u32BR

Fernando Pereira

fernando@dcc.ufmg.br

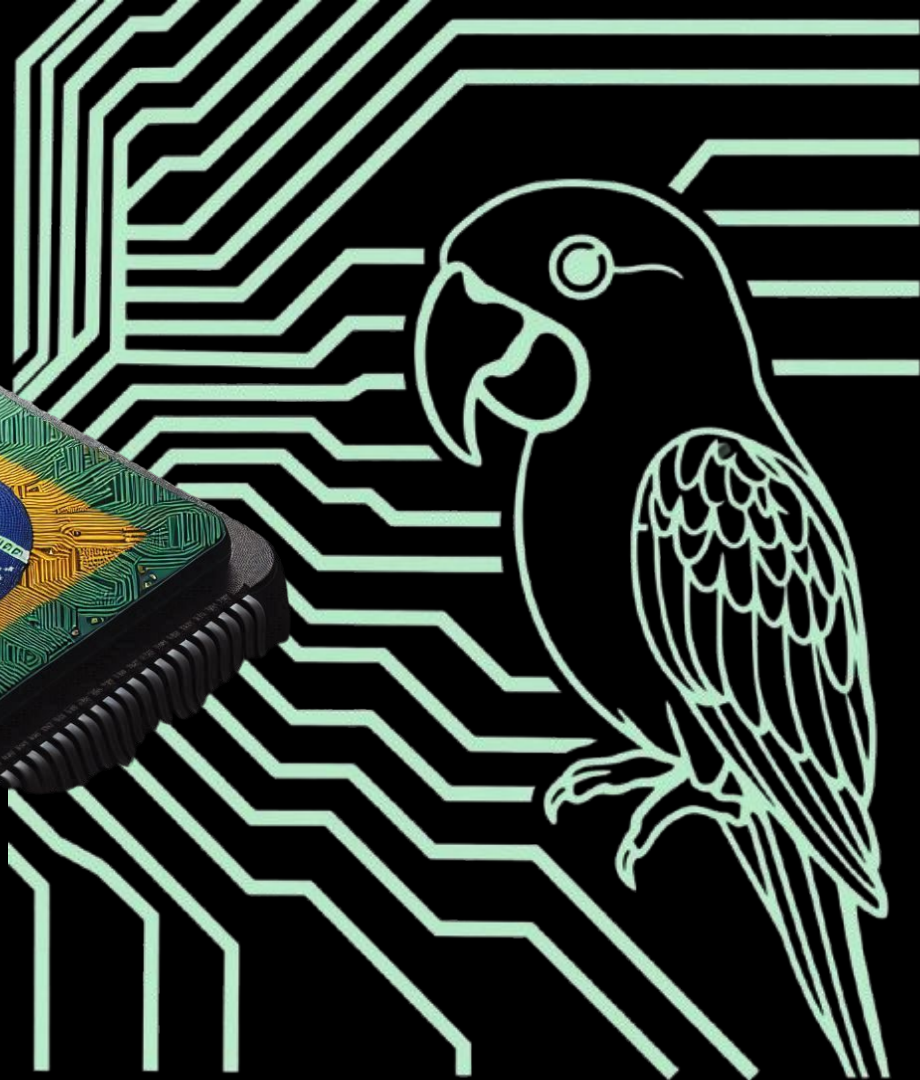
Softex

GOVERNO FEDERAL

BRASIL

UNIÃO E RECONSTRUÇÃO



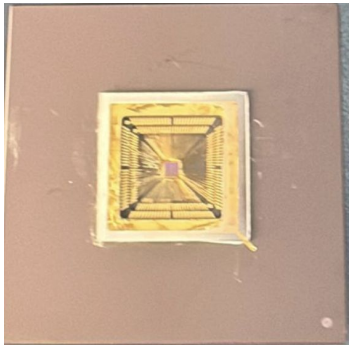


Este projeto é apoiado pelo Ministério da Ciência, Tecnologia e Inovações, com recursos da Lei 8.248, de 23 de outubro de 1991, conforme disposto no Art. 7.o da Portaria MCTI 5.275, de 5 de novembro de 2021.

Goal

Goal

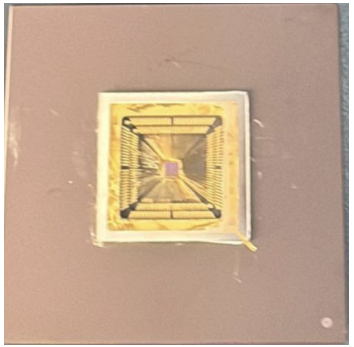
32-bit Microcontroller



Goal

32-bit Microcontroller

32KHz → ~200MHz



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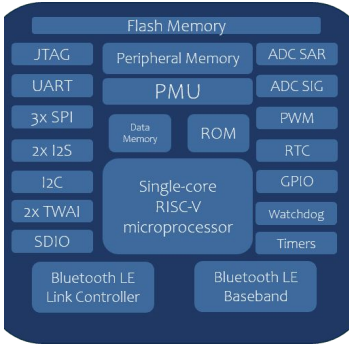
Timer/PWM, 3x SPI, I2C, UART, GPIO, etc.



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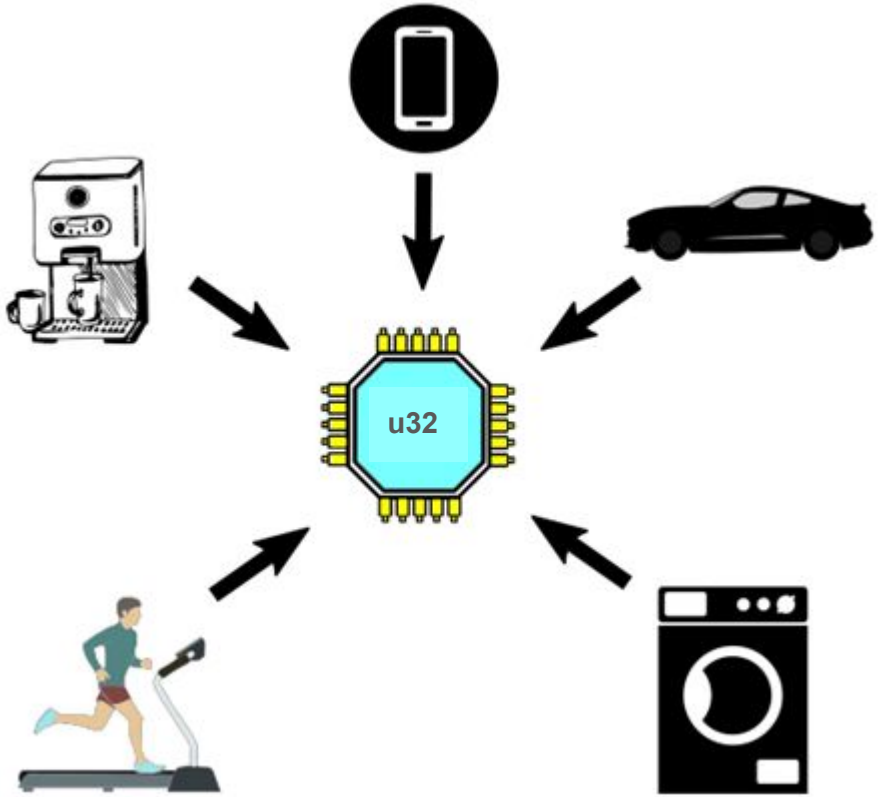
Integrated bluetooth antenna (SiP)



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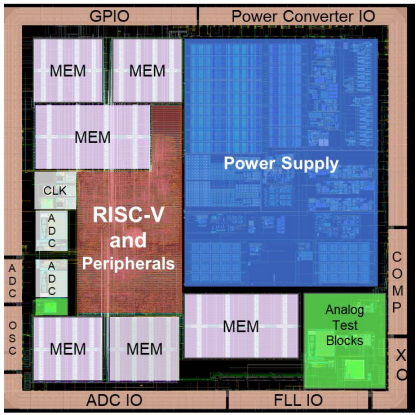
RISC-V



