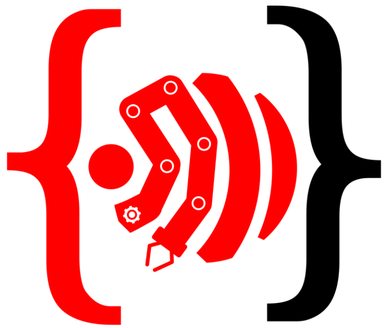


ESPRESSIF
DevCon23

ESP-IDF Getting Started

Beginner's Guide to Key Concepts and Resources

Darian Leung

Who am I ?

Software Platforms Team

- 6 years
- ESP-IDF Development
- Core subsystems
- Protocols

Darian Leung
Senior Embedded Software Engineer

r/embedded • 4 mo. ago
by [redacted]

Join

What is the best source to learn ESP IDF ?

r/esp32 • 2 yr. ago
by [redacted]

Join

Need for advice on learning to program with ESP IDF

r/esp32 • 5 yr. ago
by [redacted]

Join

How long to learn ESP-IDF, and where to start?

r/esp32 • 1 yr. ago
by [redacted]

Is ESP-IDF really worth it?

r/esp32 • 8 mo. ago
by [redacted]

Help with ESP-IDF transition.

r/esp32 • 4 yr. ago
by [redacted]

How to learn ESP-IDF?

r/embedded • 1 yr. ago
by [redacted]

How to escape arduino hell?

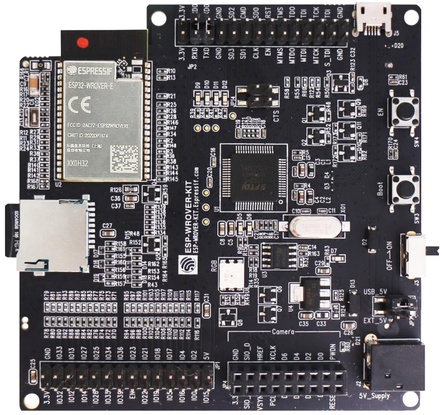
CONTENTS

Links to Resources

ESP-IDF v5.1

Ubuntu (Command Line)

Windows (Eclipse IDE)



ESP-WROVER-KIT
(ESP-32)

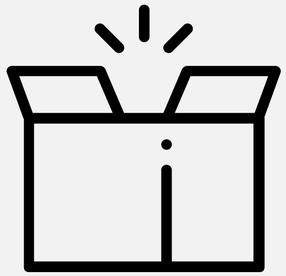
01

Why ESP-IDF?

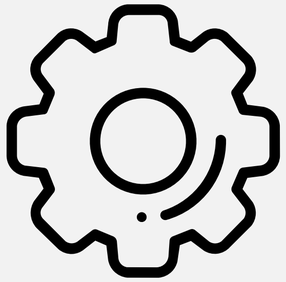
What is ESP-IDF & why use it?

SDK Considerations

Language

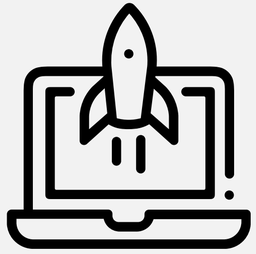


Features

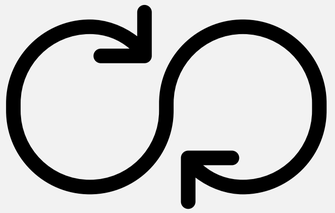


Configuration

Support & Maintenance

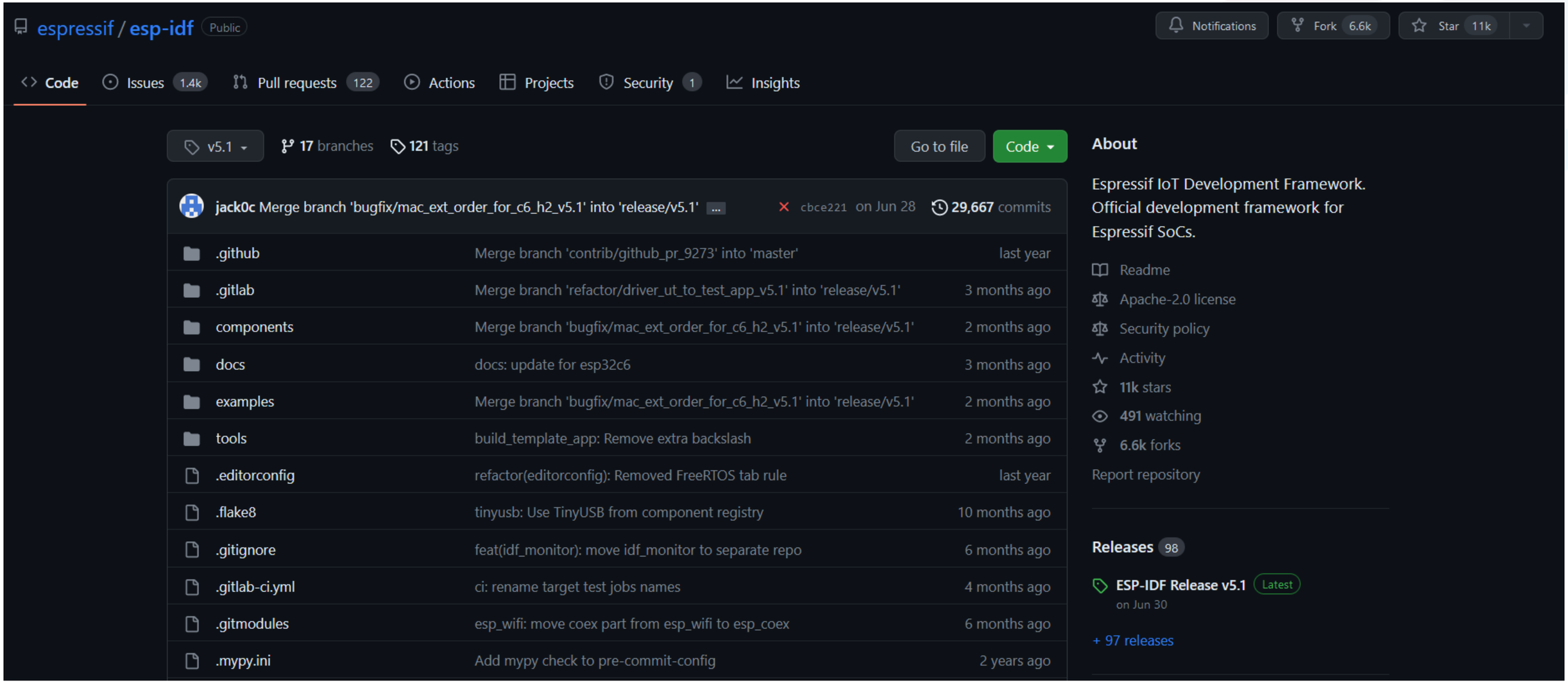


Ease of Use



Debugging & Testing

What is ESP-IDF?



Why Use ESP-IDF?

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Language

- C/C++
- Python tooling

Features

- Lots of components
- Integrated networking stacks
- Component manager

Configuration

- Component level configuration
- Supports Kconfig

Support & Maintenance

- Actively maintained
- Quickest to get new features/targets

Ease of Use

- Command line support
- Optional IDE support

Debugging & Testing

- GDB Support
- Lots of other debugging features
- Unity & CMock

02 Project Workflow

Basic workflow of an ESP-IDF Project

Select a Development Environment

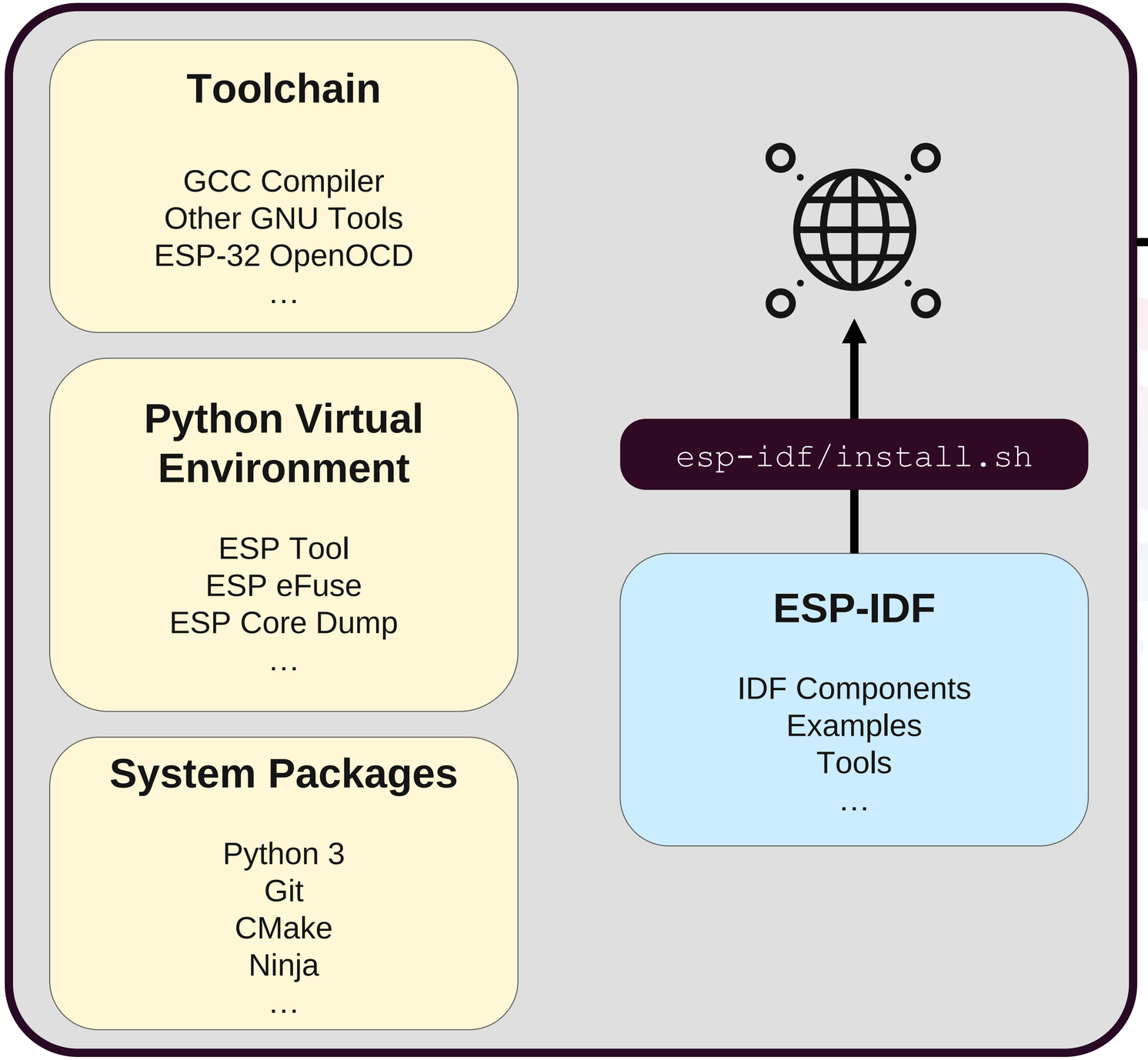




[Command Line & Editor]

