The Abdus Salam International Centre for Theoretical Physics

*Advanced Workshop on FPGA-based Systems-On-Chip for Scientific Instrumentation and Reconfigurable Computing*

# Introduction to FreeRTOS

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- FreeRTOS programming abstractions
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# Motivation

- Two main alternatives for firmware development for microcontrollers
  - Baremetal
  - Based on a O.S.
- The baremetal approach, based on a superloop:
  - forever loop that sequences the set of tasks
  - Polled or interrupt-based I/O
  - Typical in standalone implementations
  - Pros:
    - Simple
    - No OS overhead
  - Cons
    - Difficult to scale (low number of tasks)
    - Difficult to balance time and tasks priorities

```
int main() {
    init_system();
    …
    While(1) {
        do_a();
        do_b();
        do_c();
    }
    // You'l never get here
}
```

# Motivation

- Based on a O.S.
  - Multi-threaded: multiple threads spawn to carry out multiple tasks concurrently
  - Each task has different priority and timing requirements
  - The operating system provides some hardware abstraction layer
  - Extra services, such as a filesystem, network stack, ...
  - Pros:
    - More modular architecture
    - Tasks can be pre-empted. Avoid priority inversion
  - Cons:
    - More complex and extra overhead
    - Higher memory requirements
    - Thread execution is difficult to test
    - Deterministic??

# FreeRTOS

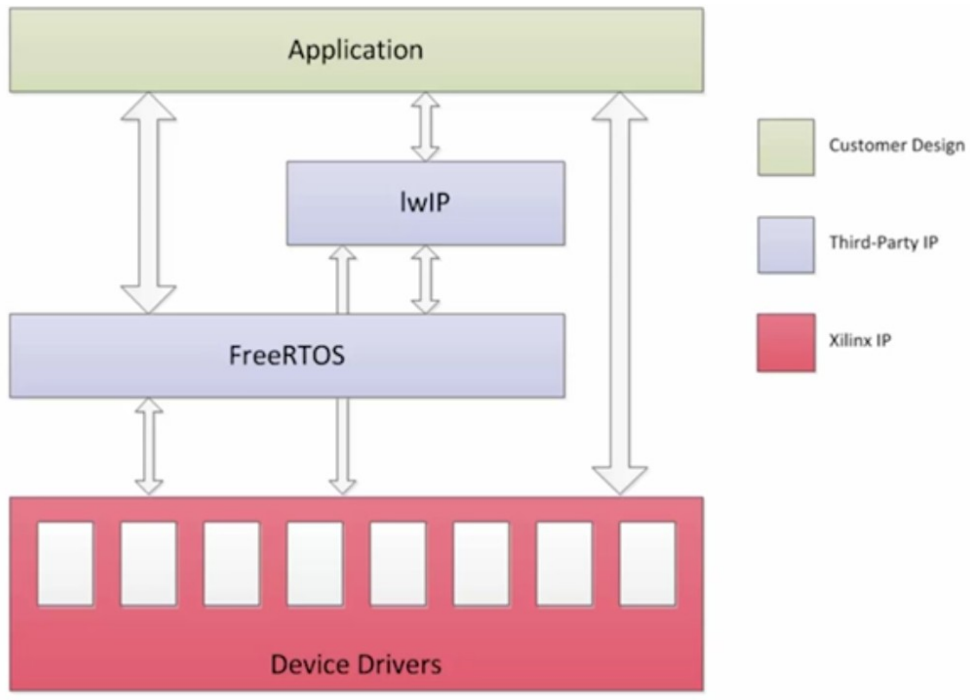
- Born in 2003 and initially conceived for microcontrollers
  - Really light
  - Really simple: the core of the O.S. are just 3 C files
  - Minimal processing overhead
    - FreeRTOS IRQ dispatch 10 cycles aprox.
    - Embedde Linux IRQ dispatch = 100 cycles aprox.
    - Ported to a large number of architectures
- Currently is Amazon the company that stewards the development of the O.S.
- Open Source MIT license
- More information at www.FreeRTOS.org

