Advanced System Software
（先端システムソフトウェア）

#4 (2018/10/15)

CSC.T431, 2018-3Q
Mon/Thu 9:00-10:30, W832
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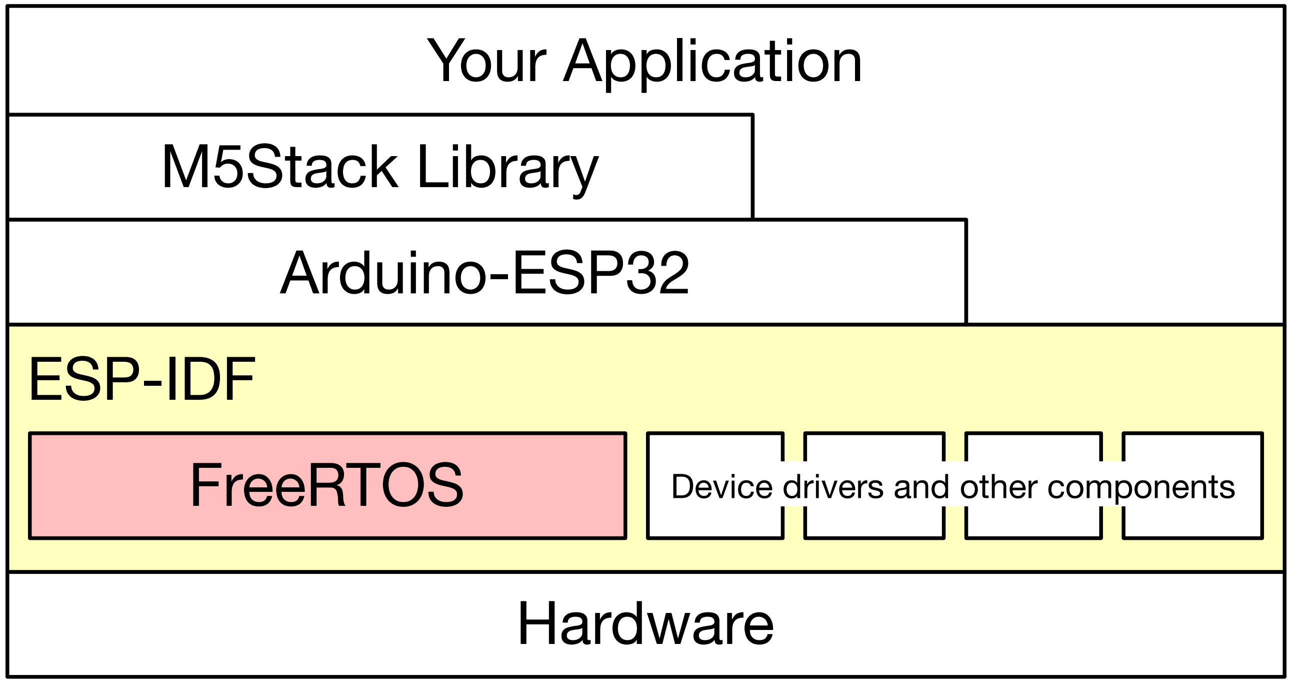
Programming M5Stack using FreeRTOS

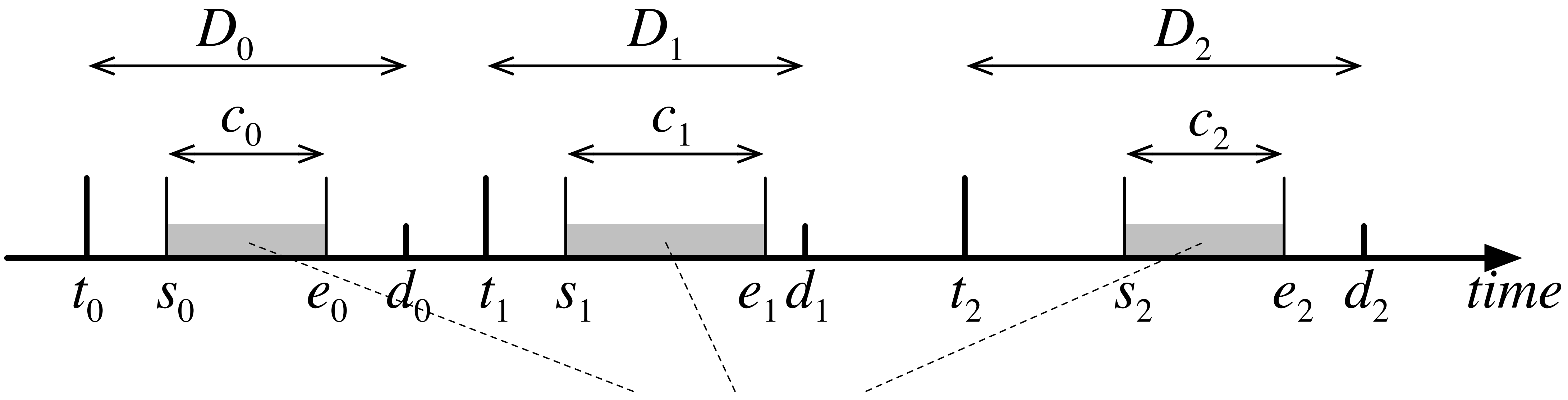
- ESP-IDF : Framework for ESP32
- FreeRTOS



