Everything You Need to Know about RTOSs in 30 Minutes

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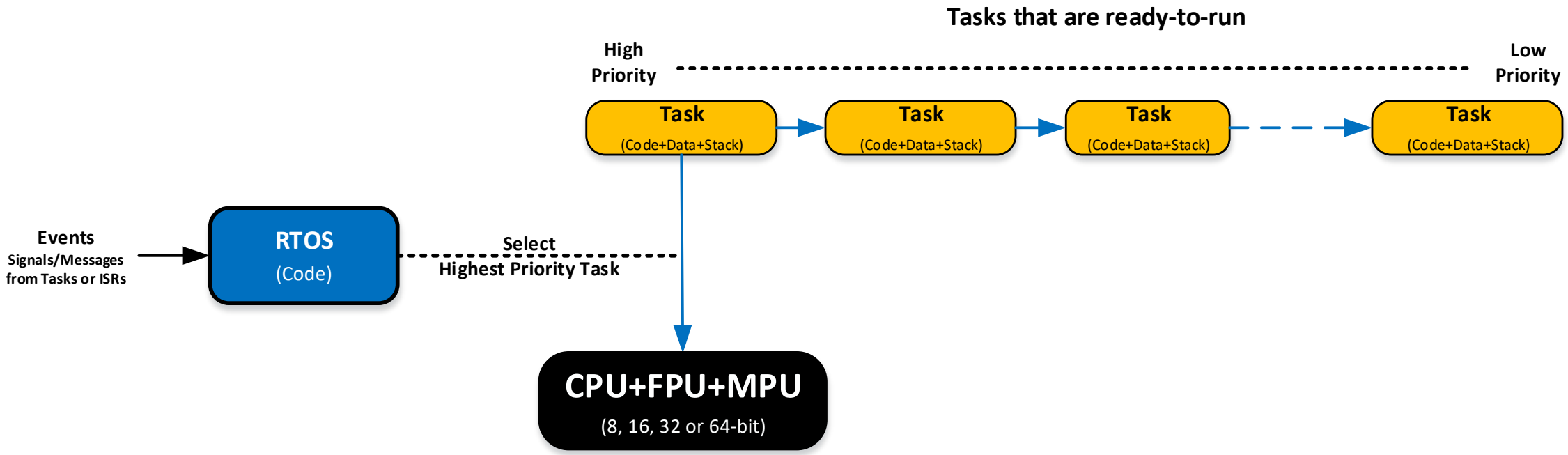
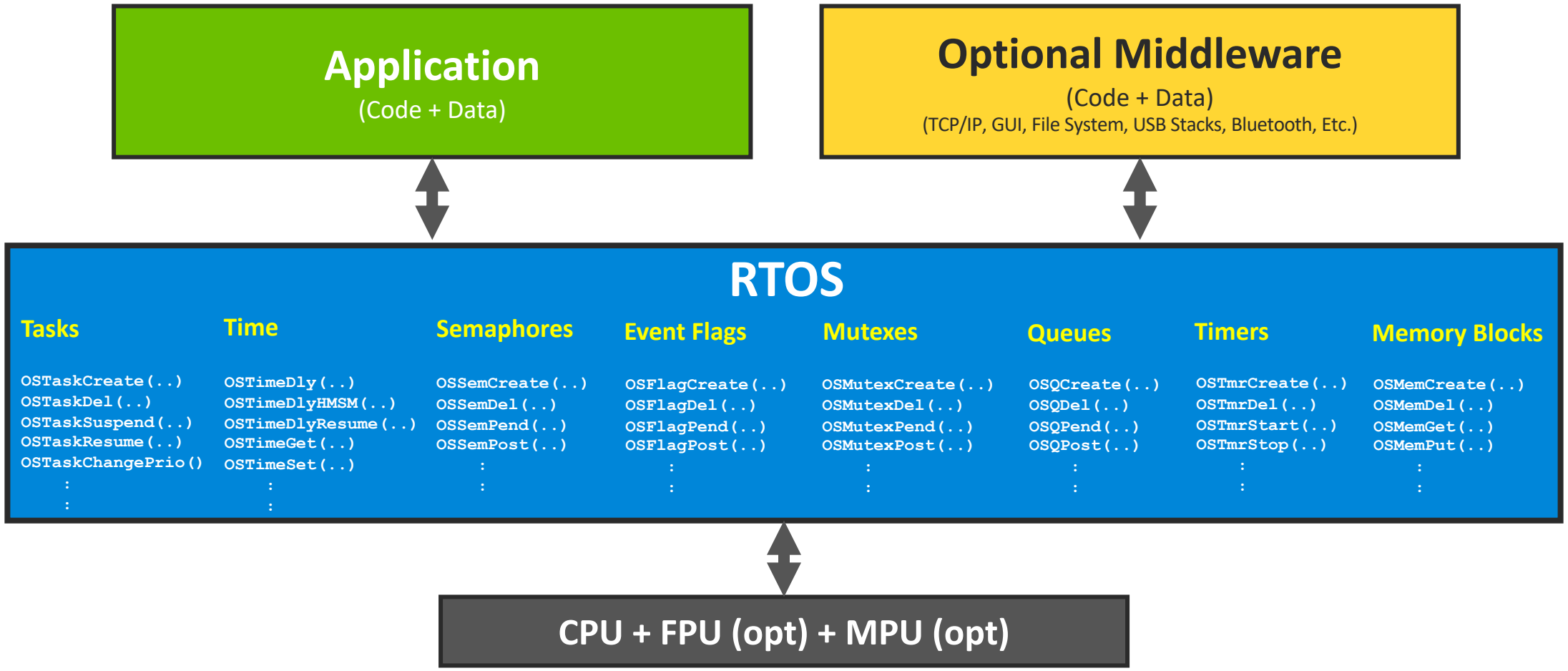
An RTOS Allows Multitasking