[Eclipse Plugin & IDE]

[VSCode Extension]



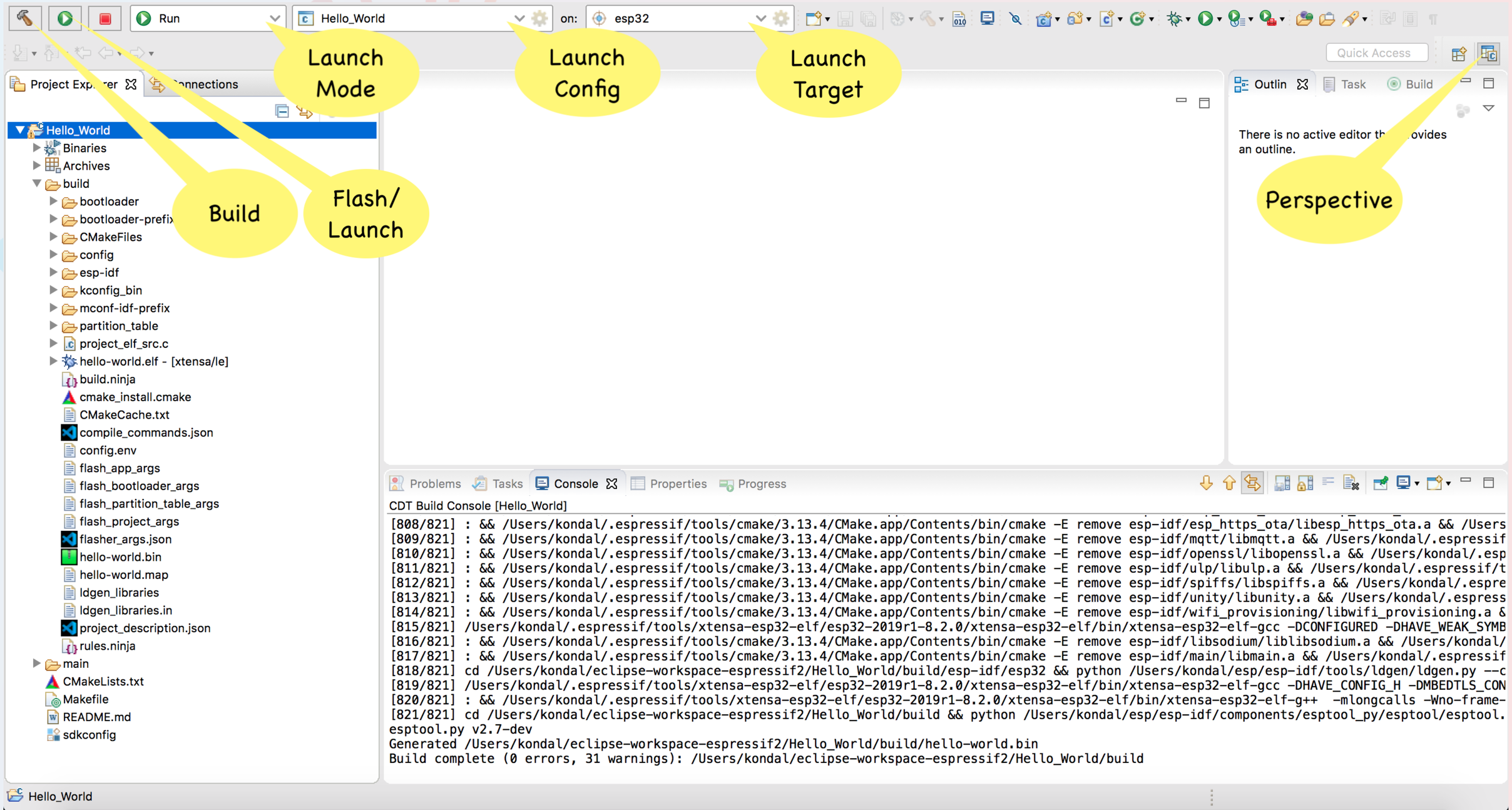
ESP-IDF Installation

Command Line Install (Ubuntu)

```
user@pc:~$ sudo apt-get install git wget flex bison gperf
python3 python3-venv cmake ninja-build ccache libffi-dev
libssl-dev dfu-util libusb-1.0-0
user@pc:~$ mkdir -p ~/esp
user@pc:~$ cd ~/esp
user@pc:~/esp$ git clone -b v5.1 –recursive
https://github.com/espressif/esp-idf.git
user@pc:~/esp$ cd ./esp-idf
user@pc:~/esp/esp-idf$ ./install.sh esp32
user@pc:~/esp/esp-idf$ . export.sh
user@pc:~/esp/esp-idf$ idf.py –help
```

```
user@pc:~/esp/esp-idf$ idf.py -help
Usage: idf.py [OPTIONS] COMMAND1 [ARGS]... [COMMAND2 [ARGS]...]...
  ESP-IDF CLI build management tool. For commands that are not known to idf.py an
attempt to execute it as a build system target will be made. Selected target: None
Options:
  --version                       Show IDF version and exit.
...
  -v, --verbose     Verbose build output.
  -p, --port TEXT   Serial port.
  --help            Show this message and exit.
Commands:
...
  all              Aliases: build. Build the project.
  clean            Delete build output files from the build directory.
  create-project   Create a new project.
  flash            Flash the project.
  fullclean        Delete the entire build directory contents.
  menuconfig       Run "menuconfig" project configuration tool.
  monitor          Display serial output.
  set-target       Set the chip target to build.
```

Eclipse IDE Install (Windows)

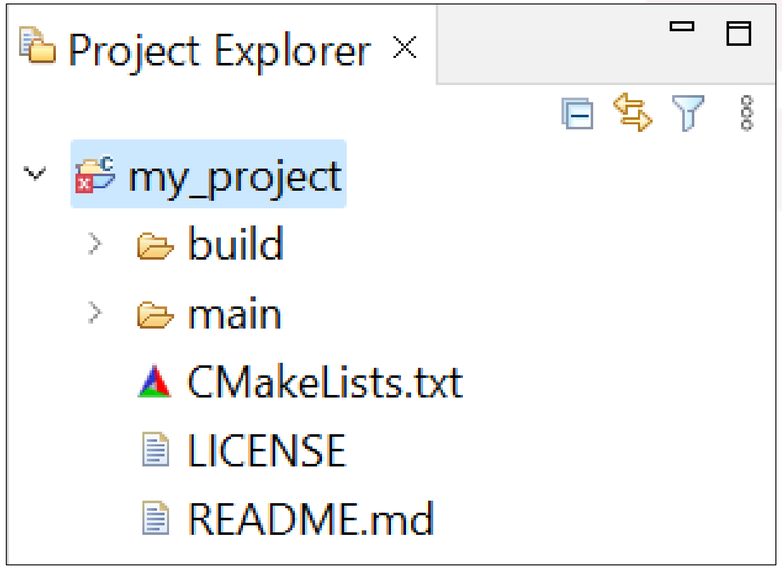


Project Creation

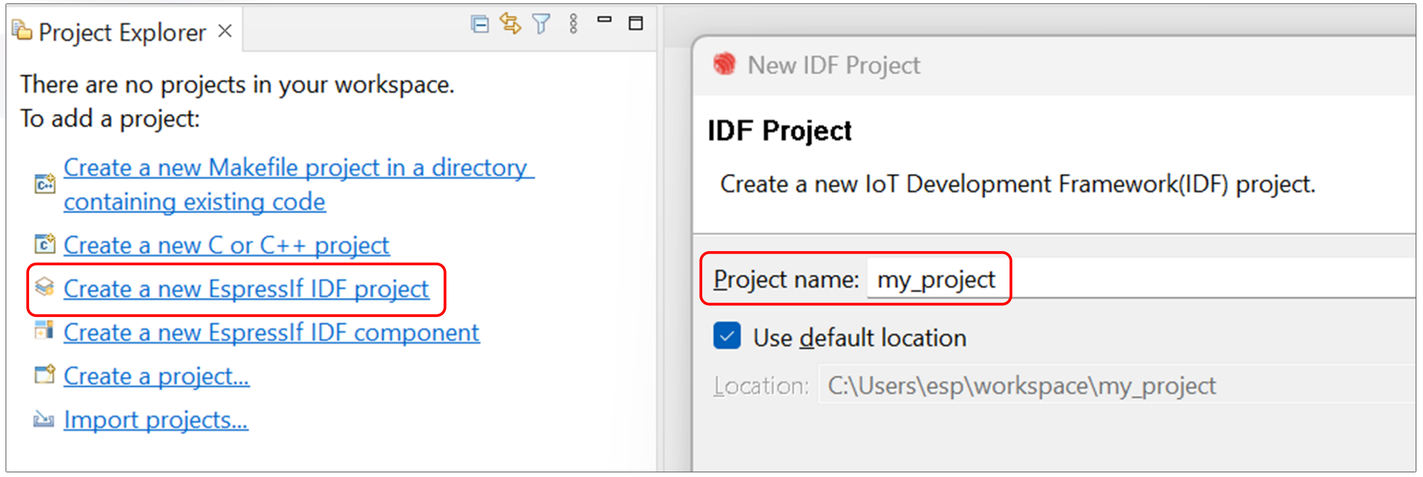
```
-  my_project/
     - main/
          - CMakeLists.txt
          - my_project.c
     - CMakeLists.txt
```

Command Line

```
user@pc:~/esp$ idf.py create-project my_project
user@pc:~/esp$ cd ./create-project
user@pc:~/esp/my_project$
```



Eclipse IDE



```
- my_project
    - main/
        - CMakeLists.txt
        - my_project.c
    - CMakeLists.txt
```

```
# In main/CMakeLists.txt
idf_component_register(
    SRCS "my_project.c"
    INCLUDE_DIRS ".")
```

```
# In CMakeLists.txt
cmake_minimum_required(VERSI
ON 3.16)

include($ENV{IDF_PATH}/tools
/cmake/project.cmake)
project(my_project)
```

```
// In main/my_project.c
#include <stdio.h>

void app_main(void)
{
    printf("Hello World\n");
}
```

Project Workflow (Overview)

