the calling core will own the mutex.

Parameters

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

Returns

• true if mutex now owned, false if timeout occurred before mutex became available

4.2.7.3.4. mutex_enter_timeout_us

Wait for mutex with timeout.

Wait for up to the specific time to take ownership of the mutex. If the calling core can take ownership of the mutex before the timeout expires, then true will be returned and the calling core will own the mutex, otherwise false will be returned and the calling core will own the mutex.

Parameters

- mtx Pointer to mutex structure
- timeout_us The timeout in microseconds.

Returns

• true if mutex now owned, false if timeout occurred before mutex became available

4.2.7.3.5. mutex_exit

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

Release ownership of a mutex.

Parameters

• mtx Pointer to mutex structure

4.2.7.3.6. mutex_init

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

Initialise a mutex structure.

Parameters

• mtx Pointer to mutex structure

4.2.7.3.7. mutex_is_initialzed

```
static bool mutex_is_initialzed (mutex_t *mtx)
```

Test for mutex initialised state.

Parameters

• mtx Pointer to mutex structure

Returns

· true if the mutex is initialised, false otherwise

4.2.7.3.8. mutex_try_enter

Attempt to take ownership of a mutex.

If the mutex wasn't owned, this will claim the mutex and return true. Otherwise (if the mutex was already owned) this will return false and the calling core will own the mutex.

Parameters

- mtx Pointer to mutex structure
- owner_out If mutex was already owned, and this pointer is non-zero, it will be filled in with the core number of the current owner of the mutex

4.2.7.3.9. recursive_mutex_init

```
void recursive_mutex_init (mutex_t *mtx)
```

Initialise a recursive mutex structure.

A recursive mutex may be entered in a nested fashion by the same owner

Parameters

• mtx Pointer to mutex structure

4.2.8. sem

Semaphore API for restricting access to a resource.

A semaphore holds a number of available permits. sem_acquire methods will acquire a permit if available (reducing the available count by 1) or block if the number of available permits is 0. sem_release() increases the number of available permits by one potentially unblocking a sem_acquire method.

Note that sem_release() may be called an arbitrary number of times, however the number of available permits is capped

to the max_permit value specified during semaphore initialization.

Although these semaphore related functions can be used from IRQ handlers, it is obviously preferable to only release semaphores from within an IRQ handler (i.e. avoid blocking)

4.2.8.1. Function List

```
    void sem_init (semaphore_t *sem, int16_t initial_permits, int16_t max_permits)
    int sem_available (semaphore_t *sem)
    bool sem_release (semaphore_t *sem)
    void sem_reset (semaphore_t *sem, int16_t permits)
    void sem_acquire_blocking (semaphore_t *sem)
    bool sem_acquire_timeout_ms (semaphore_t *sem, uint32_t timeout_ms)
    bool sem_acquire_timeout_us (semaphore_t *sem, uint32_t timeout_us)
    bool sem_acquire_block_until (semaphore_t *sem, absolute_time_t until)
```

4.2.8.2. Function Documentation

4.2.8.2.1. sem_acquire_block_until

Wait to acquire a permit from a semaphore until a specific time.

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

Parameters

- sem Pointer to semaphore structure
- until The time after which to return if the sem is not available.

Returns

• true if permit was acquired, false if the until time was reached before acquiring.

4.2.8.2.2. 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

4.2.8.2.3. sem_acquire_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.

Parameters

- sem Pointer to semaphore structure
- timeout_ms Time to wait to acquire the semaphore, in milliseconds.

Returns

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

4.2.8.2.4. sem_acquire_timeout_us

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.

Parameters

- sem Pointer to semaphore structure
- timeout_us Time to wait to acquire the semaphore, in microseconds.

Returns

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

4.2.8.2.5. sem_available

```
int sem_available (semaphore_t *sem)
```

Return number of available permits on the semaphore.

Parameters

• sem Pointer to semaphore structure

Returns

• The number of permits available on the semaphore.

4.2.8.2.6. sem_init

Initialise a semaphore structure.

Parameters

- sem Pointer to semaphore structure
- initial_permits How many permits are initially acquired
- max_permits Total number of permits allowed for this semaphore

4.2.8.2.7. sem_release

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

Release a permit on a semaphore.

Increases the number of permits by one (unless the number of permits is already at the maximum). A blocked sem_acquire will be released if the number of permits is increased.

Parameters

• sem Pointer to semaphore structure

Returns

· true if the number of permits available was increased.

4.2.8.2.8. sem_reset

Reset semaphore to a specific number of available permits.

Reset value should be from 0 to the max_permits specified in the init function

Parameters

- sem Pointer to semaphore structure
- permits the new number of available permits

4.2.9. pico_time

API for accurate timestamps, sleeping, and time based callbacks

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 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 modelled by adding or subtracting a constant value from the unmodified hardware timer.

• hardware_timer

4.2.9.1. Modules

• timestamp

Timestamp functions relating to points in time (including the current time)

• sleep

Sleep functions for delaying execution in a lower power state.

• alarm

Alarm functions for scheduling future execution.

repeating_timer

 $\label{lem:constraints} \mbox{Repeating Timer functions for simple scheduling of repeated execution.}$

4.2.10. timestamp

Timestamp functions relating to points in time (including the current time)

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.

4.2.10.1. Function List

```
static uint64_t to_us_since_boot (absolute_time_t t)
static void update_us_since_boot (absolute_time_t *t, uint64_t us_since_boot)
static absolute_time_t get_absolute_time (void)
static uint32_t to_ms_since_boot (absolute_time_t t)
static absolute_time_t delayed_by_us (const absolute_time_t t, uint64_t us)
static absolute_time_t delayed_by_ms (const absolute_time_t t, uint32_t ms)
static absolute_time_t make_timeout_time_us (uint64_t us)
static absolute_time_t make_timeout_time_ms (uint32_t ms)
static absolute_time_t diff_us (absolute_time_t from, absolute_time_t to)
static bool is_nil_time (absolute_time_t t)
```

4.2.10.2. Function Documentation

4.2.10.2.1. absolute_time_diff_us

```
static int64_t absolute_time_diff_us (absolute_time_t from,
    absolute_time_t to)
```

Return the difference in microseconds between two timestamps.

Parameters

- from the first timestamp
- to the second timestamp

Returns

• the number of microseconds between the two timestamps (positive if to is after from except in case of overflow)

4.2.10.2.2. delayed_by_ms

Return a timestamp value obtained by adding a number of milliseconds to another timestamp.

Parameters

- t the base timestamp
- ms the number of milliseconds to add

Returns

• the timestamp representing the resulting time

4.2.10.2.3. delayed_by_us

Return a timestamp value obtained by adding a number of microseconds to another timestamp.

Parameters

- t the base timestamp
- us the number of microseconds to add

Returns

• the timestamp representing the resulting time

4.2.10.2.4. get_absolute_time

```
static absolute_time_t get_absolute_time (void)
```

Return a representation of the current time.

Returns an opaque high fidelity representation of the current time sampled during the call.

Returns

• the absolute time (now) of the hardware timer

See also

- absolute_time_t
- sleep_until()
- time_us_64()

4.2.10.2.5. is_nil_time

```
static bool is_nil_time (absolute_time_t t)
```

Determine if the given timestamp is nil.

Parameters

• t the timestamp

Returns

• true if the timestamp is nil

See also

• nil_time

4.2.10.2.6. make_timeout_time_ms

```
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.

Parameters

• ms the number of milliseconds to add to the current timestamp

Returns

• the future timestamp

4.2.10.2.7. make_timeout_time_us

```
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.

Parameters

• us the number of microseconds to add to the current timestamp

Returns

• the future timestamp

4.2.10.2.8. to_ms_since_boot

```
static uint32_t to_ms_since_boot (absolute_time_t t)
```

Convert a timestamp into a number of milliseconds since boot.

fn to_ms_since_boot

Parameters

• t an absolute_time_t value to convert

Returns

• the number of microseconds since boot represented by t

See also

• to_us_since_boot()

4.2.10.2.9. to_us_since_boot

```
static uint64_t to_us_since_boot (absolute_time_t t)
```

convert an absolute_time_t into a number of microseconds since boot.

fn to_us_since_boot

Parameters

• t the absolute time to convert

Returns

• a number of microseconds since boot, equivalent to t

4.2.10.2.10. update_us_since_boot

update an absolute_time_t value to represent a given number of microseconds since boot

fn update_us_since_boot

Parameters

- t the absolute time value to update
- us_since_boot the number of microseconds since boot to represent. Note this should be representable as a signed 64 bit integer

4.2.11. sleep

Sleep functions for delaying execution in a lower power state.

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

These functions should not be called from an IRQ handler.

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.

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.

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

4.2.11.1. Function List

```
• void sleep_until (absolute_time_t target)
```

```
• void sleep_us (uint64_t us)
```

- void sleep_ms (uint32_t ms)
- bool best_effort_wfe_or_timeout (absolute_time_t timeout_timestamp)

4.2.11.2. Function Documentation

4.2.11.2.1. best_effort_wfe_or_timeout

```
bool best_effort_wfe_or_timeout (absolute_time_t timeout_timestamp)
```

Helper method for blocking on a timeout.

This method will return in response to an event (as per _wfe) or when the target time is reached, or at any point before.

This method can be used to implement a lower power polling loop waiting on some condition signalled by an event $(_sev())$.

This is called because under certain circumstances (notably the default timer pool being disabled or full) the best effort is simply to return immediately without a _wfe, thus turning the calling code into a busy wait.

Example usage:

Parameters

• timeout_timestamp the timeout time

Returns

· true if the target time is reached, false otherwise

4.2.11.2.2. sleep_ms

```
void sleep_ms (uint32_t ms)
```

Wait for the given number of milliseconds before returning.

Parameters

• ms the number of milliseconds to sleep

4.2.11.2.3. sleep_until

```
void sleep_until (absolute_time_t target)
```

Wait until after the given timestamp to return.

Parameters

• target the time after which to return

See also

- sleep_us()
- busy_wait_until()

4.2.11.2.4. sleep_us

```
void sleep_us (uint64_t us)
```

Wait for the given number of microseconds before returning.

Parameters

• us the number of microseconds to sleep

See also

busy_wait_us()

4.2.12. alarm

Alarm functions for scheduling future execution.

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 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

4.2.12.1. Macros

- #define PICO_TIME_DEFAULT_ALARM_POOL_DISABLED 0

 If 1 then the default alarm pool is disabled (so no hardware alarm is claimed for the pool)
- #define PICO_TIME_DEFAULT_ALARM_POOL_HARDWARE_ALARM_NUM 3
 Selects which hardware alarm is used for the default alarm pool.
- #define PICO_TIME_DEFAULT_ALARM_POOL_MAX_TIMERS 16
 Selects the maximum number of concurrent timers in the default alarm pool.

4.2.12.2. Typedefs

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

4.2.12.3. Function List

```
void alarm_pool_init_default (void)
• alarm_pool_t * alarm_pool_get_default (void)
• alarm_pool_t * alarm_pool_create (uint hardware_alarm_num, uint max_timers)
uint alarm_pool_hardware_alarm_num (alarm_pool_t *pool)

    void alarm_pool_destroy (alarm_pool_t *pool)

    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)
• 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)
• 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)
• bool alarm_pool_cancel_alarm (alarm_pool_t *pool, alarm_id_t alarm_id)
• static alarm_id_t add_alarm_at (absolute_time_t time, alarm_callback_t callback, void *user_data, bool fire_if_past)
• static alarm_id_t add_alarm_in_us (uint64_t us, alarm_callback_t callback, void *user_data, bool fire_if_past)
• static alarm_id_t add_alarm_in_ms (uint32_t ms, alarm_callback_t callback, void *user_data, bool fire_if_past)
• static bool cancel_alarm (alarm_id_t alarm_id)
```

4.2.12.4. Function Documentation

4.2.12.4.1. add_alarm_at

Add an alarm callback to be called at a specific time.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core of the default alarm pool (generally core 0). If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- time the timestamp when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.2. add_alarm_in_ms

Add an alarm callback to be called after a delay specified in milliseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core of the default alarm pool (generally core 0). If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- ms the delay (from now) in milliseconds when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.3. add_alarm_in_us

Add an alarm callback to be called after a delay specified in microseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core of the default alarm pool (generally core 0). If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- us the delay (from now) in microseconds when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.4. alarm_pool_add_alarm_at

Add an alarm callback to be called at a specific time.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core the alarm pool was created on. If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- pool the alarm pool to use for scheduling the callback (this determines which hardware alarm is used, and which core calls the callback)
- time the timestamp when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.5. alarm_pool_add_alarm_in_ms

Add an alarm callback to be called after a delay specified in milliseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core the alarm pool was created on. If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- pool the alarm pool to use for scheduling the callback (this determines which hardware alarm is used, and which core calls the callback)
- ms the delay (from now) in milliseconds when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.6. alarm_pool_add_alarm_in_us

Add an alarm callback to be called after a delay specified in microseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core the alarm pool was created on. If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- pool the alarm pool to use for scheduling the callback (this determines which hardware alarm is used, and which core calls the callback)
- us the delay (from now) in microseconds when (after which) the callback should fire
- callback the callback function
- user_data user data to pass to the callback function
- fire_if_past if true, this method will call the callback itself before returning 0 if the timestamp happens before or during this method call

Returns

- >0 the alarm id
- 0 the target timestamp was during or before this method call (whether the callback was called depends on fire_if_past)
- -1 if there were no alarm slots available

4.2.12.4.7. alarm_pool_cancel_alarm

Cancel an alarm.

Parameters

- pool the alarm_pool containing the alarm
- alarm_id the alarm

Returns

• true if the alarm was cancelled, false if it didn't exist

See also

• alarm_id_t for a note on reuse of IDs

4.2.12.4.8. alarm_pool_create

Create an alarm pool.

The alarm pool will call callbacks from an alarm IRQ Handler on the core of this function is called from.

In many situations there is never any need for anything other than the default alarm pool, however you might want to create another if you want alarm callbacks on core 1 or require alarm pools of different priority (IRQ priority based preemption of callbacks)

Parameters

- hardware_alarm_num the hardware alarm to use to back this pool
- max_timers the maximum number of timers

See also

- alarm_pool_get_default()
- hardware_claiming

4.2.12.4.9. alarm_pool_destroy

```
void alarm_pool_destroy (alarm_pool_t *pool)
```

Destroy the alarm pool, cancelling all alarms and freeing up the underlying hardware alarm.

Parameters

• pool the pool

Returns

• the hardware alarm used by the pool

4.2.12.4.10. alarm_pool_get_default

```
alarm_pool_t* alarm_pool_get_default (void)
```

The default alarm pool used when alarms are added without specifying an alarm pool, and also used by the SDK to support lower power sleeps and timeouts.

See also

PICO_TIME_DEFAULT_ALARM_POOL_HARDWARE_ALARM_NUM

4.2.12.4.11. alarm_pool_hardware_alarm_num

```
uint alarm_pool_hardware_alarm_num (alarm_pool_t *pool)
```

Return the hardware alarm used by an alarm pool.

Parameters

pool the pool

Returns

• the hardware alarm used by the pool

4.2.12.4.12. alarm_pool_init_default

```
void alarm_pool_init_default (void)
```

Create the default alarm pool (if not already created or disabled)

4.2.12.4.13. cancel_alarm

```
static bool cancel_alarm (alarm_id_t alarm_id)
```

Cancel an alarm from the default alarm pool.

Parameters

• alarm_id the alarm

Returns

· true if the alarm was cancelled, false if it didn't exist

See also

• alarm_id_t for a note on reuse of IDs

4.2.13. repeating_timer

Repeating Timer functions for simple scheduling of repeated execution.

