

Presentation for Probation

Wuzhenghui

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Firmware
Group





1. IDF Environment

- IDF Structure
- Project Structure
- IDF Commands
- Project Build Process

2. Bring Up

- ESP32-S3 Core System
- ROM Code & Bootloader
- Bring UP Steps

3. ROM Code (C3)

- Function
- Test

4. Cache Verification

- Cache Structure
- Verification Methods

5. RISC-V CPU

- RISC-V CPU
- ESP32 C3 ROM Code & Boot

6. FreeRTOS

- FreeRTOS API
- FreeRTOS Kernel

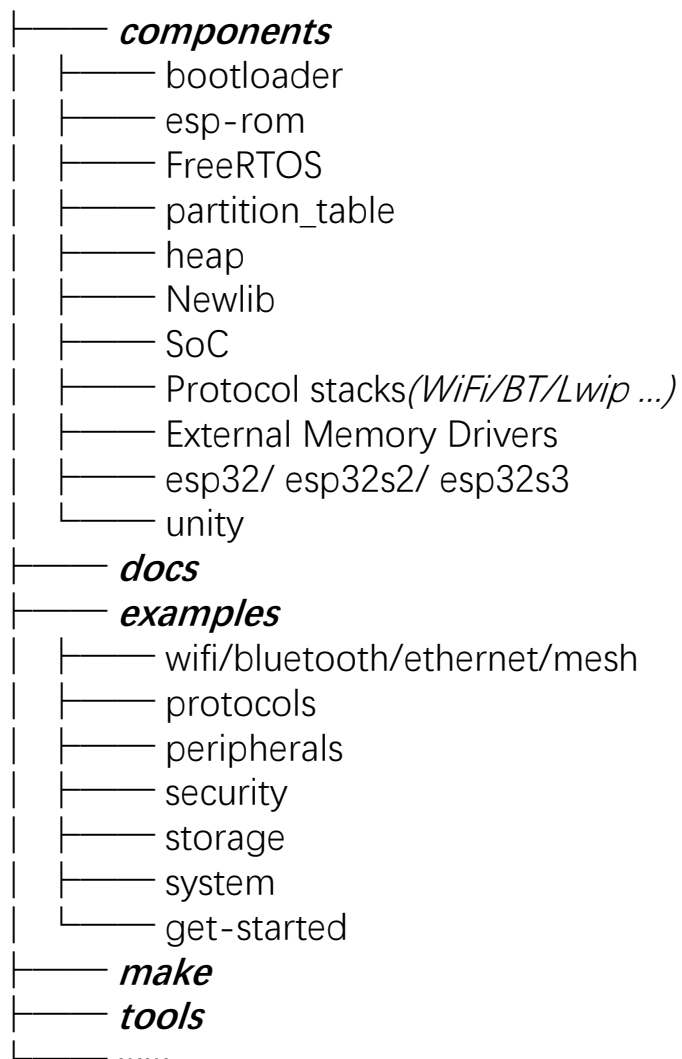
/01

IDF Environment

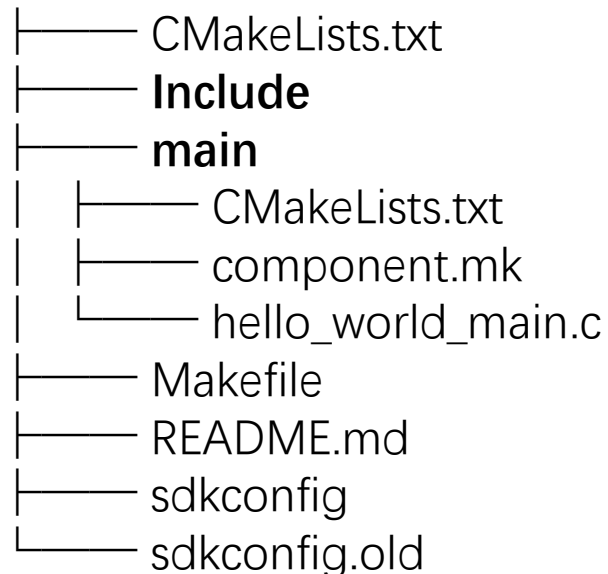
- IDF Structrue
- Project Structrue
- IDF Commands
- Project Build Process



IDF Structure:



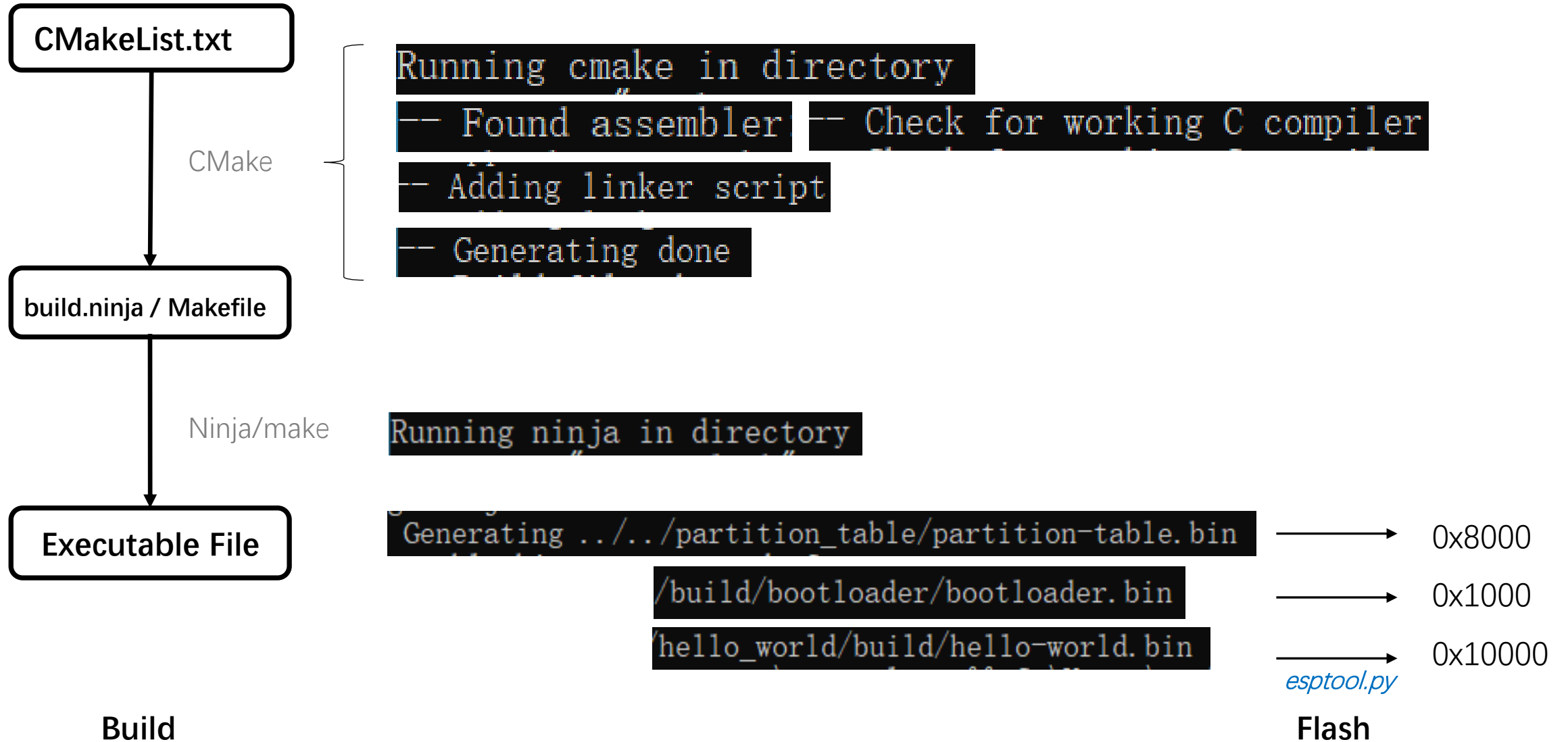
Project Structure:



Commands:

[idf.py](#) menuconfig
build
set-target <chip name>
flash
monitor
clean / fullclean
erase_flash
gdbgui/gdbtui
size
...

Project Build Process



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Bring Up

- ESP32-S3 Core System
- Boot Process
- ROM Code
- Bootloader
- Bring UP Steps

ESP32-S3 Core System



CPU:

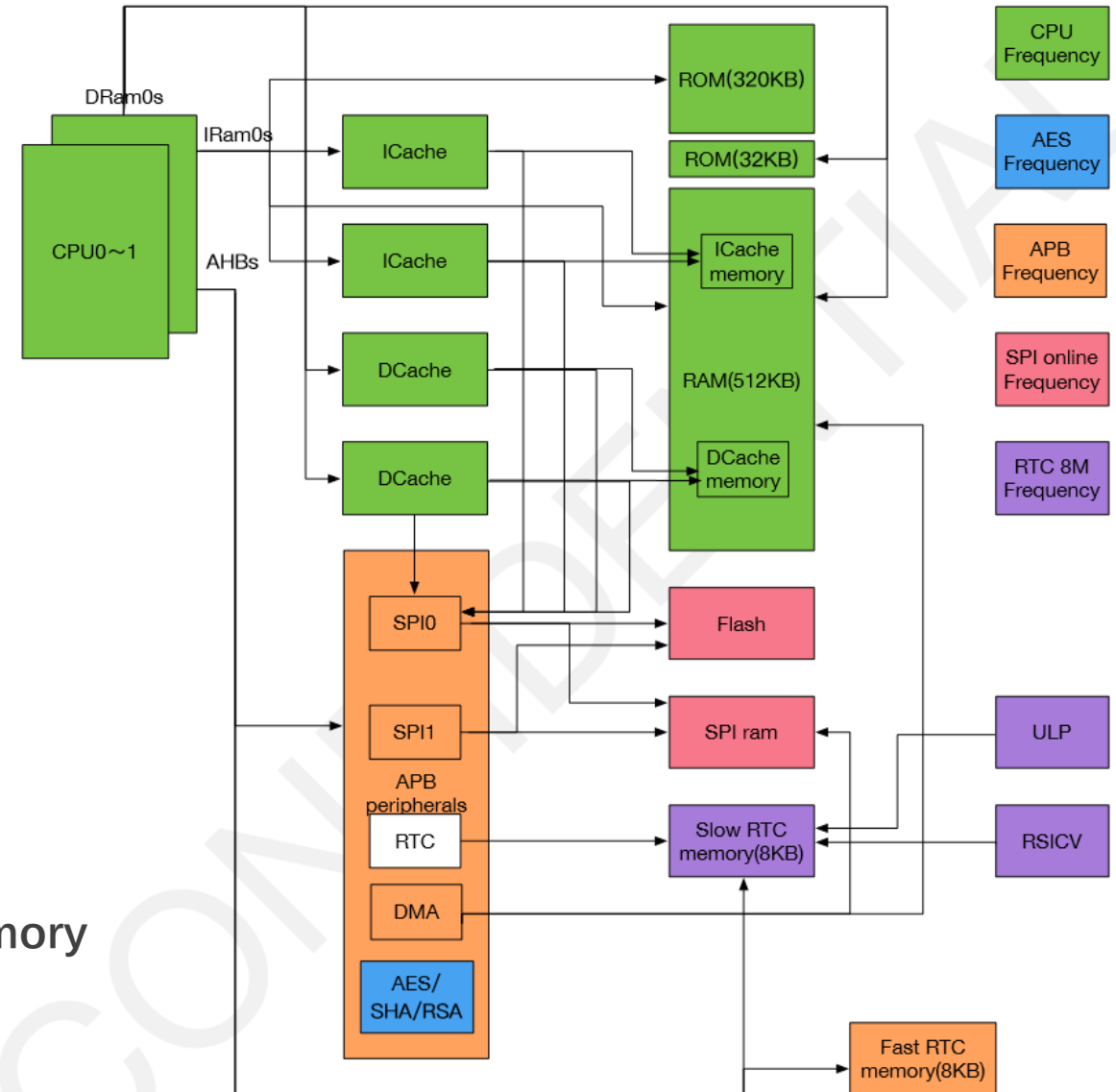
- Two Lx7 Cores
- RISC-V Core
- ULP

Buses (Click jump to Bus-Memory Map)