- An RTOS is software that manages the **time** and **resources** of a CPU
  - Application is split into **multiple tasks**
  - The RTOS's job is to **run the most important task** that is *ready-to-run*
  - On a single CPU, only **one task executes** at any given time

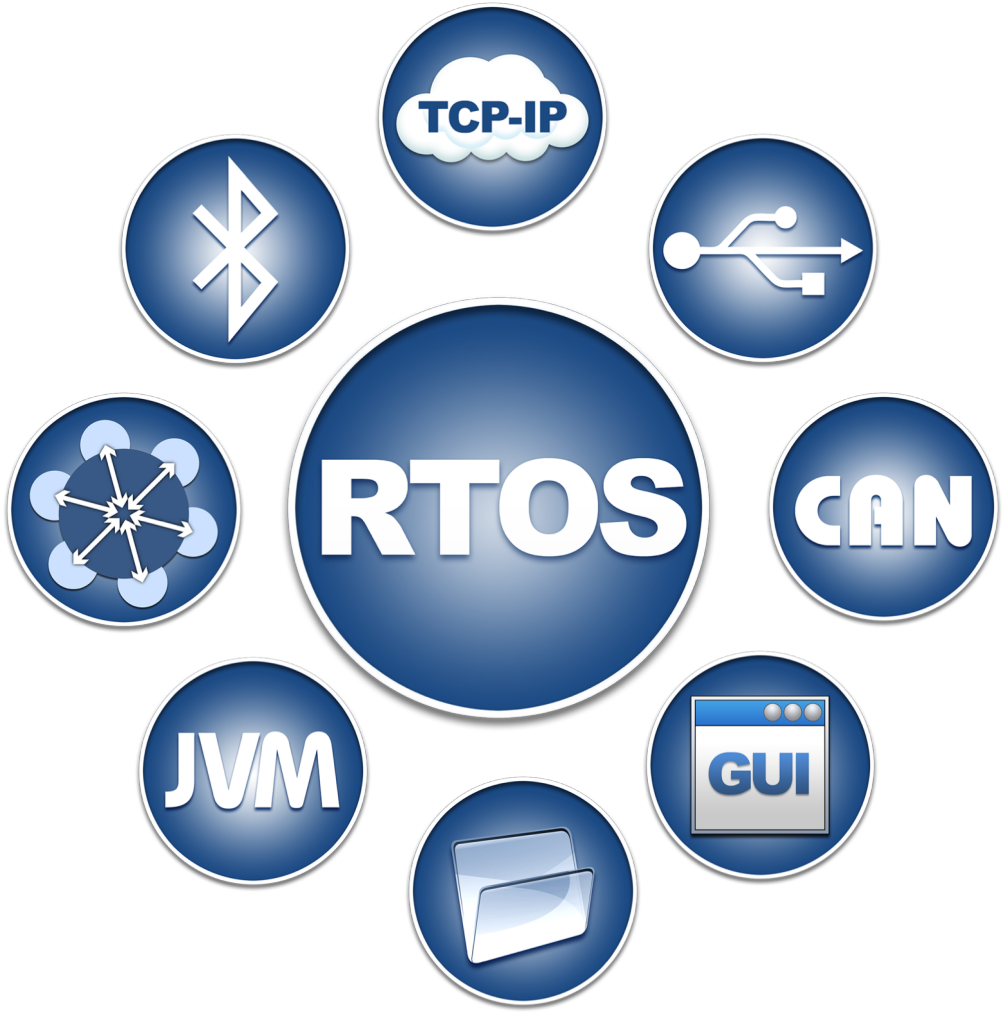


An RTOS Provides Services To Your Application



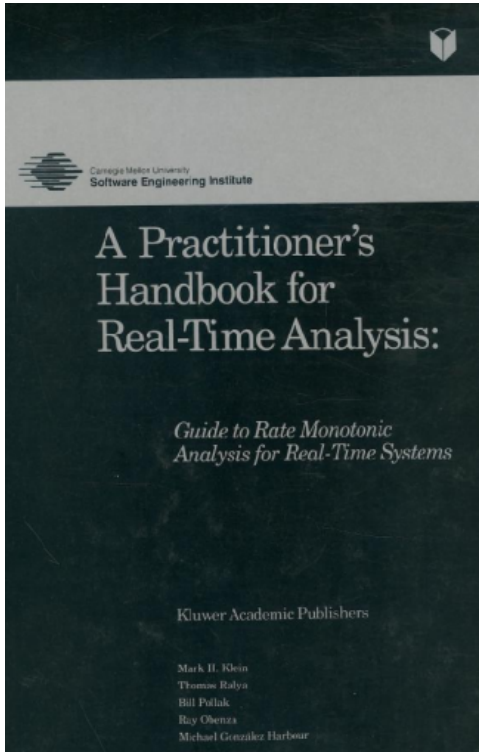
Benefits of Using an RTOS

- Allows you to **split** and **prioritize** the application code
  - The RTOS always runs the highest priority task that is ready
  - Adding low-priority tasks don't affect the responsiveness of high priority tasks
- Tasks **wait** for events
  - Avoids polling
- RTOSs make it **easy to add middleware** components
  - TCP/IP stack
  - USB stacks
  - File System
  - Graphical User Interface (GUI)
  - Etc.



Benefits of Using an RTOS

- Creates a **framework** for developing applications
  - Facilitate teams of multiple developers
- It's possible to **meet all the deadlines** of an application
  - Rate Monotonic Analysis (RMA) could be used to determine schedulability
- Most RTOSs have undergone **thorough testing**
  - Some are third-party certifiable, and even certified (DO-178B, IEC-61508, IEC-62304, etc.)
  - It's unlikely that you will find bugs in RTOSs
- RTOSs typically support many **different CPU architectures**