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).

4.2.13.1. Data Structures

struct repeating_timer
 Information about a repeating timer.

4.2.13.2. Typedefs

• typedef bool(* repeating_timer_callback_t)(repeating_timer_t *rt) Callback for a repeating timer.

4.2.13.3. Function List

- 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)
- 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)
- static bool add_repeating_timer_us (int64_t delay_us, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)
- static bool add_repeating_timer_ms (int32_t delay_ms, repeating_timer_callback_t callback, void *user_data, repeating_timer_t *out)
- bool cancel_repeating_timer (repeating_timer_t *timer)

4.2.13.4. Function Documentation

4.2.13.4.1. add_repeating_timer_ms

Add a repeating timer that is called repeatedly at the specified interval in milliseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core of the default alarm pool (generally core 0). If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- delay_ms the repeat delay in milliseconds; if >0 then this is the delay between one callback ending and the next
 starting; if <0 then this is the negative of the time between the starts of the callbacks. The value of 0 is treated as 1
 microsecond
- callback the repeating timer callback function
- user_data user data to pass to store in the repeating_timer structure for use by the callback.
- out the pointer to the user owned structure to store the repeating timer info in. BEWARE this storage location must outlive the repeating timer, so be careful of using stack space

Returns

• false if there were no alarm slots available to create the timer, true otherwise.

4.2.13.4.2. add_repeating_timer_us

Add a repeating timer that is called repeatedly at the specified interval in microseconds.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core of the default alarm pool (generally core 0). If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- delay_us the repeat delay in microseconds; if >0 then this is the delay between one callback ending and the next
 starting; if <0 then this is the negative of the time between the starts of the callbacks. The value of 0 is treated as 1
- callback the repeating timer callback function
- user_data user data to pass to store in the repeating_timer structure for use by the callback.
- out the pointer to the user owned structure to store the repeating timer info in. BEWARE this storage location must outlive the repeating timer, so be careful of using stack space

Returns

• false if there were no alarm slots available to create the timer, true otherwise.

4.2.13.4.3. alarm_pool_add_repeating_timer_ms

```
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.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core the alarm pool was created on. If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- pool the alarm pool to use for scheduling the repeating timer (this determines which hardware alarm is used, and which core calls the callback)
- delay_ms the repeat delay in milliseconds; if >0 then this is the delay between one callback ending and the next
 starting; if <0 then this is the negative of the time between the starts of the callbacks. The value of 0 is treated as 1
 microsecond
- callback the repeating timer callback function
- user_data user data to pass to store in the repeating_timer structure for use by the callback.
- out the pointer to the user owned structure to store the repeating timer info in. BEWARE this storage location must outlive the repeating timer, so be careful of using stack space

Returns

• false if there were no alarm slots available to create the timer, true otherwise.

4.2.13.4.4. alarm_pool_add_repeating_timer_us

```
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.

Generally the callback is called as soon as possible after the time specified from an IRQ handler on the core the alarm pool was created on. If the callback is in the past or happens before the alarm setup could be completed, then this method will optionally call the callback itself and then return a return code to indicate that the target time has passed.

Parameters

- pool the alarm pool to use for scheduling the repeating timer (this determines which hardware alarm is used, and which core calls the callback)
- delay_us the repeat delay in microseconds; if >0 then this is the delay between one callback ending and the next
 starting; if <0 then this is the negative of the time between the starts of the callbacks. The value of 0 is treated as 1
- callback the repeating timer callback function
- user_data user data to pass to store in the repeating_timer structure for use by the callback.
- out the pointer to the user owned structure to store the repeating timer info in. BEWARE this storage location must outlive the repeating timer, so be careful of using stack space

Returns

• false if there were no alarm slots available to create the timer, true otherwise.

4.2.13.4.5. cancel_repeating_timer

```
bool cancel_repeating_timer (repeating_timer_t *timer)
```

Cancel a repeating timer.

Parameters

• timer the repeating timer to cancel

Returns

· true if the repeating timer was cancelled, false if it didn't exist

See also

• alarm_id_t for a note on reuse of IDs

4.2.14. pico_unique_id

Unique device ID access API

RP2040 does not have an on-board unique identifier (all instances of RP2040 silicon are identical and have no persistent state). However, RP2040 boots from serial NOR flash devices which have a 64-bit unique ID as a standard feature, and there is a 1:1 association between RP2040 and flash, so this is suitable for use as a unique identifier for an RP2040-based board.

This library injects a call to the flash_get_unique_id function from the hardware_flash library, to run before main, and stores the result in a static location which can safely be accessed at any time via pico_get_unique_id().

This avoids some pitfalls of the hardware_flash API, which requires any flash-resident interrupt routines to be disabled when called into.

4.2.14.1. Data Structures

struct pico_unique_board_id_t
 Unique board identifier.

4.2.14.2. Function List

- void pico_get_unique_board_id (pico_unique_board_id_t *id_out)
- void pico_get_unique_board_id_string (char *id_out, uint len)

4.2.14.3. Function Documentation

4.2.14.3.1. pico_get_unique_board_id

```
void pico_get_unique_board_id (pico_unique_board_id_t *id_out)
```

Get unique ID.

Get the unique 64-bit device identifier which was retrieved from the external NOR flash device at boot.

On PICO_NO_FLASH builds the unique identifier is set to all 0xEE.

Parameters

• id_out a pointer to a pico_unique_board_id_t struct, to which the identifier will be written

4.2.14.3.2. pico_get_unique_board_id_string

Get unique ID in string format.

Get the unique 64-bit device identifier which was retrieved from the external NOR flash device at boot, formatted as an ASCII hex string. Will always 0-terminate.

On PICO_NO_FLASH builds the unique identifier is set to all 0xEE.

Parameters

- id_out a pointer to a char buffer of size len, to which the identifier will be written
- len the size of id_out. For full serial, len >= 2 * PICO_UNIQUE_BOARD_ID_SIZE_BYTES + 1

4.2.15. pico_util

Useful data structures and utility functions.

4.2.15.1. Modules

- datetime
 Date/Time formatting.
- pheap
- queue

4.2.16. datetime

Date/Time formatting.

4.2.16.1. Data Structures

• struct datetime_t

Structure containing date and time information.

4.2.16.2. Function List

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

4.2.16.3. Function Documentation

4.2.16.3.1. datetime_to_str

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.

4.2.17. pheap

Pairing Heap Implementation

pheap defines a simple pairing heap, the implementation simply tracks array indexes, it is up to the user to provide storage for heap entries and a comparison function.



NOTE

this class is not safe for concurrent usage. It should be externally protected. Furthermore if used concurrently, the caller needs to protect around their use of the returned id. for example, ph_remove_and_free_head returns the id of an element that is no longer in the heap.

The user can still use this to look at the data in their companion array, however obviously further operations on the heap may cause them to overwrite that data as the id may be reused on subsequent operations

4.2.18. queue

Multi-core and IRQ safe queue implementation.

Note that this queue stores values of a specified size, and pushed values are copied into the queue

4.2.18.1. Function List

```
void queue_init_with_spinlock (queue_t *q, uint element_size, uint element_count, uint spinlock_num)
• static void queue_init (queue_t *q, uint element_size, uint element_count)
• void queue_free (queue_t *q)
• static uint queue_get_level_unsafe (queue_t *q)
• static uint queue_get_level (queue_t *q)
static bool queue_is_empty (queue_t *q)
• static bool queue_is_full (queue_t *q)
• bool queue_try_add (queue_t *q, const void *data)
• bool queue_try_remove (queue_t *q, void *data)
• bool queue_try_peek (queue_t *q, void *data)
void queue_add_blocking (queue_t *q, const void *data)
• void queue_remove_blocking (queue_t *q, void *data)
• void queue_peek_blocking (queue_t *q, void *data)
```

4.2.18.2. Function Documentation

4.2.18.2.1. queue_add_blocking

```
void queue_add_blocking (queue_t *q,
      const void *data)
```

Blocking add of value to queue.

If the queue is full this function will block, until a removal happens on the queue

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to value to be copied into the queue

4.2.18.2.2. queue_free

```
void queue_free (queue_t *q)
```

Destroy the specified queue.

Does not deallocate the queue_t structure itself.

Parameters

• q Pointer to a queue_t structure, used as a handle

4.2.18.2.3. queue_get_level

```
static uint queue_get_level (queue_t *q)
```

Check of level of the specified queue.

Parameters

q Pointer to a queue_t structure, used as a handle

Returns

• Number of entries in the queue

4.2.18.2.4. queue_get_level_unsafe

```
static uint queue_get_level_unsafe (queue_t *q)
```

Unsafe check of level of the specified queue.

This does not use the spinlock, so may return incorrect results if the spin lock is not externally locked

Parameters

q Pointer to a queue_t structure, used as a handle

Returns

• Number of entries in the queue

4.2.18.2.5. queue_init

Initialise a queue, allocating a (possibly shared) spinlock.

Parameters

- q Pointer to a queue_t structure, used as a handle
- element_size Size of each value in the queue
- element_count Maximum number of entries in the queue

4.2.18.2.6. queue_init_with_spinlock

Initialise a queue with a specific spinlock for concurrency protection.

Parameters

- q Pointer to a queue_t structure, used as a handle
- element_size Size of each value in the queue
- element_count Maximum number of entries in the queue
- spinlock_num The spin ID used to protect the queue

4.2.18.2.7. queue_is_empty

```
static bool queue_is_empty (queue_t *q)
```

Returns the highest level reached by the specified queue since it was created or since the max level was reset.

Reset the highest level reached of the specified queue.

Check if queue is empty

This function is interrupt and multicore safe.

Parameters

- q Pointer to a queue_t structure, used as a handle
- q Pointer to a queue_t structure, used as a handle
- q Pointer to a queue_t structure, used as a handle

Returns

- · Maximum level of the queue
- true if queue is empty, false otherwise

4.2.18.2.8. queue_is_full

```
static bool queue_is_full (queue_t *q)
```

Check if queue is full.

This function is interrupt and multicore safe.

Parameters

• q Pointer to a queue_t structure, used as a handle

Returns

• true if queue is full, false otherwise

4.2.18.2.9. queue_peek_blocking

Blocking peek at next value to be removed from queue.

If the queue is empty function will block until a value is added

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to the location to receive the peeked value

4.2.18.2.10. queue_remove_blocking

Blocking remove entry from queue.

If the queue is empty this function will block until a value is added.

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to the location to receive the removed value

4.2.18.2.11. queue_try_add

Non-blocking add value queue if not full.

If the queue is full this function will return immediately with false, otherwise the data is copied into a new value added to the queue, and this function will return true.

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to value to be copied into the queue

Returns

• true if the value was added

4.2.18.2.12. queue_try_peek

Non-blocking peek at the next item to be removed from the queue.

If the queue is not empty this function will return immediately with true with the peeked entry copied into the location specified by the data parameter, otherwise the function will return false.

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to the location to receive the peeked value

Returns

· true if there was a value to peek

4.2.18.2.13. queue_try_remove

Non-blocking removal of entry from the queue if non empty.

If the queue is not empty function will copy the removed value into the location provided and return immediately with true, otherwise the function will return immediately with false.

Parameters

- q Pointer to a queue_t structure, used as a handle
- data Pointer to the location to receive the removed value

Returns

• true if a value was removed

4.3. Third-party Libraries

tinyusb_device	TinyUSB Device-mode support for the RP2040
tinyusb_host	TinyUSB Host-mode support for the RP2040

4.3.1. tinyusb_device

TinyUSB Device-mode support for the RP2040

4.3.2. tinyusb_host

TinyUSB Host-mode support for the RP2040

4.4. Runtime Infrastructure

boot_stage2	Second stage boot loaders responsible for setting up external flash.
pico_base	
pico_binary_info	
pico_bit_ops	
pico_bootrom	
pico_bootsel_via_dou ble_reset	
pico_cxx_options	non-code library controlling C++ related compile options
pico_divider	
pico_double	
pico_float	
pico_int64_ops	
pico_malloc	
pico_mem_ops	
pico_platform	
pico_printf	

4.3. Third-party Libraries 239

pico_runtime	
pico_stdio	
pico_stdio_semihos ting	Experimental support for stdout using RAM semihosting.
pico_stdio_uart	Support for stdin/stdout using UART.
pico_stdio_usb	Support for stdin/stdout over USB serial (CDC)
pico_standard_link	Standard link step providing the basics for creating a runnable binary.

4.4.1. boot_stage2

Second stage boot loaders responsible for setting up external flash.

4.4.2. pico_base

Core types and macros for the Raspberry Pi Pico SDK. This header is intended to be included by all source code

4.4.3. pico_binary_info

Binary info is intended for embedding machine readable information with the binary in FLASH.

Example uses include:

- Program identification / information
- Pin layouts
- Included features
- Identifying flash regions used as block devices/storage

4.4.3.1. Macros

```
    #define bi_decl(_decl) \__bi_mark_enclosure _decl; __bi_decl(bi_ptr_lineno_var_name, &bi_lineno_var_name.core, ".binary_info.keep.", __used);
    #define bi_decl_if_func_used(_decl) ({\__bi_mark_enclosure __decl; __bi_decl(bi_ptr_lineno_var_name, abi_lineno_var_name, abi_lineno_va
```

&bi_lineno_var_name.core, ".binary_info.",); *(volatile uint8_t *)8__bi_ptr_lineno_var_name;});

4.4.4. pico_bit_ops

Optimized bit manipulation functions. Additionally provides replacement implementations of the compiler built-ins builtin_popcount, builtin_clz and __bulitin_ctz

4.4.4.1. Function List

```
uint32_t __rev (uint32_t bits)uint64_t __rev11 (uint64_t bits)
```

4.4.4.2. Function Documentation

4.4.4.2.1. __rev

```
uint32_t __rev (uint32_t bits)
```

Reverse the bits in a 32 bit word.

Parameters

• bits 32 bit input

Returns

• the 32 input bits reversed

4.4.4.2.2. __revII

```
uint64_t __revll (uint64_t bits)
```

Reverse the bits in a 64 bit double word.

Parameters

• bits 64 bit input

Returns

• the 64 input bits reversed

4.4.5. pico_bootrom

Access to functions and data in the RP2040 bootrom

4.4.5.1. Function List

```
• static uint32_t rom_table_code (uint8_t c1, uint8_t c2)
```

```
• void * rom_func_lookup (uint32_t code)
```

- void * rom_data_lookup (uint32_t code)
- bool rom_funcs_lookup (uint32_t *table, unsigned int count)
- static void reset_usb_boot (uint32_t usb_activity_gpio_pin_mask, uint32_t disable_interface_mask)

4.4.5.2. Function Documentation

4.4.5.2.1. reset_usb_boot

Reboot the device into BOOTSEL mode.

This function reboots the device into the BOOTSEL mode ('usb boot").

Facilities are provided to enable an "activity light" via GPIO attached LED for the USB Mass Storage Device, and to limit the USB interfaces exposed.

Parameters

- usb_activity_gpio_pin_mask 0 No pins are used as per a cold boot. Otherwise a single bit set indicating which GPIO pin should be set to output and raised whenever there is mass storage activity from the host.
- disable_interface_mask value to control exposed interfaces
- 0 To enable both interfaces (as per a cold boot)
- · 1 To disable the USB Mass Storage Interface
- 2 To disable the USB PICOBOOT Interface

4.4.5.2.2. rom_data_lookup

```
void* rom_data_lookup (uint32_t code)
```

Lookup a bootrom address by code.

Parameters

• code the code

Returns

• a pointer to the data, or NULL if the code does not match any bootrom function

4.4.5.2.3. rom_func_lookup

```
void* rom_func_lookup (uint32_t code)
```

Lookup a bootrom function by code.