- IRam0
- DRam0
- AHB

Memory:

- 320KB ROM
- 512KB SRAM
- 8KB Fast RTC Memory & 8KB Slow RTC Memory
- Virtual memory: map to external memory
- Memory inside peripherals



Peripherals & DMA

- High speed peripherals (1x, 2x or 3x APB frequency)
- APB peripherals
- **Peripherals**
 - DMA (arbitrate with CPU buses access) → Memory
 - EDMA (arbitrate with cache access) → External Flash & SPI Ram

Cache System

- Use part of SRAM as cache memory
- MMU Table : VA to PA
- Tag memory : Record cache memory states

ROM Code & Bootloader



1. ROM中的第一级引导加载程序将Flash中 offset = 0x1000 的第二级引导加载程序映像加载到RAM (IRAM和DRAM)
2. 第二级引导程序从闪存加载分区表(0x8000)和主应用程序映像(0x10000)。

esp-idf\components\bootloader\subproject\main\bootloader_start.c ---- *bootloader.bin* (0x1000)

```
void __attribute__((noreturn)) call_start_cpu0()
{
    // 1. Hardware initialization
    if (bootloader_init() != ESP_OK) {
        bootloader_reset();
    }
    // 2. Select the number of boot partition
    bootloader_state_t bs = { 0 };
    int boot_index = select_partition_number(&bs);
    if (boot_index == INVALID_INDEX) {
        bootloader_reset();
    }
    // 3. Load the app image for booting
    bootloader_utility_load_boot_image(&bs, boot_index);
}
```

3. 应用程序 (offset = 0x10000) 启动阶段

esp-idf\components\esp32/cpu_start..c

Bring Up Steps



Check CPU related files

- CPU archive

*/*Has the Overlays we need to generate new toolchain for specific CPU*/*

- binutils: One set includes linker, assembler and other tools for object files and archives
- config: Configuration files
- cstub
- gcc
- gdb

- CPU SDK

- HAL: Hardware abstract layer files
- XTOS: A simple OS without context switch to make CPU boot

- Header files

*/*Works on specific CPU platform generated by Xtensa EDA*/*

Bring Up Steps



Toolchain

- Use script to make structure changes from the provided overlays
- Generate new toolchain

Newlib

*/*A C library intended for use on embedded systems*/*

- Make Newlib

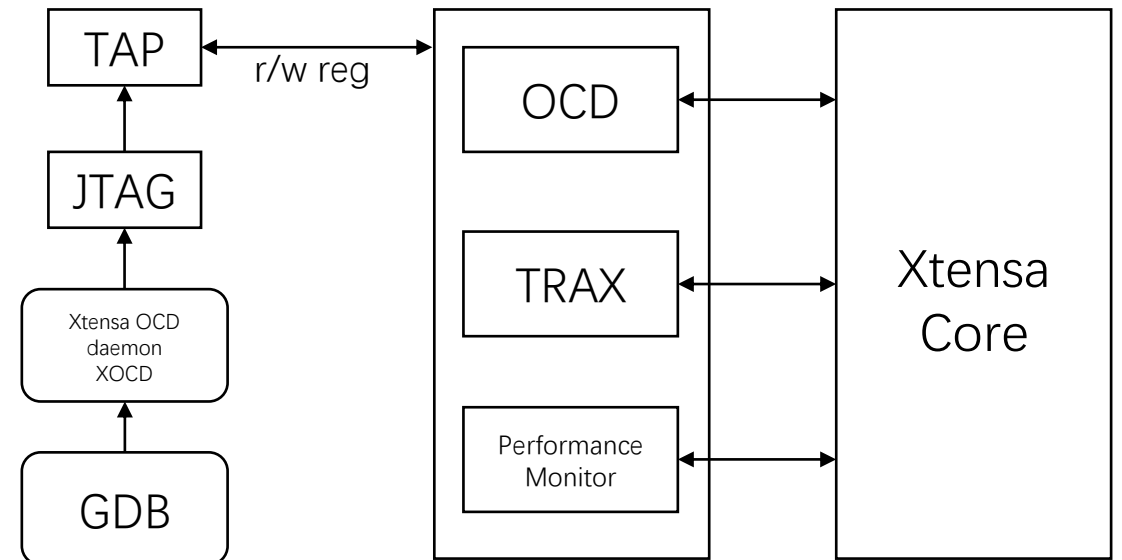
OpenOCD

- Chip memory layout and registers modifications

`xtensa-config.c` `reg-xtensa.dat` \longrightarrow `esp108_regs.h`

- Config files

*/*describes the basic features about chip,
Including chip-name, endian and tapeid*/*



Bring Up Steps



Update SoC header files

- Add/Remove registers
- Change register width
- Change register address and default value
-

Make ROM download work

- Modify makefile
- Build ROM & make it can be download

1. Download image to FPGA
2. Make Rom (eagle.pro.rom.out)
3. Generate link file for specific chip from eagle.pro.rom.out
4. Open OpenOCD Server
5. Use GDB Download ROM to FPGA by OpenOCD (Download Boot)

Bring Up Steps



Make ROM boot work

`esp-rom\rom\ets_kernel\ets_main.c`

- Choose Reset Mode
- Initial SPI
- Initial Cache
- Parse Flash header
- Load
 - Text section
 - Data section
 - rodata

```
/* ets_main.c */
main()
GET_CPUID    //获取CPUID
APP_CPU:app_code_start()
PRO_CPU:
    rtc_get_reset_reason()    //获取复位原因
    boot_prepare(reset_reason)
    Cache_Mask_All()    //屏蔽Cache
    rtc_unhold_all_pads()    //取消所有pad的hold状态
    uartAttach()    //设置uart模块的默认参数（不使能RX中断）
    ets_get_apb_freq()    //获取APB总线时钟频率
    ...    //兼容性配置
    switch (reset_reason)    //判断boot模式
    DEEPSLEEP_RESET:
        user_code_start()
    Others:
        if(ETS_IS_FLASH_BOOT)
            ets_flash_boot()
        else
            ...    //re-initialize the UART
            ets_secure_download_mode()

ets_flash_boot()
    ets_efuse_get_spiconfig()
    spi_flash_boot_attach()    //初始化SPI
    ets_run_flash_bootloader()    //运行Flash中bootloader

/* ets_loader.c */
ets_run_flash_bootloader()
    ...    //初始化Cache MMU, 设置cache 模式, 失效cache tags, 使能Cache
    ets_loader_map_range()    //映射FLASH VA->PA
    memcpy(&fhdr, tmp, sizeof(struct flash_hdr));    //从FLASH中解析header
    ...
    /*Copy Text section, Data section, rodata to RAM and verify them*/
```

Bring Up Steps

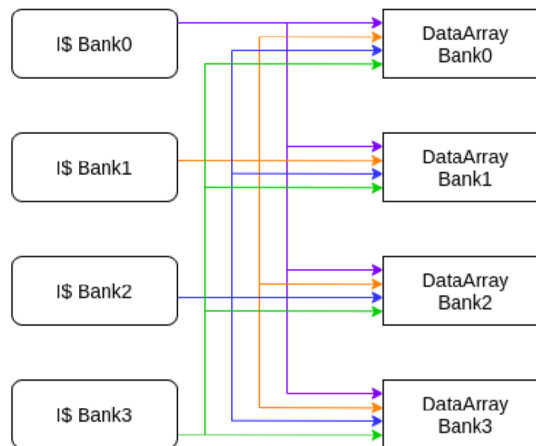


- Initialize SPI

`spi_flash_boot_attach()`

- Occupy cache bank to correct sram bank

`Cache_Occupy_DCache_MEMORY()`



DBANK0 0001

IBANK0 0001

DBANK1 0010

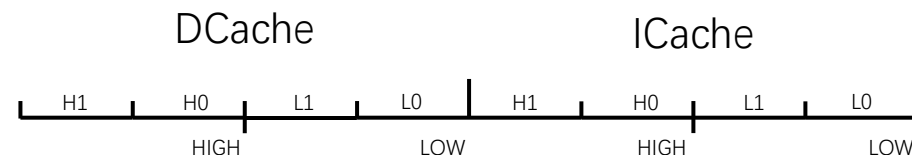
IBANK1 0010

DBANK2 0100

IBANK2 0100

DBANK3 1000

IBANK3 1000



```
void Cache_Occupy_DCache_MEMORY(cache_array_t dcache_low, cache_array_t dcache_high)
{
    uint32_t array_dcache = ((dcache_low << CACHE_DCACHE_LOW_SHIFT) | (dcache_high << CACHE_DCACHE_HIGH_SHIFT)) >> CACHE_DCACHE_LOW_SHIFT;
    uint32_t dcache_usage = (dcache_low | dcache_high) ^ SENSITIVE_INTERNAL_SRAM_DCACHE_FLATTEN;
    REG_SET_FIELD(SENSITIVE_CACHE_DATAARRAY_CONNECT_1_REG, SENSITIVE_DCACHE_DATAARRAY_CONNECT_FLATTEN, array_dcache);
    REG_SET_FIELD(SENSITIVE_INTERNAL_SRAM_USAGE_1_REG, SENSITIVE_INTERNAL_SRAM_DCACHE_FLATTEN, dcache_usage);
}
```