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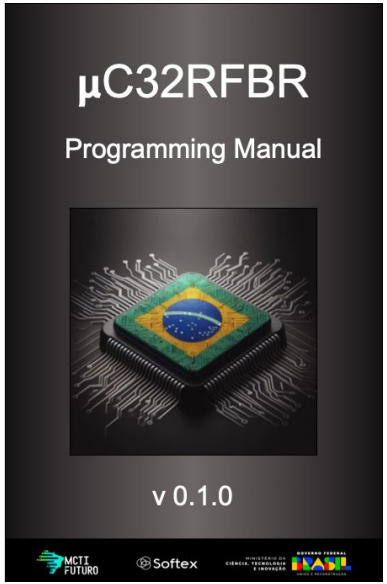
RISC-V

Software Development Kit (SDK)



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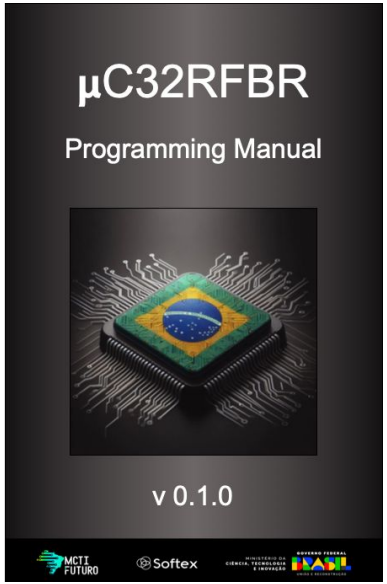


What?

30-month Project

R$ ~10M

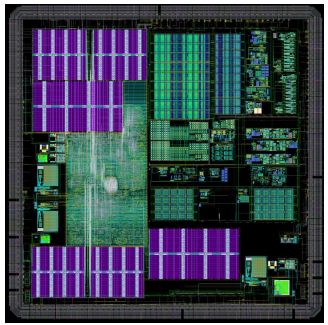


What?

30-month Project

R$ ~10M

Design:



Software:

u32BR SDK

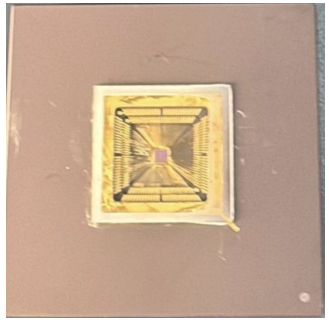
Generated by
Doxygen 1.8.5

250 pages

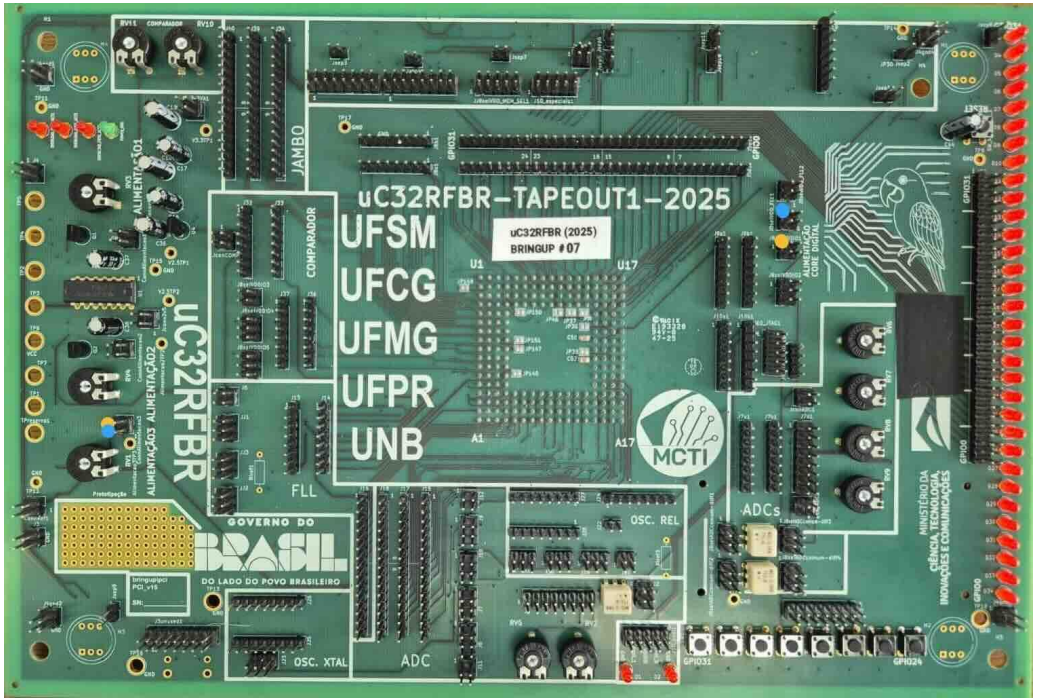
Fri May 15 2026

doxygen

Prototype:



National Effort



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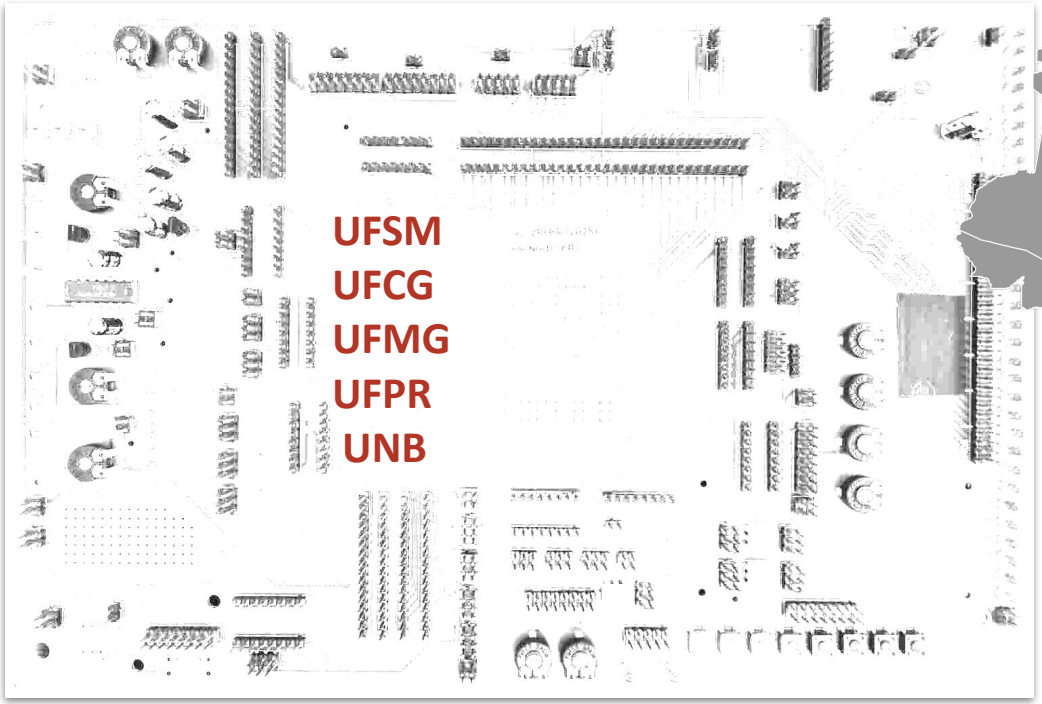