Parameters

• code the code

Returns

• a pointer to the function, or NULL if the code does not match any bootrom function

4.4.5.2.4. rom_funcs_lookup

Helper function to lookup the addresses of multiple bootrom functions.

This method looks up the 'codes' in the table, and convert each table entry to the looked up function pointer, if there is a function for that code in the bootrom.

Parameters

- table an IN/OUT array, elements are codes on input, function pointers on success.
- · count the number of elements in the table

Returns

• true if all the codes were found, and converted to function pointers, false otherwise

4.4.5.2.5. rom_table_code

Return a bootrom lookup code based on two ASCII characters.

These codes are uses to lookup data or function addresses in the bootrom

Parameters

- c1 the first character
- c2 the second character

Returns

• the 'code' to use in rom_func_lookup() or rom_data_lookup()

4.4.6. pico_bootsel_via_double_reset

When the 'pico_bootsel_via_double_reset' library is linked, a function is injected before main() which will detect when the system has been reset twice in quick succession, and enter the USB ROM bootloader (BOOTSEL mode) when this happens. This allows a double tap of a reset button on a development board to be used to enter the ROM bootloader, provided this library is always linked.

4.4.6.1. Function List

static uint32_t __uninitialized_ram (magic_location)

4.4.6.2. Function Documentation

4.4.6.2.1. _uninitialized_ram

```
static uint32_t __uninitialized_ram (magic_location)
```

Check for double reset and enter BOOTSEL mode if detected.

This function is registered to run automatically before main(). The algorithm is:

Resetting the device twice quickly will interrupt step 3, leaving the token in place so that the second boot will go to the bootloader.

4.4.7. pico_cxx_options

non-code library controlling C++ related compile options

4.4.8. pico_divider

Optimized 32 and 64 bit division functions accelerated by the RP2040 hardware divider. Additionally provides integration with the C / and % operators

4.4.8.1. Function List

```
int32_t div_s32s32 (int32_t a, int32_t b)
static int32_t divmod_s32s32_rem (int32_t a, int32_t b, int32_t *rem)
divmod_result_t divmod_s32s32 (int32_t a, int32_t b)
uint32_t div_u32u32 (uint32_t a, uint32_t b)
static uint32_t divmod_u32u32_rem (uint32_t a, uint32_t b, uint32_t *rem)
divmod_result_t divmod_u32u32 (uint32_t a, uint32_t b)
```

```
• int64_t div_s64s64 (int64_t a, int64_t b)
• int64_t divmod_s64s64_rem (int64_t a, int64_t b, int64_t *rem)
• int64_t divmod_s64s64 (int64_t a, int64_t b)
• uint64_t div_u64u64 (uint64_t a, uint64_t b)
uint64_t divmod_u64u64_rem (uint64_t a, uint64_t b, uint64_t *rem)
• uint64_t divmod_u64u64 (uint64_t a, uint64_t b)
• int32_t div_s32s32_unsafe (int32_t a, int32_t b)
• int32_t divmod_s32s32_rem_unsafe (int32_t a, int32_t b, int32_t *rem)
• int64_t divmod_s32s32_unsafe (int32_t a, int32_t b)
• uint32_t div_u32u32_unsafe (uint32_t a, uint32_t b)
• uint32_t divmod_u32u32_rem_unsafe (uint32_t a, uint32_t b, uint32_t *rem)
• uint64_t divmod_u32u32_unsafe (uint32_t a, uint32_t b)
• int64_t div_s64s64_unsafe (int64_t a, int64_t b)
• int64_t divmod_s64s64_rem_unsafe (int64_t a, int64_t b, int64_t *rem)
• int64_t divmod_s64s64_unsafe (int64_t a, int64_t b)
• uint64_t div_u64u64_unsafe (uint64_t a, uint64_t b)
• uint64_t divmod_u64u64_rem_unsafe (uint64_t a, uint64_t b, uint64_t *rem)
• uint64_t divmod_u64u64_unsafe (uint64_t a, uint64_t b)
```

4.4.8.2. Function Documentation

4.4.8.2.1. div_s32s32

Integer divide of two signed 32-bit values.

Parameters

- a Dividend
- b Divisor

Returns

quotient

4.4.8.2.2. div_s32s32_unsafe

Unsafe integer divide of two signed 32-bit values.

Do not use in interrupts

Parameters

• a Dividend

• b Divisor

Returns

quotient

4.4.8.2.3. div_s64s64

Integer divide of two signed 64-bit values.

Parameters

- a Dividend
- b Divisor

Returns

Quotient

4.4.8.2.4. div_s64s64_unsafe

Unsafe integer divide of two signed 64-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

• Quotient

4.4.8.2.5. div_u32u32

Integer divide of two unsigned 32-bit values.

Parameters

- a Dividend
- b Divisor

Returns

Quotient

4.4.8.2.6. div_u32u32_unsafe

Unsafe integer divide of two unsigned 32-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

Quotient

4.4.8.2.7. div_u64u64

Integer divide of two unsigned 64-bit values.

Parameters

- a Dividend
- b Divisor

Returns

Quotient

4.4.8.2.8. div_u64u64_unsafe

Unsafe integer divide of two unsigned 64-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

Quotient

4.4.8.2.9. divmod_s32s32

Integer divide of two signed 32-bit values.

Parameters

- a Dividend
- b Divisor

Returns

• quotient in low word/r0, remainder in high word/r1

4.4.8.2.10. divmod_s32s32_rem

```
int32_t *rem)
```

Integer divide of two signed 32-bit values, with remainder.

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

• Quotient result of dividend/divisor

4.4.8.2.11. divmod_s32s32_rem_unsafe

Unsafe integer divide of two signed 32-bit values, with remainder.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

· Quotient result of dividend/divisor

4.4.8.2.12. divmod_s32s32_unsafe

Unsafe integer divide of two unsigned 32-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

• quotient in low word/r0, remainder in high word/r1

4.4.8.2.13. divmod_s64s64

Integer divide of two signed 64-bit values.

Parameters

• a Dividend

• b Divisor

Returns

• quotient in result (r0,r1), remainder in regs (r2, r3)

4.4.8.2.14. divmod_s64s64_rem

```
int64_t divmod_s64s64_rem (int64_t a,
    int64_t b,
    int64_t *rem)
```

Integer divide of two signed 64-bit values, with remainder.

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

· Quotient result of dividend/divisor

4.4.8.2.15. divmod_s64s64_rem_unsafe

Unsafe integer divide of two signed 64-bit values, with remainder.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

• Quotient result of dividend/divisor

4.4.8.2.16. divmod_s64s64_unsafe

Unsafe integer divide of two signed 64-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

• quotient in result (r0,r1), remainder in regs (r2, r3)

4.4.8.2.17. divmod_u32u32

Integer divide of two unsigned 32-bit values.

Parameters

- a Dividend
- b Divisor

Returns

• quotient in low word/r0, remainder in high word/r1

4.4.8.2.18. divmod_u32u32_rem

Integer divide of two unsigned 32-bit values, with remainder.

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

· Quotient result of dividend/divisor

4.4.8.2.19. divmod_u32u32_rem_unsafe

Unsafe integer divide of two unsigned 32-bit values, with remainder. \\

Do not use in interrupts

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

· Quotient result of dividend/divisor

4.4.8.2.20. divmod_u32u32_unsafe

Unsafe integer divide of two unsigned 32-bit values.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor

Returns

• quotient in low word/r0, remainder in high word/r1

4.4.8.2.21. divmod_u64u64

Integer divide of two signed 64-bit values.

Parameters

- a Dividend
- b Divisor

Returns

• quotient in result (r0,r1), remainder in regs (r2, r3)

4.4.8.2.22. divmod_u64u64_rem

Integer divide of two unsigned 64-bit values, with remainder.

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

• Quotient result of dividend/divisor

4.4.8.2.23. divmod_u64u64_rem_unsafe

Unsafe integer divide of two unsigned 64-bit values, with remainder.

Do not use in interrupts

Parameters

- a Dividend
- b Divisor
- rem The remainder of dividend/divisor

Returns

· Quotient result of dividend/divisor

4.4.8.2.24. divmod_u64u64_unsafe

Unsafe integer divide of two signed 64-bit values.

Do not use in interrupts

Parameters

- a Dividend
- h Divisor

Returns

• quotient in result (r0,r1), remainder in regs (r2, r3)

4.4.9. pico_double

Optimized double-precision floating point functions

(Replacement) optimized implementations are provided of the following compiler built-ins and math library functions:

- aeabi_dadd, aeabi_ddiv, aeabi_dmul, aeabi_drsub, aeabi_dsub, aeabi_cdcmpeq, aeabi_cdcmple, aeabi_cdcmple, aeabi_dcmpeq, aeabi_dcmpeq, aeabi_dcmplt, aeabi_ldcmple, aeabi_dcmpge, aeabi_dcmpgt, aeabi_ldcmpun, aeabi_i2d, aeabi_l2d, aeabi_ui2d, aeabi_ul2d, aeabi_d2iz, aeabi_d2uiz, aeabi_d2uiz, aeabi_d2f
- sqrt, cos, sin, tan, atan2, exp, log, ldexp, copysign, trunc, floor, ceil, round, asin, acos, atan, sinh, cosh, tanh, asinh, acosh, atanh, exp2, log2, exp10, log10, pow,, hypot, cbrt, fmod, drem, remainder, remquo, expm1, log1p, fma
- powint, sincos (GNU extensions)

The following additional optimized functions are also provided:

• fix2double, ufix2double, fix642double, ufix642double, double2fix, double2ufix, double2fix64, double2int64, double2int64, double2int64_z

4.4.10. pico_float

Optimized single-precision floating point functions

(Replacement) optimized implementations are provided of the following compiler built-ins and math library functions:

- aeabi_fadd, aeabi_fdiv, aeabi_fmul, aeabi_frsub, aeabi_fsub, aeabi_cfcmpeq, aeabi_cfcmple, aeabi_cfcmple, aeabi_fcmpeq, aeabi_fcmplt, aeabi_fcmple, aeabi_fcmpge, aeabi_fcmpgt, aeabi_fcmpun, aeabi_i2f, aeabi_l2f, aeabi_ui2f, aeabi_ui2f, aeabi_f2iz, aeabi_f2iz, aeabi_f2uiz, aeabi
- Idexpf, copysignf, truncf, floorf, ceilf, roundf, asinf, acosf, atanf, sinhf, coshf, tanhf, asinhf, acoshf, atanhf, exp2f, log2f, exp10f, log10f, powf, hypotf, cbrtf, fmodf, dremf, remainderf, remquof, expm1f, log1pf, fmaf
- powintf, sincosf (GNU extensions)

The following additional optimized functions are also provided:

• fix2float, ufix2float, fix642float, ufix642float, float2fix, float2ufix, float2fix64, float2ufix64, float2int, float2int64, float2intz, float2int64, float2int6

4.4.11. pico_int64_ops

Optimized replacement implementations of the compiler built-in 64 bit multiplication

This library does not provide any additional functions

4.4.12. pico_malloc

Multi-core safety for malloc, calloc and free

This library does not provide any additional functions

4.4.13. pico_mem_ops

Provides optimized replacement implementations of the compiler built-in memcpy, memset and related functions:

- · memset, memcpy
- aeabi_memset, aeabi_memset4, aeabi_memset8, aeabi_memcpy, aeabi_memcpy4, aeabi_memcpy8

This library does not provide any additional functions

4.4.14. pico_platform

Compiler definitions for the selected PICO_PLATFORM

4.4.15. pico_printf

Compact replacement for printf by Marco Paland (info@paland.com)

4.4.16. pico_runtime

Aggregate runtime support including pico_bit_ops, pico_divider, pico_double, pico_int64_ops, pico_float, pico_malloc, pico_mem_ops and pico_standard_link

4.4.17. pico_stdio

Customized stdio support allowing for input and output from UART, USB, semi-hosting etc.

Note the API for adding additional input output devices is not yet considered stable

4.4.17.1. Modules

- pico_stdio_semihosting
 Experimental support for stdout using RAM semihosting.
- pico_stdio_uart
 Support for stdin/stdout using UART.
- pico_stdio_usb
 Support for stdin/stdout over USB serial (CDC)

4.4.17.2. Function List

- void stdio_init_all (void)
- void stdio_flush (void)
- int getchar_timeout_us (uint32_t timeout_us)
- void stdio_set_driver_enabled (stdio_driver_t *driver, bool enabled)

- void stdio_filter_driver (stdio_driver_t *driver)
- void stdio_set_translate_crlf (stdio_driver_t *driver, bool translate)

4.4.17.3. Function Documentation

4.4.17.3.1. getchar_timeout_us

```
int getchar_timeout_us (uint32_t timeout_us)
```

Return a character from stdin if there is one available within a timeout.

Parameters

• timeout_us the timeout in microseconds, or 0 to not wait for a character if none available.

Returns

• the character from 0-255 or PICO_ERROR_TIMEOUT if timeout occurs

4.4.17.3.2. stdio_filter_driver

```
void stdio_filter_driver (stdio_driver_t *driver)
```

Control limiting of output to a single driver.

Parameters

 driver if non-null then output only that driver will be used for input/output (assuming it is in the list of enabled drivers). if NULL then all enabled drivers will be used

4.4.17.3.3. stdio_flush

```
void stdio_flush (void)
```

Initialize all of the present standard stdio types that are linked into the binary.

Call this method once you have set up your clocks to enable the stdio support for UART, USB and semihosting based on the presence of the respective libraries in the binary.

See also

• stdio_uart, stdio_usb, stdio_semihosting

4.4.17.3.4. stdio_init_all

```
void stdio_init_all (void)
```

Initialize all of the present standard stdio types that are linked into the binary.

Call this method once you have set up your clocks to enable the stdio support for UART, USB and semihosting based on the presence of the respective libraries in the binary.

See also

stdio_uart, stdio_usb, stdio_semihosting

4.4.17.3.5. stdio_set_driver_enabled

Adds or removes a driver from the list of active drivers used for input/output.

Parameters

- driver the driver
- enabled true to add, false to remove

4.4.17.3.6. stdio_set_translate_crlf

control conversion of line feeds to carriage return on transmissions

Parameters

- driver the driver
- translate If true, convert line feeds to carriage return on transmissions

4.4.18. pico_stdio_semihosting

Experimental support for stdout using RAM semihosting.

Linking this library or calling pico_enable_stdio_semihosting(TARGET) in the CMake (which achieves the same thing) will add semihosting to the drivers used for standard output

4.4.18.1. Function List

• void stdio_semihosting_init (void)

4.4.18.2. Function Documentation

4.4.18.2.1. stdio_semihosting_init

```
void stdio_semihosting_init (void)
```

Explicitly initialize stdout over semihosting and add it to the current set of stdout targets.

4.4.19. pico_stdio_uart

Support for stdin/stdout using UART.

Linking this library or calling pico_enable_stdio_uart(TARGET) in the CMake (which achieves the same thing) will add UART to the drivers used for standard output

4.4.19.1. Function List

- void stdio_uart_init (void)
- void stdout_uart_init (void)
- void stdin_uart_init (void)
- void stdio_uart_init_full (uart_inst_t *uart, uint baud_rate, int tx_pin, int rx_pin)
- bool stdio_usb_init (void)

4.4.19.2. Function Documentation

4.4.19.2.1. stdin_uart_init

```
void stdin_uart_init (void)
```

Explicitly initialize stdin only (no stdout) over UART and add it to the current set of stdin drivers.