- Modify chip memory address MACRO

`/include/soc/soc.h`

`/include/soc/cache_memory.h`

Bring Up Steps



ets_loader_map_range() → *Cache_Dbus_MMU_Set()*

```

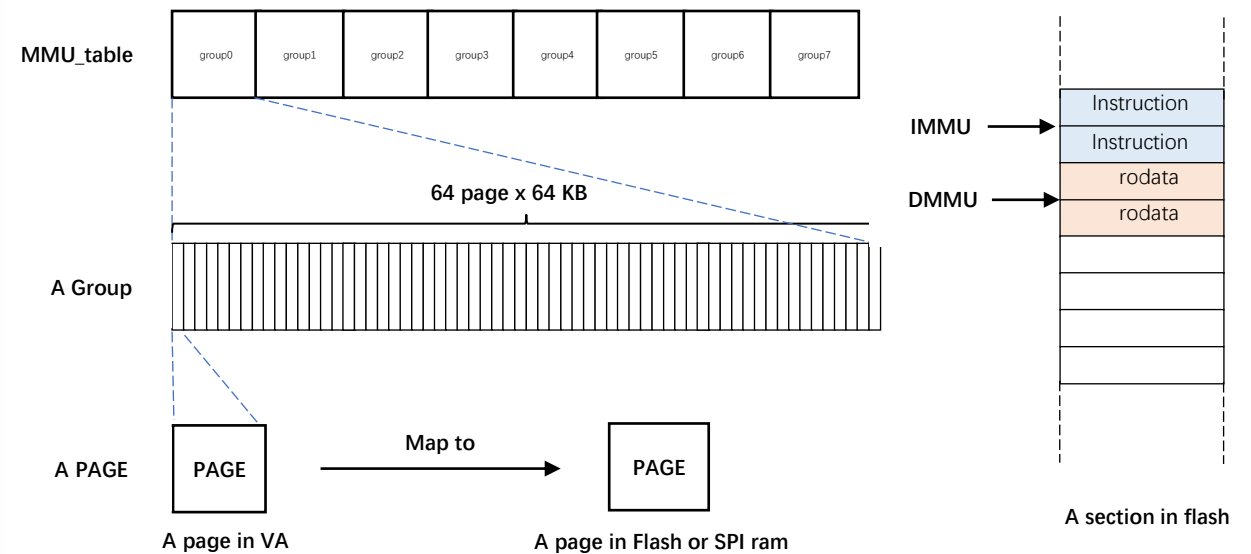
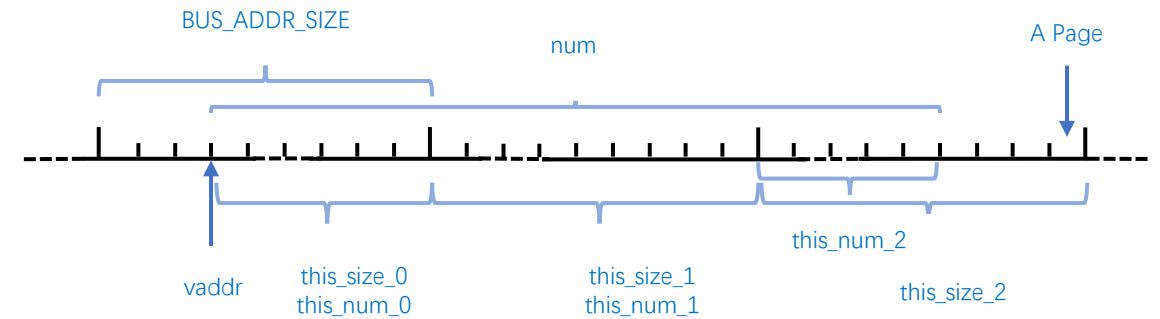
int Cache_Dbus_MMU_Set(uint32_t ext_ram, uint32_t vaddr, uint32_t psize, uint32_t num, uint32_t fixed)
{
    uint32_t i, shift, mask_s;
    uint32_t mmu_addr;
    uint32_t mmu_table_val;

    //check if address page aligned
    if (ADDRESS_CHECK(vaddr, psize) || ADDRESS_CHECK(paddr, psize)){
        return MMU_SET_ADDR_ALIGNED_ERROR;
    }
    if (psize == 64) {
        shift = 16;
        mask_s = 0;
    } else {
        return MMU_SET_PASE_SIZE_ERROR;
    }
}

while (num > 0) {
    //split the vaddr room by the bus aligned address
    int this_size = ((vaddr + BUS_ADDR_SIZE) & ~(BUS_ADDR_SIZE - 1)) - vaddr;
    //calculate the pages to map this round
    int this_num = this_size >> shift;
    if (this_num > num) {
        this_num = num;
    }
    //calculate MMU value by physical address
    mmu_table_val = paddr >> shift;
    //calculate MMU address by virtual address
    if(ADDRESS_IN_DRAM0_CACHE(vaddr)) {
        mmu_addr = ((vaddr & (BUS_ADDR_MASK >> mask_s)) >> shift) * sizeof(uint32_t);
    } else {
        return MMU_SET_VADDR_OUT_RANGE;
    }
    //write the MMU values
    for ( i = 0; i < this_num; i++){
        if (!fixed) {
            *(uint32_t *) (DR_REG_MMU_TABLE + mmu_addr) = (mmu_table_val + i) | ext_ram;
        } else { //fixed mode always map to first physical page
            *(uint32_t *) (DR_REG_MMU_TABLE + mmu_addr) = (mmu_table_val) | ext_ram;
        }
        mmu_addr += 4;
    }
    //prepare for next round
    num -= this_num;
    if (!fixed) {
        paddr += this_size;
    }
    vaddr += this_size;
}

return 0;
}

```



Bring Up Steps



Bring Up bootloader & idf

- Update cache address MACRO `esp-idf/components/soc/soc/esp32s3/include/soc/soc.h & cache_memory.h`
- Update the address and Chip_ID in esptool.py `esp-idf/components/esptool_py/esptool/esptool.py`
- Update Id file in IDF `esp-idf/components/esp32s3/ld/`

1. bootloader_init()

```
memset(&_bss_start, 0, (&_bss_end - &_bss_start) * sizeof(_bss_start));
```

```
Cache_Suspend_DCache();  
Cache_Invalidate_DCache_All();  
Cache_MMU_Init();
```

```
flash_gpio_configure(&fhdr);
```

```
bootloader_clock_configure()  
uart_console_configure()  
wdt_reset_check()
```

2. select_partition_number()

```
bootloader_utility__load_partition_table();  
selected_boot_partition();
```

3. bootloader_utility_load_boot_image()

```
try_load_partition();           //check app partition validity  
esp_image_load();  
    bootloader_flash_read();  
    bootloader_sha256_start();  
    bootloader_sha256_data();  
    verify_image_header();  
    process_segment();  
    /*Read app image header first.  
    We get to know the number of segments we should load/map.  
    Then we use cache to copy load segment to sram*/  
  
load_image()  
    esp_secure_boot_permanently_enable(); //Check Secure Boot  
    esp_flash_encryption_enabled();       //Checking flash encryption  
  
unpack_load_app();             //Copy sections to RAM, Set Cache for sections  
    set_cache_and_start_app(addr_parameters);  
    cache_flash_mmu_set();  
    Cache_Ibus_MMU_Set();  
    Cache_Dbus_MMU_Set();  
    /*Use Cache_Ibus_MMU_Set and Cache_Dbus_MMU_Set to map instruction and rodata respectively. Then  
    jump to third boot stage*/
```


Bring Up Steps



Make FreeRTOS work

```
call_start_cpu0();
memset(&_bss_start, 0, (&_bss_end - &_bss_start) * sizeof(_bss_start));

rom_config_instruction_cache_mode();
rom_config_data_cache_mode();

Cache_Set_IDROM_MMU_Size();
cpu_configure_region_protection();

esp_spiram_init_cache();

call_start_cpu1();
heap_caps_init();
start_cpu0();
```

```
start_cpu():
.....
xTaskCreatePinnedToCore(&main_task, "main",
                        SP_TASK_MAIN_STACK, NULL,
                        ESP_TASK_MAIN_PRIO, NULL, 0);
.....
vTaskStartScheduler()

main_task():
.....
app_main();
```

*Dual Core:

SoC复位后: PRO CPU立即运行, 执行复位向量代码
APP CPU仍然保持复位状态

启动过程中: PRO CPU 会执行所有的初始化操作
APP CPU 的被call_start_cpu1唤醒

Bring Up Steps

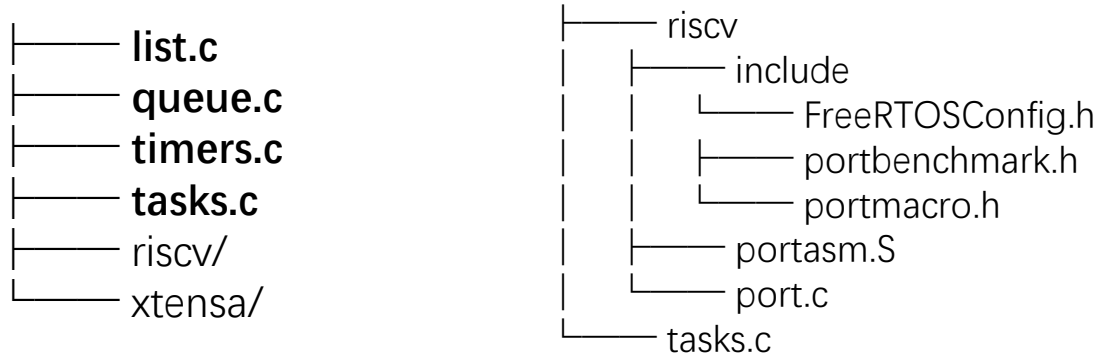


Make FreeRTOS work

- Config `esp-idf/components/freertos/include/freertos/FreeRTOSConfig.h`

```
#define config***: Configure API in FreeRTOS
#define include***: Enable or disable FreeRTOS
```

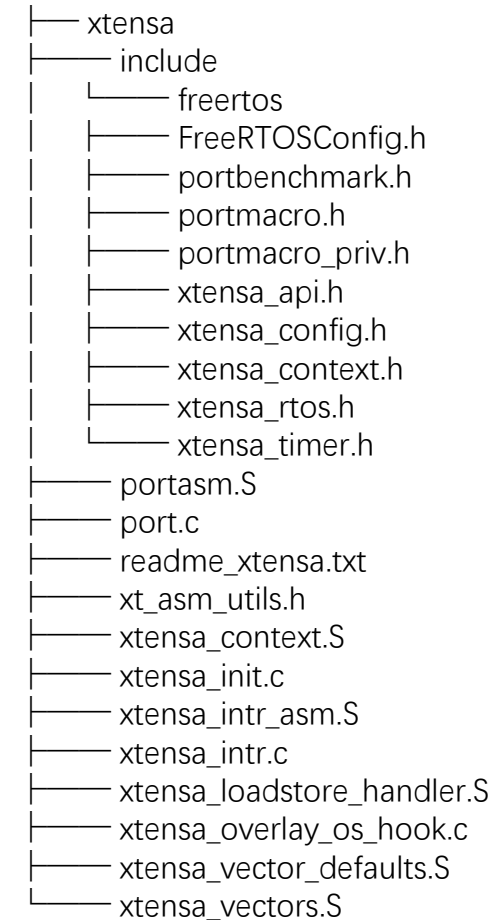
- Structure `esp-idf/components/freertos/`



- Implement functions defined in portable.h `esp-idf/components/freertos/include/freertos/portable.h`

```
xPortStartScheduler()
vPortEndScheduler()
vPortYieldOtherCore()
vPortSetStackWatchpoint()
xPortInterruptedFromISRContext()
xPortGetTickRateHz()
...
```

- Check `interrupt.csv` with `periph_defs.h`



/03

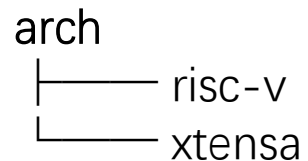
ROM Code Test (C3)

- Function
- Test

Function



ROM Scheduler:



ROM API:

- Cache
- GPIO
- Newlib
- SPI/OPI_Flash
- UART
- USB
-

ROM Boot:

```
/*ets_main.c*/
main()
GET_CPUID //获取CPUID
APP_CPU:app_code_start()
PRO_CPU:
    rtc_get_reset_reason()
    boot_prepare(reset_reason)
    Cache_Mask_All() //Mask Cache
    uartAttach() //Initialize uart (without enable RX interrupt)
    ets_get_apb_freq() //Get APB Bus Clock Frequency
    ... //Compatible Setting
switch(reset_reason):
    DEEPSLEEP_RESET:
        user_code_start()
    Others:
        if(ETS_IS_FLASH_BOOT)
            ets_flash_boot()
        else
            if (ets_efuse_download_modes_disabled)
                ETS_PRINTF_RESET("Download boot modes disabled\n")

            uartAttach(uart_rx_buff) //Initialize UART
            if(ets_efuse_security_download_modes_enabled)
                ets_secure_download_mode()
            else
                ets_contact_host()

ets_contact_host()
    UART_BOOT
    SDIO_BOOT
    SPI_DOWNLOAD_BOOT
    JOINT_DOWNLOAD_BOOT
```

ROM Scheduler Test:

- Main routine test
- Interrupt test
- Scheduler test

Switch[4 3 2 1]	Mode
1XXX	SPI Boot
01XX	UART Download
0001	SPI Download
0010	Diagnostic
0011	Test

ROM Boot Test:

SPI Flash boot modes:

- Fast SPI Flash Boot
- Legacy SPI Flash boot mode

Download boot modes:

- Joint detect download boot modes test
- SDIO_Slave_v1.1 download boot mode
- Diagnostic download boot mode
- Security of download modes

RTC RESET
DEEP SLEEP RESET
DIGITAL RESET
CPU RESET

/04

Cache Verification

- Structure
- Verification Method

Cache



A Cache Line

10+ tag	10 9 count	8 evict	7~4 attribute	3 occupy	2 lock	1 valid	0 dirty	Set Index	Offset	Block
------------	---------------	------------	------------------	-------------	-----------	------------	------------	-----------	--------	-------