FreeRTOS

- Open-Source RTOS (Real-Time Operating System) kernel for embedded devices
  - https://freertos.org
  - Recently acquired by Amazon
- Simple & Small
  - Basic features: tasks, semaphores, timers
  - Simple memory management capabilities
  - Priority-based preemptive scheduling
    - Unlike common OSs (such as Linux), no advanced memory management systems (such as VM), no file systems, no user accounting systems are provided

Real-Time Task



task instances (jobs)

t_i release (arrival) time of i-th task instance that corresponds to i-th event

s_i start time of i-th task instance

e_i end time of i-th task instance

d_i absolute deadline of i-th task instance

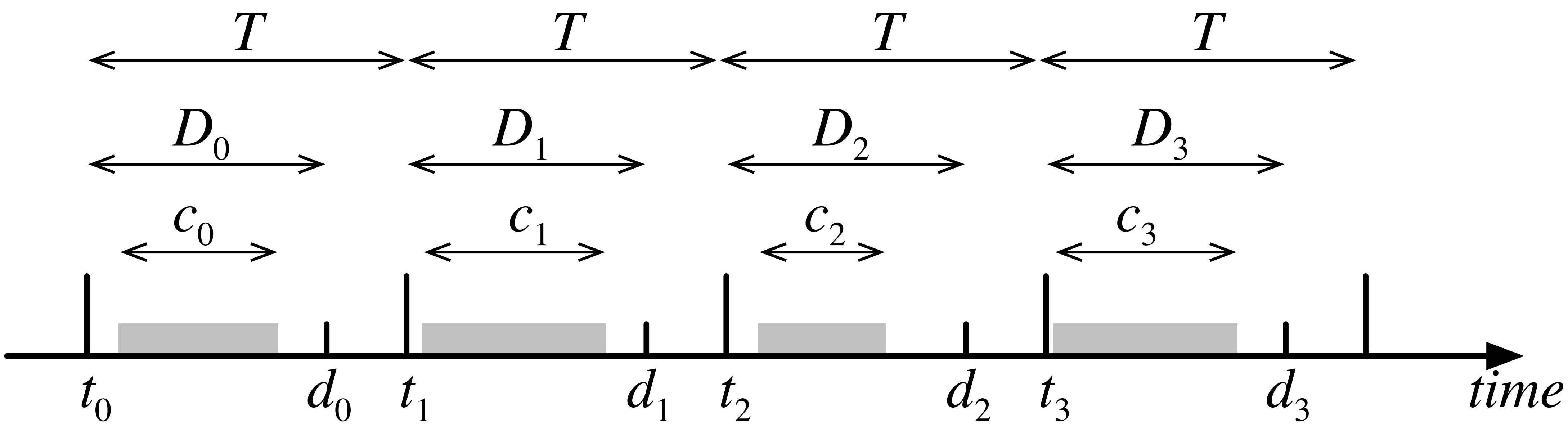
D_i relative deadline of i-th task instance $(D_i = d_i - t_i)$

c_i (worst case) execution time of i-th task instance $(c_i \leq D_i)$

Real-time Tasks

- Periodic Task
  - A task consists of a sequence of similar (or identical) jobs that are arrived at a constant rate.
  - e.g. sensor value acquisition, playing videos
- Aperiodic Task
  - A task consists of a sequence of jobs that are arrived at irregular intervals.
  - e.g. user activities
- Sporadic Task
  - An aperiodic task characterized by a minimum inter-arrival time between consecutive activities.
  - e.g. network packets