01 Configure

- **Set configuration** options from each component
- Generate ***sdkconfig*** file

02 Build

- **Compile** source files from all components.
- **Link** and generate **project binary**

03 Flash

- Reset the ESP-32 into **Firmware Download mode**
- Write the binary into **Flash memory**

04 Monitor

- Reset the ESP-32 into **execution mode**
- Monitor the log output using **idf.py monitor**

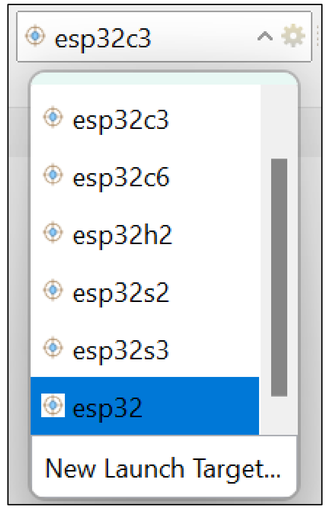
Project Workflow (Configuration)

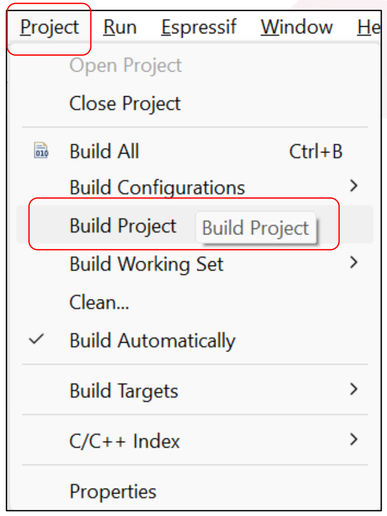
Command Line

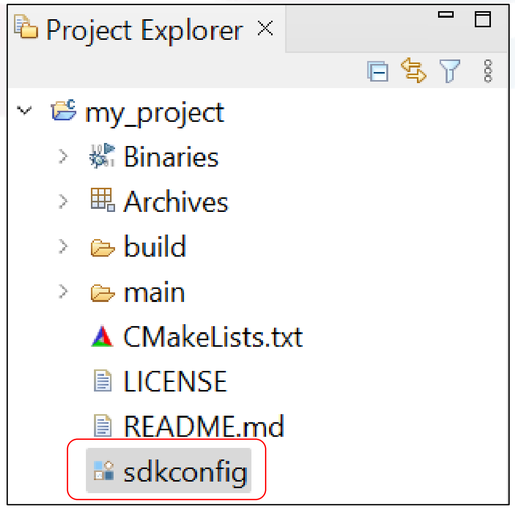
```
user@pc:~/esp/my_project$ idf.py set-target esp32
user@pc:~/esp/my_project$ idf.py menuconfig
```

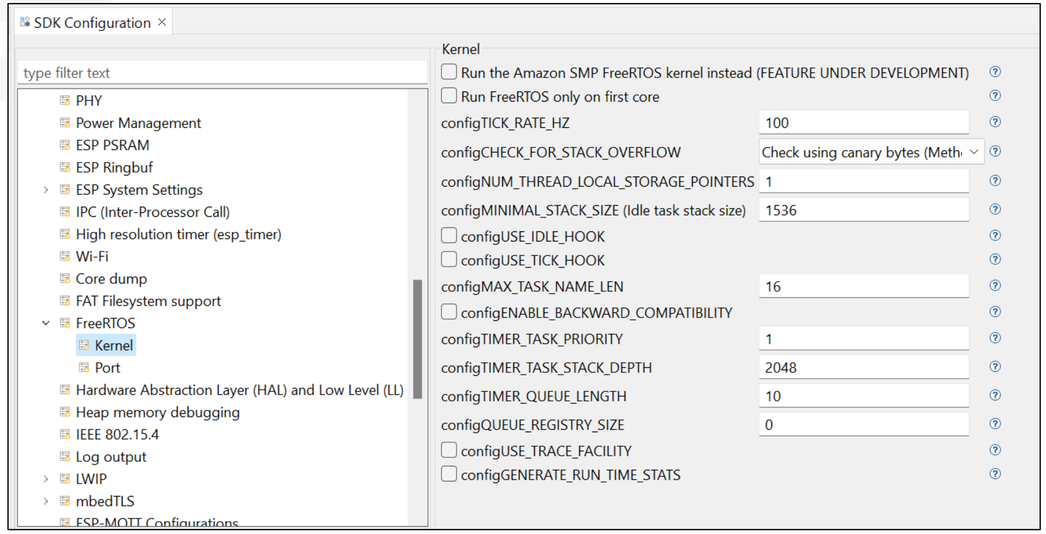
```
(Top)
        Espressif IoT Development Framework Configuration
    Build type  --->
    Bootloader config  --->
    Security features  --->
    Application manager  --->
    Serial flasher config  --->
    Partition Table  --->
    Compiler options  --->
    Component config  --->
[ ] Make experimental features visible

[Space/Enter] Toggle/enter  [ESC] Leave menu                [S] Save
[O] Load                    [?] Symbol info                 [/] Jump t
[F] Toggle show-help mode   [C] Toggle show-name mode       [A] Toggle
[Q] Quit (prompts for save) [D] Save minimal config (advanced)
```

Eclipse IDE









Project Workflow (Configuration) (2)

Generated Files

```
- my_project
    - main/
        - CMakeLists.txt
        - my_project.c
    - CMakeLists.txt
    - build/
    - sdkconfig
```

- `build` stores all build files
- *`sdkconfig`* stores generated configuration

sdkconfig

```
…
#
# Wi-Fi
#
CONFIG_ESP_WIFI_ENABLED=y
CONFIG_ESP_WIFI_STATIC_RX_BUFFER_NUM=10
…
# end of Wi-Fi
…
#
# FreeRTOS
#
CONFIG_FREERTOS_HZ=100
# CONFIG_FREERTOS_UNICORE is not set
…
# end of FreeRTOS
```

```
Executing action: all (aliases: build)
Running ninja in directory /home/User/esp/my_project/build
[0/1] Re-running CMake...
-- Project sdkconfig file
/home/User/esp/my_project/sdkconfig
...
Partition table binary generated.
...
[57/103] Building C object esp-
idf/bootloader_support/.../bootloader_init.c.obj
...
Successfully created esp32 image.
Generated
/home/User/esp/my_project/my_project/build/bootloader/boot
loader.bin
...
[370/884] Building C object esp-
idf/freertos/.../tasks.c.obj
...
[708/884] Building C object esp-idf/driver/.../i2c.c.obj
...
Successfully created esp32 image.
Generated /home/User/esp/my_project/build/my_project.bin
...
Project build complete. To flash, run this command:
```

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Command Line

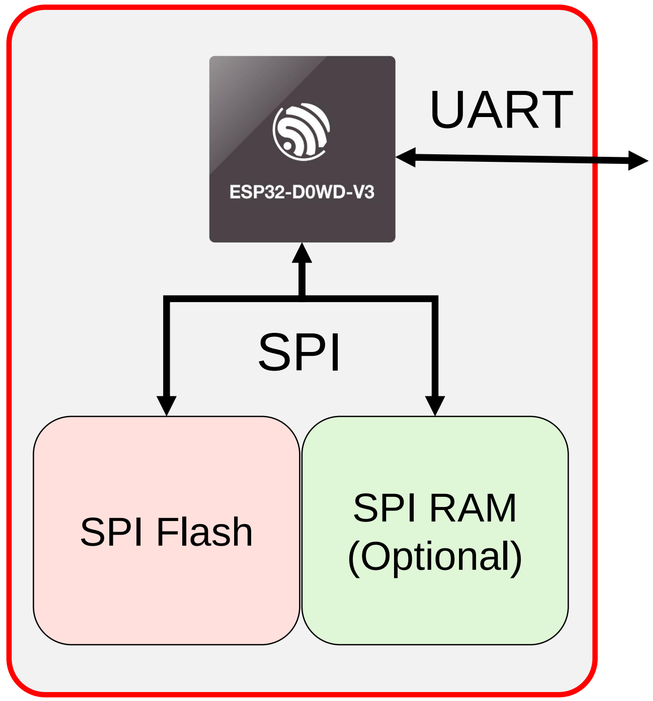
```
user@pc:~/esp/my_project$
idf.py all
```

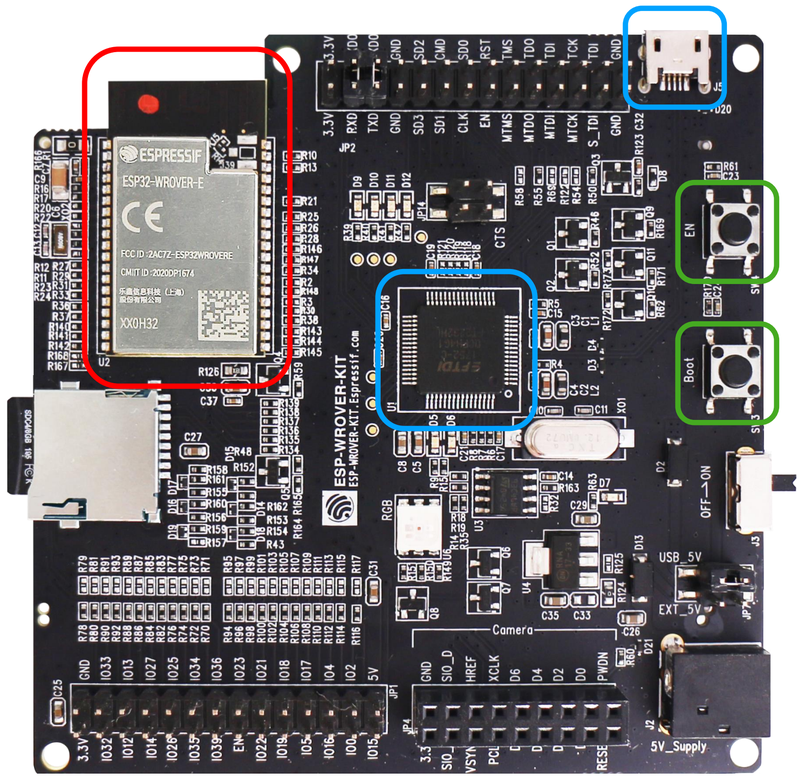
Eclipse IDE

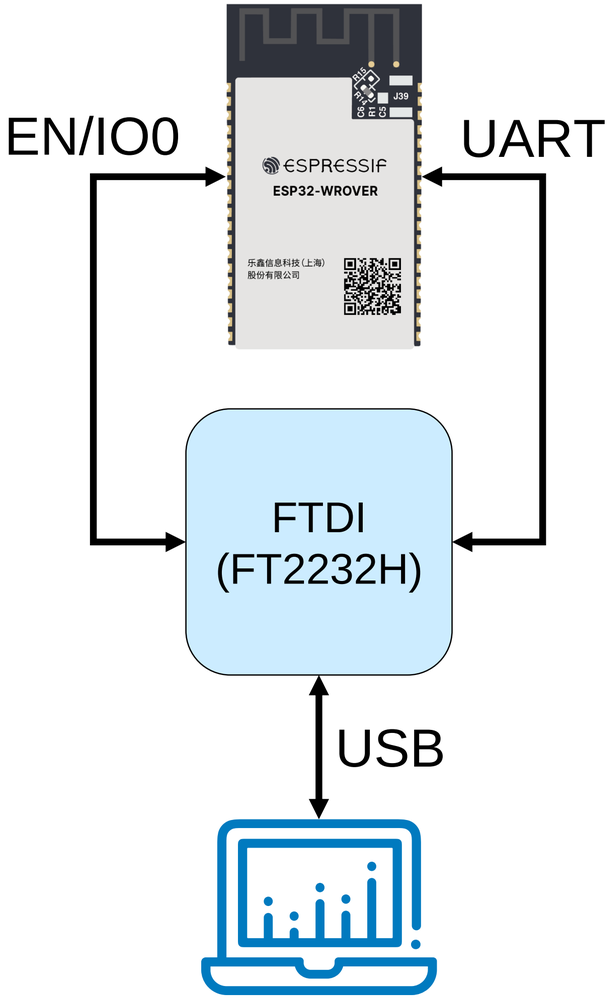
(or CTRL + B)