This method sets up PICO_DEFAULT_UART_RX_PIN for UART input (if defined) , and configures the baud rate as $PICO_DEFAULT_UART_BAUD_RATE$

4.4.19.2.2. stdio_uart_init

```
void stdio_uart_init (void)
```

Explicitly initialize stdin/stdout over UART and add it to the current set of stdin/stdout drivers.

This method sets up PICO_DEFAULT_UART_TX_PIN for UART output (if defined), PICO_DEFAULT_UART_RX_PIN for input (if defined) and configures the baud rate as PICO_DEFAULT_UART_BAUD_RATE.

4.4.19.2.3. stdio_uart_init_full

```
void stdio_uart_init_full (uart_inst_t *uart,
        uint baud_rate,
        int tx_pin,
        int rx_pin)
```

Perform custom initialization initialize stdin/stdout over UART and add it to the current set of stdin/stdout drivers.

Parameters

- uart the uart instance to use, uart0 or uart1
- baud_rate the baud rate in Hz
- tx_pin the UART pin to use for stdout (or -1 for no stdout)
- rx_pin the UART pin to use for stdin (or -1 for no stdin)

4.4.19.2.4. stdio_usb_init

```
bool stdio_usb_init (void)
```

Explicitly initialize USB stdio and add it to the current set of stdin drivers.

4.4.19.2.5. stdout_uart_init

```
void stdout_uart_init (void)
```

Explicitly initialize stdout only (no stdin) over UART and add it to the current set of stdout drivers.

This method sets up PICO_DEFAULT_UART_TX_PIN for UART output (if defined) , and configures the baud rate as $PICO_DEFAULT_UART_BAUD_RATE$

4.4.20. pico_stdio_usb

Support for stdin/stdout over USB serial (CDC)

Linking this library or calling pico_enable_stdio_usb(TARGET) in the CMake (which achieves the same thing) will add USB CDC to the drivers used for standard output

Note this library is a developer convenience. It is not applicable in all cases; for one it takes full control of the USB device precluding your use of the USB in device or host mode. For this reason, this library will automatically disengage if you try to using it alongside tinyusb_device or tinyusb_host. It also takes control of a lower level IRQ and sets up a periodic background task.

This library also includes (by default) functionality to enable the RP2040 to be reset over the USB interface.

4.4.21. pico_standard_link

Standard link step providing the basics for creating a runnable binary.

This includes

- · C runtime initialization
- Linker scripts for 'default', 'no_flash', 'blocked_ram' and 'copy_to_ram' binaries
- · 'Binary Information' support
- · Linker option control

4.5. External API Headers

boot_picoboot	
boot_uf2	

4.5.1. boot_picoboot

Header file for the PICOBOOT USB interface exposed by an RP2040 in BOOTSEL mode.

4.5.2. boot_uf2

Header file for the UF2 format supported by an RP2040 in BOOTSEL mode.

4.5. External API Headers 256

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

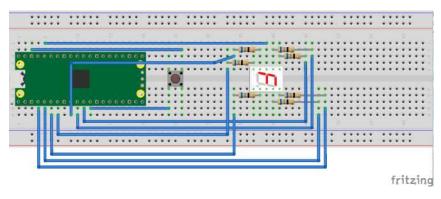
Our 7 Segment display has pins as follows.

```
--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 8. Wiring Diagram for 7 segment LED.



List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/gpio/hello_7 segment/CMakeLists.txt\ Lines\ 1-12$

```
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
8 # create map/bin/hex file etc.
```

```
9 pico_add_extra_outputs(hello_7segment)
10
11 # add url via pico_set_program_url
12 example_auto_set_url(hello_7segment)
```

hello_7segment.c

The example code.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/gpio/hello_7 segment/hello_7 segment.c\ Lines\ 1-95$

```
1 /**
2 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 4 * SPDX-License-Identifier: BSD-3-Clause
5 */
6
7 #include <stdio.h>
8 #include "pico/stdlib.h"
9 #include "hardware/gpio.h"
10
11 /*
12 Our 7 Segment display has pins as follows:
13
14
    --A--
15
    --G--
16
17
    --D--
18
19
20 By default we are allocating GPIO 2 to A, 3 to B etc.
21 So, connect GOIP 2 to pin A on the 7 segment LED display etc. Don't forget
22 the appropriate resistors, best to use one for each segment!
23
24 Connect button so that pressing the switch connects the GPIO 9 (default) to
25 ground (pull down)
26 */
27
28 #define FIRST_GPIO 2
29 #define BUTTON_GPIO (FIRST_GPIO+7)
31 // This array converts a number \theta-9 to a bit pattern to send to the GPIO's
32 int bits[10] = {
    0x3f, // 0
33
          0x06, // 1
34
          0x5b, // 2
0x4f, // 3
0x66, // 4
35
36
37
          0x6d, // 5
38
          0x7d, // 6
39
          0x07, // 7
40
          0x7f, // 8
41
          0x67 // 9
42
43 };
44
45 /// \tag::hello_gpio[]
46 int main() {
47 stdio_init_all();
48 printf("Hello, 7segment - press button to count down!\n");
49
50
   // We could use gpio_set_dir_out_masked() here
for (int gpio = FIRST_GPIO; gpio < FIRST_GPIO + 7; gpio++) {
```

```
52
           gpio_init(gpio);
53
           gpio_set_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
           gpio_set_outover(gpio, GPIO_OVERRIDE_INVERT);
56
57
58
59
       gpio_init(BUTTON_GPIO);
60
       gpio_set_dir(BUTTON_GPIO, GPIO_IN);
       // We are using the button to pull down to \theta \nu when pressed, so ensure that when
61
62
       // unpressed, it uses internal pull ups. Otherwise when unpressed, the input will
       // be floating.
63
       gpio_pull_up(BUTTON_GPIO);
64
65
66
     int val = 0;
67
       while (true) {
           // Count upwards or downwards depending on button input
68
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
           // We are starting with GPIO 2, our bitmap starts at bit 0 so shift to start at 2.
83
           int32_t mask = bits[val] << FIRST_GPIO;</pre>
84
85
           // Set all our GPIO's in one go!
86
           // If something else is using GPIO, we might want to use gpio_put_masked()
87
88
           gpio_set_mask(mask);
89
           sleep_ms(250);
90
           gpio_clr_mask(mask);
91
92
93
       return 0;
94 }
95 /// \end::hello_gpio[]
```

Table 10. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
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.

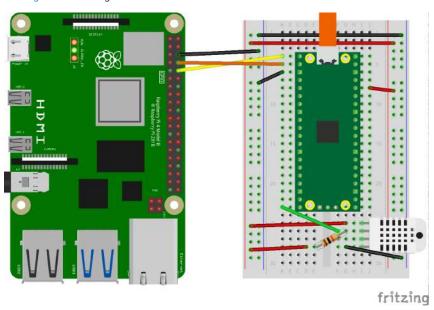
NOTE

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. The sensor is available from a number of retailers.

Wiring information

See Figure 9 for wiring instructions.

Figure 9. Wiring the DHT-22 temperature sensor to Raspberry Pi Pico, and connecting Pico's UARTO 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 $k\Omega$ resistor between VCC and the data pin, to act as a medium-strength pull up on the data line.

Connecting UARTO of Pico to Raspberry Pi as in Figure 9 and you should see something similar to Figure 10 in minicom when connected to /dev/serial0 on the Raspberry Pi.

Figure 10. Serial output over Pico's UARTO in a terminal window.

```
FT232R USB UART — 80x24 — 115200.8.N.1

Humidity = 54.9%, Temperature = 28.5C (83.3F)

Humidity = 54.9%, Temperature = 28.5C (83.3F)

Humidity = 55.0%, Temperature = 28.5C (83.3F)
```

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.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/gpio/dht_sensor/CMakeLists.txt\ Lines\ 1-11$

dht.c

The example code.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/gpio/dht_sensor/dht.c\ Lines\ 1-92$

```
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 <math.h>
9 #include "pico/stdlib.h"
10 #include "hardware/gpio.h"
12 #ifdef PICO_DEFAULT_LED_PIN
13 #define LED_PIN PICO_DEFAULT_LED_PIN
14 #endif
15
16 const uint DHT_PIN = 15;
17 const uint MAX_TIMINGS = 85;
18
19 typedef struct {
    float humidity;
21
      float temp_celsius;
22 } dht_reading;
24 void read_from_dht(dht_reading *result);
26 int main() {
27 stdio_init_all();
28
     gpio_init(DHT_PIN);
29 #ifdef LED_PIN
30
    gpio_init(LED_PIN);
31
     gpio_set_dir(LED_PIN, GPIO_OUT);
32 #endif
33
     while (1) {
34
          dht_reading reading;
35
          read_from_dht(&reading);
          float fahrenheit = (reading.temp_celsius * 9 / 5) + 32;
36
37
          printf("Humidity = %.1f%, Temperature = %.1fC (%.1fF)\n",
                 reading.humidity, reading.temp_celsius, fahrenheit);
38
39
40
          sleep_ms(2000);
41
42 }
44 void read_from_dht(dht_reading *result) {
45 int data[5] = \{0, 0, 0, 0, 0\};
46
   uint last = 1;
47
   uint j = 0;
48
    gpio_set_dir(DHT_PIN, GPIO_OUT);
49
    gpio_put(DHT_PIN, 0);
50
51
     sleep_ms(20);
52
     gpio_set_dir(DHT_PIN, GPIO_IN);
53
54 #ifdef LED_PIN
55 gpio_put(LED_PIN, 1);
56 #endif
57
    for (uint i = 0; i < MAX_TIMINGS; i++) {</pre>
58
          uint count = 0;
59
          while (gpio_get(DHT_PIN) == last) {
60
             count++;
61
              sleep_us(1);
              if (count == 255) break;
62
63
64
          last = gpio_get(DHT_PIN);
65
          if (count == 255) break;
```

```
if ((i >= 4) && (i % 2 == 0)) {
68
               data[j / 8] <<= 1;
69
               if (count > 16) data[j / 8] |= 1;
70
               j++;
71
73 #ifdef LED_PIN
74
      gpio_put(LED_PIN, 0);
75 #endif
76
77
       if ((j >= 40) \& (data[4] == ((data[0] + data[1] + data[2] + data[3]) \& 0xFF))) {
           result->humidity = (float) ((data[0] << 8) + data[1]) / 10;
78
79
           if (result->humidity > 100) {
80
               result->humidity = data[0];
81
82
           result->temp_celsius = (float) (((data[2] & 0x7F) << 8) + data[3]) / 10;
83
           if (result->temp_celsius > 125) {
               result->temp_celsius = data[2];
85
           if (data[2] & 0x80) {
87
               result->temp_celsius = -result->temp_celsius;
88
           }
    } else {
89
90
           printf("Bad data\n");
91
92 }
```

Table 11. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
Raspberry Pi Pico	1	http://raspberrypi.org/
10 kΩ resistor	1	generic part
M/M Jumper wires	4	generic part
DHT-22 sensor	1	generic part

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 appropriate compensation 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 \rightarrow SDO/SDO on bme280 board

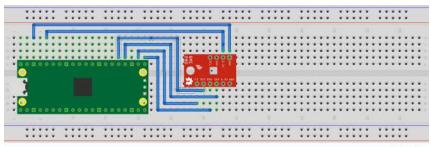
- GPIO 17 (pin 22) Chip select → CSB/!CS on bme280 board
- GPIO 18 (pin 24) SCK/spi0_sclk → SCL/SCK on bme280 board
- GPIO 19 (pin 25) MOSI/spi0_tx \rightarrow SDA/SDI on bme280 board
- 3.3v (pin 3;6) → VCC on bme280 board
- GND (pin 38) → GND on bme280 board

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 11. Wiring
Diagram for bme280.



fritzing

List of Files

CMakeLists.txt

CMake file to incorporate the example in to the examples build tree.

 $Pico\ Examples: https://github.com/raspberrypi/pico-examples/tree/master/spi/bme280_spi/CMakeLists.txt\ Lines\ 1-12$

bme280_spi.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/spi/bme280_spi/bme280_spi.c Lines 1 - 241

```
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 "pico/binary_info.h"
11 #include "hardware/spi.h"
12
13 /* Example code to talk to a bme280 humidity/temperature/pressure sensor.
14
15
           NOTE: Ensure the device is capable of being driven at 3.3v NOT 5v. The Pico
16
           GPIO (and therefor SPI) cannot be used at 5v.
17
           You will need to use a level shifter on the SPI lines if you want to run the
18
19
           board at 5v.
20
21
          Connections on Raspberry Pi Pico board and a generic bme280 board, other
22
          boards may vary.
23
24
          GPIO 16 (pin 21) MISO/spi0_rx-> SDO/SDO on bme280 board
25
          GPIO 17 (pin 22) Chip select -> CSB/!CS on bme280 board
26
          GPIO 18 (pin 24) SCK/spi0_sclk -> SCL/SCK on bme280 board
27
          GPIO 19 (pin 25) MOSI/spi0_tx -> SDA/SDI on bme280 board
          3.3v (pin 36) -> VCC on bme280 board
28
29
          GND (pin 38) -> GND on bme280 board
30
31
          Note: SPI devices can have a number of different naming schemes for pins. See
32
          the Wikipedia page at https://en.wikipedia.org/wiki/Serial_Peripheral_Interface
33
          for variations.
34
          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
38 */
39
40 #define READ_BIT 0x80
41
42 int32_t t_fine;
44 uint16_t dig_T1;
45 int16_t dig_T2, dig_T3;
46 uint16_t dig_P1;
47 int16_t dig_P2, dig_P3, dig_P4, dig_P5, dig_P6, dig_P7, dig_P8, dig_P9;
48 uint8_t dig_H1, dig_H3;
49 int8_t dig_H6;
50 int16_t dig_H2, dig_H4, dig_H5;
51
52 /* The following compensation functions are required to convert from the raw ADC
53 data from the chip to something usable. Each chip has a different set of
54 compensation parameters stored on the chip at point of manufacture, which are
55 read from the chip at startup and used inthese routines.
56 */
57 int32_t compensate_temp(int32_t adc_T) {
58
             int32_t var1, var2, T;
             var1 = ((((adc_T >> 3) - ((int32_t) dig_T1 << 1))) * ((int32_t) dig_T2)) >> 11;
59
           var2 = (((((adc_T >> 4) - ((int32_t) dig_T1)) * ((adc_T >> 4) - ((int32_t) dig_T1))) >> ((adc_T >> 4) - ((int32_t) dig_T1)))
     12) * ((int32_t) dig_T3))
61
                            >> 14;
62
63
             t_fine = var1 + var2;
64
            T = (t_fine * 5 + 128) >> 8;
             return T;
```