Periodic Task (1)



T period ($T = t_{i+1} - t_i$)

ϕ phase ($= t_0$)

t_i release time of i-th task instance ($t_i = \phi + iT$)

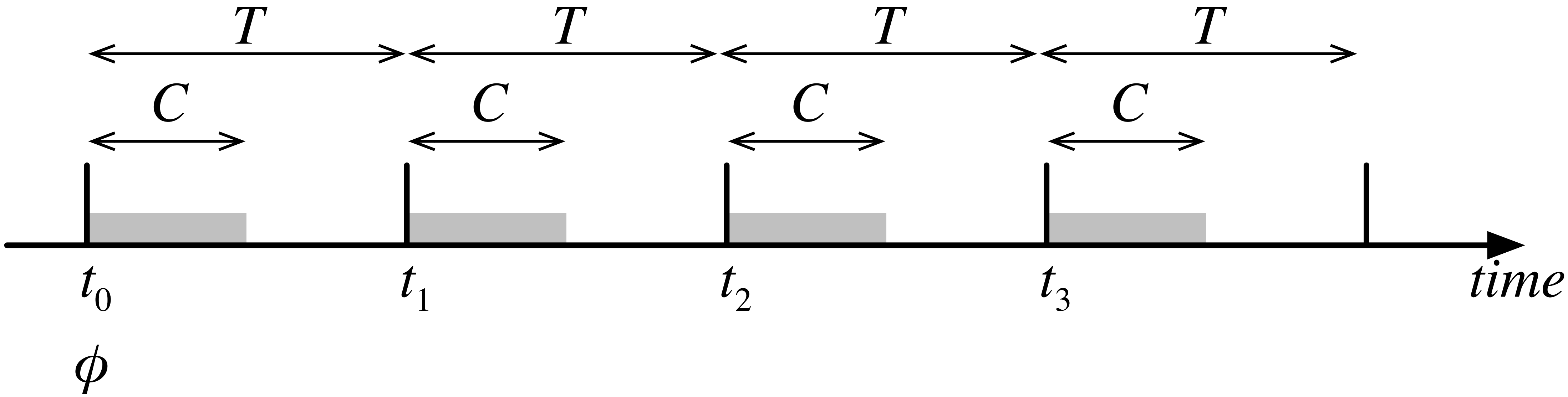
d_i absolute deadline of i-th task instance

D_i relative deadline of i-th task instance ($D_i = d_i - t_i$)

c_i (worst case) execution time of i-th task instance ($c_i \le D_i$)

Periodic Task (2)

- To make things simpler, we assume that
  - $\forall i \in N.\ D_i = T$,
  - $\forall i \in N.\ s_i = t_i$, and
  - $\forall i \in N.\ c_i = C$.
- Thus we can describe a periodic task τ as a triple (T, C, ϕ).