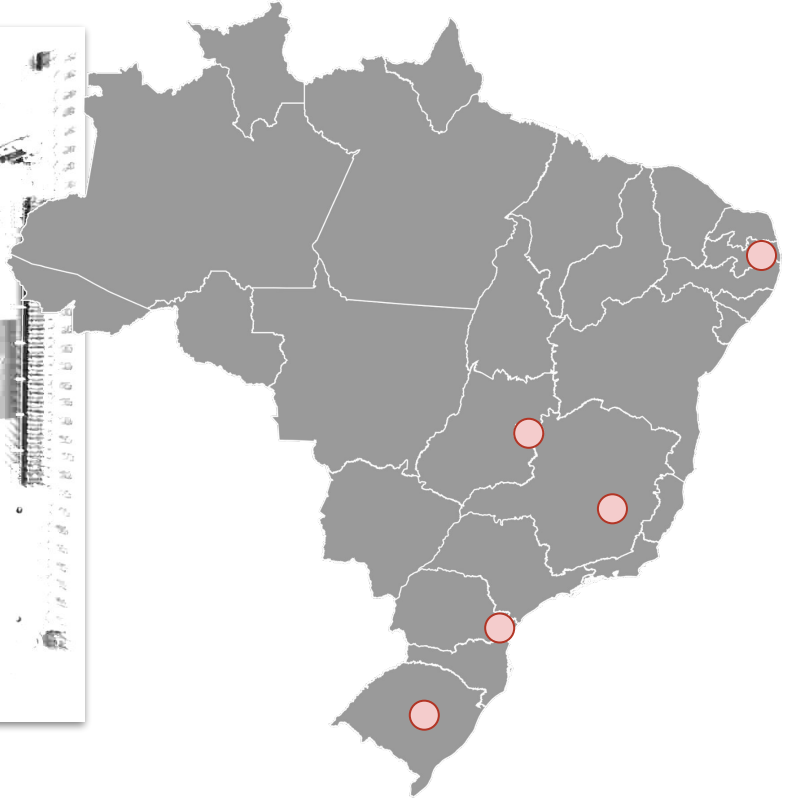

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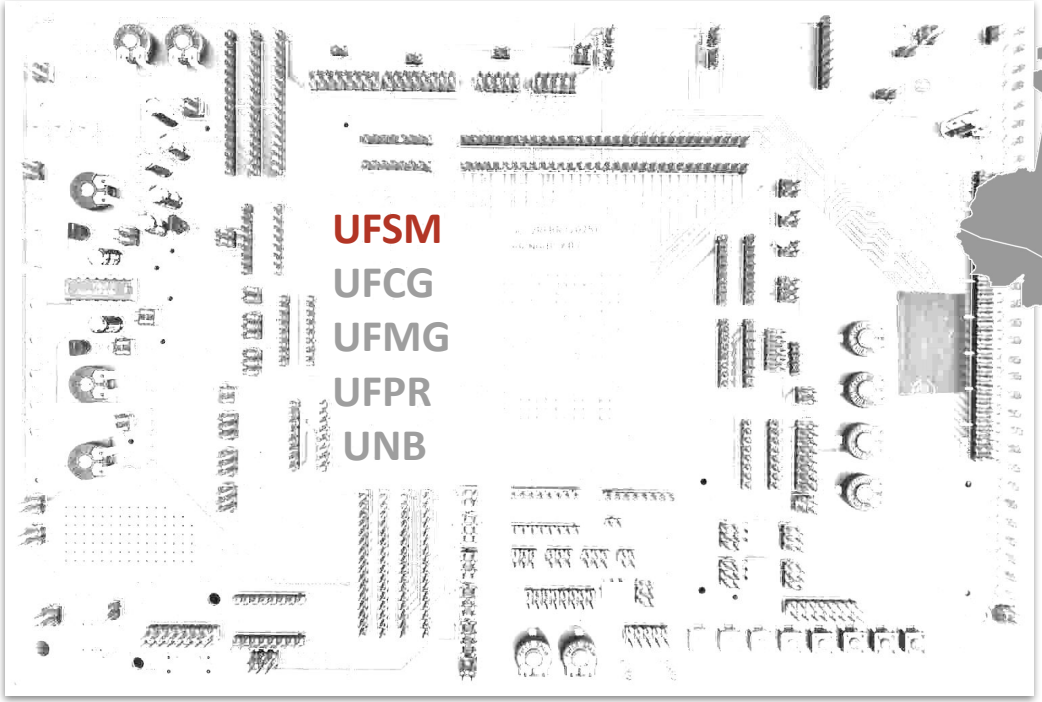




Universidade Federal de Santa Maria

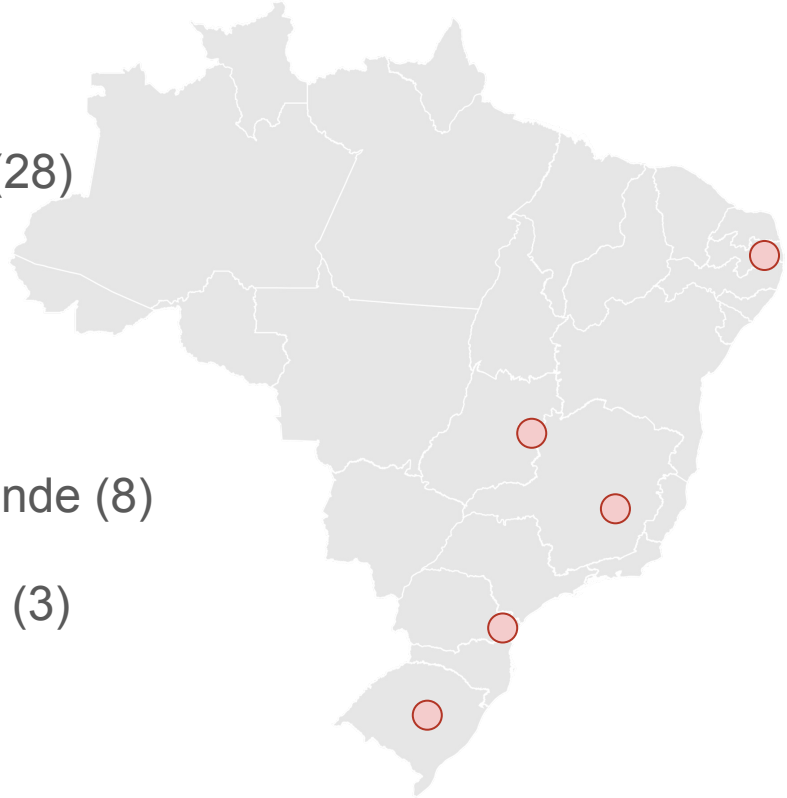
SEDES SAPIENTIÆ

1960

National Effort

Academic Partners

- Universidade Federal de Santa Maria (28)
- Universidade Federal do Paraná (6)
- Universidade Federal de Brasília (9)
- Universidade Federal de Campina Grande (8)
- Universidade Federal de Minas Gerais (3)



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Softex

Industry Partners

- Exatron
- Intral
- Novus
- FKS
- TecnoFlex

Why?

"We already have so many microcontrollers..."

Why?

"Between 2020 and 2023, there was a worldwide chip shortage affecting more than 169 industries."



https://en.wikipedia.org/wiki/2020%E2%80%932023_global_chip_shortage

"~~We already have so many microcontrollers...~~"

Why?