Project Workflow (Build)

Hardware Overview







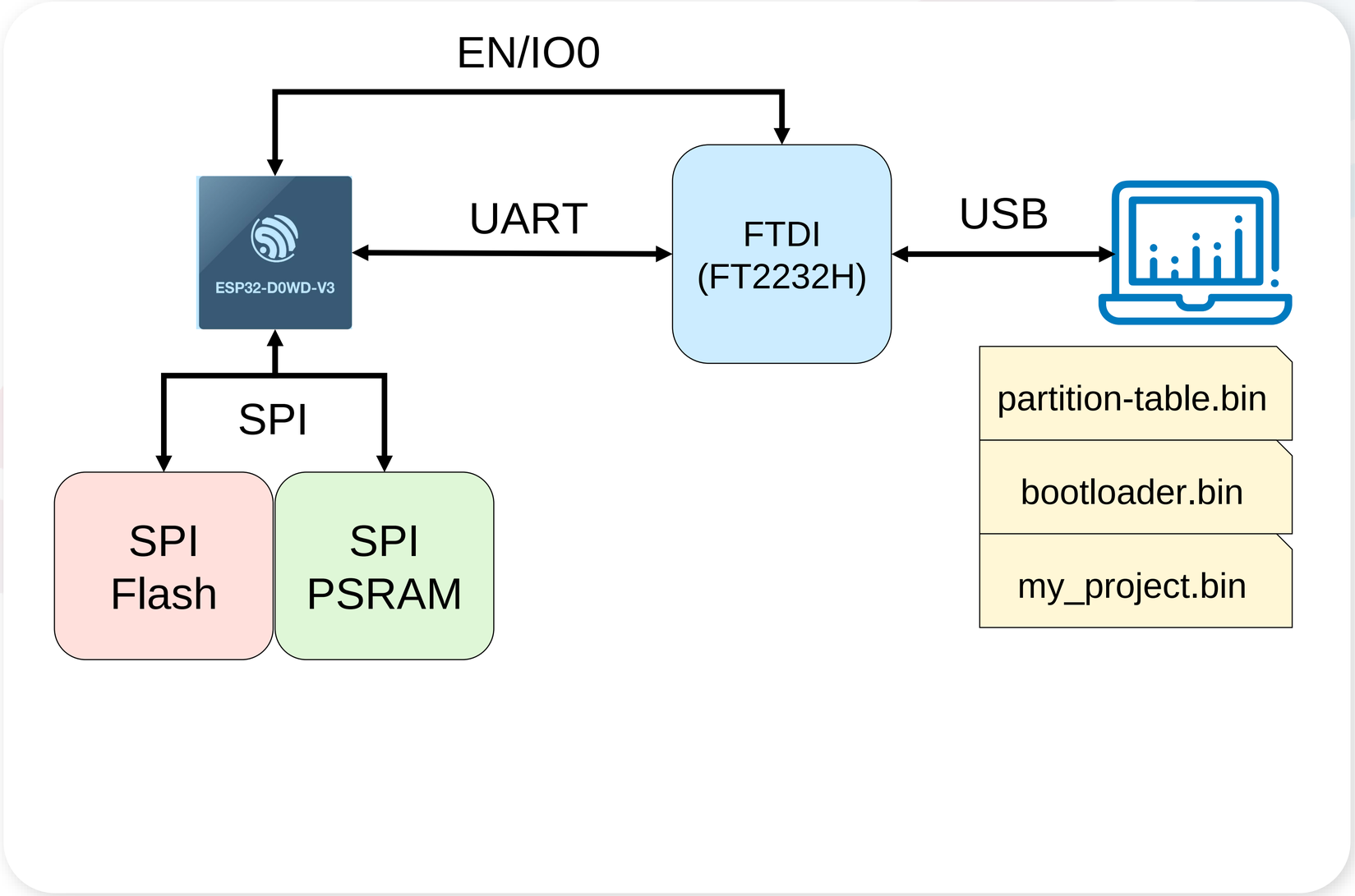
Project Workflow (Flash)

Download Mode

Reset ESP-32 while holding IO0 is low

Flashing Binaries

Write binaries to SPI Flash via ESP-32



Project Workflow (Flash) (2)

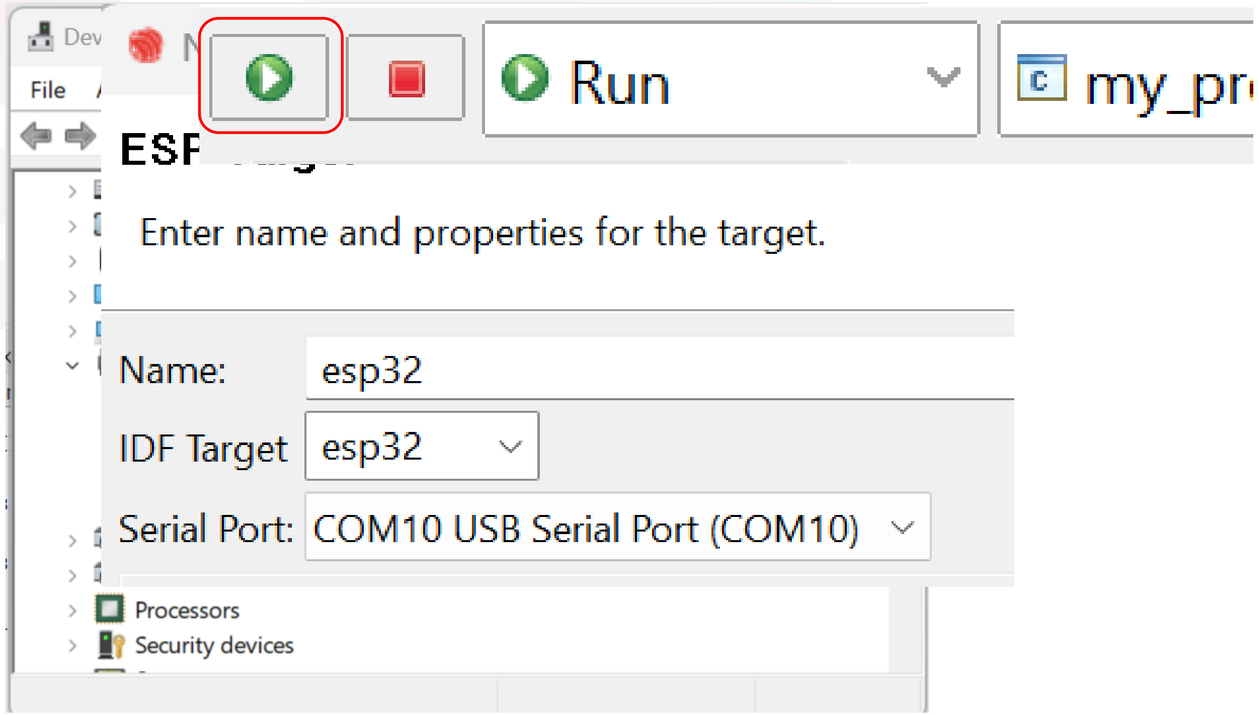
Command Line

- Find correct serial port
- Call **idf.py flash**

```
user@pc:~/esp/my_project$
ls /dev/ttyUSB*
user@pc:~/esp/my_project$
idf.py -p /dev/ttyUSB1
flash
```

Eclipse IDE

- Find correct serial port (via Device Manager)
- Create a new launch target
- Flash via **Run** button



```
user@pc:~/esp/esp-idf$ idf.py -p dev/ttyUSB1 flash
Executing action: flash
...
esptool esp32 -p /dev/ttyUSB1 -b 460800 --before=default_reset --
after=hard_reset write_flash --flash_mode dio --flash_freq 40m --
flash_size 2MB 0x1000 bootloader/bootloader.bin 0x10000
my_project.bin 0x8000 partition_table/partition-table.bin
...
Leaving...
Hard resetting via RTS pin...
Done
```

Project Workflow (Monitor)

Running the IDF Monitor tool

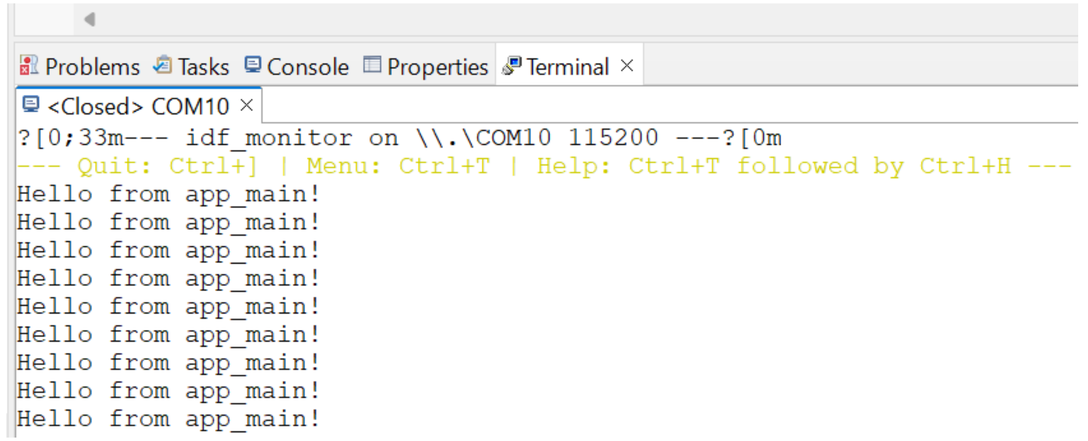
Command Line

- Call **idf.py monitor**

```
user@pc:~/esp/my_project$
idf.py -p /dev/ttyUSB1
monitor
```