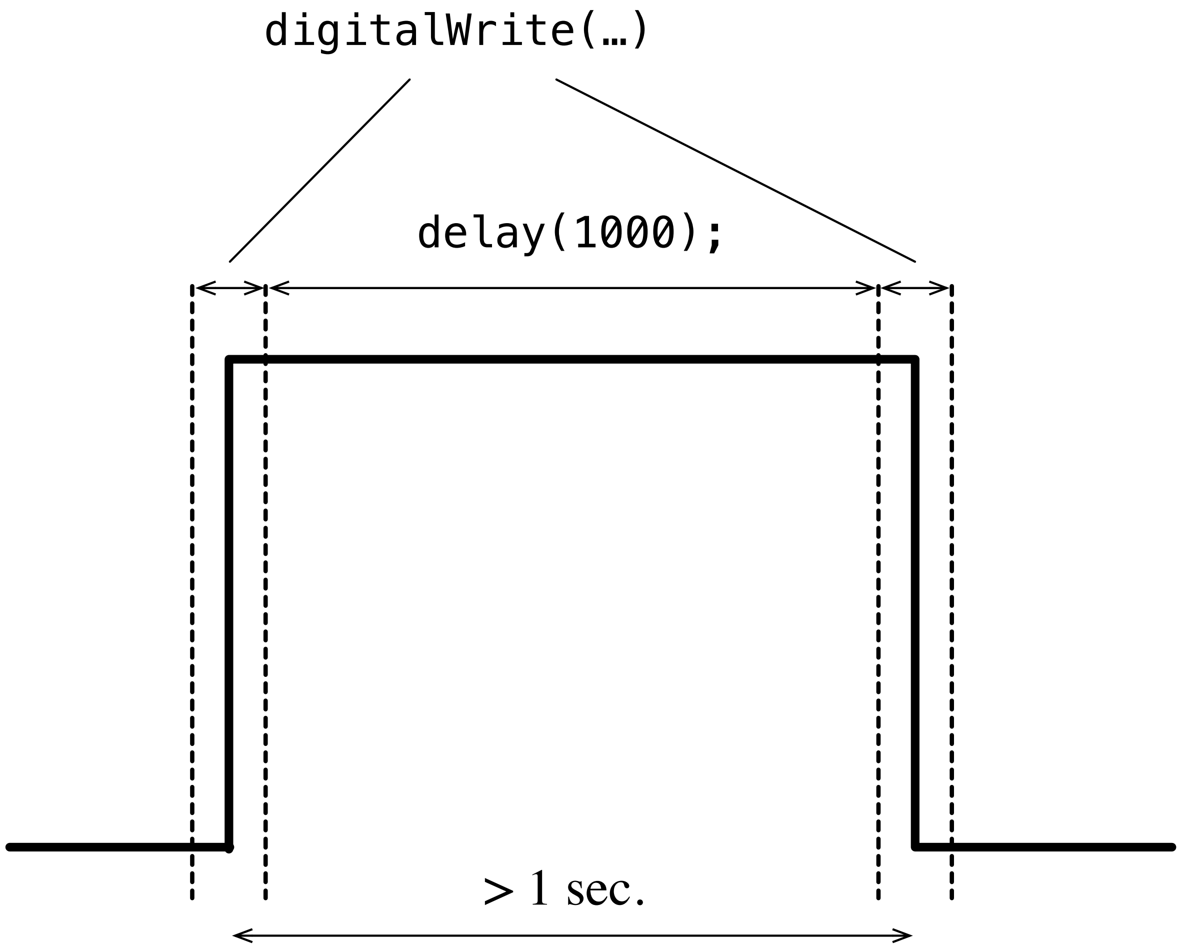
Programming Periodic Tasks

- T: Toggle an LED at a 1 second interval.
- S: Its easy.

```
#define LED_PIN 21

void setup() {
  pinMode(LED_PIN, OUTPUT);
}

void loop() {
  digitalWrite(LED_PIN, !digitalRead(LED_PIN));
  delay(1000);
}
```

Programming Periodic Tasks

- T: Is it really a 1 second interval?
- S: Well ... almost?



Programming Periodic Tasks

- T: Yes. The function digitalRead/Write are simple and sufficiently fast. But if you insert some work like the following, the resulting interval is longer than 1 second.

```
void loop() {
  digitalWrite(LED_PIN, !digitalRead(LED_PIN));
  work_in_less_than_1s();
  delay(1000);
}
```

Programming Periodic Tasks

- T: Toggle an LED at an exactly 1 second interval, but with *work_in_less_than_1s*().
- S: Hmm... Here it is.

```
unsigned long target;

void setup() {
    pinMode(LED_PIN, OUTPUT);
    target = millis();
}

void loop() {
    if (millis() > target) {
        target = millis() + 1000;
        digitalWrite(LED_PIN, !digitalRead(LED_PIN));
        work_in_less_than_1s();
    }
}
```

Programming Periodic Tasks

- T: OK. Can you identify any drawbacks of your last solution?
- S: The CPU is too busy while idle running. It is possible to put a *pause time* like the following. But this may lower the accuracy of the interval.

```
void loop() {
    if (millis() > target) {
        target = millis() + 1000;
        digitalWrite(LED_PIN, !digitalRead(LED_PIN));
        work_in_less_than_1s();
    }
    delay(10);
}
```

Programming Periodic Tasks

- T: Do you think you can show another solution?
- S: (Google, Google, ...) OK. It works!

```
TickType_t lastWakeTime;

void setup() {
    pinMode(LED_PIN, OUTPUT);
    lastWakeTime = xTaskGetTickCount();
}

void loop() {
    vTaskDelayUntil(&lastWakeTime, 1000 / portTICK_PERIOD_MS);
    digitalWrite(LED_PIN, !digitalRead(LED_PIN));
    work_in_less_than_1s();
}
```