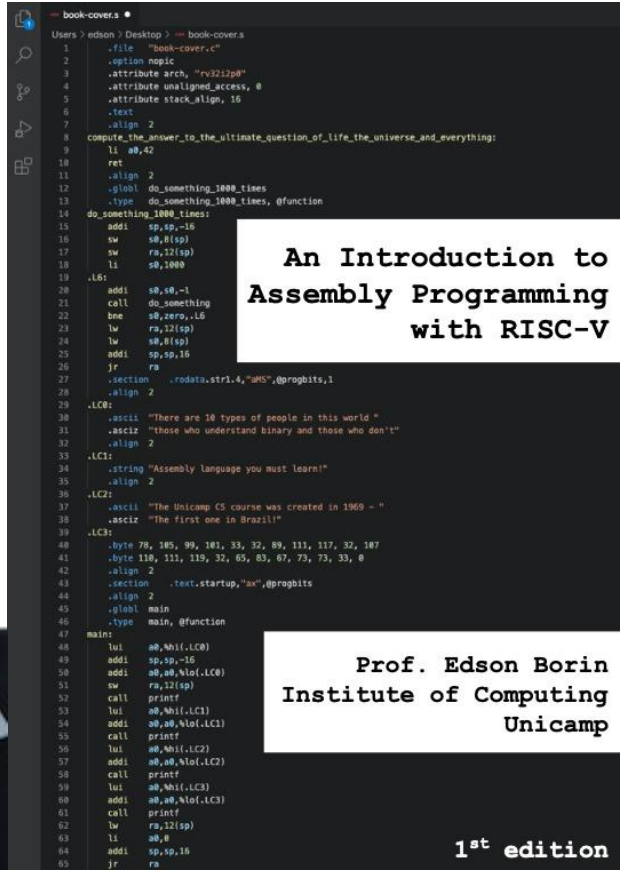
Know how

Why?

Know how

Prof. Edson Borin, UNICAMP





Why?

Know how

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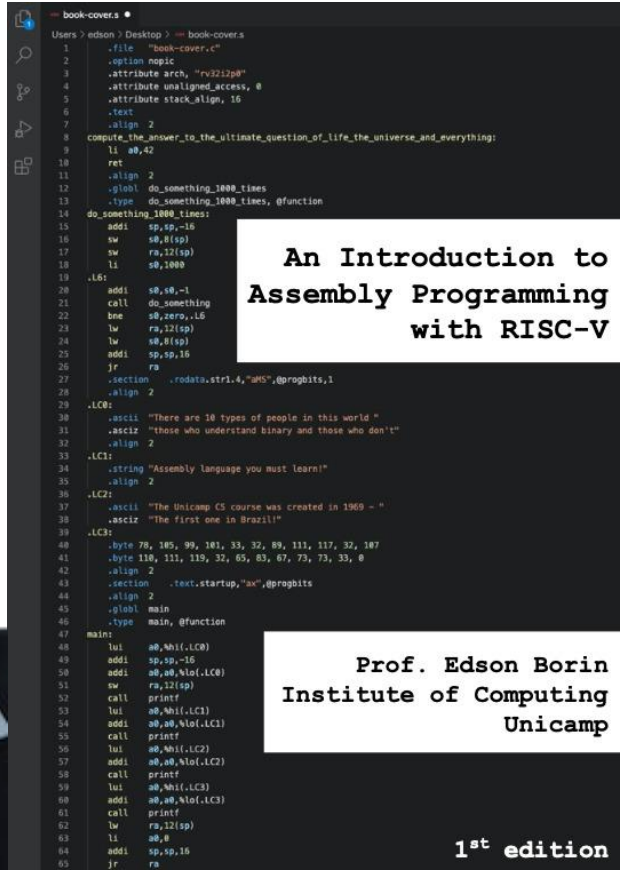
The Ministry of Education recognizes 662 courses of Computer Engineering in Brazil





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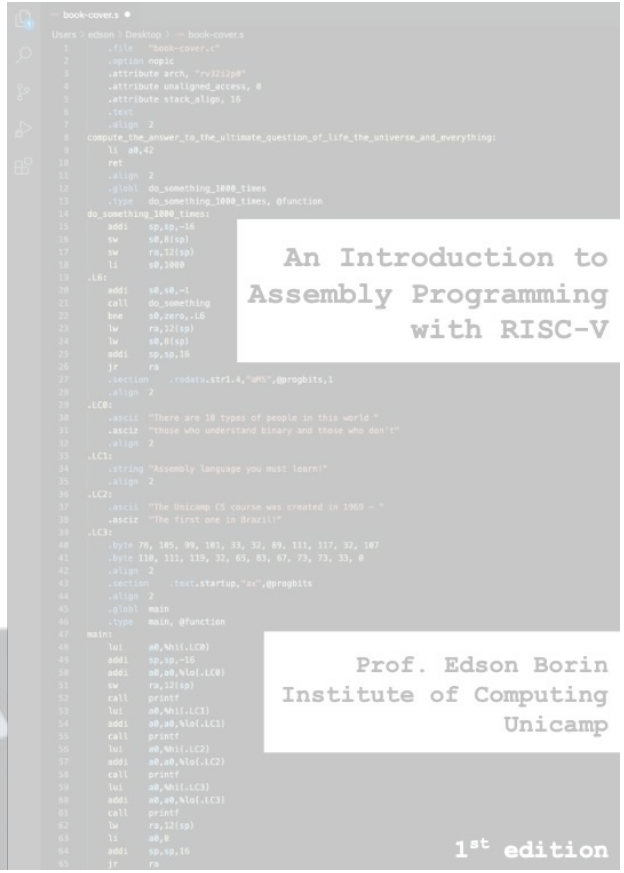

GDP: R$ 12.7 T

Population: 213 M

Why?

Know how

Trust

Why?

Know how

Trust

> *"Since the design of modern microprocessors is usually kept as a trade secret, there is no efficient method for the user to verify that a single multiplication bug does not exist."*
>
> David Wagner, CRYPTO 2008, Advances in Cryptology

Why?

Know how

Trust

ZDNET tomorrow belongs to those who embrace it today

Home / Tech / Security

Researchers find backdoor on ZTE Android phones

Security researchers have reported a hidden backdoor in the ZTE Score M and Skate Android phones, which could give a hacker root access



Written by **Michael Lee,** Contributor

May 15, 2012 at 2:45 a.m. PT

https://www.zdnet.com/article/researchers-find-backdoor-on-zte-android-phones/

Why?

Know how

Trust

- The Shenzhen 2018 Supermicro Incident
- The Tailored Access Operations Unit (2013)
- The 2012 ZTE Phones (confirmed by D. Alperovitch)
- The Cisco 2008 FBI Report
- Jonathan Brossard Rakshasa Backdoor (2011)
- ...

Why?

Know how

Trust



Why?

Know how

Trust





Why?

Know how

Trust

Partnerships

UFSM



UnB



etc, etc...

Why?

Know how

Trust

Partnerships



	Professors	Engineers	Students
Digital	7	9	6
Analog	5	9	8
Radio	3	3	0
Software	2	0	1

The Software Stack



The Software Development Kit (SDK)

Tools

Libraries

Documentation

u32BR SDK

Generated by
Doxygen 1.8.5

250 pages

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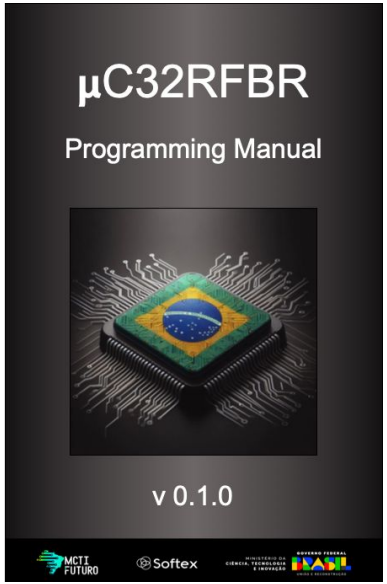

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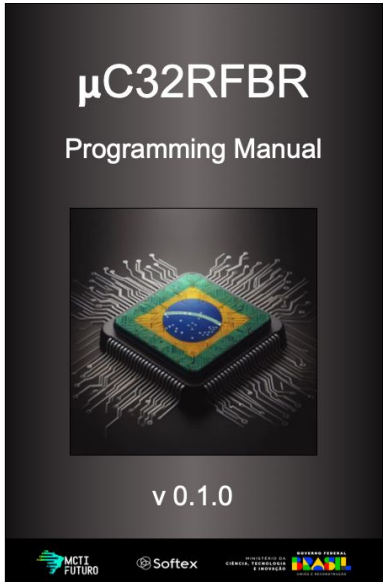
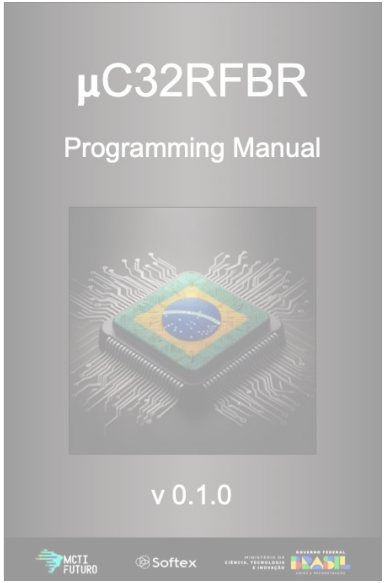


What is this good for?