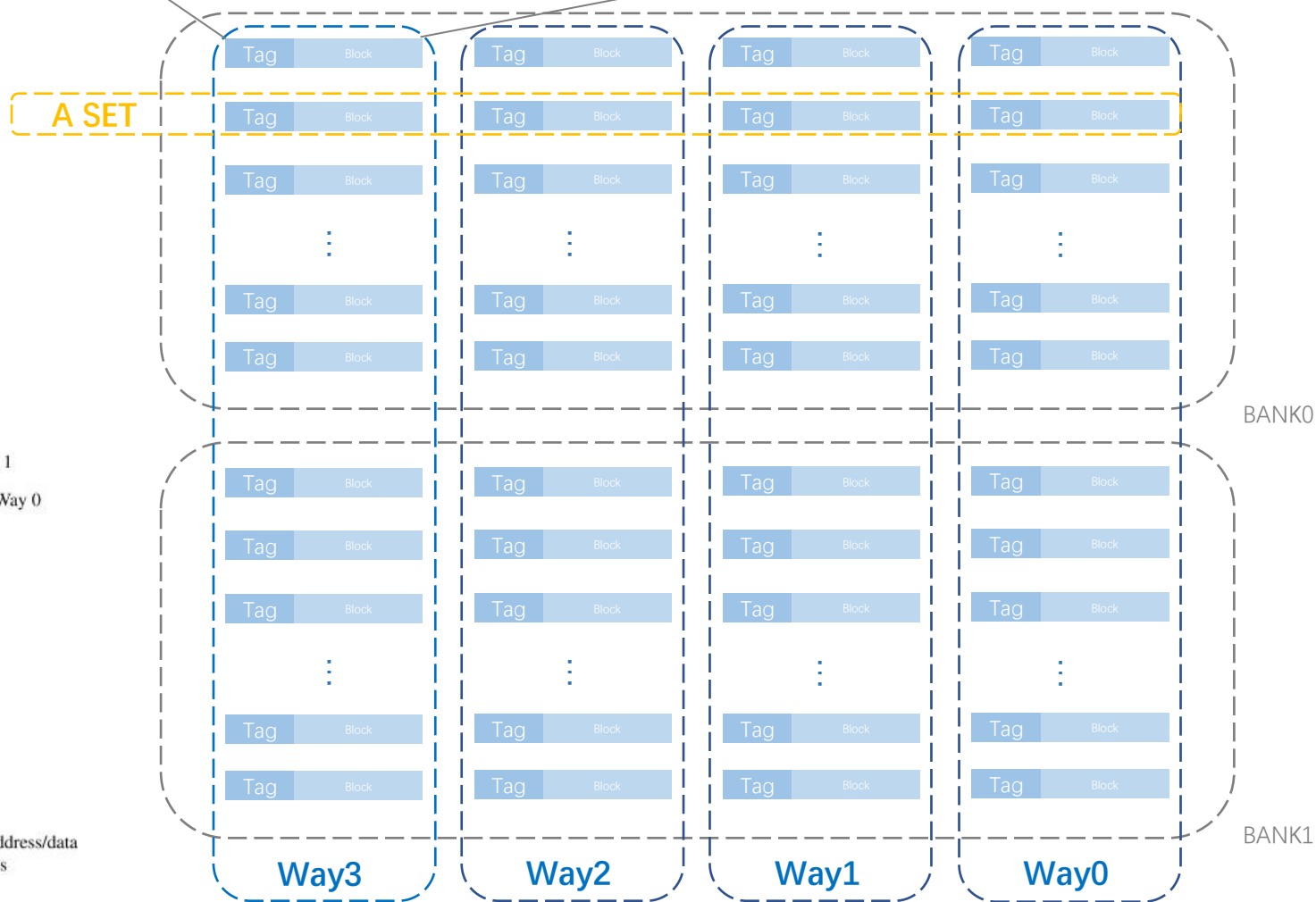
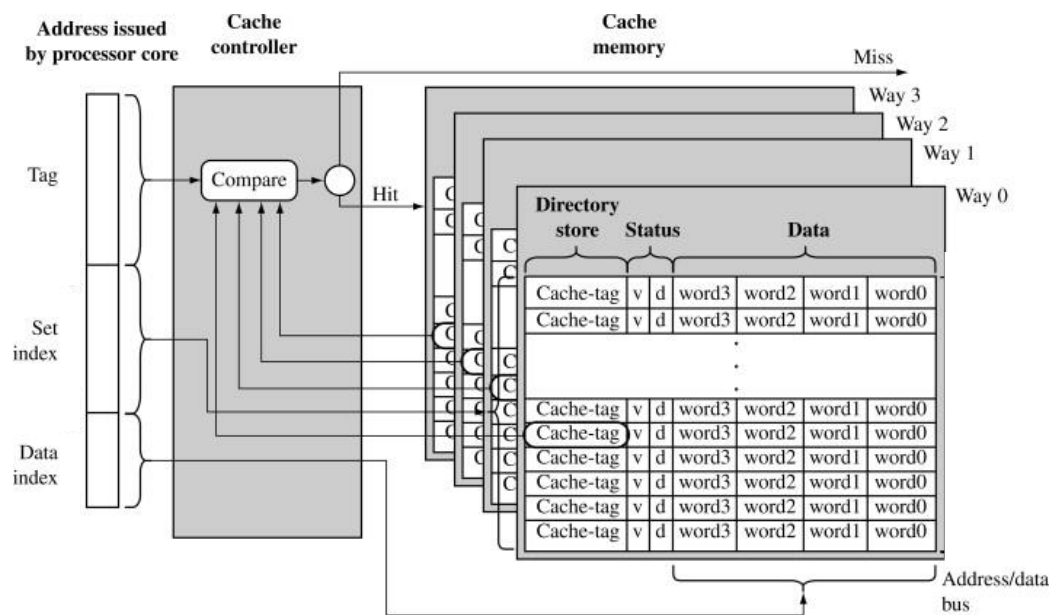
Cache Architecture:

Instruction cache size: 16KB / 32KB

Data cache size: 32KB / 64KB

Block Size: 16Bytes / 32Bytes / 64Bytes

Associated ways: 4way_(Dcache/ICache) / 8way_(ICache)



Cache Verification Methods



Cache address and access control test

1. IRam0 Data access test:

- Use Cache/SPI to Read/Execute content/code in Flash/SPI RAM.
- Use Cache/SPI read Content in whole Flash/SPI RAM.

2. DRam0 Data access test:

- Use Cache/SPI Read/Write Content in whole SPI RAM.
- Use Cache/SPI read Content in whole Flash.

Cache path test

4.3.1.1 Cache path integration test					
Instruction	Rodata	data	Priority	core0	core1
Flash	Flash	SPI ram	High		
Flash	SPI ram	SPI ram	High		
SPI ram	Flash	SPI ram	High		
SPI ram	SPI ram	SPI ram	High		
Flash	Flash	SPI ram , Flash (rodata)	High		

Cache Verification Methods



Cache mode test

1. **Instruction cache mode test:** Data cache parameters: size=16KB, block size=32Byte, set-associative=4
2. **Data cache mode test:** Data cache parameters: size=16KB, block size=32Byte, set-associative=4

4.4.1.1 Instruction cache mode test					
ICache size(KB)	ICache ways	ICache block size(Bytes)	Priority	core0	core1
32	8	64	medium		
32	8	32	High		
32	8	16	High		
16	8	64	medium		
16	8	32	High		
16	8	16	High		
32	4	64	medium		
32	4	32	High		
32	4	16	High		
16	4	64	medium		
16	4	32	High		
16	4	16	High		

4.4.2.1 Data cache mode test					
DCache size(KB)	DCache ways	DCache block size(Bytes)	Priority	core0	core1
64	8	64	medium		
64	8	32	High		
64	8	16	High		
32	8	64	medium		
32	8	32	High		
32	8	16	High		
64	4	64	medium		
64	4	32	High		
64	4	16	High		
32	4	64	medium		
32	4	32	High		
32	4	16	High		

3. **Cache Flash/SPI ram mode test:** Different Flash Mode, Flash clock divider, I/Dcache block size
4. **Cache SPI wrap mode test:** Different SPI ram clock divider, Flash clock divider, I/Dcache block size
5. **Cache mode integration test:** Different ICache size, DCache size, ICache block size, DCache block size

Cache Verification Methods



Cache operation test

1. ICache: Pre-lock, Lock/Unlock, Invalidation operation, time test
2. DCache: Lock/Unlock, Invalidation operation, clean/flush, time test

Cache replacement and write back policy test

1. ICache: replacement policy with 0/1/2/3/4 way locked,
replacement policy with invalidate/lock & invalidate
2. Dcache: replacement policy with 0/1/2/3/4 way locked,
replacement policy with invalidate/lock & invalidate

Cache preload & autoload test

1. ICache: autoload, preload
2. DCache: auto autoload, manually preload
3. Speed test

Cache Verification Methods



Cache encryption and decryption test

1. Cache encryption path test
2. Cache encryption SPI Flash mode test
3. Cache encryption SPI ram mode test
4. Cache encryption SPI wrap mode test
5. Cache encryption mode integration test
6. Encryption SPI write test

Cache miss delay test

1. Flash Cache miss delay
2. SPI ram Cache(without/with write back) miss delay
3. Dual core cache delay test

Cache error interrupt

MMU Tag and Cache memory utility

EDMA function test

Cache & SPI arbiter test

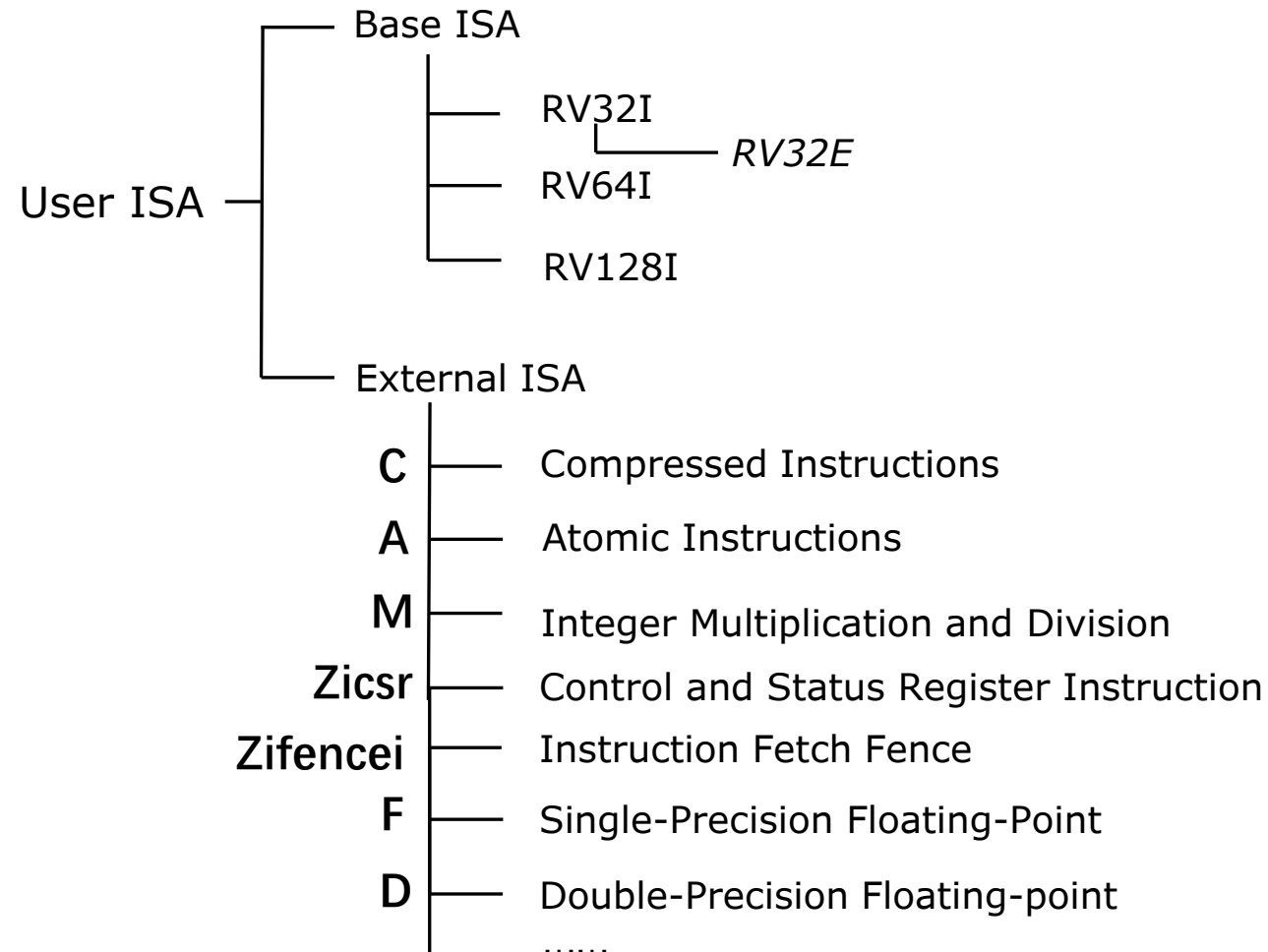
Cache stress test

/05

RISC-V

-
- RISC-V CPU
 - ESP32 C3 ROM Code & Boot

ISA



Privileged ISA

Application
ABI
AEE

Application	Application
ABI	ABI
OS	
SBI	
SEE	

Application	Application	Application	Application
ABI	ABI	ABI	ABI
OS		OS	
SBI		SBI	
Hypervisor			
HBI			
HEE			