Programming Periodic Tasks

- T: (Hmm... How did S find FreeRTOS API?) OK. Now, can you program two periodic tasks with different intervals in a single loop?
  - ex) Toggle an LED at a 1 second interval and output "Hello" to the USB-serial port at 3 second interval.
- S: Well .... I think I could (in the next slide)

```
#include <Arduino.h>
#define LED_PIN 21

unsigned long last_a;
unsigned long last_b;

void setup() {
    pinMode(LED_PIN, OUTPUT);
    Serial.begin(115200);
    last_a = last_b = millis();
}

void loop() {
    unsigned long curr = millis();
    if (curr > last_a + 1000) {
        last_a = curr;
        digitalWrite(LED_PIN, !digitalRead(LED_PIN));
    }
    if (curr > last_b + 3000) {
        last_b = curr;
        Serial.println("Hello");
    }
}
```

Programming Periodic Tasks

- T: Hmm. Good.
- T: Can you do the same thing using vTaskDelayUntil ?
- S: ...
- T: Now, Write a program that can start several periodic tasks at runtime. Can you add some aperiodic tasks to your code? And, can you ...
- S: ....

MultiTask (in M5Stack Example)

```
void task1(void *pvParameters) {
    for (;;) {
        Serial.print("task1 Uptime (ms): ");
        Serial.println(millis());
        delay(100);
    }
}

void task2(void *pvParameters) {
    for (;;) {
        Serial.print("task2 Uptime (ms): ");
        Serial.println(millis());
        delay(200);
    }
}
void task3(void *pvParameters) {
    for (;;) {
        Serial.print("task3 Uptime (ms): ");
        Serial.println(millis());
        delay(1000);
    }
}
```

MultiTask (in M5Stack Example)

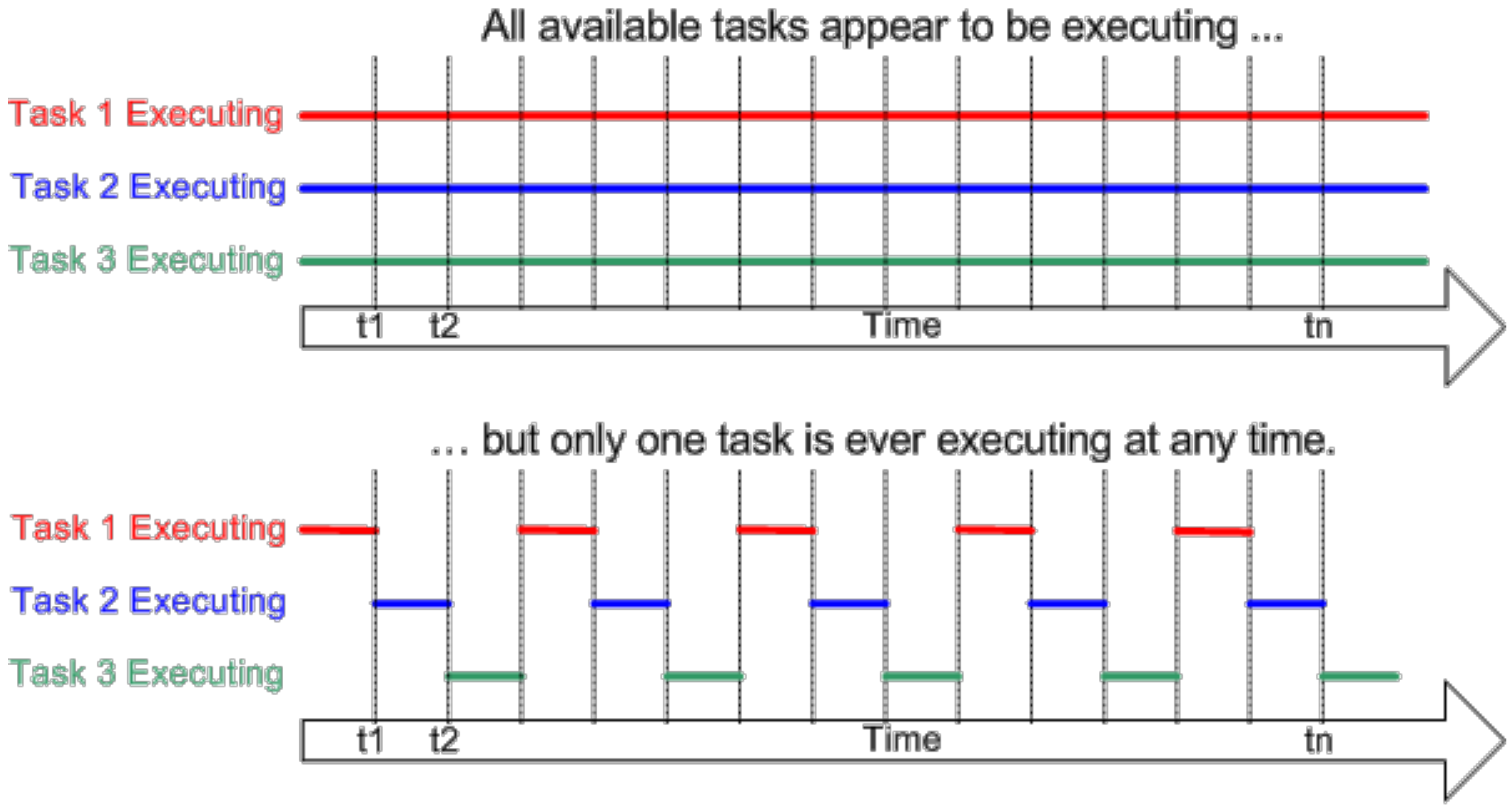
```
void setup() {
    // Task 1
    xTaskCreatePinnedToCore(
                    task1,     /∗ Function to implement the task ∗/
                    "task1",   /∗ Name of the task ∗/
                    4096,      /∗ Stack size in words ∗/
                    NULL,      /∗ Task input parameter ∗/
                    1,         /∗ Priority of the task ∗/
                    NULL,      /∗ Task handle. ∗/
                    0);        /∗ Core where the task should run ∗/

    // Task 2
    xTaskCreatePinnedToCore( ... );

    // Task 3
    xTaskCreatePinnedToCore( ... );
}

void loop() { }
```