```
66 }
  67
  68 uint32_t compensate_pressure(int32_t adc_P) {
  69
               int32_t var1, var2;
  70
               uint32_t p;
  71
               var1 = (((int32_t) t_fine) >> 1) - (int32_t) 64000;
  72
               var2 = (((var1 >> 2) * (var1 >> 2)) >> 11) * ((int32_t) dig_P6);
  73
               var2 = var2 + ((var1 * ((int32_t) dig_P5)) << 1);
               var2 = (var2 >> 2) + (((int32_t) dig_P4) << 16);
  74
               var1 = (((dig_P3 * (((var1 >> 2) * (var1 >> 2)) >> 13)) >> 3) + ((((int32_t) dig_P2) * (var1 >> 2)) >> 13)) >> 3) + ((((int32_t) dig_P2) * (var1 >> 2)) >> 13)) >> 3) + ((((int32_t) dig_P2) * (((int32_t) dig_P2) * ((((int32_t) dig_P2) dig_P2) * (((int32_t) dig_P2) dig_P2) * (((int32_t) dig_P2) dig_P2) * (((int32_t) dig_P2) dig_P2) * (((int32_t) dig_P2) dig_P2) dig_P2) * (((int32_t) dig_P2) dig_
       var1) >> 1)) >> 18;
  76
               var1 = ((((32768 + var1)) * ((int32_t) dig_P1)) >> 15);
  77
               if (var1 == 0)
  78
                      return 0;
  79
               p = (((uint32_t) (((int32_t) 1048576) - adc_P) - (var2 >> 12))) * 3125;
  80
  81
               if (p < 0x80000000)
  82
                      p = (p << 1) / ((uint32_t) var1);
  83
                      p = (p / (uint32_t) var1) * 2;
  84
  85
  86
               var1 = (((int32_t) dig_P9) * ((int32_t) (((p >> 3) * (p >> 3)) >> 13))) >> 12;
  87
               var2 = (((int32_t) (p >> 2)) * ((int32_t) dig_P8)) >> 13;
  88
               p = (uint32_t) ((int32_t) p + ((var1 + var2 + dig_P7) >> 4));
  89
  90
               return p;
  91 }
  92
  93 uint32_t compensate_humidity(int32_t adc_H) {
               int32_t v_x1_u32r;
               v_x1_u32r = (t_fine - ((int32_t) 76800));
  96
               v_x1_u32r = (((((adc_H << 14) - (((int32_t) dig_H4) << 20) - (((int32_t) dig_H5) *
       v_x1_u32r)) +
  97
                                            10) * (((v_x1_u32r *
  98
        ((int32_t) dig_H3))
                              >> 11) + ((int32_t) 32768))) >> 10) + ((int32_t) 2097152)) *
100
                                                                                                     ((int32_t) dig_H2) + 8192) >> 14));
101
               v_x1_u32r = (v_x1_u32r - (((((v_x1_u32r >> 15) * (v_x1_u32r >> 15)) >> 7) * ((int32_t))
       dig_H1)) >> 4));
102
               v_x1_u32r = (v_x1_u32r < 0 ? 0 : v_x1_u32r);
103
               v_x1_u32r = (v_x1_u32r > 419430400 ? 419430400 : v_x1_u32r);
104
105
               return (uint32_t) (v_x1_u32r >> 12);
106 }
197
108 #ifdef PICO_DEFAULT_SPI_CSN_PIN
109 static inline void cs_select() {
110
               asm volatile("nop \n nop \n nop");
111
               gpio_put(PICO_DEFAULT_SPI_CSN_PIN, 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");
               gpio_put(PICO_DEFAULT_SPI_CSN_PIN, 1);
117
               asm volatile("nop \n nop \n nop");
118
119 }
120 #endif
121
122 #if defined(spi_default) && defined(PICO_DEFAULT_SPI_CSN_PIN)
123 static void write_register(uint8_t reg, uint8_t data) {
```

```
uint8_t buf[2];
124
125
        buf[0] = reg \& 0x7f; // remove read bit as this is a write
126
        buf[1] = data;
127
        cs_select();
        spi_write_blocking(spi_default, buf, 2);
128
129
        cs deselect():
130
        sleep_ms(10);
131 }
132
133 static void read_registers(uint8_t reg, uint8_t *buf, uint16_t len) {
134
        // For this particular device, we send the device the register we want to read
135
        // first, then subsequently read from the device. The register is auto incrementing
136
        // so we don't need to keep sending the register we want, just the first.
137
        reg |= READ_BIT;
        cs_select();
138
139
        spi_write_blocking(spi_default, &reg, 1);
140
        sleep ms(10):
141
        spi_read_blocking(spi_default, 0, buf, len);
142
        cs_deselect();
143
        sleep_ms(10);
144 }
145
146 /* This function reads the manufacturing assigned compensation parameters from the device */
147 void read_compensation_parameters() {
        uint8_t buffer[26];
148
149
150
        read_registers(0x88, buffer, 24);
151
152
        dig_T1 = buffer[0] | (buffer[1] << 8);</pre>
153
        dig_T2 = buffer[2] \mid (buffer[3] << 8);
154
        dig_T3 = buffer[4] | (buffer[5] << 8);</pre>
155
        dig_P1 = buffer[6] | (buffer[7] << 8);</pre>
156
157
        dig_P2 = buffer[8] \mid (buffer[9] << 8);
        dig_P3 = buffer[10] | (buffer[11] << 8);</pre>
158
        dig_P4 = buffer[12] | (buffer[13] << 8);
159
        dig_P5 = buffer[14] | (buffer[15] << 8);</pre>
160
        dig_P6 = buffer[16] | (buffer[17] << 8);</pre>
161
        dig_P7 = buffer[18] | (buffer[19] << 8);</pre>
162
163
        dig_P8 = buffer[20] | (buffer[21] << 8);</pre>
164
        dig_P9 = buffer[22] | (buffer[23] << 8);</pre>
165
166
        dig_H1 = buffer[25];
167
168
        read_registers(0xE1, buffer, 8);
169
170
        dig_H2 = buffer[0] \mid (buffer[1] << 8);
        dig_H3 = (int8_t) buffer[2];
171
        dig_H4 = buffer[3] << 4 | (buffer[4] & 0xf);
172
173
        dig_{H5} = (buffer[5] >> 4) | (buffer[6] << 4);
174
        dig_H6 = (int8_t) buffer[7];
175 }
176
177 static void bme280_read_raw(int32_t *humidity, int32_t *pressure, int32_t *temperature) {
178
        uint8_t buffer[8];
179
180
        read_registers(0xF7, buffer, 8);
        *pressure = ((uint32_t) buffer[0] << 12) | ((uint32_t) buffer[1] << 4) | (buffer[2] >> ^{*}
181
182
        *temperature = ((uint32_t) buffer[3] << 12) | ((uint32_t) buffer[4] << 4) | (buffer[5]
183
        *humidity = (uint32_t) buffer[6] << 8 | buffer[7];
184 }
```

```
185 #endif
186
187 int main() {
188
     stdio_init_all();
189 #if !defined(spi_default) || !defined(PICO_DEFAULT_SPI_SCK_PIN) ||
    !defined(PICO_DEFAULT_SPI_TX_PIN) || !defined(PICO_DEFAULT_SPI_RX_PIN) ||
    !defined(PICO_DEFAULT_SPI_CSN_PIN)
190 #warning spi/bme280_spi example requires a board with SPI pins
        puts("Default SPI pins were not defined");
191
192 #else
193
194
        printf("Hello, bme280! Reading raw data from registers via SPI...\n");
195
        // This example will use SPI0 at 0.5MHz.
196
        spi_init(spi_default, 500 * 1000);
197
198
        gpio_set_function(PICO_DEFAULT_SPI_RX_PIN, GPIO_FUNC_SPI);
199
        gpio_set_function(PICO_DEFAULT_SPI_SCK_PIN, GPIO_FUNC_SPI);
200
        gpio_set_function(PICO_DEFAULT_SPI_TX_PIN, GPIO_FUNC_SPI);
        // Make the SPI pins available to picotool
201
        bi_decl(bi_3pins_with_func(PICO_DEFAULT_SPI_RX_PIN, PICO_DEFAULT_SPI_TX_PIN,
   PICO_DEFAULT_SPI_SCK_PIN, GPIO_FUNC_SPI));
203
204
        // Chip select is active-low, so we'll initialise it to a driven-high state
205
        gpio_init(PICO_DEFAULT_SPI_CSN_PIN);
        gpio_set_dir(PICO_DEFAULT_SPI_CSN_PIN, GPIO_OUT);
206
        gpio_put(PICO_DEFAULT_SPI_CSN_PIN, 1);
207
208
        // Make the CS pin available to picotool
209
       bi_decl(bi_1pin_with_name(PICO_DEFAULT_SPI_CSN_PIN, "SPI_CS"));
210
211
        // See if SPI is working - interrograte the device for its I2C ID number, should be 0x60
212
        uint8_t id;
213
        read_registers(0xD0, &id, 1);
214
        printf("Chip ID is 0x%x\n", id);
215
216
        read_compensation_parameters();
217
        write_register(0xF2, 0x1); // Humidity oversampling register - going for x1
218
219
        write_register(0xF4, 0x27);// Set rest of oversampling modes and run mode to normal
220
221
        int32_t humidity, pressure, temperature;
222
223
        while (1) {
224
            bme280_read_raw(&humidity, &pressure, &temperature);
225
226
            // These are the raw numbers from the chip, so we need to run through the
227
            // compensations to get human understandable numbers
228
            pressure = compensate_pressure(pressure);
229
            temperature = compensate_temp(temperature);
230
            humidity = compensate_humidity(humidity);
231
232
            printf("Humidity = %.2f%%\n", humidity / 1024.0);
233
            printf("Pressure = %dPa\n", pressure);
234
            printf("Temp. = %.2fC\n", temperature / 100.0);
235
236
            sleep_ms(1000);
237
238
239
        return 0;
240 #endif
241 }
```

Table 12. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
Raspberry Pi Pico	1	http://raspberrypi.org/
BME280 board	1	generic part
M/M Jumper wires	6	generic part

Attaching a MPU9250 accelerometer/gyroscope 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

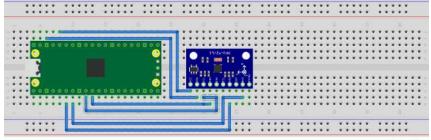
The example here uses SPI port 0. Power is supplied from the 3.3V pin.



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 12. Wiring Diagram for MPU9250.



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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/master/spi/mpu9250_spi/CMakeLists.txt Lines 1 - 12

mpu9250_spi.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/spi/mpu9250_spi/mpu9250_spi.c Lines 1 - 155

```
1 /**
2 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
3 *
4 * SPDX-License-Identifier: BSD-3-Clause
5 */
7 #include <stdio.h>
8 #include <string.h>
9 #include "pico/stdlib.h"
10 #include "pico/binary_info.h"
11 #include "hardware/spi.h"
12
13 /* Example code to talk to a MPU9250 MEMS accelerometer and gyroscope.
14
    Ignores the magnetometer, that is left as a exercise for the reader.
15
16
    This is taking to simple approach of simply reading registers. It's perfectly
17
     possible to link up an interrupt line and set things up to read from the
18
     inbuilt FIFO to make it more useful.
19
20
      NOTE: Ensure the device is capable of being driven at 3.3v NOT 5v. The Pico
21
     GPIO (and therefor SPI) cannot be used at 5v.
22
23
      You will need to use a level shifter on the I2C lines if you want to run the
      board at 5v.
24
25
26
      Connections on Raspberry Pi Pico board and a generic MPU9250 board, other
27
      boards may vary.
28
29
      GPIO 4 (pin 6) MISO/spi0_rx-> ADO on MPU9250 board
30
      GPIO 5 (pin 7) Chip select -> NCS on MPU9250 board
     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
37 the Wikipedia page at https://en.wikipedia.org/wiki/Serial_Peripheral_Interface
38
     for variations.
39
     The particular device used here uses the same pins for I2C and SPI, hence the
40
     using of I2C names
41 */
42
43 #define PIN_MISO 4
44 #define PIN_CS 5
45 #define PIN_SCK 6
46 #define PIN_MOSI 7
47
48 #define SPI_PORT spi0
49 #define READ_BIT 0x80
51 static inline void cs_select() {
      asm volatile("nop \n nop \n nop");
     gpio_put(PIN_CS, 0); // Active low
53
      asm volatile("nop \n nop \n nop");
54
55 }
56
57 static inline void cs_deselect() {
asm volatile("nop \n nop \n nop");
    gpio_put(PIN_CS, 1);
59
60
      asm volatile("nop \n nop \n nop");
61 }
62
63 static void mpu9250_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
66
      uint8_t buf[] = {0x6B, 0x00};
67
      cs_select();
      spi_write_blocking(SPI_PORT, buf, 2);
68
69
      cs_deselect();
70 }
71
72
73 static void read_registers(uint8_t reg, uint8_t *buf, uint16_t len) {
      // For this particular device, we send the device the register we want to read
75
      // first, then subsequently read from the device. The register is auto incrementing
76
      // so we don't need to keep sending the register we want, just the first.
77
78
      reg |= READ_BIT;
79
      cs_select();
80
      spi_write_blocking(SPI_PORT, &reg, 1);
81
      sleep_ms(10);
82
      spi_read_blocking(SPI_PORT, 0, buf, len);
83
      cs_deselect();
84
       sleep_ms(10);
85 }
86
87
88 static void mpu9250_read_raw(int16_t accel[3], int16_t gyro[3], int16_t *temp) {
89
       uint8_t buffer[6];
90
91
       // Start reading acceleration registers from register 0x3B for 6 bytes
92
       read_registers(0x3B, buffer, 6);
93
94
       for (int i = 0; i < 3; i++) {
           accel[i] = (buffer[i * 2] << 8 | buffer[(i * 2) + 1]);
95
96
       }
97
```

```
// Now gyro data from reg 0x43 for 6 bytes
98
99
        read_registers(0x43, buffer, 6);
100
        for (int i = 0; i < 3; i++) {
101
            gyro[i] = (buffer[i * 2] << 8 | buffer[(i * 2) + 1]);;
102
103
104
105
        // Now temperature from reg 0x41 for 2 bytes
106
        read_registers(0x41, buffer, 2);
107
        *temp = buffer[0] << 8 | buffer[1];
108
109 }
110
111 int main() {
112
        stdio_init_all();
113
114
        printf("Hello, MPU9250! Reading raw data from registers via SPI...\n");
115
        // This example will use SPI0 at 0.5MHz.
116
117
        spi_init(SPI_PORT, 500 * 1000);
118
        gpio_set_function(PIN_MISO, GPIO_FUNC_SPI);
119
        gpio_set_function(PIN_SCK, GPIO_FUNC_SPI);
        gpio_set_function(PIN_MOSI, GPIO_FUNC_SPI);
120
121
        // Make the SPI pins available to picotool
       \verb|bi_decl(bi_3pins_with_func(PIN_MISO, PIN_MOSI, PIN_SCK, GPIO_FUNC_SPI))|;\\
122
123
124
       // Chip select is active-low, so we'll initialise it to a driven-high state
125
        gpio_init(PIN_CS);
126
        gpio_set_dir(PIN_CS, GPIO_OUT);
127
        gpio_put(PIN_CS, 1);
128
        // Make the CS pin available to picotool
129
        bi_decl(bi_1pin_with_name(PIN_CS, "SPI CS"));
130
131
        mpu9250_reset();
132
        // See if SPI is working - interrograte the device for its I2C ID number, should be 0x71
133
134
        uint8 t id:
135
        read_registers(0x75, &id, 1);
        printf("I2C address is 0x%x\n", id);
136
137
       int16_t acceleration[3], gyro[3], temp;
138
139
140
        while (1) {
141
           mpu9250_read_raw(acceleration, gyro, &temp);
142
143
            // These are the raw numbers from the chip, so will need tweaking to be really
   useful.
144
            // See the datasheet for more information
            printf("Acc. X = %d, Y = %d, Z = %d n", acceleration[0], acceleration[1],
145
   acceleration[2]):
146
           printf("Gyro. X = %d, Y = %d, Z = %d\n", gyro[0], gyro[1], gyro[2]);
147
            // Temperature is simple so use the datasheet calculation to get deg C.
148
            // Note this is chip temperature.
149
            printf("Temp. = f\n", (temp / 340.0) + 36.53);
150
151
            sleep_ms(100);
152
153
154
        return 0;
155 }
```

Table 13. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
Raspberry Pi Pico	1	http://raspberrypi.org/
MPU9250 board	1	generic part
M/M Jumper wires	6	generic part

Attaching a MPU6050 accelerometer/gyroscope 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

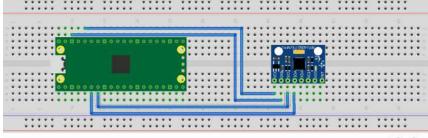
Wiring up the device requires 4 jumpers, to connect VCC (3.3v), GND, SDA and SCL. The example here uses I2C port 0, which is assigned to GPIO 4 (SDA) and 5 (SCL) in software. Power is supplied from the 3.3V pin.



O 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 13. Wiring Diagram for MPU6050.



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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/master/i2c/mpu6050_i2c/CMakeLists.txt Lines 1 - 12

mpu6050_i2c.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/i2c/mpu6050_i2c/mpu6050_i2c.c Lines 1 - 117