# FreeRTOS

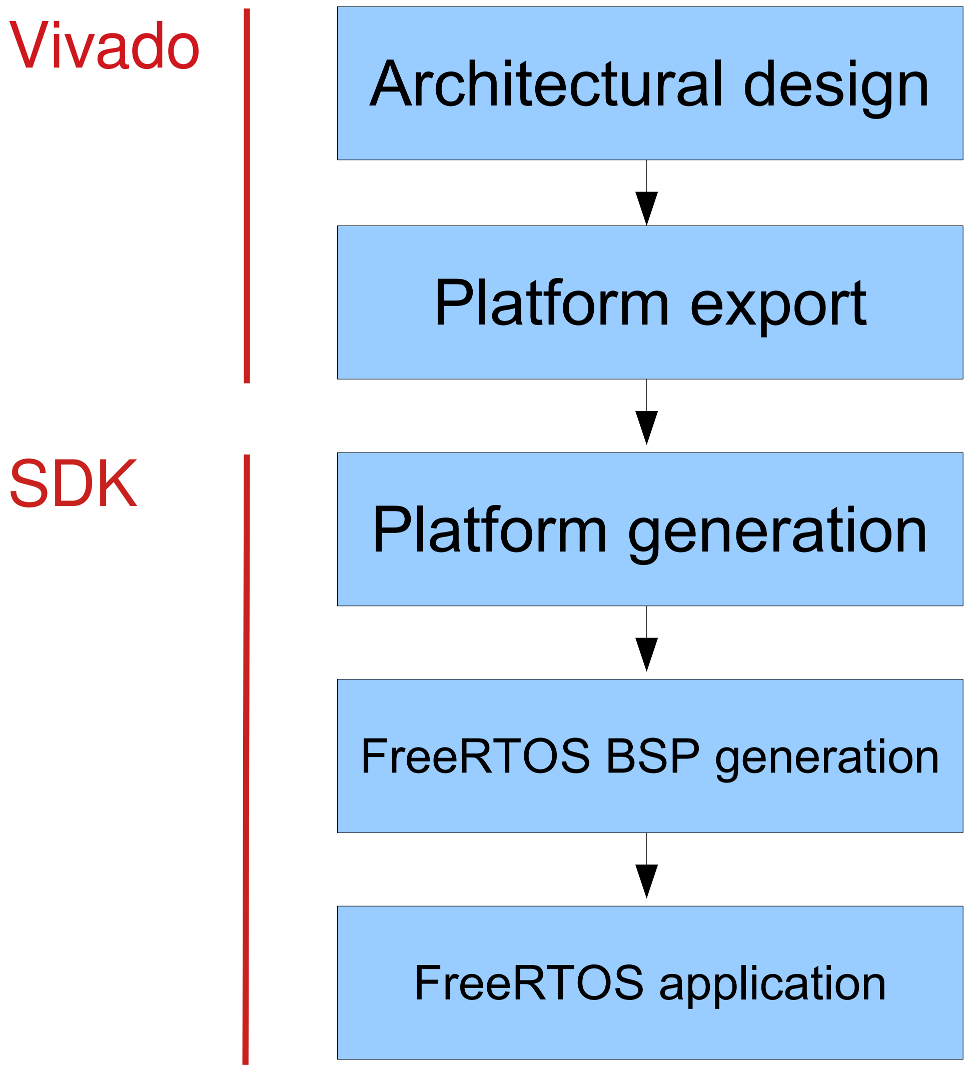
- An ecosystem of products:
  - Amazon FreeRTOS for IoT devices
  - Network communication stack
  - Command Line Interface
  - SSL and TLS security
  - FAT file system

# FreeRTOS & Zynq

- FreeRTOS completely integrated in Xilinx Software Development Flow
- Provided as a BSP:
  - Extension of the standalone BSP
    - All low level drivers can be directly used
  - Includes the O.S. runtime
  - Optional extensions:
    - Filesystem
    - Network
    - ...