Eclipse IDE

- Open the integrated terminal



Project Workflow (Monitor) (2)

1st Stage Bootloader

```
user@pc:~/esp/esp-idf$ idf.py -p dev/ttyUSB1 monitor
ets Jun  8 2016 00:22:57

rst:0x1 (POWERON_RESET),boot:0x3e (SPI_FAST_FLASH_BOOT)
…
load:0x3fff0030,len:7076
load:0x40078000,len:15576
load:0x40080400,len:4
0x40080400: _init at ??:?

load:0x40080404,len:3876
entry 0x4008064c
```

Project Workflow (Monitor) (3)

2nd Stage Bootloader

```
I (29) boot: ESP-IDF v5.1 2nd stage bootloader
...
I (56) boot: Partition Table:
I (60) boot: ## Label            Usage          Type ST Offset   Length
I (67) boot:  0 nvs              WiFi data        01 02 00009000 00006000
I (75) boot:  1 phy_init         RF data          01 01 0000f000 00001000
I (82) boot:  2 factory          factory app      00 00 00010000 00100000
I (90) boot: End of partition table
...
I (177) boot: Loaded app from partition at offset 0x10000
...
I (189) cpu_start: Starting app cpu, entry point is 0x400810d8
0x400810d8: call_start_cpu1 at /home/User/esp/esp-
idf/components/esp_system/port/cpu_start.c:154
```

Project Workflow (Monitor) (3)

App Startup

```
I (0) cpu_start: App cpu up.
I (207) cpu_start: Pro cpu start user code
...
I (207) cpu_start: cpu freq: 160000000 Hz
I (207) cpu_start: Application information:
I (212) cpu_start: Project name:     my_project
...
I (313) app_start: Starting scheduler on CPU0
I (317) app_start: Starting scheduler on CPU1
I (317) main_task: Started on CPU0
I (327) main_task: Calling app_main()
```

Project Workflow (Monitor) (4)

User Entry Point

```
Hello World
I (327) main_task: Returned from app_main()
```

```c
// In main/my_project.c

#include <stdio.h>

void app_main(void)
{
    printf("Hello World\n");
}
```

See Boot Process Documentation for more details

03 Programming Model

ESP-IDF Programming Model

Where do we go from here?

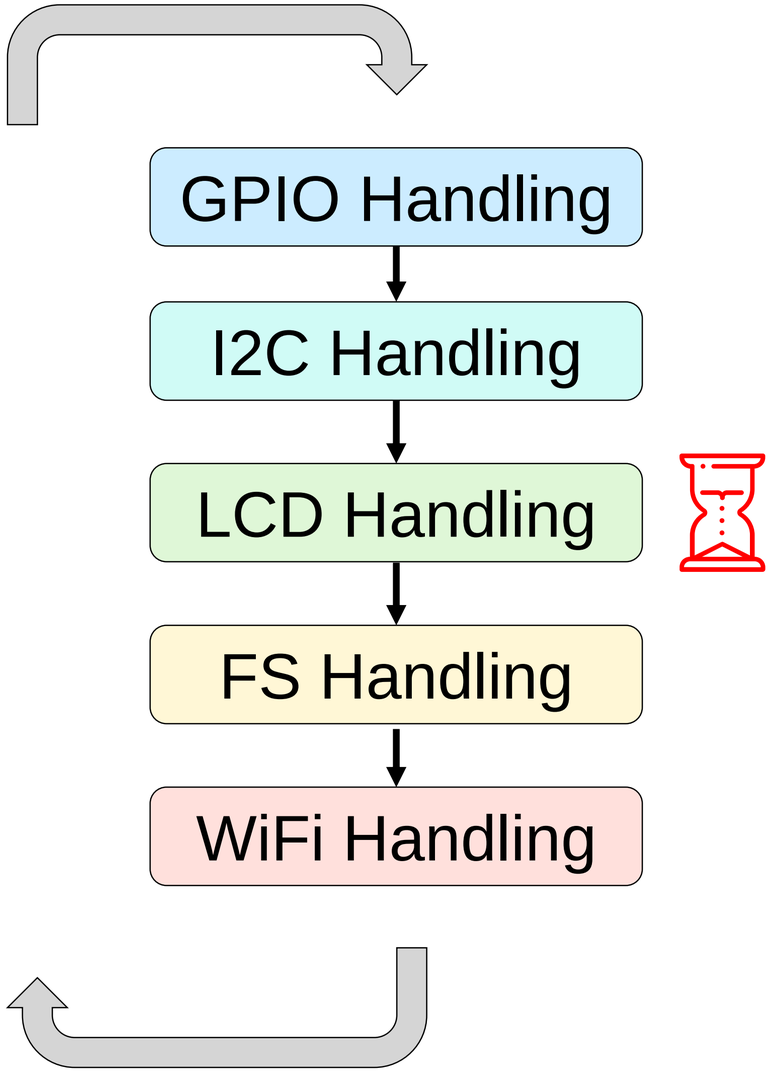
Arduino?

```c
// In main/my_project.c

#include <stdio.h>

void app_main(void)
{
    printf("Hello World\n");
    setup();
    while (1) {
        loop();
    }
}
```

STM32 CubeMX?

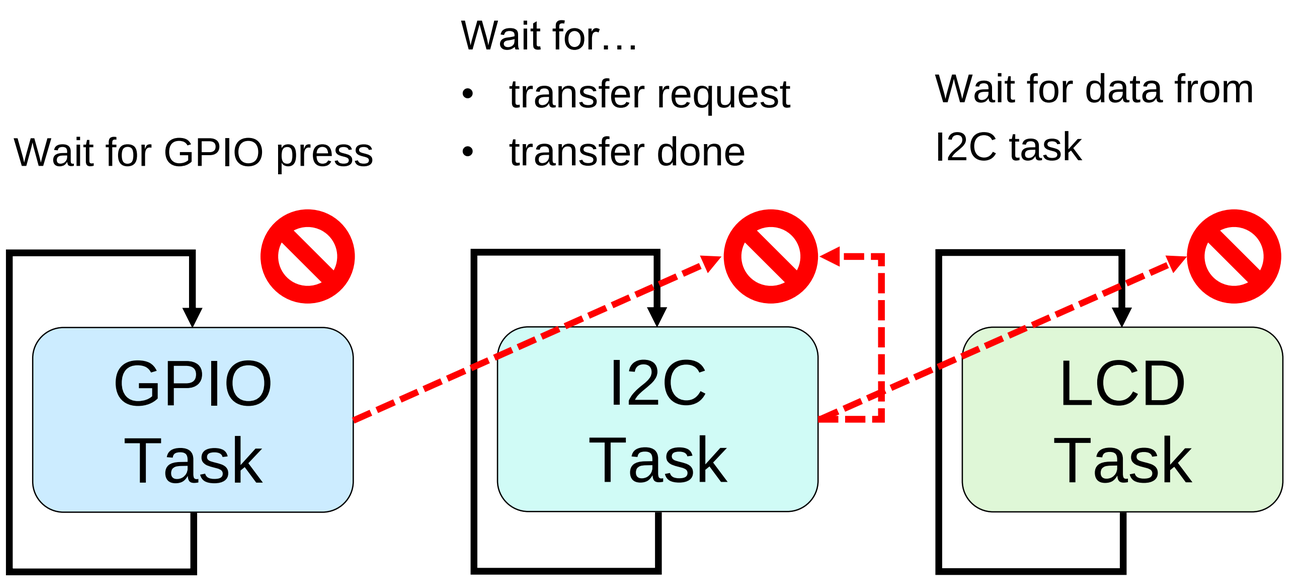
```c
// In main/my_project.c
#include <stdio.h>

void app_main(void)
{
    printf("Hello World\n");
   /* USER CODE BEGIN 2 */
    user_setup();
    /* USER CODE END 2 */
    /* USER CODE BEGIN WHILE */
    while (1) {
        /* USER CODE END WHILE */
        /* USER CODE BEGIN 3 */
        user_loop();
    }
    /* USER CODE BEGIN 3 */
}
```

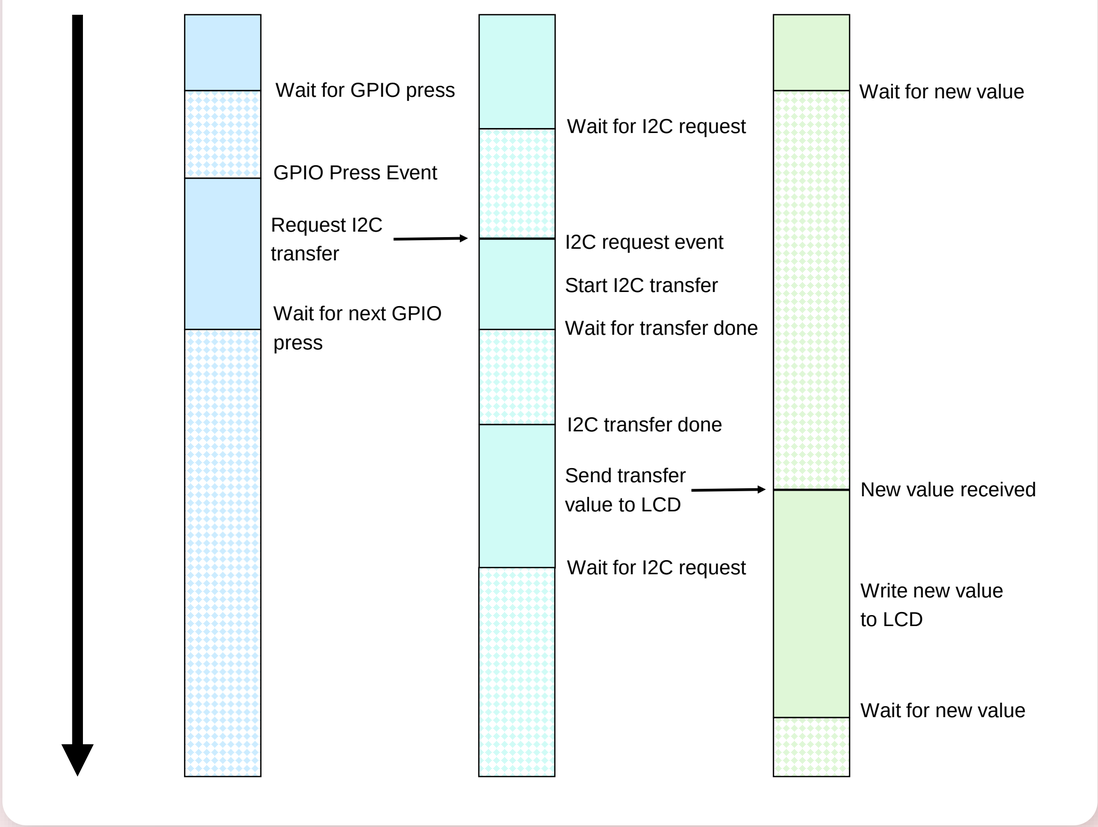
Issues with Superloop




```c
static void loop(void)
{
    /*
    Button press triggers I2C sensor read.
    Ready value gets output to LCD
    */
    if (check_gpio_press()) {
        int val;
        // Handle debounce
        handle_gpio();
        // Blocking read to I2C
        val = handle_i2c();
        // Output value to LCD
        handle_lcd(val);
    }
}
```

Multi-threading via an OS





FreeRTOS (Overview)

What is FreeRTOS?