```
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 "pico/binary_info.h"
11 #include "hardware/i2c.h"
12
13 /* Example code to talk to a MPU6050 MEMS accelerometer and gyroscope
14
     This is taking to simple approach of simply reading registers. It's perfectly
15
      possible to link up an interrupt line and set things up to read from the
16
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 I2C) 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
     Connections on Raspberry Pi Pico board, other boards may vary.
25
26
    GPIO PICO_DEFAULT_I2C_SDA_PIN (On Pico this is 4 (pin 6)) -> SDA on MPU6050 board
27
28 GPIO PICO_DEFAULT_I2C_SCK_PIN (On Pico this is 5 (pin 7)) -> SCL on MPU6050 board
29 3.3v (pin 36) -> VCC on MPU6050 board
30
     GND (pin 38) -> GND on MPU6050 board
31 */
32
33 // By default these devices are on bus address 0x68
34 static int addr = 0x68;
35
36 #ifdef i2c_default
37 static void mpu6050_reset() {
38
      // 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\};
```

```
i2c_write_blocking(i2c_default, addr, buf, 2, false);
41
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
       // first, then subsequently read from the device. The register is auto incrementing
46
47
       // so we don't 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_default, addr, &val, 1, true); // true to keep master control of
   hus
54
        i2c_read_blocking(i2c_default, 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_default, addr, &val, 1, true);
       i2c_read_blocking(i2c_default, addr, buffer, 6, false); // False - finished with bus
64
65
       for (int i = 0; i < 3; i++) {
66
67
           gyro[i] = (buffer[i * 2] << 8 | buffer[(i * 2) + 1]);;</pre>
68
69
70
       // Now temperature from reg 0x41 for 2 bytes
       // The register is auto incrementing on each read
       val = 0x41;
72
73
       i2c_write_blocking(i2c_default, addr, &val, 1, true);
       i2c_read_blocking(i2c_default, addr, buffer, 2, false); // False - finished with bus
74
75
        *temp = buffer[0] << 8 | buffer[1];
76
77 }
78 #endif
79
80 int main() {
      stdio_init_all();
81
82 #if !defined(i2c_default) || !defined(PICO_DEFAULT_I2C_SDA_PIN) ||
   !defined(PICO_DEFAULT_I2C_SCL_PIN)
83
      #warning i2c/mpu6050_i2c example requires a board with I2C pins
84
       puts("Default I2C pins were not defined");
85 #else
       printf("Hello, MPU6050! Reading raw data from registers...\n");
86
87
88
       // This example will use I2CO on the default SDA and SCL pins (4, 5 on a Pico)
89
       i2c_init(i2c_default, 400 * 1000);
       gpio_set_function(PICO_DEFAULT_I2C_SDA_PIN, GPIO_FUNC_I2C);
90
       gpio_set_function(PICO_DEFAULT_I2C_SCL_PIN, GPIO_FUNC_I2C);
91
       gpio_pull_up(PICO_DEFAULT_I2C_SDA_PIN);
92
93
        gpio_pull_up(PICO_DEFAULT_I2C_SCL_PIN);
94
        // Make the I2C pins available to picotool
       bi_decl(bi_2pins_with_func(PICO_DEFAULT_I2C_SDA_PIN, PICO_DEFAULT_I2C_SCL_PIN,
95
   GPIO_FUNC_I2C));
96
97
       mpu6050_reset();
98
99
       int16_t acceleration[3], gyro[3], temp;
100
```

```
while (1) {
101
102
            mpu6050_read_raw(acceleration, gyro, &temp);
103
            // These are the raw numbers from the chip, so will need tweaking to be really
104
    useful.
105
            // See the datasheet for more information
            printf("Acc. X = %d, Y = %d, Z = %d n", acceleration[0], acceleration[1],
106
    acceleration[2]);
107
            printf("Gyro. X = %d, Y = %d, Z = %d\n", gyro[0], gyro[1], gyro[2]);
108
            // Temperature is simple so use the datasheet calculation to get \deg \, \mathcal{C}.
109
            // Note this is chip temperature.
110
            printf("Temp. = %f\n", (temp / 340.0) + 36.53);
111
112
            sleep_ms(100);
113
114
115 #endif
116
        return 0;
117 }
```

Table 14. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
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.

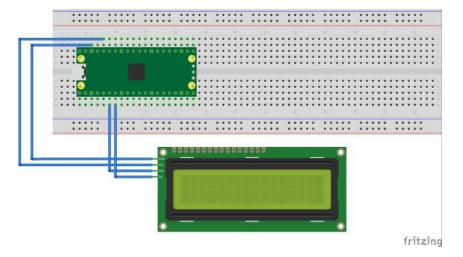
Wiring information

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 14. 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.

lcd_1602_i2c.c

The example code.

Pico Examples: https://github.com/raspberrypi/pico-examples/tree/master/i2c/lcd_1602_i2c/lcd_1602_i2c.c Lines 1 - 169

```
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 #include "pico/binary_info.h"
12
13 /* Example code to drive a 16x2 LCD panel via a I2C bridge chip (e.g. PCF8574)
14
15
      NOTE: The panel must be capable of being driven at 3.3v NOT 5v. The Pico
16
      GPIO (and therefor I2C) cannot be used at 5v.
17
18
      You will need to use a level shifter on the I2C lines if you want to run the
19
      board at 5v.
20
21
      Connections on Raspberry Pi Pico board, other boards may vary.
22
23
    GPIO 4 (pin 6)-> SDA on LCD bridge board
24
    GPIO 5 (pin 7)-> SCL on LCD bridge board
25
    3.3v (pin 36) -> VCC on LCD bridge board
26
    GND (pin 38) -> GND on LCD bridge board
27 */
28 // commands
29 const int LCD_CLEARDISPLAY = 0x01;
30 const int LCD_RETURNHOME = 0x02;
31 const int LCD_ENTRYMODESET = 0x04;
32 const int LCD_DISPLAYCONTROL = 0x08;
33 const int LCD_CURSORSHIFT = 0x10;
34 const int LCD_FUNCTIONSET = 0x20;
35 const int LCD_SETCGRAMADDR = 0x40;
36 const int LCD_SETDDRAMADDR = 0x80;
38 // flags for display entry mode
39 const int LCD_ENTRYSHIFTINCREMENT = 0x01;
40 const int LCD_ENTRYLEFT = 0x02;
41
42 // flags for display and cursor control
43 const int LCD_BLINKON = 0 \times 01;
44 const int LCD_CURSORON = 0 \times 02;
45 const int LCD_DISPLAYON = 0x04;
46
47 // flags for display and cursor shift
48 const int LCD_MOVERIGHT = 0 \times 04;
49 const int LCD_DISPLAYMOVE = 0x08;
50
51 // flags for function set
52 const int LCD_5x10DOTS = 0x04;
53 const int LCD_2LINE = 0x08;
54 const int LCD_8BITMODE = 0x10;
56 // flag for backlight control
57 const int LCD_BACKLIGHT = 0x08;
58
59 const int LCD_ENABLE_BIT = 0x04;
61 // By default these LCD display drivers are on bus address 0x27
62 static int addr = 0x27;
64 // Modes for lcd_send_byte
65 #define LCD_CHARACTER 1
66 #define LCD_COMMAND
67
68 #define MAX LINES
69 #define MAX_CHARS
                         16
71 /* Quick helper function for single byte transfers */
72 void i2c_write_byte(uint8_t val) {
```

```
73 #ifdef i2c_default
 74 i2c_write_blocking(i2c_default, addr, &val, 1, false);
 75 #endif
 76 }
 77
 78 void lcd_toggle_enable(uint8_t val) {
       // Toggle enable pin on LCD display
 80
       // We cannot do this too quickly or things don't work
 81 #define DELAY_US 600
 82
       sleep_us(DELAY_US);
        i2c_write_byte(val | LCD_ENABLE_BIT);
 83
 84
       sleep_us(DELAY_US);
       i2c_write_byte(val & ~LCD_ENABLE_BIT);
 85
 86
       sleep_us(DELAY_US);
 87 }
 88
 89 // The display is sent a byte as two separate nibble transfers
 90 void lcd_send_byte(uint8_t val, int mode) {
       uint8_t high = mode | (val & 0xF0) | LCD_BACKLIGHT;
 92
       uint8_t low = mode | ((val << 4) & 0xF0) | LCD_BACKLIGHT;</pre>
 93
 94
     i2c_write_byte(high);
 95
       lcd_toggle_enable(high);
 96
       i2c_write_byte(low);
 97
       lcd_toggle_enable(low);
 98 }
99
100 void lcd_clear(void) {
101
       lcd_send_byte(LCD_CLEARDISPLAY, LCD_COMMAND);
102 }
103
104 // go to location on LCD
105 void lcd_set_cursor(int line, int position) {
       int val = (line == 0) ? 0x80 + position : 0xC0 + position;
106
107
        lcd_send_byte(val, LCD_COMMAND);
108 }
109
110 static void inline lcd_char(char val) {
       lcd_send_byte(val, LCD_CHARACTER);
111
112 }
113
114 void lcd_string(const char *s) {
       while (*s) {
115
116
           lcd_char(*s++);
117
118 }
119
120 void lcd_init() {
121
       lcd_send_byte(0x03, LCD_COMMAND);
122
        lcd_send_byte(0x03, LCD_COMMAND);
123
        lcd_send_byte(0x03, LCD_COMMAND);
124
        lcd_send_byte(0x02, LCD_COMMAND);
125
126
        lcd_send_byte(LCD_ENTRYMODESET | LCD_ENTRYLEFT, LCD_COMMAND);
127
        lcd_send_byte(LCD_FUNCTIONSET | LCD_2LINE, LCD_COMMAND);
        lcd_send_byte(LCD_DISPLAYCONTROL | LCD_DISPLAYON, LCD_COMMAND);
128
129
        lcd_clear();
130 }
131
132 int main() {
133 #if !defined(i2c_default) || !defined(PICO_DEFAULT_I2C_SDA_PIN) ||
   !defined(PICO_DEFAULT_I2C_SCL_PIN)
       #warning i2c/lcd_1602_i2c example requires a board with I2C pins
```