# FreeRTOS Design Flow




This information will be used for the generation of the appropriate drivers for the peripherals

It includes the standalone drivers plus the extra libraries selected

Based on the FreeRTOS API plus the peripheral drivers

# FreeRTOS Configuration

- Through a header file: FreeRTOSConfig.h

```
#define configUSE_PREEMPTION 1

#define configUSE_MUTEXES 1

#define INCLUDE_xSemaphoreGetMutexHolder 1

#define configUSE_RECURSIVE_MUTEXES 1

#define configUSE_COUNTING_SEMAPHORES 1

#define configUSE_TIMERS 1

#define configUSE_IDLE_HOOK 0

#define configUSE_TICK_HOOK 0

#define configUSE_DAEMON_TASK_STARTUP_HOOK 0

#define configUSE_TICKLESS_IDLE 0
#define configTASK_RETURN_ADDRESS    NULL
#define INCLUDE_vTaskPrioritySet            1
#define INCLUDE_uxTaskPriorityGet           1
#define INCLUDE_vTaskDelete                 1
#define INCLUDE_vTaskCleanUpResources       1
#define INCLUDE_vTaskSuspend                1
#define INCLUDE_vTaskDelayUntil             1
#define INCLUDE_vTaskDelay                  1
#define INCLUDE_eTaskGetState               1
#define INCLUDE_xTimerPendFunctionCall      1
#define INCLUDE_pcTaskGetTaskName           1
#define configMAX_API_CALL_INTERRUPT_PRIORITY (18)
```