The 'main' function in Arduino-ESP32

```
#include "freertos/FreeRTOS.h"
#include "freertos/task.h"
#include "Arduino.h"

...

void loopTask(void *pvParameters) {
    setup();
    for (;;) {
        loop();
    }
}

extern "C" void app_main() {
    initArduino();
    xTaskCreatePinnedToCore(loopTask, "loopTask", 8192, NULL,
                            1, NULL, ARDUINO_RUNNING_CORE);
}
```

FreeRTOS Tasks

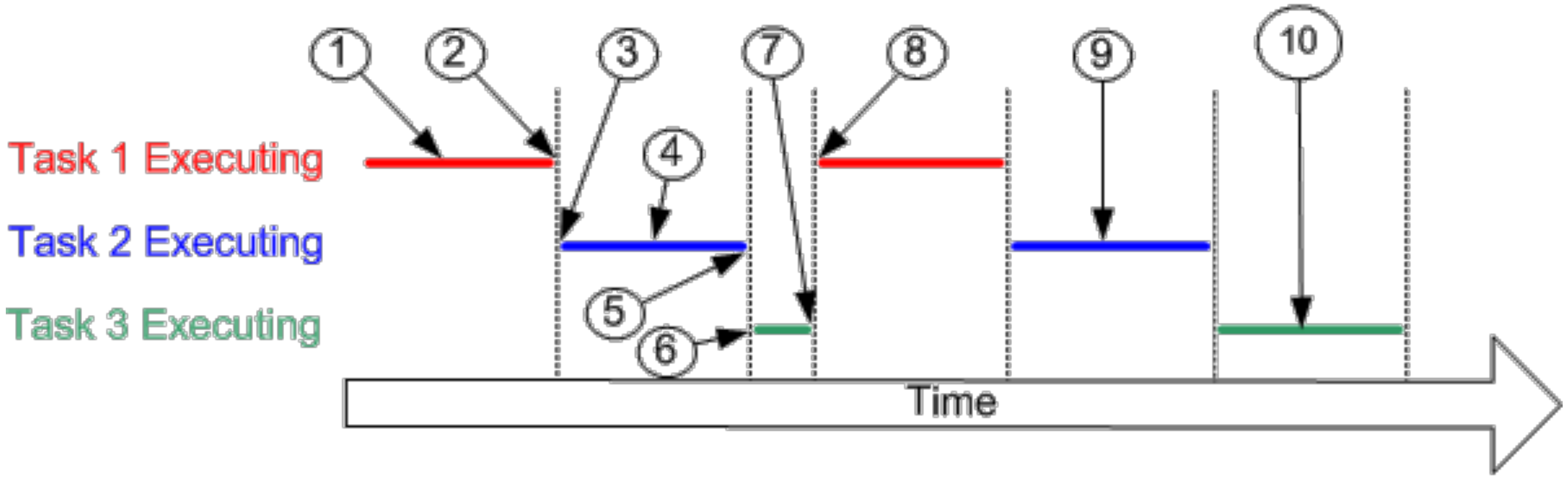
- A task corresponds to a thread of control.
- FreeRTOS provides multitasking.