- *ABI: Application Binary Interface*
- *AEE: Application Execution Environment*
- *SBI: Supervisor Binary Interface*
- *SEE: Supervisor Execution Environment*
- *HBI: Hypervisor Binary Interface*
- *HEE: Hypervisor Execution Environment*

Level	Encoding	Name	Abbreviation
0	00	User/Application	U
1	01	Supervisor	S
2	10	Hypervisor	H
3	11	Machine	M

Number of levels	Supported Modes	Intended Usage
1	M	Simple embedded systems
2	M, U	Secure embedded systems
3	M, S, U	Systems running Unix-like operating systems
4	M, H, S, U	Systems running Type-1 hypervisors

RISC-V CPU



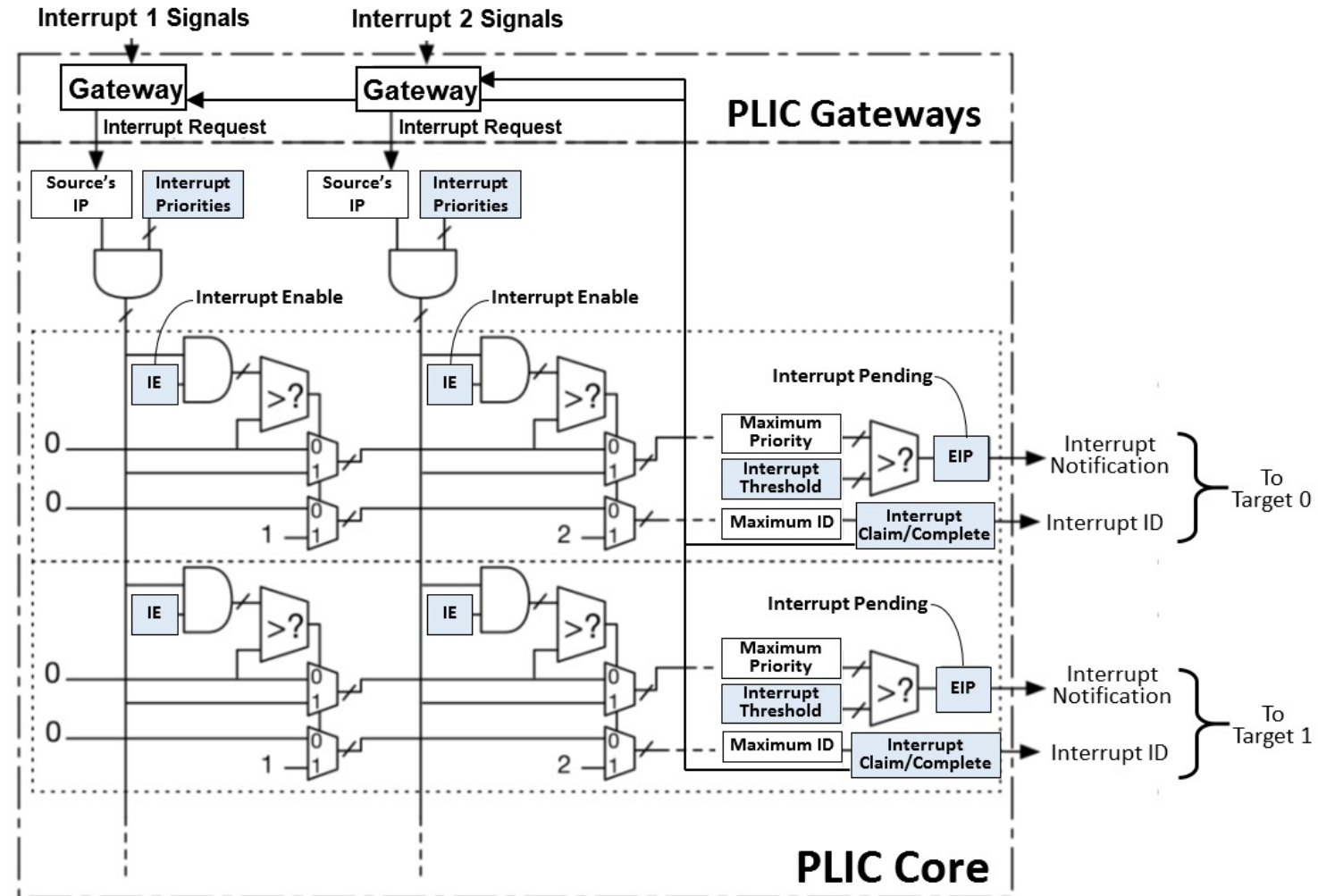
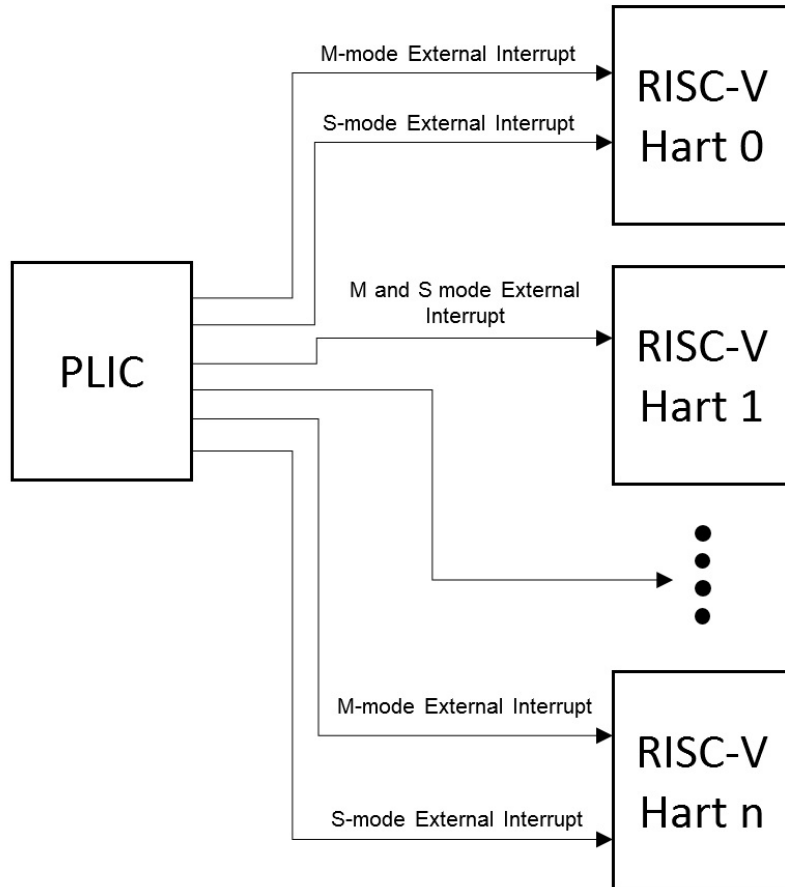
31	0
x0 / zero	Hardwired zero
x1 / ra	Return address
x2 / sp	Stack pointer
x3 / gp	Global pointer
x4 / tp	Thread pointer
x5 / t0	Temporary
x6 / t1	Temporary
x7 / t2	Temporary
x8 / s0 / fp	Saved register, frame pointer
x9 / s1	Saved register
x10 / a0	Function argument, return value
x11 / a1	Function argument, return value
x12 / a2	Function argument
x13 / a3	Function argument
x14 / a4	Function argument
x15 / a5	Function argument
x16 / a6	Function argument
x17 / a7	Function argument
x18 / s2	Saved register
x19 / s3	Saved register
x20 / s4	Saved register
x21 / s5	Saved register
x22 / s6	Saved register
x23 / s7	Saved register
x24 / s8	Saved register
x25 / s9	Saved register
x26 / s10	Saved register
x27 / s11	Saved register
x28 / t3	Temporary
x29 / t4	Temporary
x30 / t5	Temporary
x31 / t6	Temporary
32	
31	0
pc	
32	

General register

Name	Description
sstatus	Supervisor status register
sie	Supervisor interrupt-enable register
stvec	Supervisor trap handler base address
sscratch	Scratch register for supervisor trap handlers
sepc	Supervisor exception program counter
scause	Supervisor trap cause
sbadaddr	Supervisor bad address
sip	Supervisor interrupt pending
sptbr	Page-table base register
mstatus	Machine status register
medeleg	Machine exception delegation register
mideleg	Machine interrupt delegation register
mie	Machine interrupt-enable register
mtvec	Machine trap-handler base address
mscratch	Scratch register for machine trap handlers
mepc	Machine exception program counter
mcause	Machine trap cause
mbadaddr	Machine bad address
mip	Machine interrupt pending

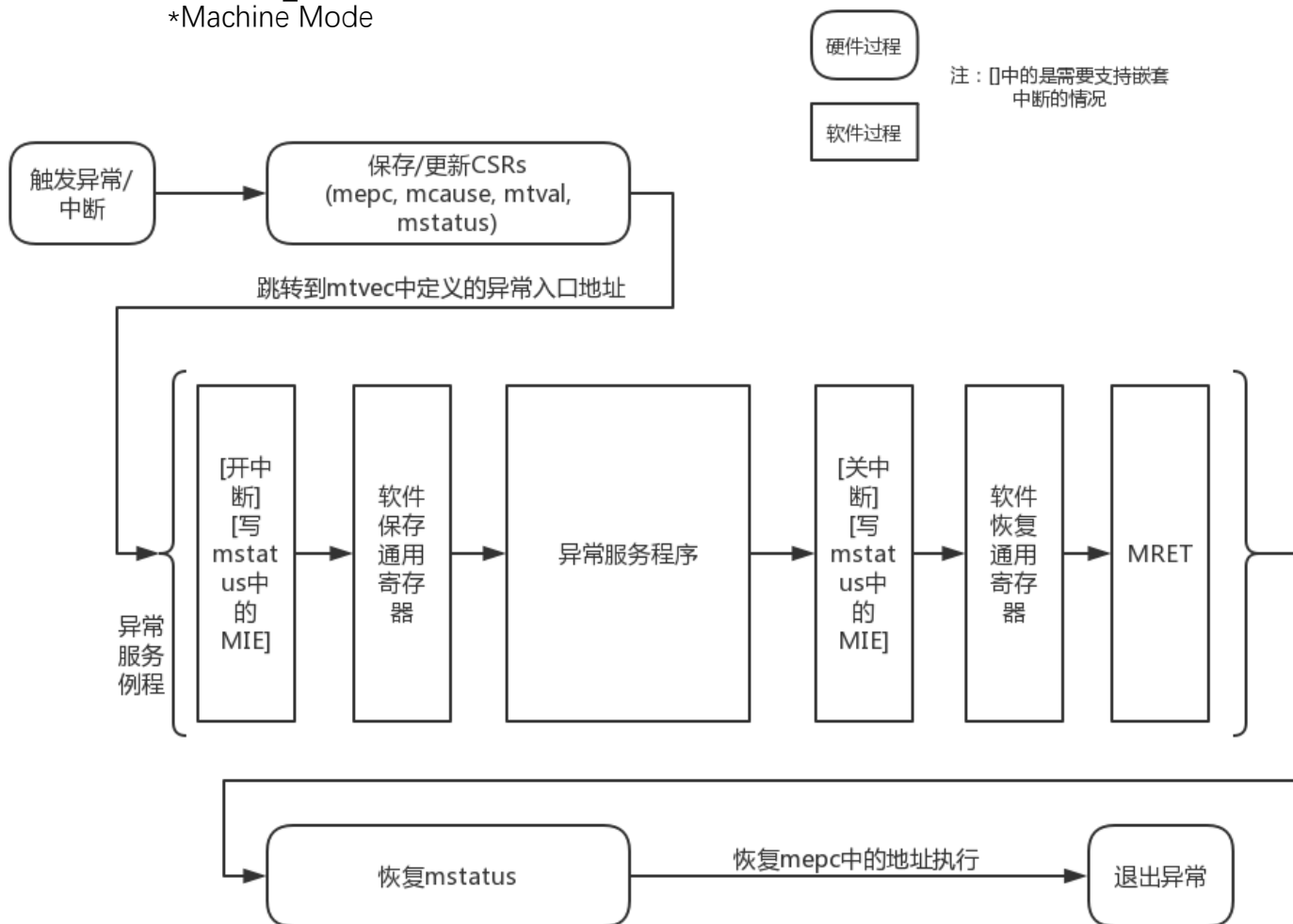
CSR

Interrupts



Exception

*Machine Mode



Enter the exception

1. **Update mepc:** If interrupt, write next instruction address to mepc
If exception, write current instruction address to mepc
2. **Update mcause:** Update mcause according to the type of exception
3. **Update mtval:** Some exceptions need to write exception-related information into mtval
4. **Update mstatus:**
 - Save the MIE to MPIE before the exception occurred
 - Save the privilege level before the exception occurred in the MPP
 - Update the value of MIE to 0