- Popular RTOS (Real Time Operating System)
- Integrated into ESP-IDF (central to programming model)
- Allows multi-threading (known as tasks)

FreeRTOS Features

- Small and simple
- Free and open source
- Multiple synchronization primitives

FreeRTOS (Tasks)

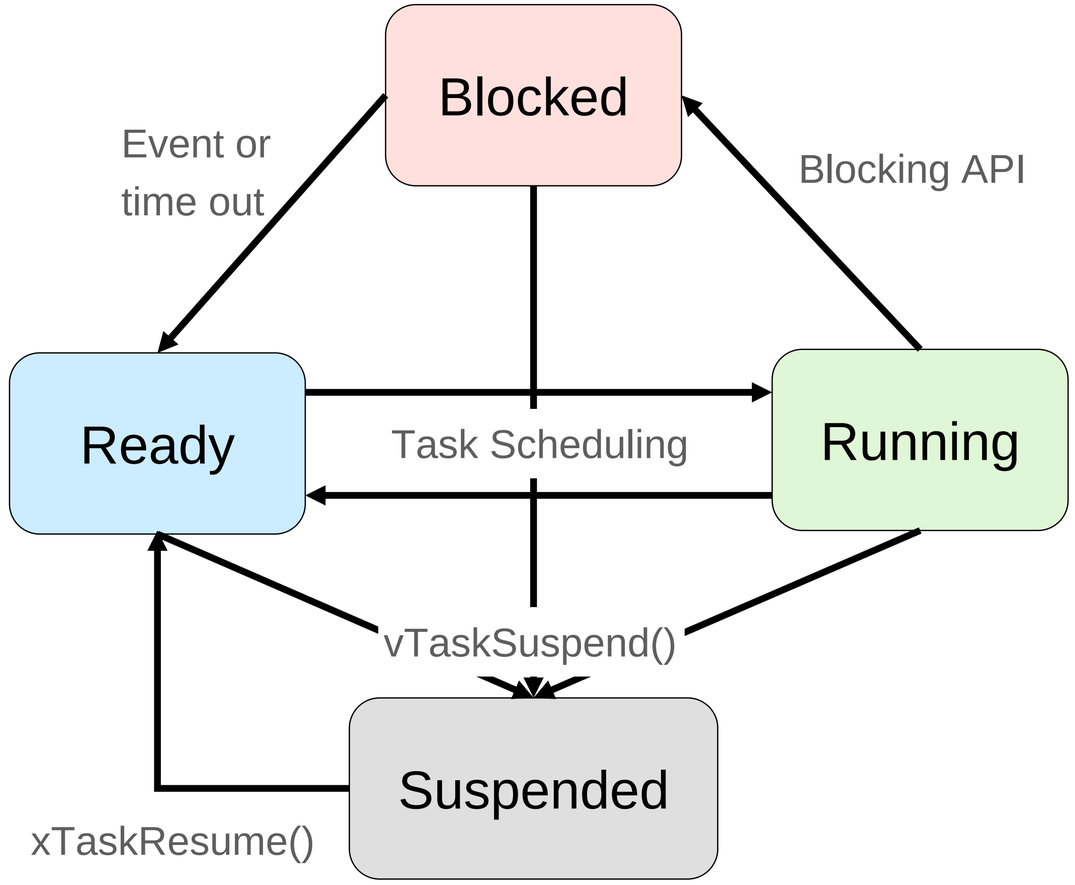
```c
void example_task(void *pvParameters)
{
    // Initialize local variables here
    int local_variable = (int) pvParameters;

    while (1) {
        // Task main loop
        ...
        // Block on some event (e.g., 1000ms)
        xSemaphoreTake(event_sem, pdMS_TO_TICKS(1000));
        // Do some work
        handle_event();
        // Give some event
        xSemaphoreGive(other_event_sem);
        ...
        // Check for exit condition
        if (exit_condition_met) {
            break;
        }
    }

    // Delete task here
    vTaskDelete(NULL);
    // MUST NEVER RETURN!
}
```

Overview of FreeRTOS Task

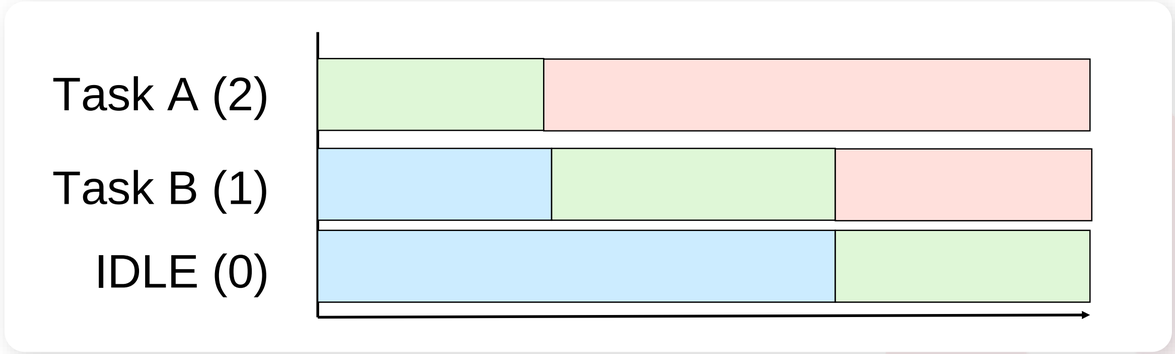
- Implemented as C function
- Usually implemented as an infinite loop
- Tasks can block on events (does not consume CPU time)
- Tasks can give events (unblock other tasks)
- Function must never return

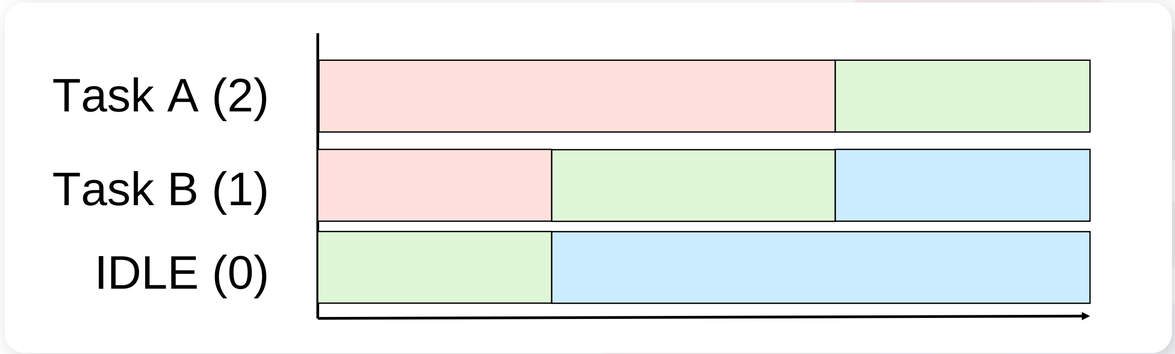
FreeRTOS (Task States)

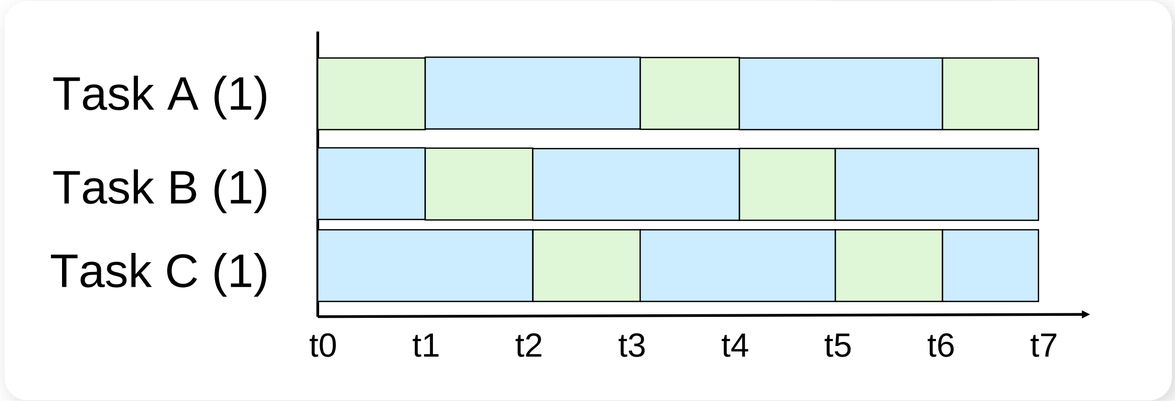
Task State	Description
Running	The task is currently be executed
Ready	The task is able to execute but is not currently executing
Blocked	The task is waiting for a temporal or external event. The task will not be scheduled until it is unblocked by the event or times out.
Suspended	Task will not be scheduled until explicitly unsuspended



FreeRTOS (Scheduling Algorithm)







Running Ready Blocked

Fixed Priority

- Each task has a fixed priority
- Scheduler always executes the **highest priority ready state** task

Preemptive

- Scheduler can **switch out current task at any time** (without cooperation)
- Higher priority tasks will preempt current task.

Time Slicing

- Periodic switching of **ready tasks of the same priority**, governed by tick interrupt.
- Switch in Round Robin fashion.