Tasks can be interrupted by others with higher priority

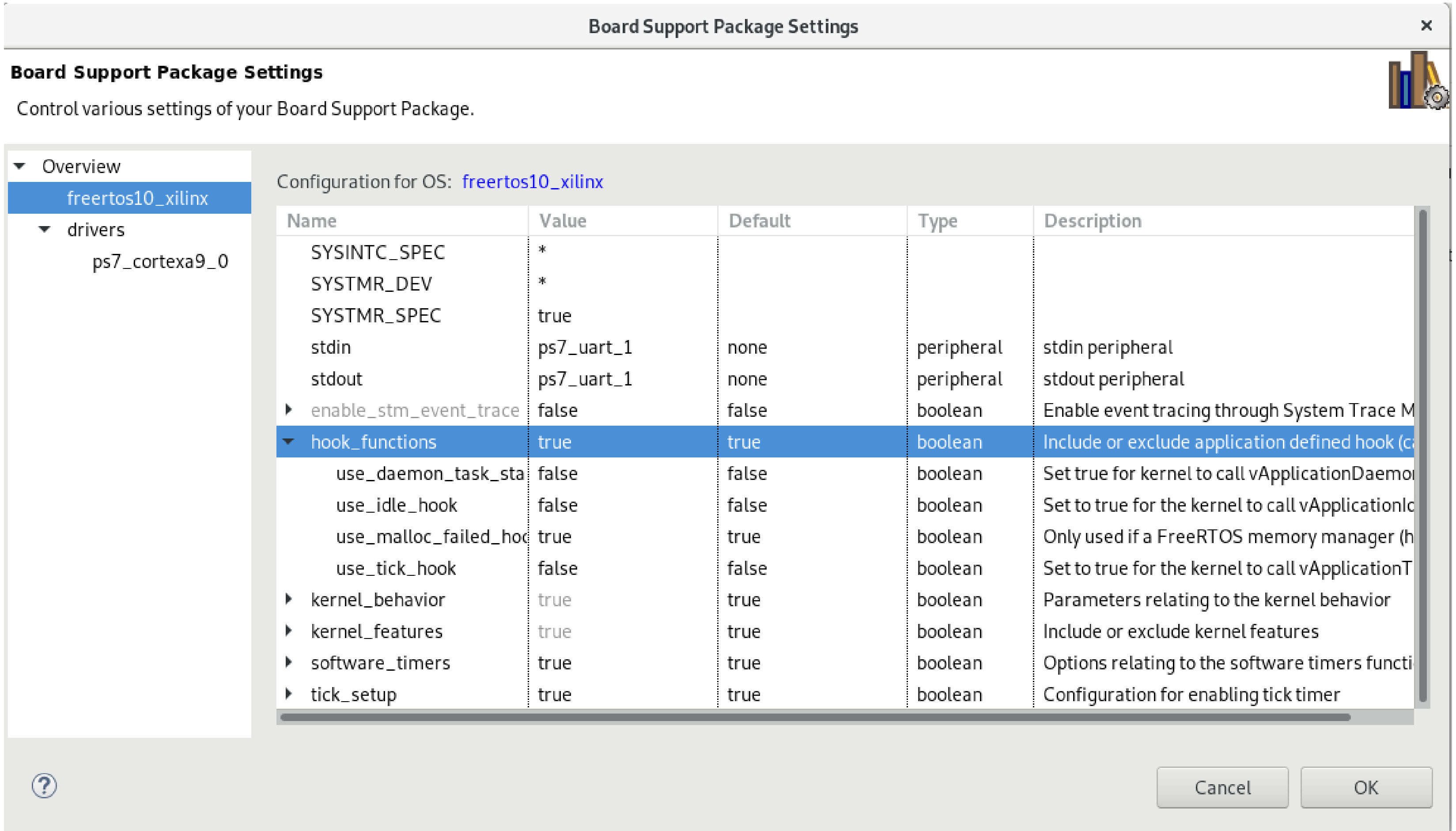
This will include a timer service task

Hooks are used to trigger the execution of functions upon the happening of certain events

Some functionality can be optionally included/excluded from the core of the O.S.

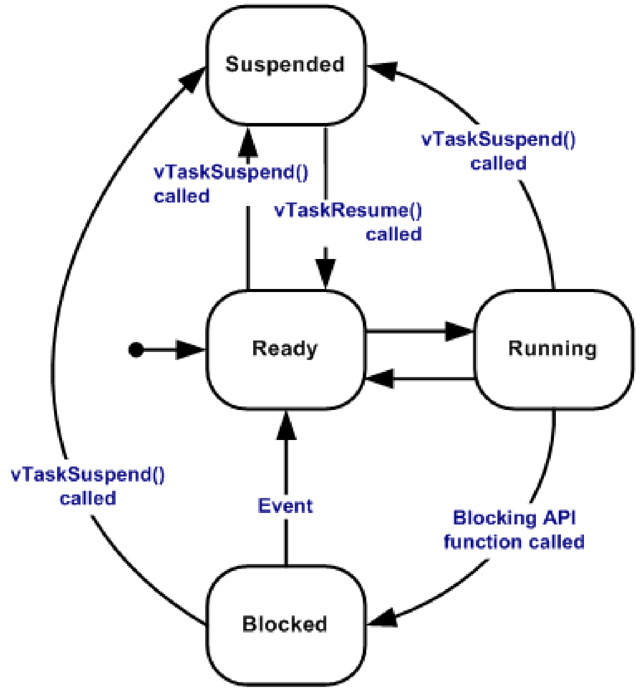
# FreeRTOS Configuration

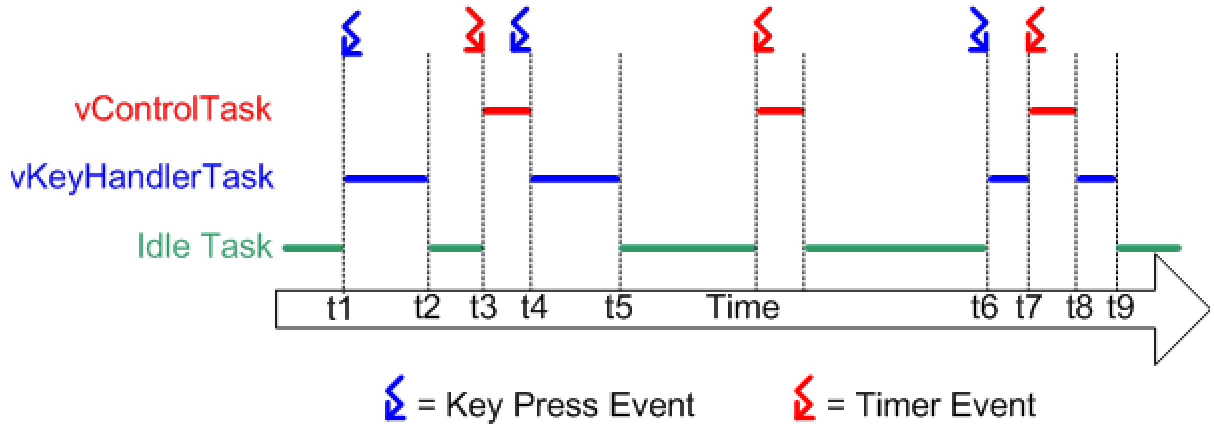
- The Xilinx way to handle configuration is through the mss file in the FreeRTOS BSP generated in the SDK