Exit the exception

1. Update mstatus
2. Execute from the address stored in mepc

ESP32-C3 ROM Code

Start.S



```
#include "riscv/csr.h"
#include "soc/interrupt_reg.h"
#include "soc/soc.h"

.section .startup.text,"ax"

.align 4,0xff
.global _start
_start:

/* Mask all interrupts */
csrw mstatus, zero
csrw ustatus, zero
/* Set interrupt enable to 0 */
la t0, INTERRUPT_CORE0_CPU_INT_ENABLE_REG
sw zero, (t0)

/* Set performance mode to clock cycle count and enable*/
li t0, PCER_CYCLES
csrw pcer, t0
li t0, PCMR_GLOBAL_EN
csrw pcmr, t0

.option push
.option norelax

li gp, 0
.option pop
```

```
/* Set MTVEC */
la t0, _vector_table
ori t0, t0, MTVEC_MODE_VECTORED
csrw mtvec, t0

/* Set interrupt level to 1*/
li t1, 1
la t0, INTERRUPT_CORE0_CPU_INT_THRESH_REG
sw t1, (t0)

/* Enable interrupts */
li t0, MSTATUS_MIE | MSTATUS_UIE
li t1, USTATUS_UIE
csrw mstatus, t0
csrw ustatus, t1

/* init stack */
la sp, __stack

/* init .data */
la a1, _data_start
la a2, _data_end
ble a2, a1, 2f
```

```
unpackloop:
lw a3, 0(a1) /* VMA of .data segment start */
lw a4, 4(a1) /* VMA of .data segment end */
lw a5, 8(a1) /* LMA of .data segment start */

/*Copy .data from FLASH to RAM*/
1: lw t0, (a5)
sw t0, (a3)
addi a3, a3, 4
addi a5, a5, 4
bltu a3, a4, 1b

addi a1, a1, 16
bltu a1, a2, unpackloop

/* init .bss */
2: la a1, _bss_start
la a2, _bss_end
ble a2, a1, 2f
clearloop:
lw a3, 0(a1) /* VMA of .bss segment start */
lw a4, 4(a1) /* VMA of .bss segment end */

1: sw zero, (a3)
addi a3, a3, 4
blt a3, a4, 1b

addi a1, a1, 12
bltu a1, a2, clearloop
2:

tail main
/* Never returns here */

.size _start, . - _start
```

/06

FreeRTOS

Task

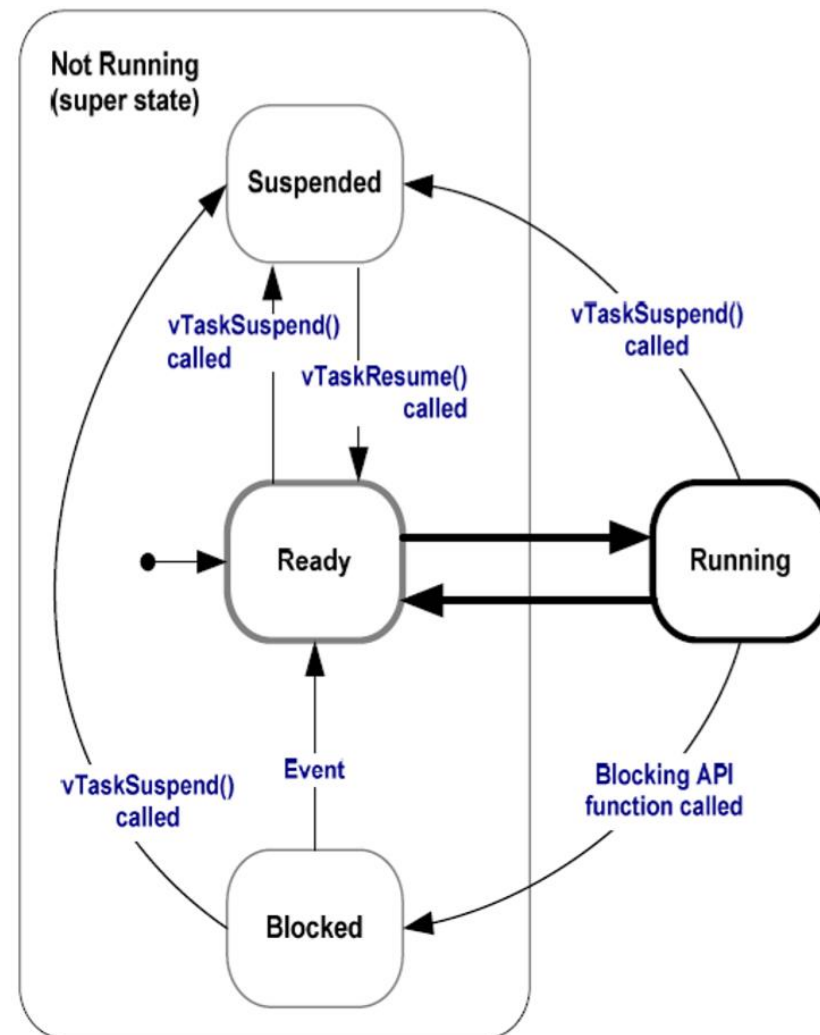
```
void example_task(void *pvParameters)
{
    //Initialize local variables here

    while (1) {
        //Task main loop
    }

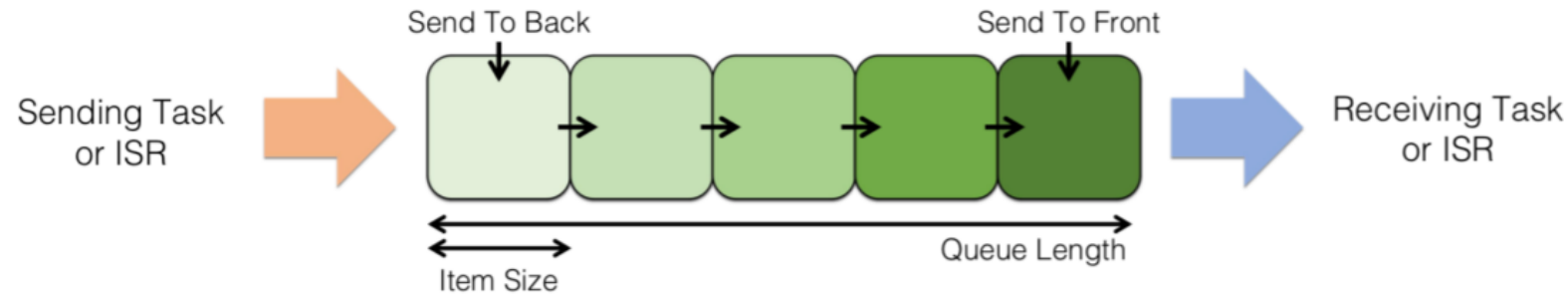
    //Delete task here
    vTaskDelete(NULL);
}
```

- A task function must be a function that accepts a void pointer parameter and returns void.
- User can use the parameter as a pointer to a structure containing parameter values, or cast the pointer directly as a value.
- Main body of task is usually implemented as an infinite loop.
- To prevent the loop constantly consuming CPU time, a task will usually **block** (calling a delay or waiting for an event).
- Breaking out of the loop usually means the task has run to completion.
- A task should **never return or execute past the end of the function**, doing so will likely lead to an unrecoverable error.
- A task should exit by deleting itself.

```
xTaskCreate( vTask1,      /* 指向任务函数的指针 */
            "Task 1",     /* 任务的文本名字, 只会在调试中用到 */
            1000,         /* 栈深度 - 大多数小型微控制器会使用的值会比此值小得多 */
            NULL,         /* 没有任务参数 */
            1,            /* 此任务运行在优先级1上. */
            NULL );       /* 不会用到任务句柄 */
```



Queue

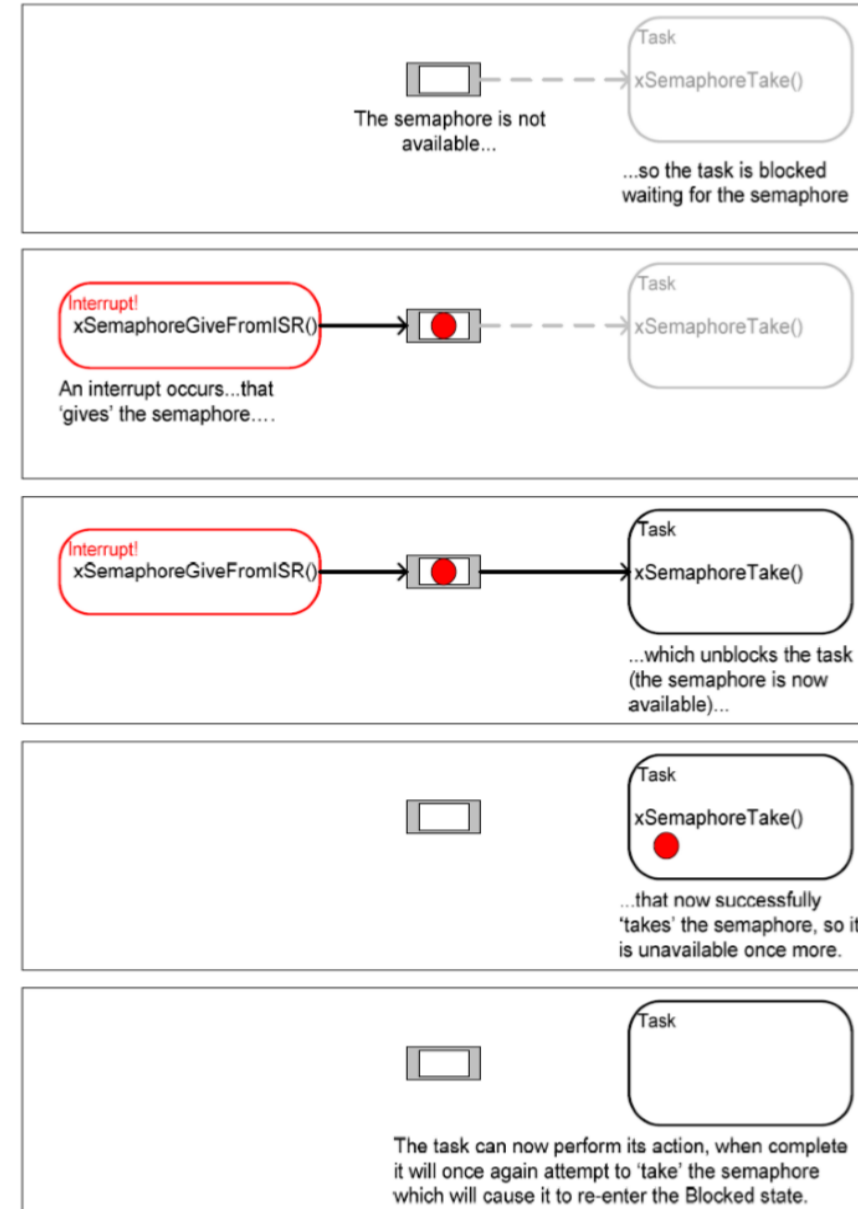
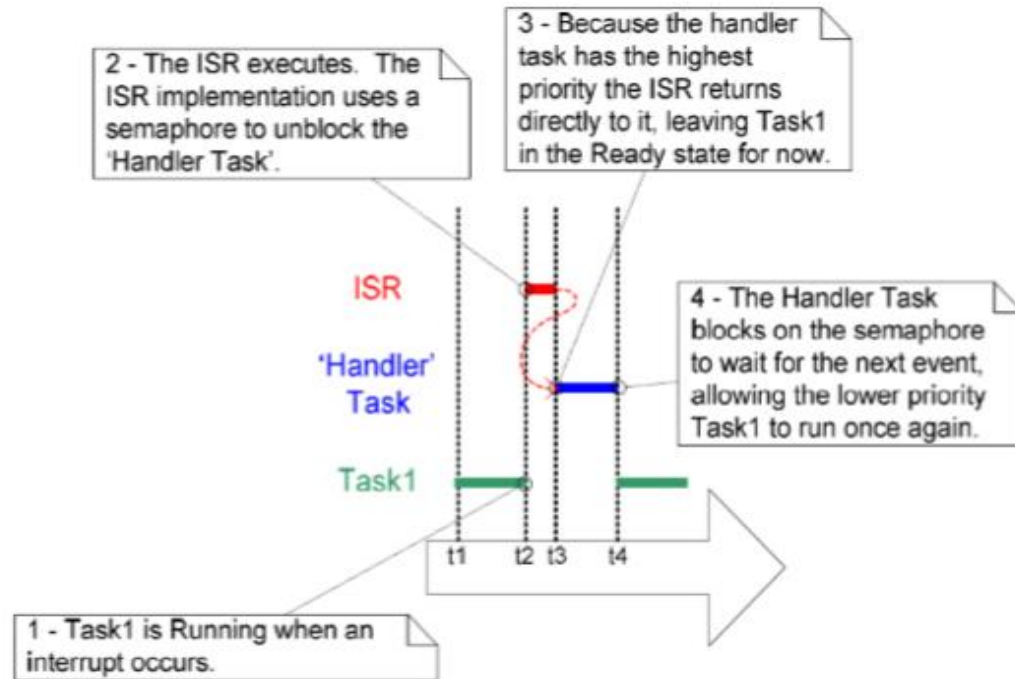