https://www.freertos.org/implementation/a00004.html

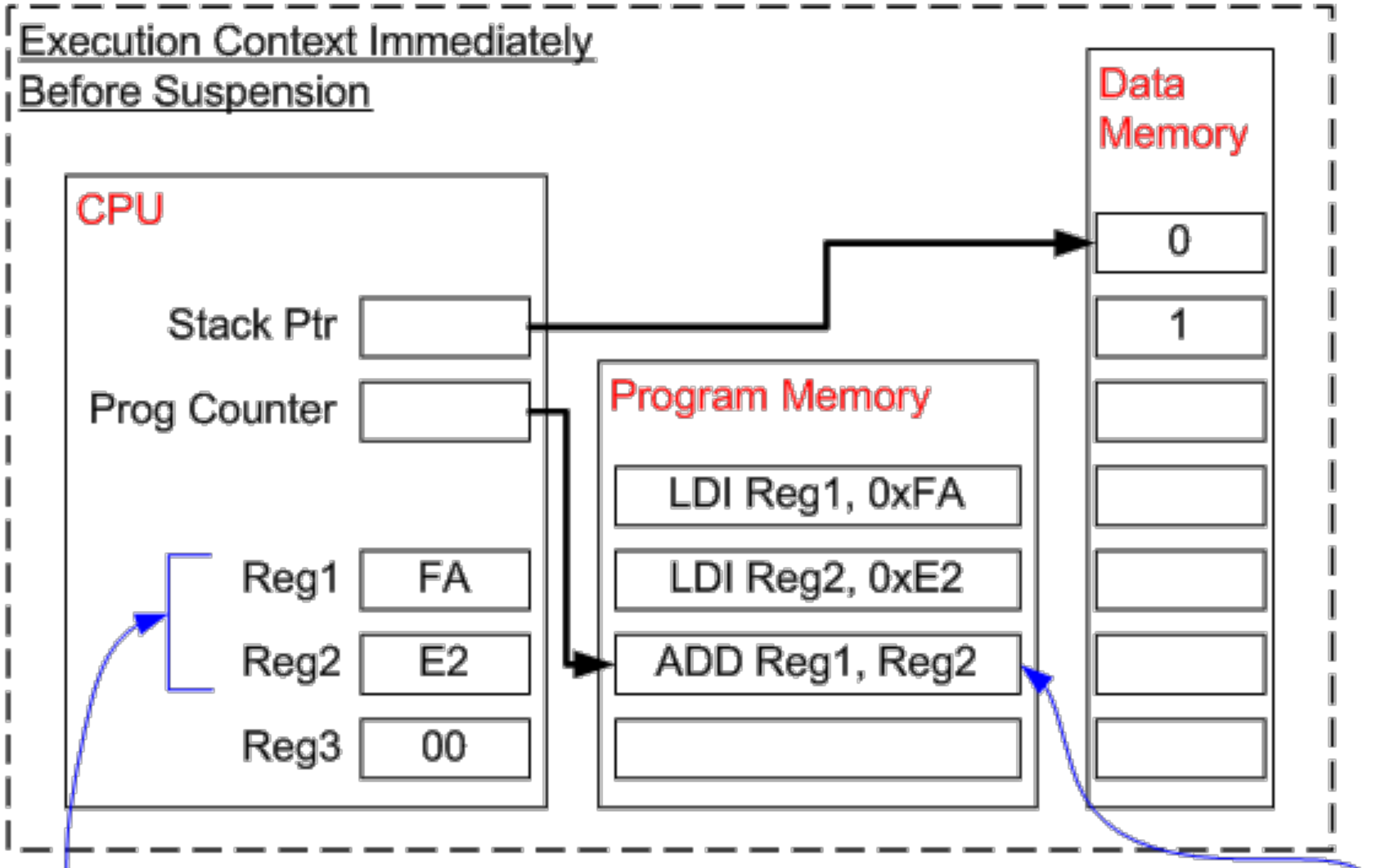
Scheduling

- The scheduler decides which task should be executing at any particular time.
- Scheduling policy: prioritized, fair