Workflow using the SDK (for u32BR clients)

1. Setup the development environment



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   a. Install SDK
   b. Install IDE (Integrated Development Environment)

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   a. Use a project template from the SDK
   b. Configure settings (frequency, peripherals, etc)

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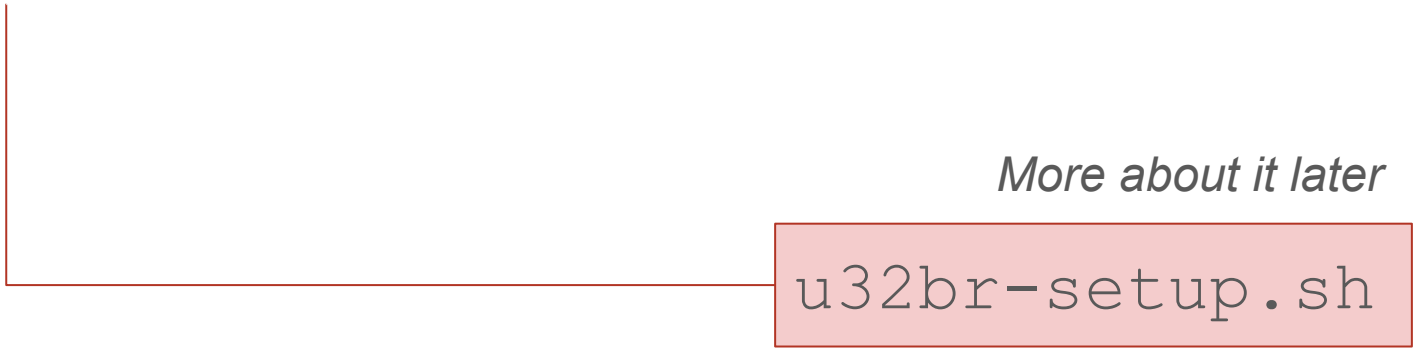

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   a. Load binary via bootloader
   b. Set breakpoints and step through
   c. Inspect variables

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   a. Use profiling tools
   b. Play with compiler options

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6. Optimize
   a. Use profiling tools
   b. Play with compiler options
7. **Deploy**
   a. **Simulate**
   b. **Test on the microcontroller**

Reference Implementation

Reference Implementation

Pulp Platform (Parallel Ultra-Low Power)

https://github.com/pulp-platform/pulp-sdk

Reference Implementation

Pulp Platform

https://github.com/pulp-platform/pulp-sdk

Integrated Systems Laboratory (*ETH Zurich*)

Energy-Efficient Embedded Systems (*University of Bologna*)

Bruschi, Nazareno and Haugou, Germain and Tagliavini, Giuseppe and Conti, Francesco and Benini, Luca and Rossi, Davide **GVSoC: A Highly Configurable, Fast and Accurate Full-Platform Simulator for RISC-V based IoT Processors.** ICCD 2021

Reference Implementation

Pulp Platform

https://github.com/pulp-platform/pulp-sdk

Apache 2.0 License

Reference Implementation

Pulp Platform

- Toolchain (GCC-based)
- Runtime Libraries
- RTOS Support (FreeRTOS)
- Examples and Templates

Reference Implementation

Pulp Platform

- Toolchain (GCC-based)
  - Compiler (gcc)
  - Assembler
  - Linker
- ~~Runtime Libraries~~
- ~~RTOS Support (FreeRTOS)~~
- ~~Examples and Templates~~

Reference Implementation

Pulp Platform

- ~~Toolchain (GCC based)~~ gcc 7 (custom) → gcc 15 (general)
- ~~Runtime Libraries~~
- ~~RTOS Support (FreeRTOS)~~
- ~~Examples and Templates~~

- Compiler (gcc)
- Assembler
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Reference Implementation

Pulp Platform

- ~~Toolchain (GCC-based)~~
- ~~Runtime Libraries~~
- ~~RTOS Support (FreeRTOS)~~
- ~~Examples and Templates~~

Removed lots of unnecessary code

Modified lots of old code

Added lots of new code

Reference Implementation

Runtime Libraries

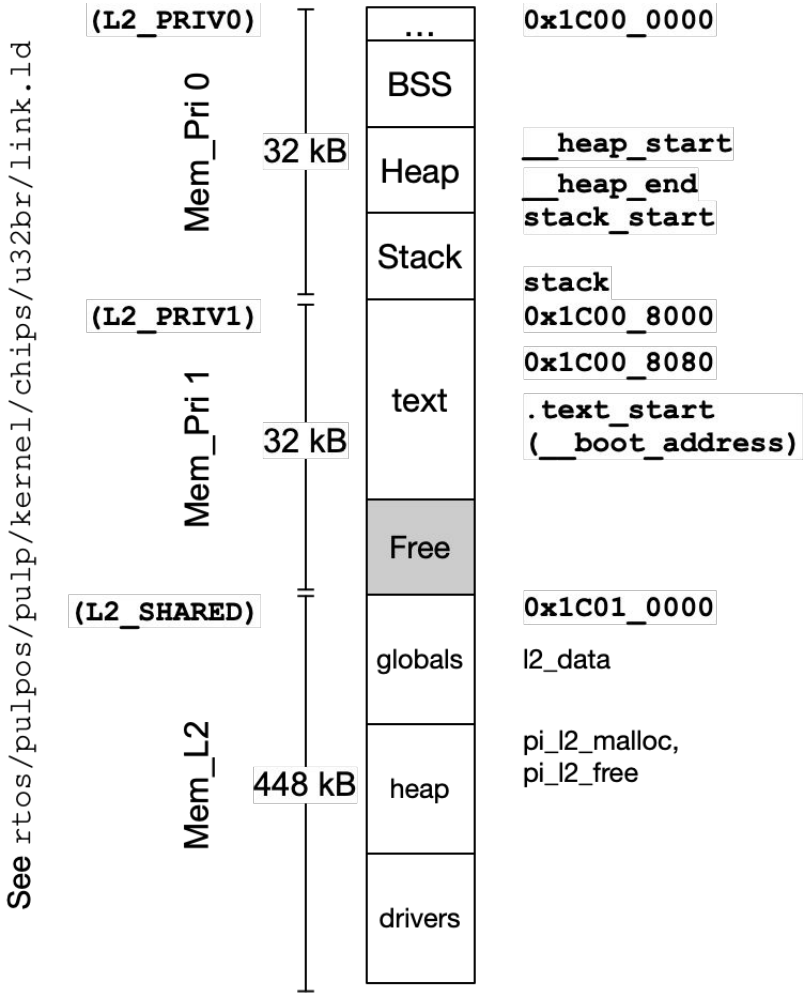
→ Memory allocation system

Reference Implementation

Runtime Libraries

→ Memory allocation system

malloc/free



Simulation

- Xcelium
- FPGA

Simulation

- Xcelium → UFMG/CEFET-MG
- FPGA → UFSM

Simulation

- Xcelium → UFMG/CEFET-MG
- FPGA → UFMS

- RTL Simulation
- Signal verification
- Coverage analysis

Simulation

- Xcelium → UFMG/CEFET-MG
- FPGA → UFSM



- Artix-7 FPGA (Xilinx)
- Nexys 4DDR Board (Digilent)