Sending Functions	
xQueueSendToBack() xQueueSendToBackFromISR()	Copy an item to the back of the queue from a task/ISR. ISR version will not block.
xQueueSendToFront() xQueueSendToFrontFromISR()	Copy an item to the front of the queue from a task/ISR. ISR version will not block.
xQueueOverwrite() xQueueOverwriteFromISR()	Copy and item to the back of the queue from a task/ISR but overwrite if there is not space available. Only call on queues of length one.

Receiving Functions	
xQueueReceive() xQueueReceiveFromISR()	Receive and remove an item from the front of the queue. ISR version will not block.
xQueuePeek() xQueuePeekFromISR()	Receive but don't remove an item from the front of the queue. ISR version will not block.

Utility Functions	
xQueueCreate()	Creates a queue
vQueueDelete()	Deletes a queue. Only call when no tasks are blocked on the queue.

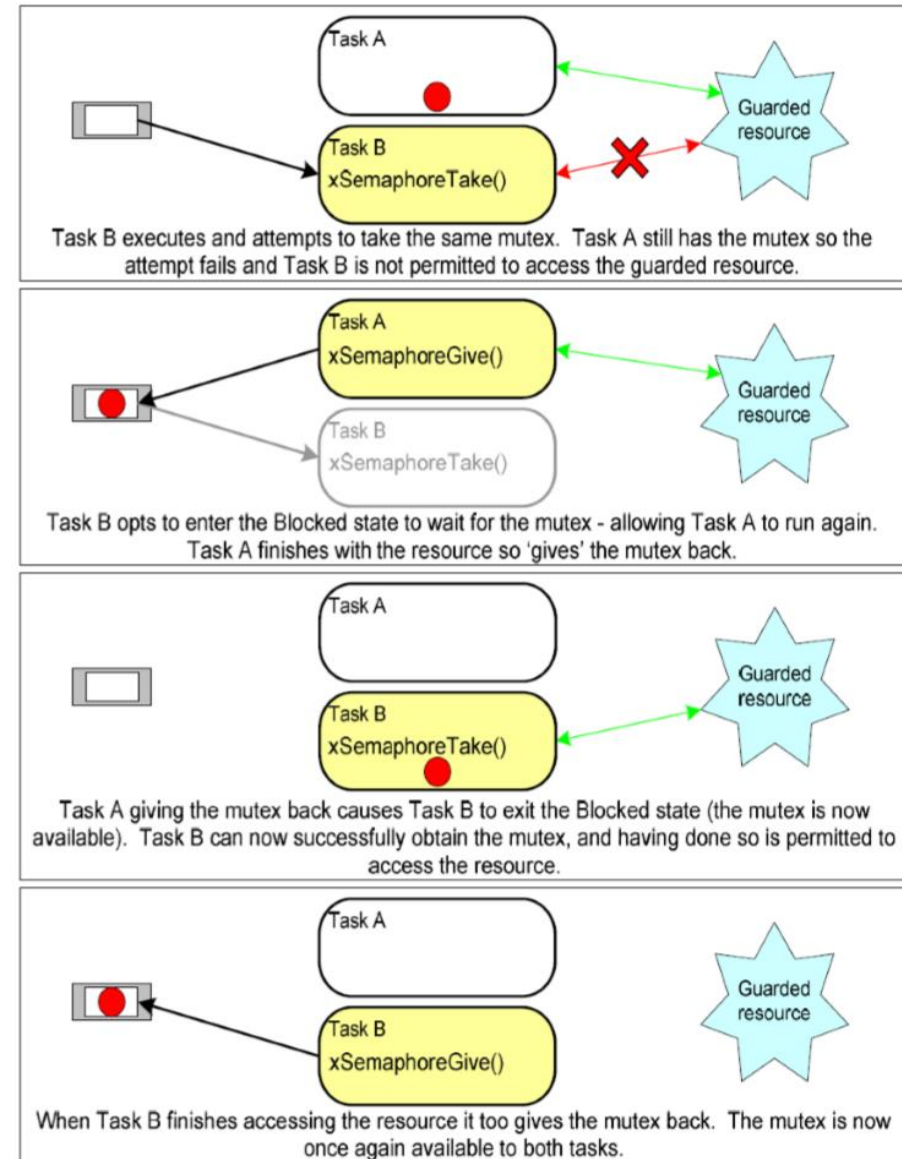
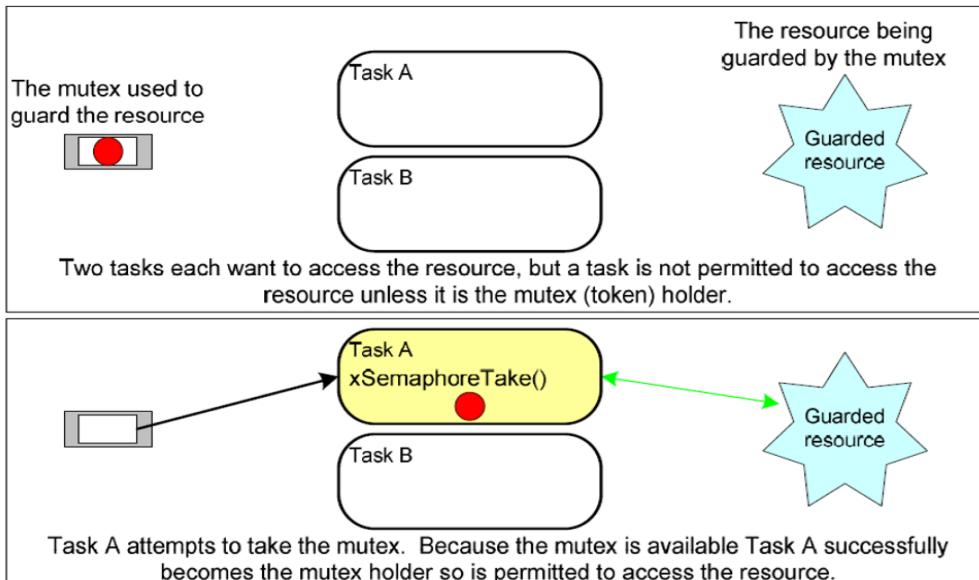
Semaphore



Critical

```
taskENTER_CRITICAL()
.....
taskEXIT_CRITICAL()
```

Mutex



Task

[esp-idf/components/freertos/tasks.c](https://github.com/espressif/esp-idf/blob/master/components/freertos/tasks.c)

- TCB (Task Control Block)

```
typedef struct tskTaskControlBlock
{
    volatile portSTACK_TYPE *pxTopOfStack; //指向任务堆栈结束处
    xListItem xGenericListItem; //用于把TCB插入就绪链表或等待链表
    xListItem xEventListItem; //用于把TCB插入事件链表（如消息队列）
    unsigned portBASE_TYPE uxPriority; //任务优先级
    portSTACK_TYPE *pxStack; //指向任务堆栈起始处
    signed portCHAR pcTaskName[ configMAX_TASK_NAME_LEN ]; //任务名称
    unsigned portCHAR uxTCBNumber; //用于记录功能
}
```

- 任务堆栈

```
#define portSTACK_TYPE uint32_t
typedef portSTACK_TYPE StackType_t
```

- xTaskCreate()
- xTaskCreatStatic()
- xTaskCreateRestricted()
- vTaskDelete()
- vTaskSuspend()
- vTaskResume()
- vTaskResumeFromISR()
- portENABLE_INTERRUPTS()
- portDISABLE_INTERRUPTS()
-

List

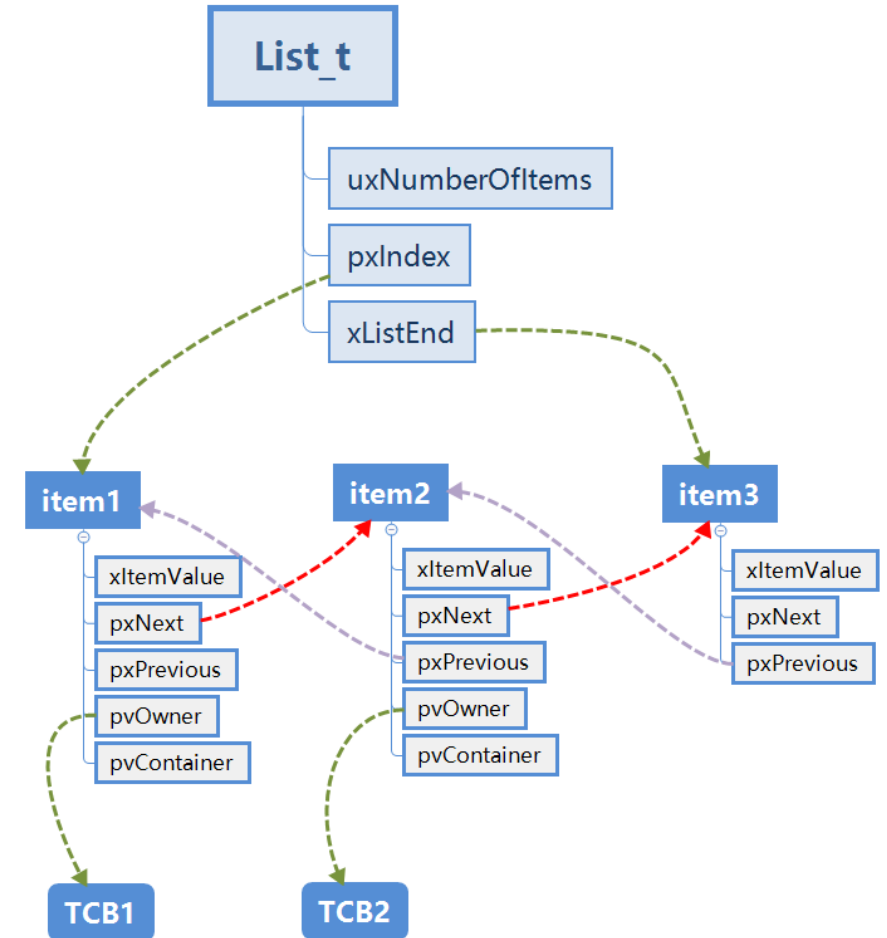
esp-idf/components/freertos/list.c

```
typedef struct xLIST
{
    configLIST_VOLATILE UBaseType_t uxNumberOfItems;
    ListItem_t * configLIST_VOLATILE pxIndex;
    MiniListItem_t xListEnd;
} List_t;
```

xLIST_ITEM & xMINI_LIST_ITEM

```
typedef struct xMINI_LIST_ITEM
{
    configLIST_VOLATILE TickType_t xItemValue;
    struct xLIST_ITEM * configLIST_VOLATILE pxNext;
    struct xLIST_ITEM * configLIST_VOLATILE pxPrevious;
    void * pvOwner;
    void * configLIST_VOLATILE pvContainer;
} ListItem_t;
```