https://www.freertos.org/implementation/a00005.html

Context Switching



Execution Context Immediately Before Suspension

CPU

Stack Ptr

Prog Counter

Reg1 FA

Reg2 E2

Reg3 00

Program Memory

LDI Reg1, 0xFA

LDI Reg2, 0xE2

ADD Reg1, Reg2

Data Memory

0

1

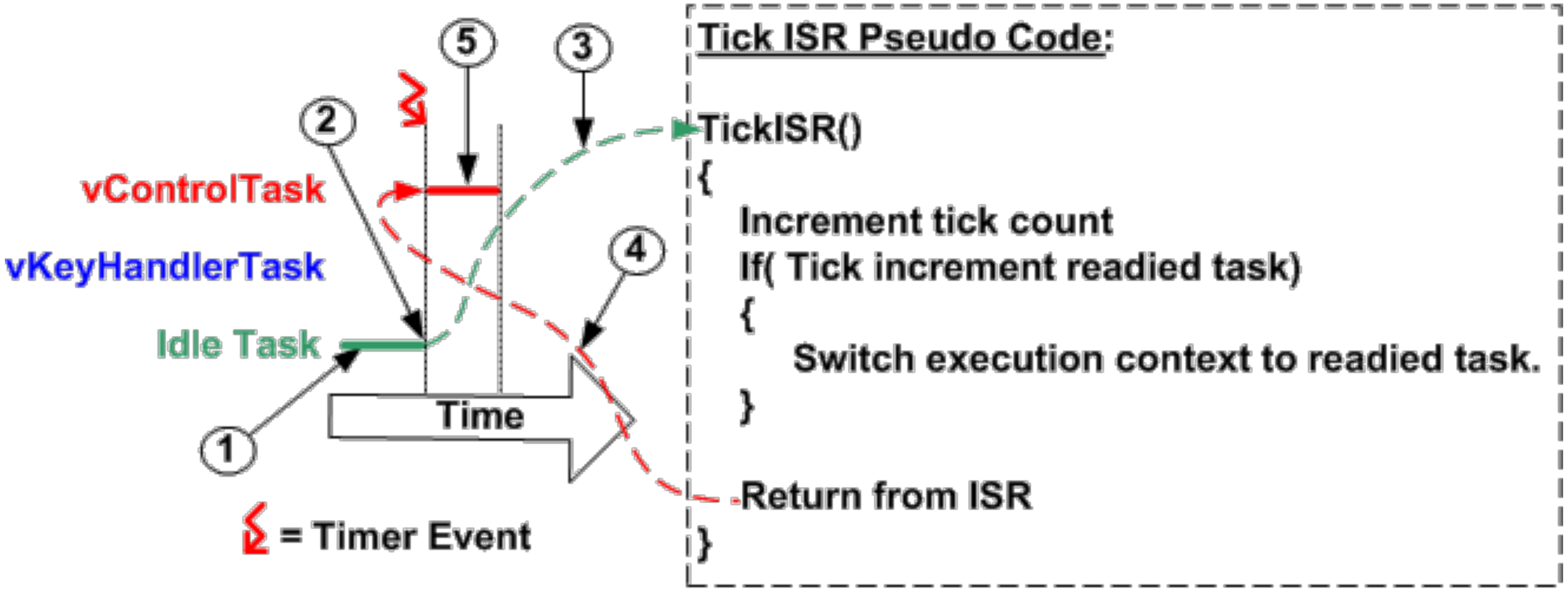
The task gets suspended as it is about to execute an ADD.

The previous instructions have already set the registers used by the ADD. When the task is resumed the ADD instruction will be the first instruction to execute. The task will not know if a different task modified Reg1 or Reg2 in the interim.

https://www.freertos.org/implementation/a00006.html

Ticks

- A tick corresponds to a timer event (an interruption event issued by the interval timer)



```
Tick ISR Pseudo Code:

TickISR()
{
    Increment tick count
    If( Tick increment readied task)
    {
        Switch execution context to readied task.
    }

    Return from ISR
}
```