# FreeRTOS task model

- Every thread of execution is a task
- Tasks are never called from the program
- Tasks are executed by the FreeRTOS scheduler depending on their priorities and as a response to events
- Only one task active at the same time
- Tasks never return
- Independent contexts



# FreeRTOS tasks

- Tasks are modelled after normal C functions

```
static void prvTxTask( void *pvParameters )
```

  - void return
  - void pointer for arguments. Can be later casted to the right type
- Since not called, they must be registered (created) into the scheduler
  - The IDLE task is created automatically (special case)
- Can also be destroyed at run-time
- Some related functions:
  - xtaskCreate()
  - xtaskDelete()

# FreeRTOS Tasks

- In order to create a Task:

```
BaseType_t xTaskCreate(TaskFunction_t pxTaskCode,
                       const char * const pcName,
                       const configSTACK_DEPTH_TYPE usStackDepth,
                       void * const pvParameters,
                       UBaseType_t uxPriority,
                       TaskHandle_t * const pxCreatedTask
```

  - **pxTaskCode**: pointer to the function that really implements the task
  - **pcName:** name assigned, mainly used for debug purposes
  - **usStackDepth:** refers to the local memory assigned to the task
    - The **configMINIMAL_STACK_SIZE** parameter set in the FreeRTOSConfig.h configuration file
  - **pvParameters**: since no parameters are sent to the task
  - **uxPriority**: priority assigned to the task.
    - This constant is defined as the minimum possible priority
    - The lowest the number, the lowest the priority
  - **pxCreatedTask**: task handler
    - Previously declared as:

```
static TaskHandle_t xTxTask;
```

```
xTaskCreate(    prvTxTask,
                ( const char * ) "Tx",
                configMINIMAL_STACK_SIZE,
                NULL,
                tskIDLE_PRIORITY,
                &xTxTask );
```

Task creation example

# FreeRTOS Task Communication

- Two mechanisms:
  - Global variables which can be read from all tasks
  - Queues as the main mechanism for inter-task communication
- Queues:
  - Asynchronous model of communication based on a FIFO
  - Data can written to both the head and tail of the queue
  - Of arbitrary size and depth, but defined at compile time
  - Items are passed by value $\rightarrow$ not zero copy
  - Access can be blocking or non-blocking

# FreeRTOS queues

- Queue creation:

```
xQueueHandle xQueueCreate (unsigned portBASE_TYPE uxQueueLength,
                           unsigned portBASE_TYPE uxItemSize)
```

- Queue data insertion at the back of the queue:

```
portBASE_TYPE xQueueSend (xQueueHandle xQueue,
                          const void * pvItemToQueue,
                          portTickType xTicksToWait)
```

  - If *xTicksToWait* is 0 it will return immediately if full otherwise it will wait

- Data insertion at the front of the queue:

```
portBASE_TYPE xQueueSend (xQueueHandle xQueue,
                          const void * pvItemToQueue,
                          portTickType xTicksToWait)
```

- Data extraction:
  - `portBASE_TYPE xQueueReceive (xQueueHandle xQueue,`
  - `void * pvBuffer,`
  - `portTickType xTicksToWait)`

# FreeRTOS synchronization

- Queues can also be used as a synchronization primitive
- But FreeRTOS includes some other types:
  - Binary semaphores
    - Also used for mutual exclusion
    - Typically used in Interrupt Service Routines (ISR)
  - Counting semaphores
  - Mutexes