Actual Hardware

- Xcelium → UFMG/CEFET-MG
- FPGA → UFSM
- Development board



Actual Hardware

- Xcelium
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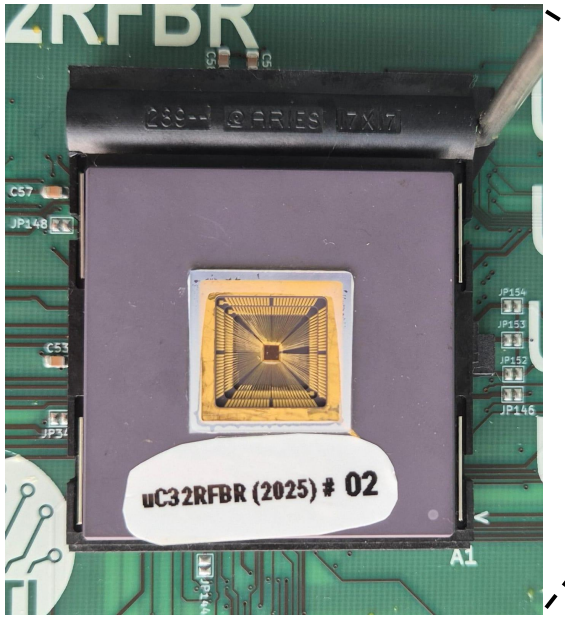

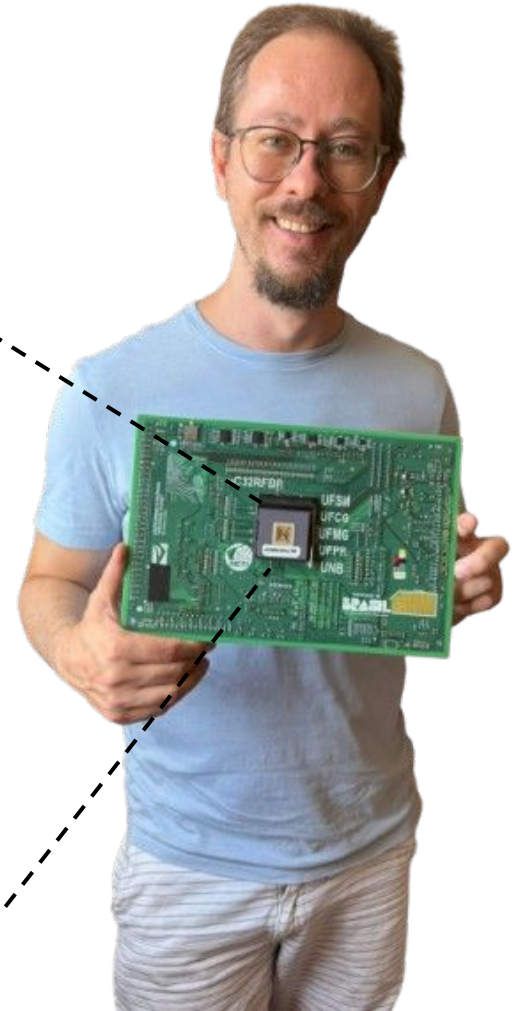

u32br-setup

u32br-setup

```
Usage: ../u32br-setup.sh <options>

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  -a|--app=[name]                    Use an application based on its name.
  -c|--clean                         Clean the project before building.
  -d|--debug=[none|rtl|openocd|gdb]  Debug none (default), rtl, openocd or gdb.
  -g|--gui                           Use GUI interface.
  -h|--help                          Show this usage.
  -o|--output=[stdout|uart]          Output mode to stdout (default) or uart.
  -p|--platform=[rtl|fpga|board]     Use rtl (default), fpga, or board as execution platform.
  -r|--run=[yes|no]                  Run the project yes (default) or no on the platform.
  -s|--setup=<all|projects>          Setup projects, all or a selection of the following
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  -s|--setup=<all|projects>          Setup projects, all or a selection of the following
                                       dependencies,toolchain,openocd,pulpissimo,sdk
  -t|--toolchain=[prebuilt|compile]  Use toolchain prebuilt or compile it from source.
  -v|--verbose                       Verbose mode
```

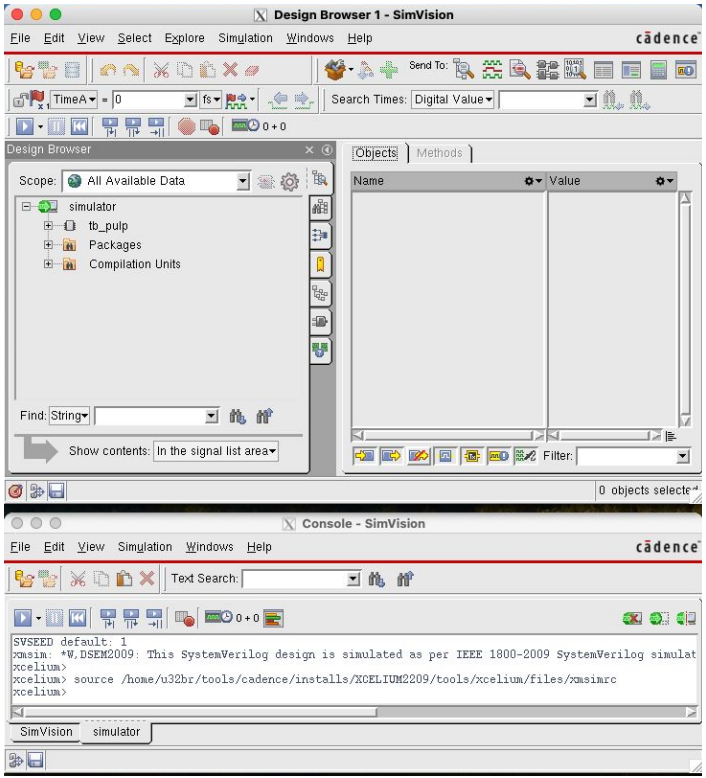
u32br-setup - Example

```
$ ./u32br-setup.sh -v --app=uart/loopback
...
```

u32br-setup - Example

```
$ ./u32br-setup.sh -v --app=uart/loopback
...
```

```
$ ./u32br-setup.sh -v \
--app=uart/loopback --gui
```



Development Flow

Development Flow - Example GPIO

UFSM

Raw test

```
...
// gpio set mask followed by a clear mask
gpio_set_mask(0x555555FF);
gpio_clear_mask(0x11111100);

// negate all GPIOs
printf("main(): test gpio_write()\n");
gpio_values = ~(archi_read32(GPIO_ADDR_PAD_DOUT));
for (int i=0; i<GPIO_TOTAL; i++)
  gpio_write(i, (gpio_values >> i) & 0x01);

// print current GPIO input value one by one
printf("main(): test gpio_read()\n");
for (int i=0; i<GPIO_TOTAL; i++)
  printf("main(): gpio_read(%d)=%d\n", i, gpio_read(i));
...
```



Development Flow - Example GPIO

```
static void test_entry() {
  int status = 0;
  struct pi_device gpio;

  if (pi_gpio_open(&gpio)) {
     status = 1;
     pmsis_exit(status);
  }

  for (pi_gpio_e pin = PI_GPIO_0; pin <= PI_GPIO_31; pin += 2)
     status |= test_pin(gpio, pin);

  for (pi_gpio_e pin = PI_GPIO_1; pin <= PI_GPIO_31; pin += 2)
     status |= test_pin(gpio, pin);

  if (!pi_gpio_mask_set(0x555555FF))
     status |= 1;

  pmsis_exit(status);

}
```