- vListInitialise()
- vListInitialiseItem()
- vListInsert()
- vListInsertEnd()
- uxListRemove()
- listGET_OWNER_OF_NEXT_ENTRY()



xTaskCreatePinnedToCore

```

BaseType_t xTaskCreatePinnedToCore( TaskFunction_t pxTaskCode,
                                     const char * const pcName,
                                     const uint32_t usStackDepth,
                                     void * const pvParameters,
                                     UBaseType_t uxPriority,
                                     TaskHandle_t * const pxCreatedTask,
                                     const BaseType_t xCoreID)

```

//函数指针, 指向任务函数的入口
 //任务描述, 用于调试
 //任务堆栈大小
 //传递任务参数指针
 //任务优先级
 //任务句柄
 //指定核



[vTaskCreate Flow Chart](#)

Scheduler

esp-idf/components/freertos/tasks.c

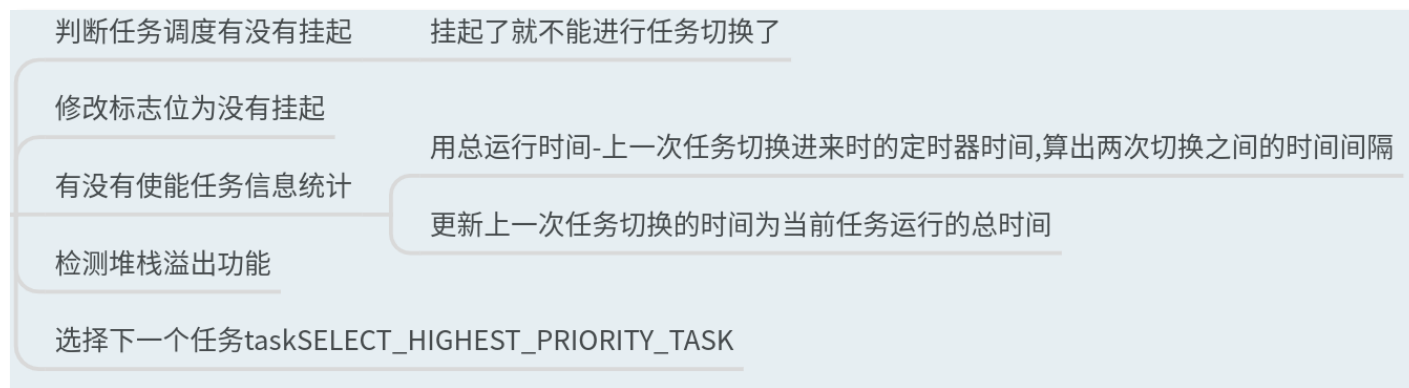
- vTaskStartScheduler()



- xPortStartScheduler()

- vPortSetupTimer
- vPortSetupSoftwareInterrupt()
- esprv_intc_int_set_threshold(1)
- riscv_global_interrupts_enable()
- vPortYield()
 - *REG_WRITE(SYSTEM_CPU_INTR_FROM_CPU_0_REG, 1)*

- vTaskSwitchContext



[vTaskStartScheduler FlowChart](#)

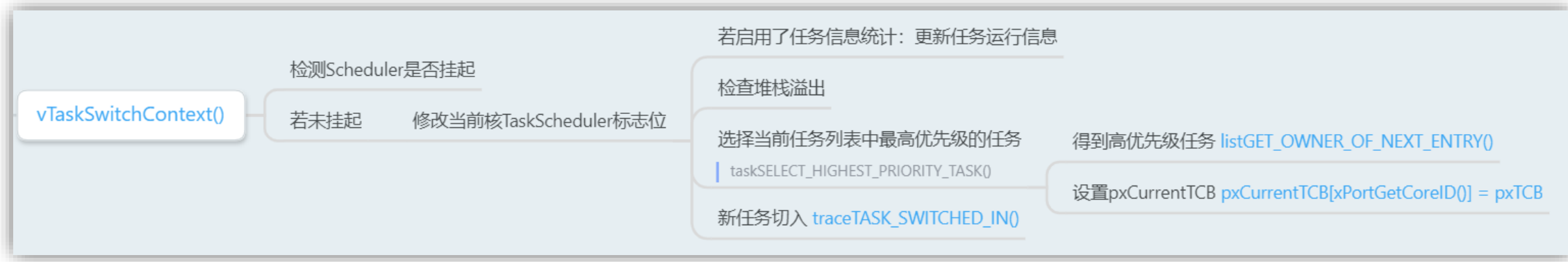
TaskSwitching

- 执行系统调用切换

taskYIELD() → portYIELD() → vPortYield() → 检查中断嵌套 → 触发软件中断 → vPortSoftwareInterrupt → vTaskSwitchContext()

- SysTick定时器中断切换

触发定时器中断 → vPortSysTickHandler() → vTaskSwitchContext()



IdleTask

- 当任务自己删除自己的时候,需要在空闲任务中释放掉任务申请的任务控制块和任务堆栈等内存
- 运行用户设置的空闲任务钩子函数
- 判断是否开启低功耗tickless模式,
- 用户可以创建与空闲任务优先级相同的应用任务, 当宏configIDLE_SHOULD_YIELD为1时, 空闲任务会让出时间片给相同优先级的应用任务。



FreeRTOS Time management

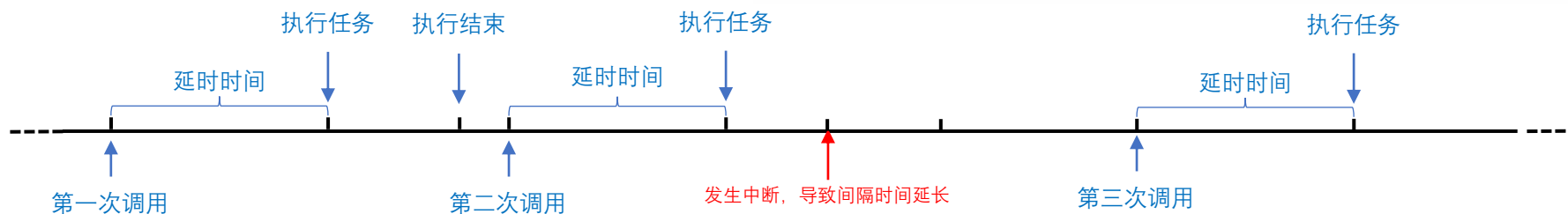
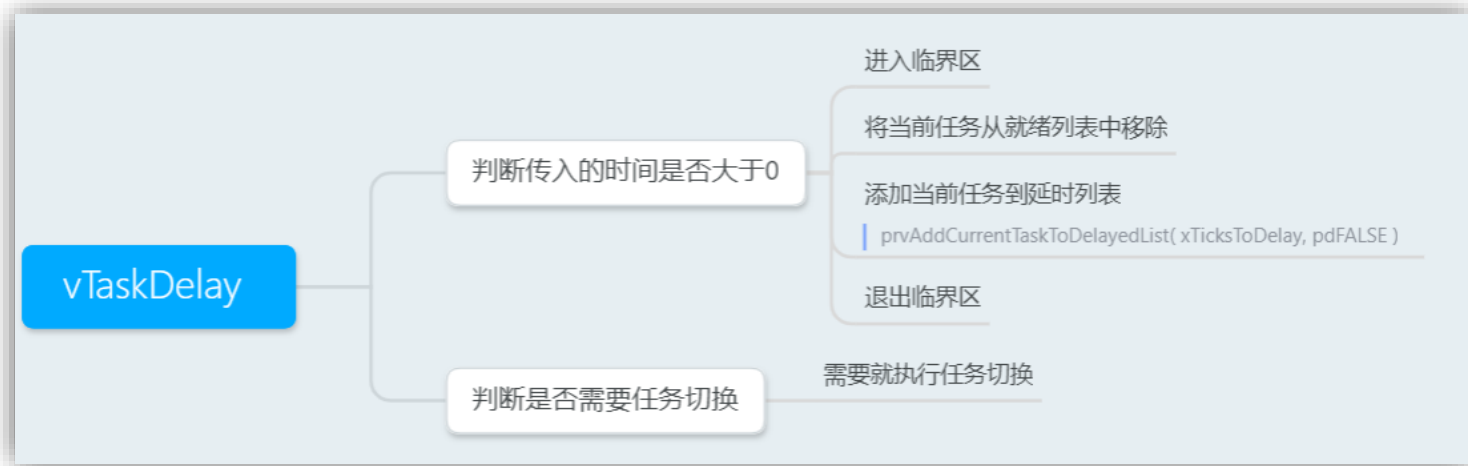
- `xTaskIncrementTick()`

`xTickCount`是FreeRTOS的系统节拍计数器，每个滴答定时器中断后加一
`xTickCount`的具体操作是在函数`xTaskIncrementTick`中进行的

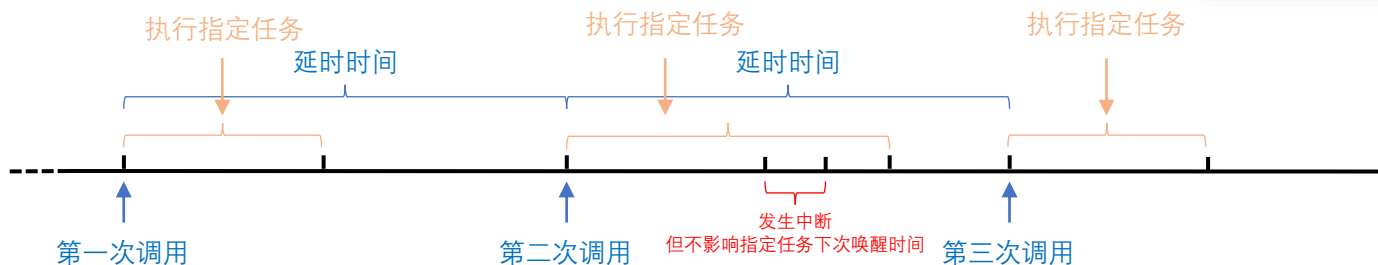
- 系统节拍计数器的值加1
- 判断是否有任务的延时等待时间已到，如果就就将其恢复
- 处理时间片调度

- `vTaskDelay(xTicksToDelay)`

- 相对于其调用者函数而言的延时
- 不确保周期性



- `vTaskDelayUntil(pxPreviousWakeTime, xTimeIncrement)`
 - 主调函数+延时任务的时间是确定的,可以实现周期性
 - 添加的延时值 = 唤醒时间点`xTimeToWake` - 当前时间值`xConstTickCount`(动态变化的,主体任务变化而变化)
 - `pxPreviousWakeTime` 保存上一次该任务被唤醒的时刻值,`xTimeIncrement`是需要延时的时间
 - 首次调用,需要将`pxPreviousWakeTime`初始化为进入while循环体的事件点的值
 - 在后续的运行中,任务会自动更新这个`pxPreviousWakeTime`





Thank you !