FreeRTOS (Further Resources)

FreeRTOS (Upstream)

- RTOS Fundamentals
- Mastering the FreeRTOS Kernel
- FreeRTOS Configuration

FreeRTOS (IDF Integration & SMP)

- ESP-IDF FreeRTOS Integration
- ESP-IDF FreeRTOS SMP Changes
- ESP-IDF FreeRTOS Supplemental Features
- 2022 Devcon FreeRTOS Presentation

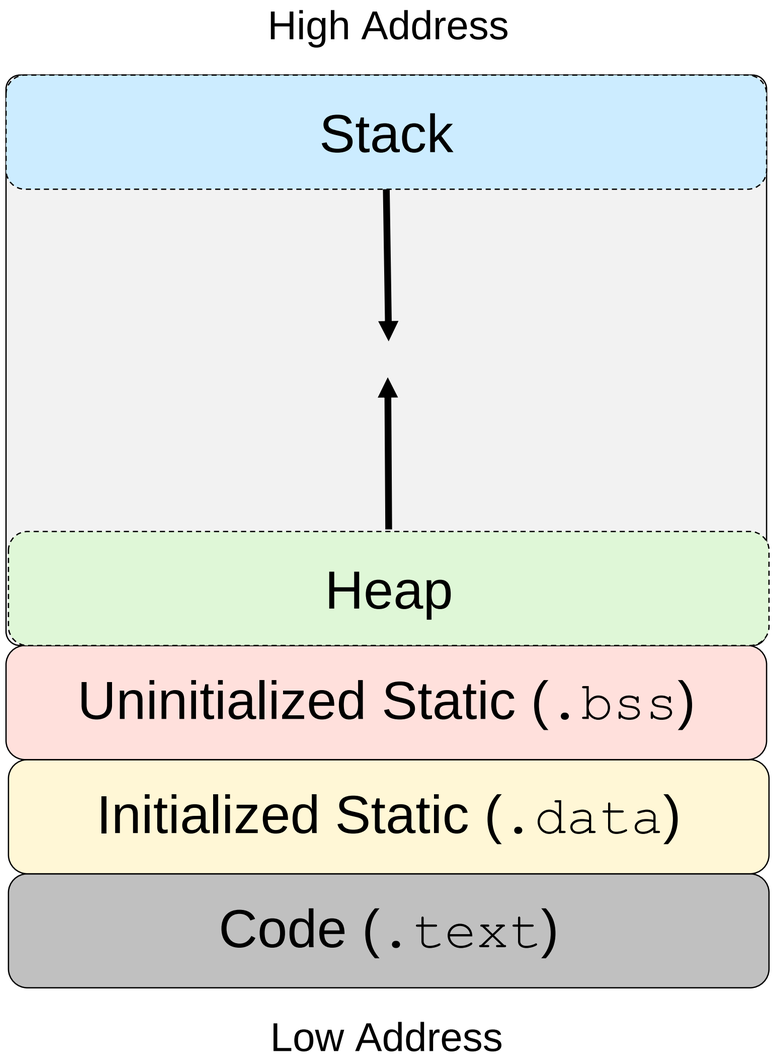
Memory Model

The ideal C memory model assumptions:

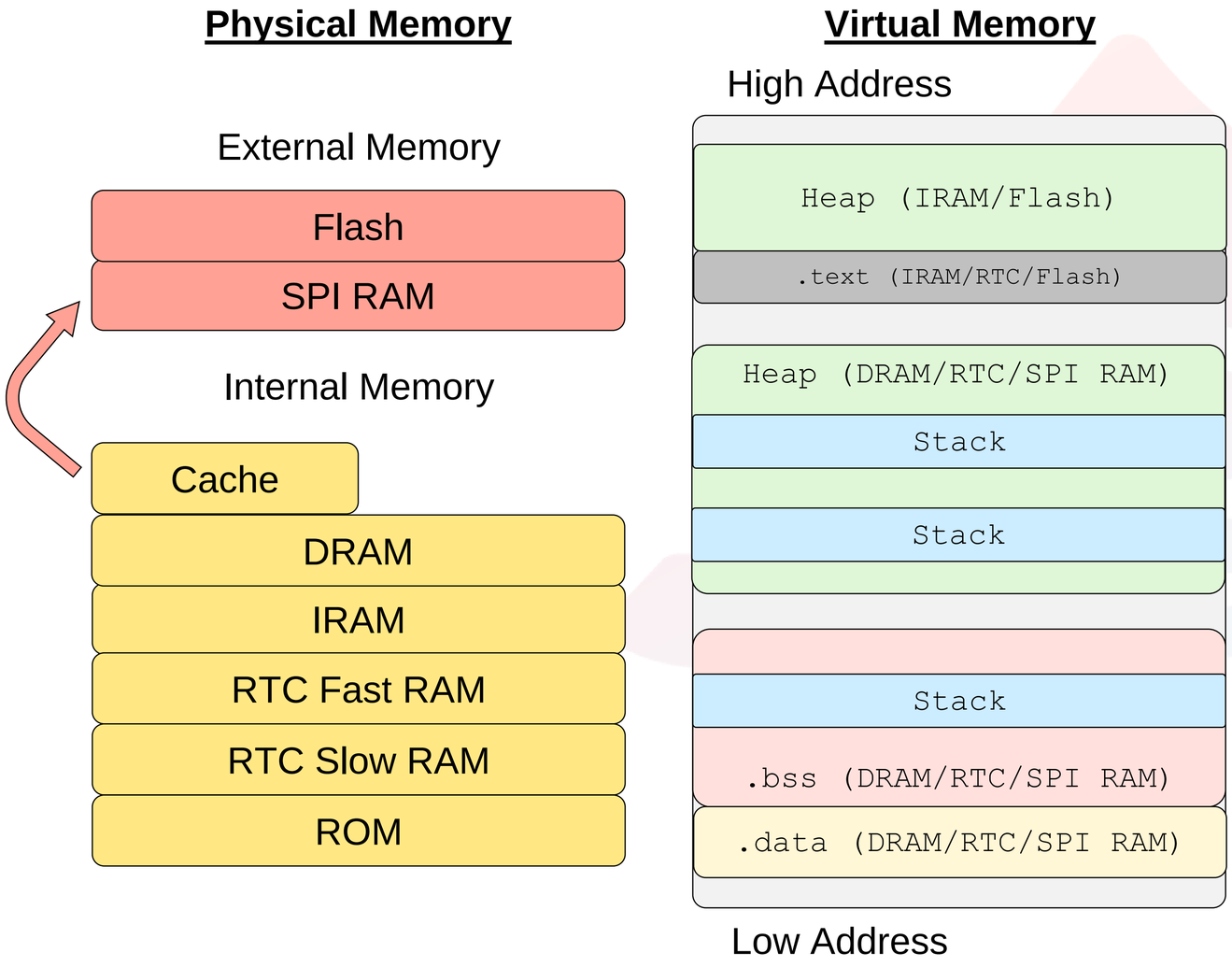
- All memory is physically identical
- Single stack
- Heap and stack grow in opposite directions

Issues:

- **Multiple stacks**
- **Memory is not physically identical**



Memory Model (2) [SIMPLIFIED]



Physical Memory

- Internal memory with different capabilities
- External Memory accessed via Cache

Virtual Memory

- Expanded static sections to cover different physical memories
- Heap can allocate from different physical memories
- Each stack is now allocated from heap or static memory

Memory Model (3)

Key Takeaways

- Memory is non-uniform
- Multiple tasks means multiple stacks
- Task stacks can be allocated from heap/.data/.bss

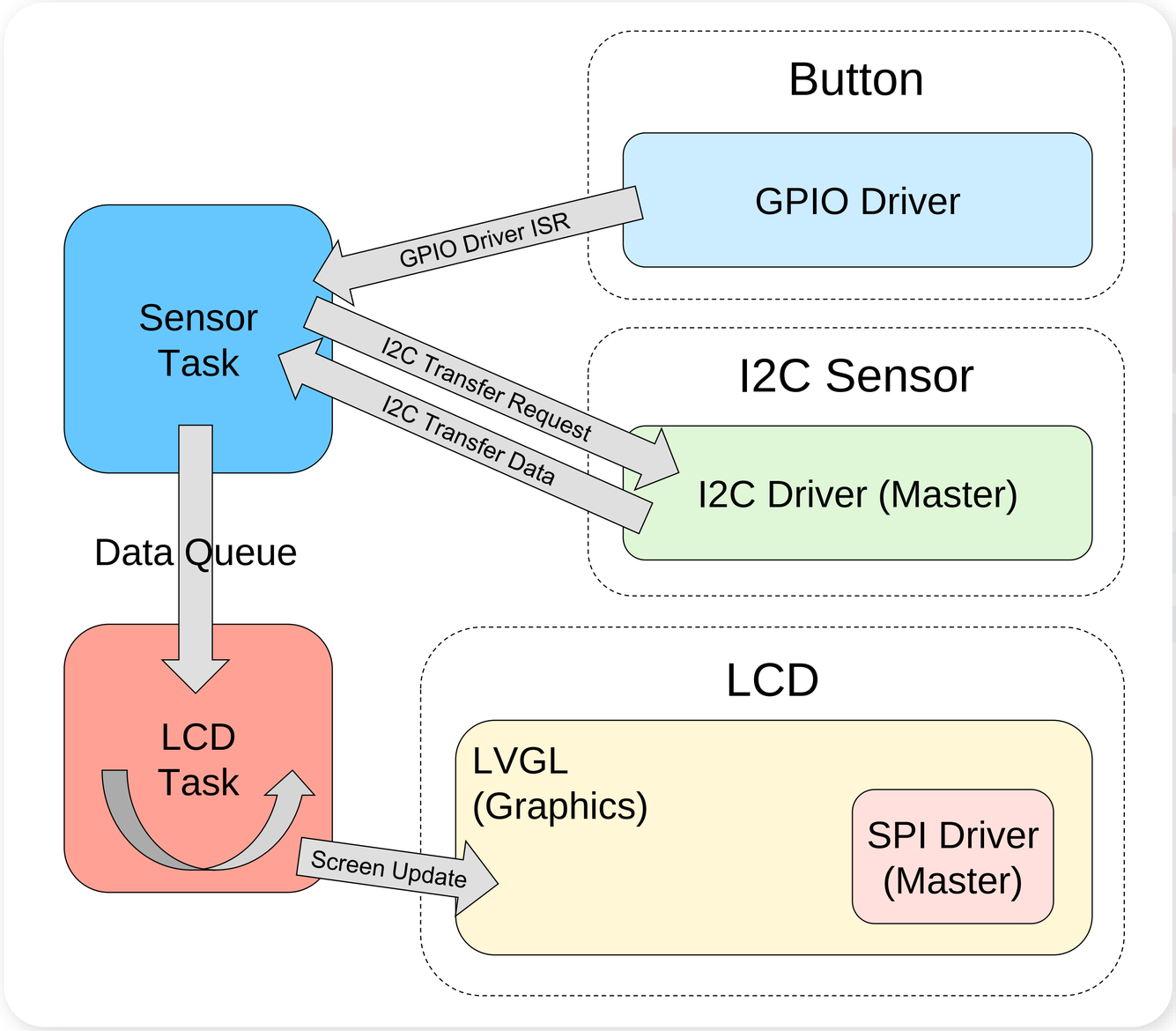
Memory: Further Reading

- ESP-32 TRM (System & Memory)
- ESP-IDF Memory Types
- Heap Memory Allocator
- ESP-IDF SPI-RAM Guide
- Linker Script Generation (How to place data/functions into particular type of memory)

04 ESP-IDF Features

Where to find ESP-IDF features

IDF Features In a Project



1. Breakdown project into subsystems
2. Find/write components and libraries required for each subsystem
3. Read API of each required component and library
4. Implement glue logic to connect subsystems

Where to Find Components?