```
135 #else
136
       // This example will use I2CO on the default SDA and SCL pins (4, 5 on a Pico)
137
        i2c_init(i2c_default, 100 * 1000);
138
        gpio_set_function(PICO_DEFAULT_I2C_SDA_PIN, GPIO_FUNC_I2C);
139
        gpio_set_function(PICO_DEFAULT_I2C_SCL_PIN, GPIO_FUNC_I2C);
140
        gpio_pull_up(PICO_DEFAULT_I2C_SDA_PIN);
141
        gpio_pull_up(PICO_DEFAULT_I2C_SCL_PIN);
142
        // Make the I2C pins available to picotool
        bi_decl(bi_2pins_with_func(PICO_DEFAULT_I2C_SDA_PIN, PICO_DEFAULT_I2C_SCL_PIN,
    GPIO_FUNC_I2C));
144
145
        lcd_init();
146
147
        static char *message[] =
148
                {
149
                        "RP2040 by", "Raspberry Pi",
                        "A brand new", "microcontroller",
150
                        "Twin core M0", "Full C SDK",
151
152
                        "More power in", "your product",
153
                        "More beans", "than Heinz!"
154
                };
155
156
        while (1) {
157
            for (int m = 0; m < sizeof(message) / sizeof(message[0]); m += MAX_LINES) {</pre>
158
                for (int line = 0; line < MAX_LINES; line++) {</pre>
                    lcd_set_cursor(line, (MAX_CHARS / 2) - strlen(message[m + line]) / 2);
159
160
                    lcd_string(message[m + line]);
161
                }
162
                sleep_ms(2000);
163
                lcd_clear();
164
165
166
167
        return 0;
168 #endif
169 }
```

Table 15. A list of materials required for the example

Item	Quantity	Details
Breadboard	1	generic part
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 wanted to change the default pins used by the UART, you would add the following to your project header files, before any SDK includes.

#define PICO_DEFAULT_UART_TX_PIN 16
#define PICO_DEFAULT_UART_RX_PIN 17

Configuration Parameters

Table 16. SDK and Board Configuration Parameters

Parameter name	Defined in	Default	Description
PARAM_ASSERTIONS_DISABLE_ALL	assert.h	0	Global assert disable
PARAM_ASSERTIONS_ENABLED_ADC	adc.h	0	Enable/disable assertions in the ADC module
PARAM_ASSERTIONS_ENABLED_CLO CKS	clocks.h	0	Enable/disable assertions in the clocks module
PARAM_ASSERTIONS_ENABLED_DM A	dma.h	0	Enable/disable DMA assertions
PARAM_ASSERTIONS_ENABLED_EXC EPTION	exception.h	0	Enable/disable assertions in the exception module
PARAM_ASSERTIONS_ENABLED_FLASH	flash.h	0	Enable/disable assertions in the flash module
PARAM_ASSERTIONS_ENABLED_GPI 0	gpio.h	0	Enable/disable assertions in the GPIO module
PARAM_ASSERTIONS_ENABLED_I2C	i2c.h	0	Enable/disable assertions in the I2C module
PARAM_ASSERTIONS_ENABLED_INT ERP	interp.h	0	Enable/disable assertions in the interpolation module
PARAM_ASSERTIONS_ENABLED_IRQ	irq.h	0	Enable/disable assertions in the IRQ module
PARAM_ASSERTIONS_ENABLED_LOC K_CORE	lock_core.h	0	Enable/disable assertions in the lock core
PARAM_ASSERTIONS_ENABLED_PHE AP	pheap.h	0	Enable/disable assertions in the pheap module
PARAM_ASSERTIONS_ENABLED_PIO	pio.h	0	Enable/disable assertions in the PIO module

Parameter name	Defined in	Default	Description
PARAM_ASSERTIONS_ENABLED_PIO_ INSTRUCTIONS	pio_instructions.h	0	Enable/disable assertions in the PIO instructions
PARAM_ASSERTIONS_ENABLED_PW M	pwm.h	0	Enable/disable assertions in the PWM module
PARAM_ASSERTIONS_ENABLED_SPI	spi.h	0	Enable/disable assertions in the SPI module
PARAM_ASSERTIONS_ENABLED_SYN C	sync.h	0	Enable/disable assertions in the HW sync module
PARAM_ASSERTIONS_ENABLED_TIM E	time.h	0	Enable/disable assertions in the time module
PARAM_ASSERTIONS_ENABLED_TIM ER	timer.h	0	Enable/disable assertions in the timer module
PARAM_ASSERTIONS_ENABLED_UAR T	uart.h	0	Enable/disable assertions in the UART module
PARAM_ASSERTIONS_ENABLE_ALL	assert.h	0	Global assert enable
PICO_BOOTSEL_VIA_DOUBLE_RESET_ ACTIVITY_LED	pico_bootsel_via_ double_reset.c		Optionally define a pin to use as bootloader activity LED when BOOTSEL mode is entered via reset double tap
PICO_BOOTSEL_VIA_DOUBLE_RESET_ INTERFACE_DISABLE_MASK	pico_bootsel_via_ double_reset.c	0	Optionally disable either the mass storage interface (bit 0) or the PICOBOOT interface (bit 1) when entering BOOTSEL mode via double reset
PICO_BOOTSEL_VIA_DOUBLE_RESET_ TIMEOUT_MS	pico_bootsel_via_ double_reset.c	200	Window of opportunity for a second press of a reset button to enter BOOTSEL mode (milliseconds)
PICO_BOOT_STAGE2_CHOOSE_AT25 SF128A	config.h	0	Select boot2_at25sf128a as the boot stage 2 when no boot stage 2 selection is made by the CMake build
PICO_BOOT_STAGE2_CHOOSE_GENE RIC_03H	config.h	1	Select boot2_generic_03h as the boot stage 2 when no boot stage 2 selection is made by the CMake build
PICO_BOOT_STAGE2_CHOOSE_IS25L P080	config.h	0	Select boot2_is25lp080 as the boot stage 2 when no boot stage 2 selection is made by the CMake build
PICO_BOOT_STAGE2_CHOOSE_W25Q 080	config.h	0	Select boot2_w25q080 as the boot stage 2 when no boot stage 2 selection is made by the CMake build
PICO_BOOT_STAGE2_CHOOSE_W25X 10CL	config.h	0	Select boot2_w25x10cl as the boot stage 2 when no boot stage 2 selection is made by the CMake build
PICO_BUILD_BOOT_STAGE2_NAME	config.h		The name of the boot stage 2 if selected by the build

Parameter name	Defined in	Default	Description
PICO_CMSIS_RENAME_EXCEPTIONS	rename_exception s.h	1	Whether to rename SDK exceptions such as isr_nmi to their CMSIS equivalent i.e. NMI_Handler
PICO_CORE1_STACK_SIZE	multicore.h	PICO_STACK_SIZ E (0x800)	Stack size for core 1
PICO_DEBUG_MALLOC	malloc.h	0	Enable/disable debug printf from malloc
PICO_DEBUG_MALLOC_LOW_WATER	malloc.h	0	Define the lower bound for allocation addresses to be printed by PICO_DEBUG_MALLOC
PICO_DEBUG_PIN_BASE	gpio.h	19	First pin to use for debug output (if enabled)
PICO_DEBUG_PIN_COUNT	gpio.h	3	Number of pins to use for debug output (if enabled)
PICO_DEFAULT_I2C	i2c.h		Define the default I2C for a board
PICO_DEFAULT_I2C_SCL_PIN	i2c.h		Define the default I2C SCL pin
PICO_DEFAULT_I2C_SDA_PIN	i2c.h		Define the default I2C SDA pin
PICO_DEFAULT_IRQ_PRIORITY	irq.h	0x80	Define the default IRQ priority
PICO_DEFAULT_LED_PIN	stdlib.h		Optionally define a pin that drives a regular LED on the board
PICO_DEFAULT_LED_PIN_INVERTED	stdlib.h	0	1 if LED is inverted or 0 if not
PICO_DEFAULT_SPI	spi.h		Define the default SPI for a board
PICO_DEFAULT_SPI_CSN_PIN	spi.h		Define the default SPI CSN pin
PICO_DEFAULT_SPI_RX_PIN	spi.h		Define the default SPI RX pin
PICO_DEFAULT_SPI_SCK_PIN	spi.h		Define the default SPI SCK pin
PICO_DEFAULT_SPI_TX_PIN	spi.h		Define the default SPI TX pin
PICO_DEFAULT_UART	uart.h		Define the default UART used for printf etc
PICO_DEFAULT_UART_BAUD_RATE	uart.h	115200	Define the default UART baudrate
PICO_DEFAULT_UART_RX_PIN	uart.h		Define the default UART RX pin
PICO_DEFAULT_UART_TX_PIN	uart.h		Define the default UART TX pin
PICO_DEFAULT_WS2812_PIN	stdlib.h		Optionally define a pin that controls data to a WS2812 compatible LED on the board
PICO_DEFAULT_WS2812_POWER_PIN	stdlib.h		Optionally define a pin that controls power to a WS2812 compatible LED on the board
PICO_DISABLE_SHARED_IRQ_HANDL ERS	irq.h	0	Disable shared IRQ handers
PICO_FLASH_SIZE_BYTES	flash.h		size of primary flash in bytes
PICO_HEAP_SIZE	platform_defs.h	0x800	Heap size to reserve

Parameter name	Defined in	Default	Description
PICO_MALLOC_PANIC	malloc.h	1	Enable/disable panic when an allocation failure occurs
PICO_MAX_SHARED_IRQ_HANDLERS	irq.h	4	Maximum Number of shared IRQ handers
PICO_NO_FPGA_CHECK	platform.h	0	Remove the FPGA platform check for small code size reduction
PICO_NO_RAM_VECTOR_TABLE	platform_defs.h	0	Enable/disable the RAM vector table
PICO_PANIC_FUNCTION	runtime.c		Name of a function to use in place of the stock panic function or empty string to simply breakpoint on panic
PICO_PHEAP_MAX_ENTRIES	pheap.h	255	Maximum number of entries in the pheap
PICO_PRINTF_ALWAYS_INCLUDED	printf.h	1 in debug build 0 otherwise	Whether to always include printf code even if only called weakly (by panic)
PICO_PRINTF_DEFAULT_FLOAT_PRE CISION	printf.c	6	Define default floating point precision
PICO_PRINTF_FTOA_BUFFER_SIZE	printf.c	32	Define printf ftoa buffer size
PICO_PRINTF_MAX_FLOAT	printf.c	1e9	Define the largest float suitable to print with %f
PICO_PRINTF_NTOA_BUFFER_SIZE	printf.c	32	Define printf ntoa buffer size
PICO_PRINTF_SUPPORT_EXPONENTI AL	printf.c	1	Enable exponential floating point printing
PICO_PRINTF_SUPPORT_FLOAT	printf.c	1	Enable floating point printing
PICO_PRINTF_SUPPORT_LONG_LONG	printf.c	1	Enable support for long long types (%llu or %p)
PICO_PRINTF_SUPPORT_PTRDIFF_T	printf.c	1	Enable support for the ptrdiff_t type (%t)
PICO_QUEUE_MAX_LEVEL	queue.h	0	Maintain a field for the highest level that has been reached by a queue
PICO_SHARED_IRQ_HANDLER_DEFAU LT_ORDER_PRIORITY	irq.h	0x80	Set default shared IRQ order priority
PICO_SPINLOCK_ID_CLAIM_FREE_FIR ST	sync.h	24	Lowest Spinlock ID in the 'claim free' range
PICO_SPINLOCK_ID_CLAIM_FREE_LA ST	sync.h	31	Highest Spinlock ID in the 'claim free' range
PICO_SPINLOCK_ID_HARDWARE_CLA IM	sync.h	11	Spinlock ID for Hardware claim protection
PICO_SPINLOCK_ID_IRQ	sync.h	9	Spinlock ID for IRQ protection
PICO_SPINLOCK_ID_OS1	sync.h	14	First Spinlock ID reserved for use by low level OS style software
PICO_SPINLOCK_ID_OS2	sync.h	15	Second Spinlock ID reserved for use by low level OS style software

Parameter name	Defined in	Default	Description
PICO_SPINLOCK_ID_STRIPED_FIRST	sync.h	16	Lowest Spinlock ID in the 'striped' range
PICO_SPINLOCK_ID_STRIPED_LAST	sync.h	23	Highest Spinlock ID in the 'striped' range
PICO_SPINLOCK_ID_TIMER	sync.h	10	Spinlock ID for Timer protection
PICO_STACK_SIZE	platform_defs.h	0x800	Stack Size
PICO_STDIO_DEFAULT_CRLF	stdio.h	1	Default for CR/LF conversion enabled on all stdio outputs
PICO_STDIO_ENABLE_CRLF_SUPPOR T	stdio.h	1	Enable/disable CR/LF output conversion support
PICO_STDIO_SEMIHOSTING_DEFAUL T_CRLF	stdio_semihosting .h	PICO_STDIO_DEF AULT_CRLF	Default state of CR/LF translation for semihosting output
PICO_STDIO_STACK_BUFFER_SIZE	stdio.h	128	Define printf buffer size (on stack) this is just a working buffer not a max output size
PICO_STDIO_UART_DEFAULT_CRLF	stdio_uart.h	PICO_STDIO_DEF AULT_CRLF	Default state of CR/LF translation for UART output
PICO_STDIO_USB_DEFAULT_CRLF	stdio_usb.h	PICO_STDIO_DEF AULT_CRLF	Default state of CR/LF translation for USB output
PICO_STDIO_USB_ENABLE_RESET_VI A_BAUD_RATE	stdio_usb.h	1	Enable/disable resetting into BOOTSEL mode if the host sets the baud rate to a magic value (PICO_STDIO_USB_RESET_MAGIC_BA UD_RATE)
PICO_STDIO_USB_ENABLE_RESET_VI A_VENDOR_INTERFACE	stdio_usb.h	1	Enable/disable resetting into BOOTSEL mode via an additional VENDOR USB interface - enables picotool based reset
PICO_STDIO_USB_LOW_PRIORITY_IR Q	stdio_usb.h	31	low priority (non hardware) IRQ number to claim for tud_task() background execution
PICO_STDIO_USB_RESET_BOOTSEL_A CTIVITY_LED	stdio_usb.h		Optionally define a pin to use as bootloader activity LED when BOOTSEL mode is entered via USB (either VIA_BAUD_RATE or VIA_VENDOR_INTERFACE)
PICO_STDIO_USB_RESET_BOOTSEL_F IXED_ACTIVITY_LED	stdio_usb.h	0	Whether the pin specified by PICO_STDIO_USB_RESET_BOOTSEL_A CTIVITY_LED is fixed or can be modified by picotool over the VENDOR USB interface

Parameter name	Defined in	Default	Description
PICO_STDIO_USB_RESET_BOOTSEL_I NTERFACE_DISABLE_MASK	stdio_usb.h	0	Optionally disable either the mass storage interface (bit 0) or the PICOBOOT interface (bit 1) when entering BOOTSEL mode via USB (either VIA_BAUD_RATE or VIA_VENDOR_INTERFACE)
PICO_STDIO_USB_RESET_INTERFACE _SUPPORT_RESET_TO_BOOTSEL	stdio_usb.h	1	If vendor reset interface is included allow rebooting to BOOTSEL mode
PICO_STDIO_USB_RESET_INTERFACE _SUPPORT_RESET_TO_FLASH_BOOT	stdio_usb.h	1	If vendor reset interface is included allow rebooting with regular flash boot
PICO_STDIO_USB_RESET_MAGIC_BA UD_RATE	stdio_usb.h	1200	baud rate that if selected causes a reset into BOOTSEL mode (if PICO_STDIO_USB_ENABLE_RESET_VI A_BAUD_RATE is set)
PICO_STDIO_USB_RESET_RESET_TO_ FLASH_DELAY_MS	stdio_usb.h	100	delays in ms before rebooting via regular flash boot
PICO_STDIO_USB_STDOUT_TIMEOUT _US	stdio_usb.h	500000	Number of microseconds to be blocked trying to write USB output before assuming the host has disappeared and discarding data
PICO_STDIO_USB_TASK_INTERVAL_U S	stdio_usb.h	1000	Period of microseconds between calling tud_task in the background
PICO_STDOUT_MUTEX	stdio.h	1	Enable/disable mutex around stdout
PICO_TIME_DEFAULT_ALARM_POOL_ DISABLED	time.h	0	Disable the default alarm pool
PICO_TIME_DEFAULT_ALARM_POOL_ HARDWARE_ALARM_NUM	time.h	3	Select which HW alarm is used for the default alarm pool
PICO_TIME_DEFAULT_ALARM_POOL_ MAX_TIMERS	time.h	16	Selects the maximum number of concurrent timers in the default alarm pool
PICO_TIME_SLEEP_OVERHEAD_ADJU ST_US	time.h	6	How many microseconds to wake up early (and then busy_wait) to account for timer overhead when sleeping in low power mode
PICO_UART_DEFAULT_CRLF	uart.h	0	Enable/disable CR/LF translation on UART
PICO_UART_ENABLE_CRLF_SUPPORT	uart.h	1	Enable/disable CR/LF translation support
PICO_USE_MALLOC_MUTEX	malloc.h	1 with pico_multicore, 0 otherwise	Whether to protect malloc etc with a mutex
PICO_XOSC_STARTUP_DELAY_MULTI PLIER	xosc.h	1	Multiplier to lengthen xosc startup delay to accommodate slow-starting oscillators
USB_DPRAM_MAX	usb.h	4096	Set amount of USB RAM used by USB system

Appendix C: CMake Build Configuration

CMake configuration variables can be used to customize the way the SDK performs builds

Configuration Parameters

Table 17. CMake Configuration Variables

Parameter name	Defined in	Default	Description
PICO_BARE_METAL	CMakeLists.txt	0	Flag to exclude anything except base headers from the build
PICO_BOARD	board_setup.cma ke	rp2040	The board name being built for. This is overridable from the user environment
PICO_BOARD_CMAKE_DIRS	board_setup.cma ke	ш	Directories to look for <pico_board>.cmake in. This is overridable from the user environment</pico_board>
PICO_BOARD_HEADER_DIRS	generic_board.cm ake	ш	Directories to look for <pico_board>.h in. This is overridable from the user environment</pico_board>
PICO_CMAKE_RELOAD_PLATFORM_F ILE	pico_pre_load_pla tform.cmake	none	custom CMake file to use to set up the platform environment
PICO_COMPILER	pico_pre_load_too lchain.cmake	none	Optionally specifies a different compiler (other than pico_arm_gcc.cmake) - this is not yet fully supported
PICO_CONFIG_HEADER_FILES	CMakeLists.txt	un	List of extra header files to include from pico/config.h for all platforms
PICO_CONFIG_HOST_HEADER_FILES	CMakeLists.txt	un	List of extra header files to include from pico/config.h for host platform
PICO_CONFIG_RP2040_HEADER_FILE S	CMakeLists.txt	ш	List of extra header files to include from pico/config.h for rp2040 platform
PICO_CXX_ENABLE_CXA_ATEXIT	CMakeLists.txt	0	Enabled cxa-atexit
PICO_CXX_ENABLE_EXCEPTIONS	CMakeLists.txt	0	Enabled CXX exception handling
PICO_CXX_ENABLE_RTTI	CMakeLists.txt	0	Enabled CXX rtti
PICO_DEFAULT_BOOT_STAGE2_FILE	CMakeLists.txt	 /boot2_w25q080. S	Default stage2 file to use unless overridden by pico_set_boot_stage2 on the TARGET
PICO_NO_GC_SECTIONS	CMakeLists.txt	0	Disable -ffunction-sections -fdata -sections andgc-sections
PICO_NO_HARDWARE	rp2_common.cma ke	1 for PICO_PLATFORM host 0 otherwise	OPTION: Whether the build is not targeting an RP2040 device

Parameter name	Defined in	Default	Description
PICO_NO_TARGET_NAME	rp2_common.cma ke	0	Don't defined PICO_TARGET_NAME
PICO_NO_UF2	rp2_common.cma ke	0	Disable UF2 output
PICO_ON_DEVICE	rp2_common.cma ke	0 for PICO_PLATFORM host 1 otherwise	OPTION: Whether the build is targeting an RP2040 device
PICO_PLATFORM	pico_pre_load_pla tform.cmake	rp2040 or environment value	platform to build for e.g. rp2040/host
PICO_STDIO_SEMIHOSTING	CMakeLists.txt	0	OPTION: Globally enable stdio semihosting
PICO_STDIO_UART	CMakeLists.txt	1	OPTION: Globally enable stdio UART
PICO_STDIO_USB	CMakeLists.txt	0	OPTION: Globally enable stdio USB
PICO_TOOLCHAIN_PATH	pico_pre_load_too lchain.cmake	none (i.e. search system paths)	Path to search for compiler

Control of binary type produced (advanced)

These variables control how executables for RP2040 are laid 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



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

Appendix D: 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 through 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 specific 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.

SDK: https://github.com/raspberrypi/pico-sdk/tree/master/src/boards/include/boards/pico.h Lines 1 - 88