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Unit test



Development Flow - Example GPIO

```
static void test_entry() {
  int status = 0;
  struct pi_device gpio;

  if (pi_gpio_open(&gpio)) {
    status = 1;
    pmsis_exit(status);
  }

  for (pi_gpio_e pin = PI_GPIO_0; pin <= PI_GPIO_31; pin += 2)
    status |= test_pin(gpio, pin);

  for (pi_gpio_e pin = PI_GPIO_1; pin <= PI_GPIO_31; pin += 2)
    status |= test_pin(gpio, pin);

  if (!pi_gpio_mask_set(0x555555FF))
    status |= 1;

  pmsis_exit(status)

}
```

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Unit test



Development Flow - Example GPIO

```
pi gpio open(&gpio)
```

```
int pi_gpio_open(struct pi_device *device) {
  int irq = hal_irq_disable();

  pi_gpio_t *gpio = &pos_gpio;
  device->data = (void *)gpio;

  hal_irq_restore(irq);

  return 0;
}
```

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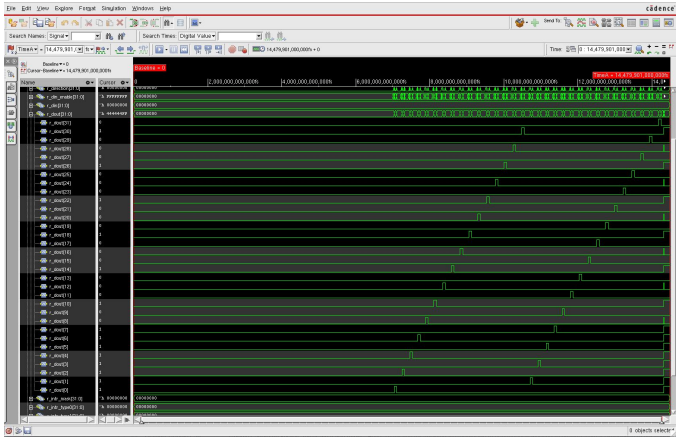
Implementation



Development Flow - Example GPIO



```
int pi_gpio_open(struct pi_device *device) {
  int irq = hal_irq_disable();

  pi_gpio_t *gpio = &pos_gpio;
  device->data = (void *)gpio;

  hal_irq_restore(irq);

  return 0;
}
```

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Validated on Xcelium



Development Flow - Example GPIO

```
/**
 * @brief Opens a GPIO port.
 *
 * This function initializes and opens a GPIO port specified
 * by the input parameter.
 * It returns an integer indicating the status of the operation.
 *
 * @param[in] gpio A pointer to a `struct pi_device`
 * representing the GPIO device to be opened.
 * @return int Returns 0 if the GPIO port is successfully
 * opened, otherwise returns a non-zero error code.
 *
 * Example usage:
 * @code
 * struct pi_device gpio_device;
 * int status = pi_gpio_open(&gpio_device);
 * if (status != 0) {
 *   // Error handling
 * }
 * @endcode
 */
int pi_gpio_open(struct pi_device* gpio);
```

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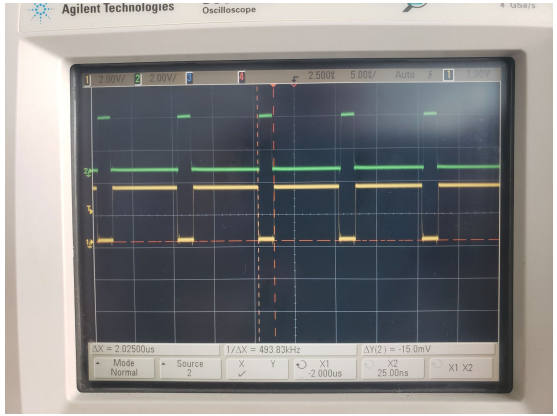
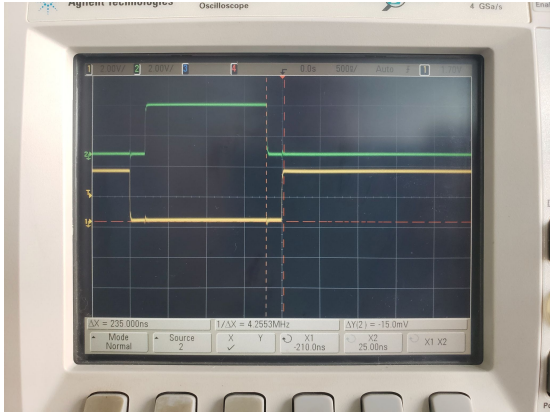
Documentation



Development Flow - Example GPIO





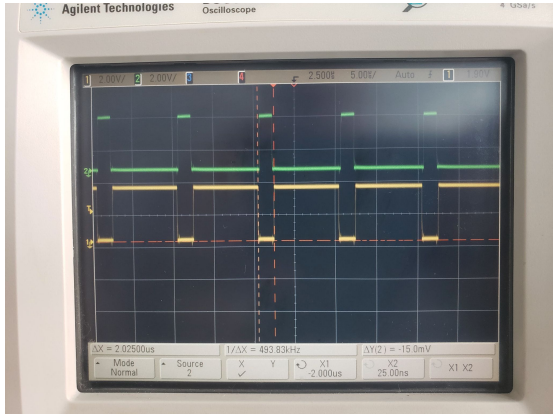


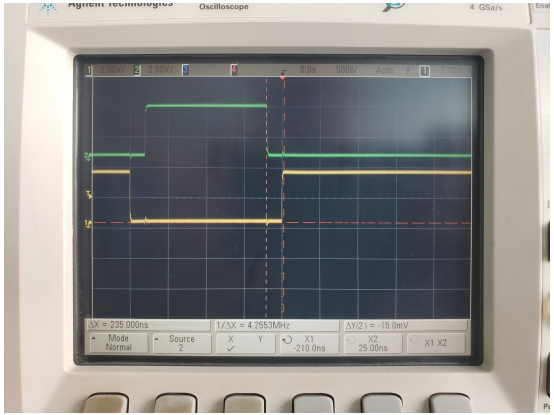
UFSM

Deployment on Artix 7



Development Flow - Example GPIO









UFSM

~~Deployment on Artix 7~~

Actual Hardware!



GPIO (Doxygen)

u32BR SDK

Generated by
Doxygen 1.8.5

250 pages

Fri May 15 2026

doxygen

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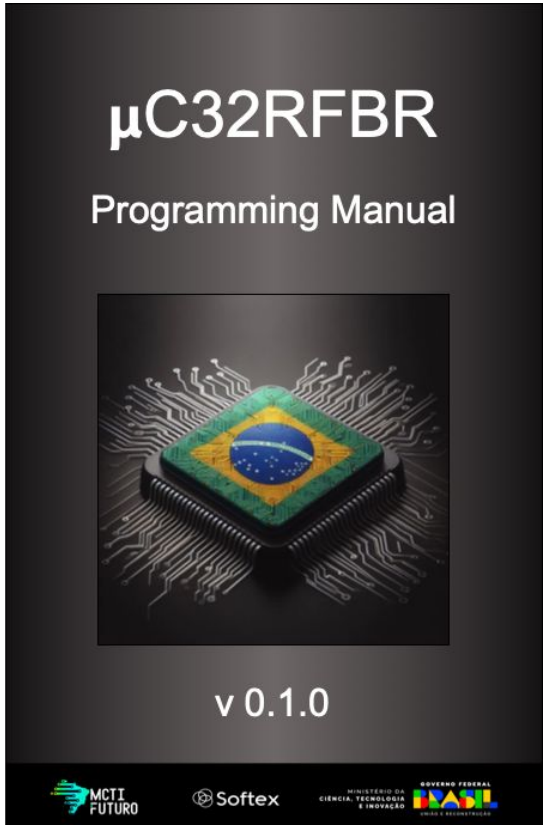
Programming manual