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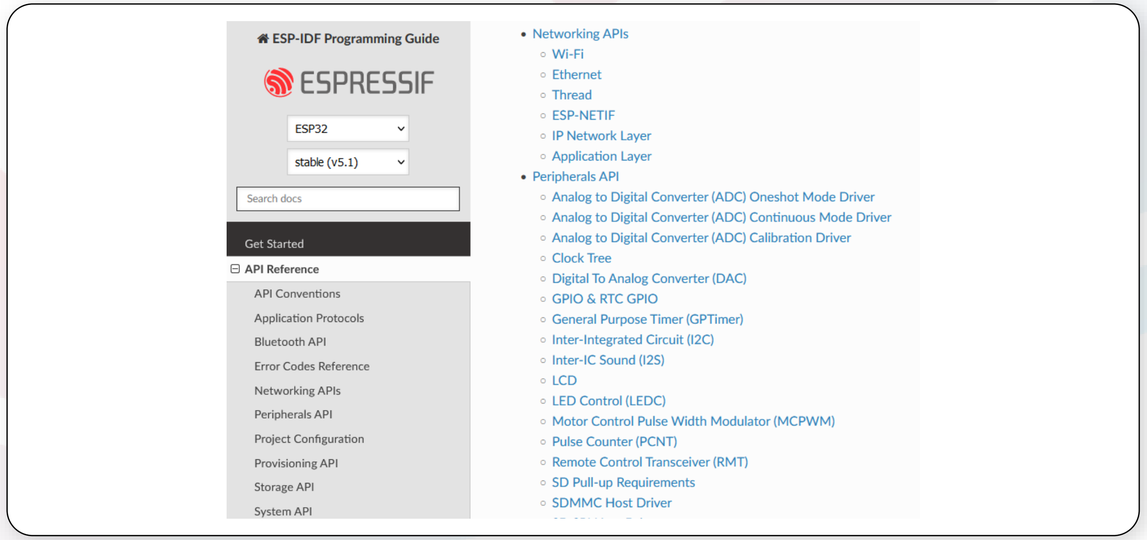
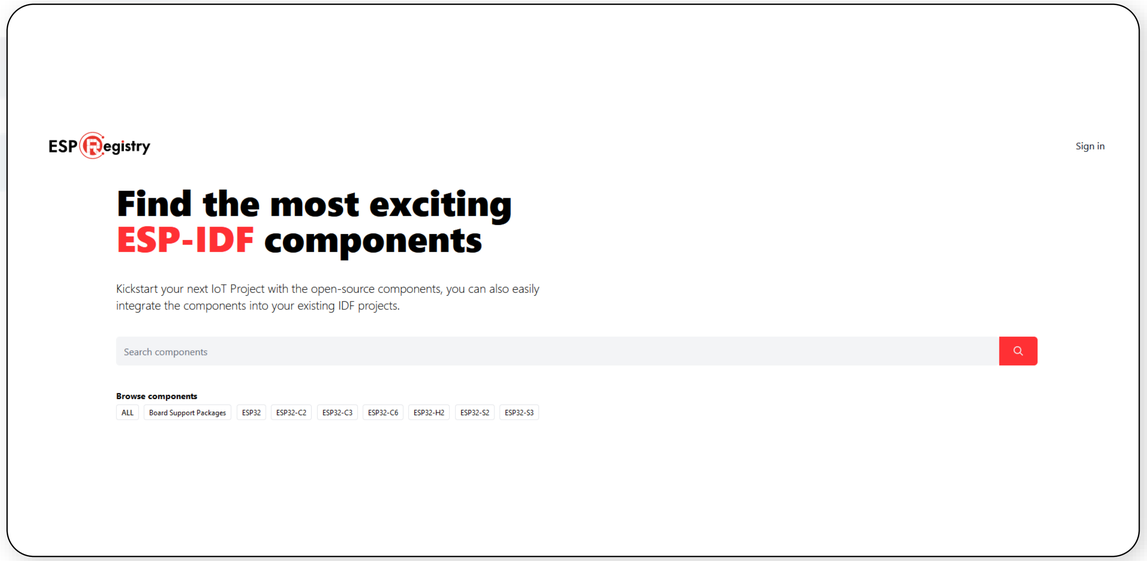
1. ESP-IDF components
2. IDF Component Registry (Component Manager)
3. Create your own

```
- my_project/
  - components/
    - my_i2c_sensor/
      - i2c_sensor.c
      - CMakeLists.txt
      …
    - my_graphics_lib/
      - graphics_lib.c
      - CMakeLists.txt
      …
  - main/
  - CMakeLists.txt
```





05 Build System & Components

Overview of ESP-IDF build system and what components are.

ESP-IDF Build System Overview

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The ESP-IDF build system is **based on CMake**.

01

Components > Libraries

02

CMake wrapper commands to accommodate components

03

Integrate into idf.py frontend

04

Still possible to use pure CMake

Components vs Library

Component is a library but with extra stuff

- Source files, headers, include directories
- Linker Fragments
- Embedded binary/text files
- Other pre-compiled libraries
- Kconfig configuration
- Unit tests

```
some_component/
  - include/
    - some_component.h
    …
  - src/
    - some_component.c
    …
  - linker.lf
  - data.txt
  - some_other_lib.a
  - Kconfig
  - tests/
    …
```

Component CMakeLists.txt

```
project(libX)
add_library(libX libX.c)
target_link_libraries(libX PRIVATE libY PRIVATE libZ)
```

```
# Register component
idf_component_register(
  # Source files for this component
  SRCS ./src/my_component.c ./src/algo.c
  # Include directories for this component
  INCLUDE_DIRS ./include
  # Other components required by this component
  REQUIRES esp_lcd
  PRIV_REQUIRES driver
  # Linker fragment for this component
  LDFRAGMENTS linker.lf)
```

Project CMakeLists.txt

```
project(my_project)
add_executable(my_app my_app.c)
target_link_libraries(my_app PUBLIC libA PRIVATE libX)
```

```
cmake_minimum_required(VERSION 3.16)

# Pull in IDF Cmake Wrappers
include($ENV{IDF_PATH}/tools/cmake/project.cmake)

# Default directories that are searched for components
#   - “esp-idf/components/”
#   - “my_project/components/”
# Declare any extra directories to search for components
set(EXTRA_COMPONENT_DIRS "$ENV{MY_LIBS}/components")

# Declare project
project(my_project)
```

Build Systems (Further Resources)

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[ESP-IDF Build System Documentation]

06 More Resources

Where to get more help & resources

Guru Meditation Error?

```c
#include <stdio.h>

static void some_func(int *some_ptr)
{
    *some_ptr = 1;  ← NULL pointer access
}

void app_main(void)
{
    printf("Hello World\n");
    some_func((int *)NULL);
}
```

```
Guru Meditation Error: Core  0 panic'ed (StoreProhibited). Exception was unhandled.

Core  0 register dump:
PC      : 0x400e23f1  PS      : 0x00060a30  A0      : 0x800d50df  A1      : 0x3ffb4c20
A2      : 0x00000000  A3      : 0x3f4028fc  A4      : 0x3f40297c  A5      : 0x3ffb4c40
A6      : 0x3ffb4c20  A7      : 0x0000000c  A8      : 0x00000001  A9      : 0x3ffb4be0
A10     : 0x0000000a  A11     : 0x3ffaeb44  A12     : 0x3ffb4c20  A13     : 0x0000000c
A14     : 0x3ffb2934  A15     : 0xb33fffff  SAR     : 0x00000004  EXCCAUSE: 0x0000001d
EXCVADDR: 0x00000000  LBEG    : 0x400014fd  LEND    : 0x4000150d  LCOUNT  : 0xfffffffc

Backtrace: 0x400e23ee:0x3ffb4c20 0x400d50dc:0x3ffb4c40 0x400e30b8:0x3ffb4c60
0x40087bad:0x3ffb4c90
```

Fatal Errors

- Fatal error cause
- Register Dump
- Backtrace
- Auto address decoding by IDF monitor

```
Guru Meditation Error: Core  0 panic'ed (StoreProhibited). Exception was unhandled.

Core  0 register dump:
PC      : 0x400e23f1  PS      : 0x00060a30  A0      : 0x800d50df  A1      : 0x3ffb4c20
0x400e23f1: some_func at /home/User/my_project/build/../main/my_project.c:5
A2      : 0x00000000  A3      : 0x3f4028fc  A4      : 0x3f40297c  A5      : 0x3ffb4c40
A6      : 0x3ffb4c20  A7      : 0x0000000c  A8      : 0x00000001  A9      : 0x3ffb4be0
A10     : 0x0000000a  A11     : 0x3ffaeb44  A12     : 0x3ffb4c20  A13     : 0x0000000c
A14     : 0x3ffb2934  A15     : 0xb33fffff  SAR     : 0x00000004  EXCCAUSE: 0x0000001d
EXCVADDR: 0x00000000  LBEG    : 0x400014fd  LEND    : 0x4000150d  LCOUNT  : 0xfffffffc

Backtrace: 0x400e23ee:0x3ffb4c20 0x400d50dc:0x3ffb4c40 0x400e30b8:0x3ffb4c60 0x40087bad:0x3ffb4c90

0x400e23ee: some_func at /home/User/my_project/build/../main/my_project.c:4

0x400d50dc: app_main at /home/User/my_project/build/../main/my_project.c:12

0x400e30b8: main_task at /home/User/esp/esp-idf/components/freertos/app_startup.c:217 (discriminator 13)

0x40087bad: vPortTaskWrapper at /home/User/esp/esp-idf/components/freertos/FreeRTOS-
Kernel/portable/xtensa/port.c:162
```

Debugging Tools

Runtime Debugging Tools

- GDB & OpenOCD
- Application Tracing
- GDB Stub (Runtime)

Post-Mortem Debugging Tools

- Core Dump
- GDB Stub (Panic)

Support

Github

- Report issues or feature requests
- Contribute pull requests (see ESP-IDF Contributors Guide)

ESP32 Forum

- Ask questions
- Discuss ESP32/ESP-IDF

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Thanks for watching !