```
2 * Copyright (c) 2020 Raspberry Pi (Trading) Ltd.
 4 * SPDX-License-Identifier: BSD-3-Clause
 5 */
 7 // -----
8 // NOTE: THIS HEADER IS ALSO INCLUDED BY ASSEMBLER SO
        SHOULD ONLY CONSIST OF PREPROCESSOR DIRECTIVES
10 // --
11
12 // This header may be included by other board headers as "boards/pico.h"
14 #ifndef _BOARDS_PICO_H
15 #define _BOARDS_PICO_H
17 // For board detection
18 #define RASPBERRYPI_PICO
20 // --- UART ---
21 #ifndef PICO_DEFAULT_UART
22 #define PICO_DEFAULT_UART 0
24 #ifndef PICO_DEFAULT_UART_TX_PIN
25 #define PICO_DEFAULT_UART_TX_PIN 0
27 #ifndef PICO_DEFAULT_UART_RX_PIN
28 #define PICO_DEFAULT_UART_RX_PIN 1
29 #endif
30
31 // --- LED ---
```

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```
32 #ifndef PICO_DEFAULT_LED_PIN
33 #define PICO_DEFAULT_LED_PIN 25
34 #endif
35 // no PICO_DEFAULT_WS2812_PIN
36
37 // --- I2C ---
38 #ifndef PICO_DEFAULT_I2C
39 #define PICO_DEFAULT_I2C 0
41 #ifndef PICO_DEFAULT_I2C_SDA_PIN
42 #define PICO_DEFAULT_I2C_SDA_PIN 4
43 #endif
44 #ifndef PICO_DEFAULT_I2C_SCL_PIN
45 #define PICO_DEFAULT_I2C_SCL_PIN 5
46 #endif
47
48 // --- SPI ---
49 #ifndef PICO_DEFAULT_SPI
50 #define PICO_DEFAULT_SPI 0
51 #endif
52 #ifndef PICO_DEFAULT_SPI_SCK_PIN
53 #define PICO_DEFAULT_SPI_SCK_PIN 18
54 #endif
55 #ifndef PICO_DEFAULT_SPI_TX_PIN
56 #define PICO_DEFAULT_SPI_TX_PIN 19
57 #endif
58 #ifndef PICO_DEFAULT_SPI_RX_PIN
59 #define PICO_DEFAULT_SPI_RX_PIN 16
61 #ifndef PICO_DEFAULT_SPI_CSN_PIN
62 #define PICO_DEFAULT_SPI_CSN_PIN 17
63 #endif
64
65 // --- FLASH ---
67 #define PICO_BOOT_STAGE2_CHOOSE_W25Q080 1
68
69 #ifndef PICO_FLASH_SPI_CLKDIV
70 #define PICO_FLASH_SPI_CLKDIV 2
71 #endif
72
73 #ifndef PICO_FLASH_SIZE_BYTES
74 #define PICO_FLASH_SIZE_BYTES (2 * 1024 * 1024)
75 #endif
76
77 // Drive high to force power supply into PWM mode (lower ripple on 3V3 at light loads)
78 #define PICO_SMPS_MODE_PIN 23
79
80 #ifndef PICO_FLOAT_SUPPORT_ROM_V1
81 #define PICO_FLOAT_SUPPORT_ROM_V1 1
82 #endif
84 #ifndef PICO_DOUBLE_SUPPORT_ROM_V1
85 #define PICO_DOUBLE_SUPPORT_ROM_V1 1
86 #endif
87
88 #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 on-board LED, and the flash size.

To create your own configuration file, create a file in the board ../source/folder with the name of your board, for

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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

Table 16 lists all the available configuration parameters available within the SDK. You can set any configuration variable in a board configuration header file, however the convention is to limit that to configuration items directly affected by the board design (e.g. pins, clock frequencies etc.). Other configuration items should generally be overridden in the CMake configuration (or another configuration header) for the application being built.

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Appendix E: Building the SDK API documentation

The SDK documentation can be viewed online, but is also part of the SDK itself and can be built directly from the command line. If you haven't already checked out the SDK repository you should do so,

```
$ cd ~/
$ mkdir pico
$ cd pico
$ git clone -b master https://github.com/raspberrypi/pico-sdk.git
$ cd pico-sdk
$ git submodule update --init
$ cd ..
$ git clone -b master https://github.com/raspberrypi/pico-examples.git
```

Install doxygen if you don't already have it,

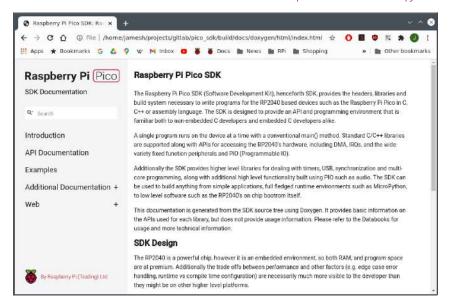
```
$ sudo apt install doxygen
```

Then afterwards you can go ahead and build the documentation,

```
$ cd pico-sdk
$ mkdir build
$ cd build
$ cmake -DPICO_EXAMPLES_PATH=../../pico-examples ..
$ make docs
```

The API documentation will be built and can be found in the pico-sdk/build/docs/doxygen/html directory, see Figure 15.





Appendix F: SDK Release History

Release 1.0.0 (20/Jan/2021)

Initial release

Release 1.0.1 (01/Feb/2021)

- add pico_get_unique_id method to return a unique identifier for a Pico board using the identifier of the external flash
- exposed all 4 pacing timers on the DMA peripheral (previously only 2 were exposed)
- fixed ninja build (i.e. cmake -6 ninja .. ; ninja)
- · minor other improvements and bug fixes

Boot Stage 2

Additionally, a low level change was made to the way flash binaries start executing after boot_stage2. This was at the request of folks implementing other language runtimes. It is not generally of concern to end users, however it did require a change to the linker scripts so if you have cloned those to make modifications then you need to port across the relevant changes. If you are porting a different language runtime using the SDK boot_stage2 implementations then you should be aware that you should now have a vector table (rather than executable code) - at 0x10000100.

Release 1.1.0 (05/Mar/2021)

- Added board headers for Adafruit, Pimoroni & SparkFun boards
 - o new values for PICO_BOARD are adafruit_feather_rp2040, adafruit_itsybitsy_rp2040, adafruit_qtpy_rp2040, pimoroni_keybow2040, pimoroni_picosystem, pimoroni_tiny2040, sparkfun_micromod, sparkfun_promicro, sparkfun_thingplus, in addition to the existing pico and vgaboard.
 - o Added additional definitions for a default SPI, I2C pins as well as the existing ones for UART
 - Allow default pins to be undefined (not all boards have UART for example), and SDK will compile but warn as needed in the absence of default.
 - o Added additional definition for a default WS2812 compatible pin (currently unused).
- New reset options
 - Added pico_bootsel_via_double_reset library to allow reset to BOOTSEL mode via double press of a RESET button
 - When using pico_stdio_usb i.e. stdio connected via USB CDC to host, setting baud rate to 1200 (by default) can
 optionally be used to reset into BOOTSEL mode.
 - When using pico-stdio_usb i.e. stdio connected via USB CDC to host, an additional interface may be added to give picotool control over resetting the device.
- · Build improvement for non SDK or existing library builds
 - o Removed additional compiler warnings (register headers now use _u(x) macro for unsigned values though).
 - o Made build more clang friendly.

This release also contains many bug fixes, documentation updates and minor improvements.

Backwards incompatibility

There are some nominally backwards incompatible changes not worthy of a major version bump:

- PICO_DEFAULT_UART_ defines now default to undefined if there is no default rather than -1 previously
- The broken multicore_sleep_core1() API has been removed; multicore_reset_core1 is already available to put core 1 into a deep sleep.

Release 1.1.1 (01/Apr/2021)

This fixes a number of bugs, and additionally adds support for a board configuration header to choose the boot_stage2

Release 1.1.2 (07/Apr/2021)

Fixes issues with boot_stage2 selection

Release 1.2.0 (03/Jun/2021)

This release contains numerous bug fixes and documentation improvements. Additionally it contains the following improvements/notable changes:

A CAUTION

The lib/tinyusb submodule has been updated from 0.8.0 and now tracks upstream https://github.com/hathach/tinyusb.git. It is worth making sure you do a

```
git submodule sync
git submodule update
```

to make sure you are correctly tracking upstream TinyUSB if you are not checking out a clean pico-sdk repository.

Moving from TinyUSB 0.8.0 to TinyUSB 0.10.1 may require some minor changes to your USB code.

New/improved Board headers

- New board headers support for PICO_BOARDs arduino_nano_rp240_connect, pimoroni_picolipo_4mb and pimoroni_picolipo_16mb
- Missing/new #defines for default SPI and I2C pins have been added

Updated TinyUSB to 0.10.1

The lib/tinyusb submodule has been updated from 0.8.0 and now tracks upstream https://github.com/hathach/tinyusb.git

Added CMSIS core headers

CMSIS core headers (e.g. core_cm0plus.h and RP2040.h) are made available via cmsis_core INTERFACE library. Additionally, CMSIS standard exception naming is available via PICO_CMSIS_RENAME_EXCEPTIONS=1

API improvements

pico_sync

- Added support for recursive mutexes via recursive_mutex_init() and auto_init_recrursive_mutex()
- Added mutex_enter_timeout_us()
- Added critical_section_deinit()
- Added sem_acquire_timeout_ms() and sem_acquire_block_until()

hardware_adc

Added adc_get_selected_input()

hardware_clocks

• clock_get_hz() now returns actual achieved frequency rather than desired frequency

hardware_dma

- Added dma_channel_is_claimed()
- Added new methods for configuring/acknowledging DMA IRQs. dma_irqn_set_channel_enabled(), dma_irqn_set_channel_mask_enabled(), dma_irqn_get_channel_status(), dma_irqn_acknowledge_channel() etc.

hardware_exception

New library for setting ARM exception handlers:

• Added exception_set_exclusive_handler(), exception_restore_handler(), exception_get_vtable_handler()

hardware_flash

• Exposed previously private function flash_do_cmd() for low level flash command execution

hardware_gpio

Added gpio_set_input_hysteresis_enabled(), gpio_is_input_hysteresis_enabled(), gpio_set_slew_rate(), gpio_get_slew_rate(), gpio_set_drive_strength(), gpio_get_drive_strength(), gpio_get_out_level(), gpio_set_irqover()

hardware_i2c

- · Corrected a number of incorrect hardware register definitions
- A number of edge cases in the i2c code fixed

hardware_interp

• Added interp_lane_is_claimed(), interp_unclaim_lane_mask()

hardware_irq

• Notably fixed the PICO_LOWEST/HIGHEST_IRQ_PRIORITY values which were backwards!

hardware_pio

- Added new methods for configuring/acknowledging PIO interrupts (pio_set_irqn_source_enabled(), pio_set_irqn_source_mask_enabled(), pio_interrupt_get(), pio_interrupt_clear() etc.)
- Added pio_sm_is_claimed()

hardware_spi

- Added spi_get_baudrate()
- Changed spi_init() to return the set/achieved baud rate rather than void
- Changed spi_is_writable() to return bool not size_t (it was always 1/0)

hardware_sync

- · Notable documentation improvements for spin lock functions
- Added spin_lock_is_claimed()

hardware_timer

- Added busy_wait_ms() to match busy_wait_us()
- Added hardware_alarm_is_claimed()

pico_float/pico_double

• Correctly save/restore divider state if floating point is used from interrupts

pico_int64_ops

Added PICO_INT64_OPS_IN_RAM flag to move code into RAM to avoid veneers when calling code is in RAM

pico_runtime

 Added ability to override panic function by setting PICO_PANIC_FUNCTION=foo to then use foo as the implementation, or setting PICO_PANIC_FUNCITON= to simply breakpoint, saving some code space

pico_unique_id

• Added pico_get_unique_board_id_string().

General code improvements

- · Removed additional classes of compiler warnings
- Adding some missing const to method parameters

SVD

· USB DPRAM for device mode is now included

pioasm

• Added #pragma once to C/C++ output

RTOS interoperability

Improvements designed to make porting RTOSes either based on the SDK or supporting SDK code easier.

- Added PICO_DIVIDER_DISABLE_INTERRUPTS flag to optionally configure all uses of the hardware divider to be guarded by
 disabling interrupts, rather than requiring on the RTOS to save/restore the divider state on context switch
- Added new abstractions to pico/lock_core.h to allow an RTOS to inject replacement code for SDK based low level wait, notify and sleep/timeouts used by synchronization primitives in pico_sync and for sleep_ methods. If an RTOS implements these few simple methods, then all SDK semaphore, mutex, queue, sleep methods can be safely used both within/to/from RTOS tasks, but also to communicate with non RTOS task aware code, whether it be existing libraries and IRQ handlers or code running perhaps (though not necessarily) on the other core

CMake build changes

Substantive changes have been made to the CMake build, so if you are using a hand crafted non-CMake build, you will need to update your compile/link flags. Additionally changed some possibly confusing status messages from CMake build generation to be debug only

Boot Stage 2

• New boot stage 2 for AT25SF128A

Appendix G: Documentation Release History

Table 18.
Documentation
Release History

Release	Date	Description
1.0	21/Jan/2021	Initial release
1.1	26/Jan/2021	 Minor corrections Extra information about using DMA with ADC Clarified M0+ and SIO CPUID registers Added more discussion of Timers Update Windows and macOS build instructions Renamed books and optimised size of output PDFs
1.2	01/Feb/2021	 Minor corrections Small improvements to PIO documentation Added missing TIMER2 and TIMER3 registers to DMA Explained how to get MicroPython REPL on UART To accompany the V1.0.1 release of the C SDK
1.3	23/Feb/2021	 Minor corrections Changed font Additional documentation on sink/source limits for RP2040 Major improvements to SWD documentation Updated MicroPython build instructions MicroPython UART example code Updated Thonny instructions Updated Project Generator instructions Added a FAQ document Added errata E7, E8 and E9
1.3.1	05/Mar/2021	 Minor corrections To accompany the V1.1.0 release of the C SDK Improved MicroPython UART example Improved Pinout diagram
1.4	07/Apr/2021	 Minor corrections Added errata E10 Note about how to update the C SDK from Github To accompany the V1.1.2 release of the C SDK

Release	Date	Description
1.4.1	13/Apr/2021	Minor corrections
		 Clarified that all source code in the documentation is under the 3-Clause BSD license.
1.5	07/Jun/2021	Minor updates and corrections
		Updated FAQ
		Added SDK release history
		To accompany the V1.2.0 release of the C SDK
1.6	23/Jun/2021	Minor updates and corrections
		ADC information updated
		Added errata E11

 $The \ latest\ release\ can\ be\ found\ at\ https://datasheets.raspberrypi.org/pico/raspberry-pi-pico-c-sdk.pdf.$