GPIO (Programmer Manual)



u32BR SDK

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250 pages

Fri May 15 2026

doxygen

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Programming manual



Drivers

```
% cd ~/u32br-sdk/rtos/pmsis/pmsis_api/include/pmsis/drivers
% ls
adc.h          gpio.h         perf.h         spi.h
adcsd.h        i2c.h          pmu.h          timer.h
can.h          i2s.h          rtc.h          uart.h
fdcan.h        pad.h          sdio.h         watchdog.h
```

Drivers

```
% cd ~/u32br-sdk/rtos/pmsis/pmsis_api/include/pmsis/drivers
% ls
adc.h          gpio.h         perf.h         spi.h
adcsd.h        i2c.h          pmu.h          timer.h
can.h          i2s.h          rtc.h          uart.h
fdcan.h        pad.h          sdio.h         watchdog.h
```



Industrial Edge Gateway

Drivers

```
% cd ~/u32br-sdk/rtos/pmsis/pmsis_api/include/pmsis/drivers
% ls
adc.h          gpio.h         perf.h         spi.h
adcsd.h        i2c.h          pmu.h          timer.h
can.h          i2s.h          rtc.h          uart.h
fdcan.h        pad.h          sdio.h         watchdog.h
```



Industrial Edge Gateway



Automotive Control Unit

Drivers

```
% cd ~/u32br-sdk/rtos/pmsis/pmsis_api/include/pmsis/drivers
% ls
adc.h          gpio.h         perf.h         spi.h
adcsd.h        i2c.h          pmu.h          timer.h
can.h          i2s.h          rtc.h          uart.h
fdcan.h        pad.h          sdio.h         watchdog.h
```



Industrial Edge Gateway



Automotive Control Unit



Wearable Device

Drivers

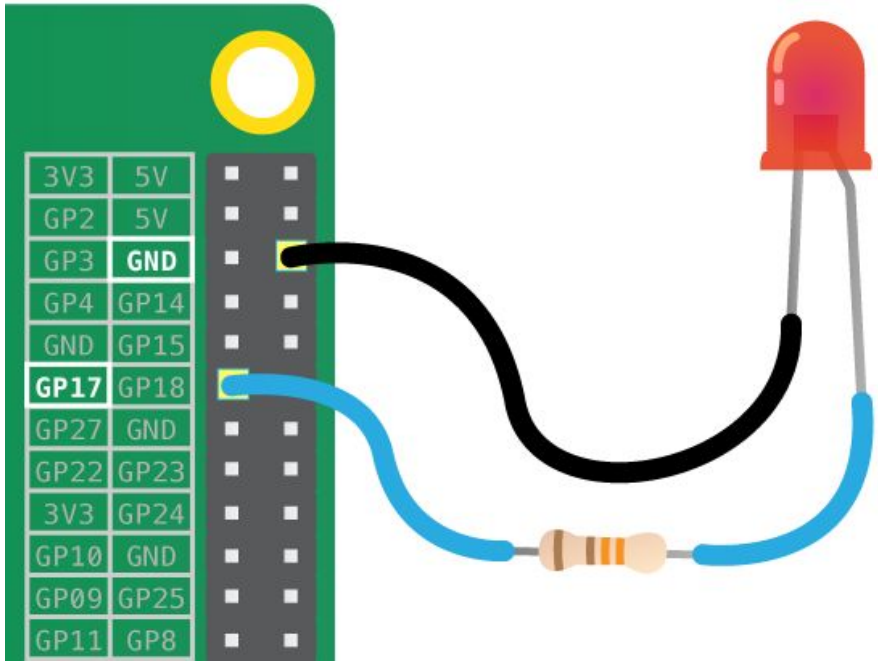
```
% cd ~/u32br-sdk/rtos/pmsis/pmsis_api/include/pmsis/drivers
% ls
adc.h          gpio.h         perf.h         spi.h
adcsd.h        i2c.h          pmu.h          timer.h
can.h          i2s.h          rtc.h          uart.h
fdcan.h        pad.h          sdio.h         watchdog.h
```

Testes

```
~/Programs/u32br-sdk/tests % ls
README.md      can            i2s            sdio           watchdog
adc            fdcan          perf           spi
adcsd          gpio           pmu            timer
apb_soc        hello          ptypes         uart
bootconfig     i2c            rtc            udma
```

Example: GPIO

```
static void test_entry() {
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
}
```



Example: GPIO

```
static void test_entry() {
    struct pi_gpio_conf conf;
    struct pi_device gpio;
    pi_gpio_e pin = PI_GPIO_0;
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
}
```



Declare data structures available in the standard library.

Example: GPIO

```
static void test_entry() {
    struct pi_gpio_conf conf;
    struct pi_device gpio;
    pi_gpio_e pin = PI_GPIO_0;

    printf("GPIO Hello World Example\n");
    printf("Configuring GPIO pin %d as output\n", pin);
    ...
    ...
    ...
    ...
    ...
    ...
}
```



Use standard input/output functions.

Example: GPIO

```
static void test_entry() {
    ...
    pi_gpio_conf_init(&conf);
    conf.gpio_id = 0;
    pi_setup_from_conf(&gpio, &conf);
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
}
```



Initialize the GPIO configuration structure

Example: GPIO

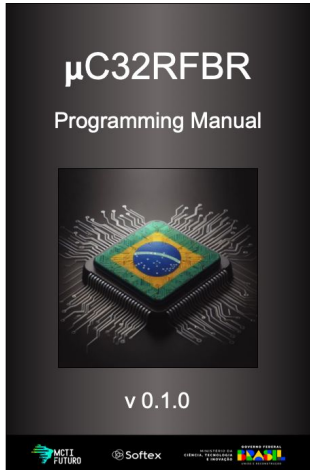
```
static void test_entry() {
    ...
    pi_gpio_conf_init(&conf);
    conf.gpio_id = 0;
    pi_setup_from_conf(&gpio, &conf);
    ...
    if (pi_gpio_open(&gpio)) {
        printf("Failed to open\n");
        pmsis_exit(-1);
    }
    ...
    ...
    ...
}
```



Open the GPIO device and check for errors.

Example: GPIO

```
static void test_entry() {
    ...
    pi_gpio_pin_configure(&gpio, pin,
        PI_GPIO_OUTPUT | PI_GPIO_ENABLE);
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
    ...
}
```



Configure the pin as output with enable.

Example: GPIO

```
static void test_entry() {
    ...
    for (int i = 0; i < 5; i++) {
        pi_gpio_pin_write(&gpio, pin, 1);
        printf("LED ON\n");

        pi_time_wait_us(500000);
        pi_gpio_pin_write(&gpio, pin, 0);
        printf("LED OFF\n");

        pi_time_wait_us(500000);
    }
    ...
}
```



Turn LED on.

Example: GPIO

```
static void test_entry() {
    ...
    for (int i = 0; i < 5; i++) {
        pi_gpio_pin_write(&gpio, pin, 1);
        printf("LED ON\n");

        pi_time_wait_us(500000);
        pi_gpio_pin_write(&gpio, pin, 0);
        printf("LED OFF\n");

        pi_time_wait_us(500000);
    }
    ...
}
```



Wait 500 ms.

Example: GPIO

```
static void test_entry() {
    ...
    for (int i = 0; i < 5; i++) {
        pi_gpio_pin_write(&gpio, pin, 1);
        printf("LED ON\n");

        pi_time_wait_us(500000);
        pi_gpio_pin_write(&gpio, pin, 0);
        printf("LED OFF\n");

        pi_time_wait_us(500000);
    }
    ...
}
```



Turn LED off.

Example: GPIO

```
static void test_entry() {
    ...
    ...
    ...
    ...
    printf("GPIO test completed successfully\n");
    ...
    ...
    ...
    ...
    pi_gpio_close(&gpio);
    pmsis_exit(0);
    ...
}
```



Close the GPIO device.

Final Thoughts



Learning Experience



UFMG's Compilers Lab

Learning Experience



UFMG's Compilers Lab





Learning Experience

Learning low-level programming





Learning Experience

Learning low-level programming

Computer Engineering at UFMG







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