- Very easy to add **power management**



Drawbacks of Using an RTOS

- The RTOS itself is **code** and thus requires more Flash
  - Typically between 6-20K bytes
- An **RTOS requires extra RAM**
  - **Each task requires its own stack**
    - The size of each task depends on the application
  - **Each task** needs to be assigned a Task Control Block (TCB)
    - About 32 to 128 bytes of RAM
  - About 256 bytes for the RTOS variables
- **You** have to assign task priorities
  - Deciding on what priority to give tasks is not always trivial
- The services provided by the **RTOS consume CPU time**
  - Overhead is typically 2-10% of the CPU cycles
- There is a **learning curve** associated with the RTOS you select

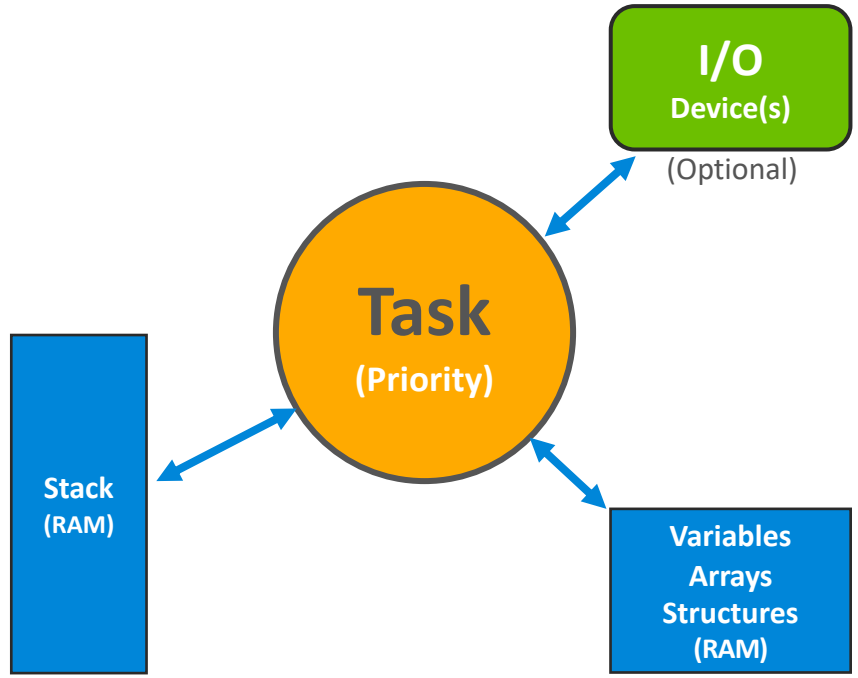
Tasks

- For each task:
  - **YOU** assign a **priority** based on its importance
  - Requires its own **Stack**
  - Manages its own variables, arrays and structures
  - Is typically an **infinite loop**
  - Possibly manages I/O devices
  - Contains **YOUR** application code

```
CPU_STK  MyTaskStk[MY_TASK_STK_SIZE];   // Task Stack


void MyTask (void *p_arg)               // Task Code
{
  Local Variables;

  Task initialization;
  while (1) {                           // Infinite Loop (Typ.)
    Wait for Event;
    Perform task operation;             // Do something useful
  }
}
```

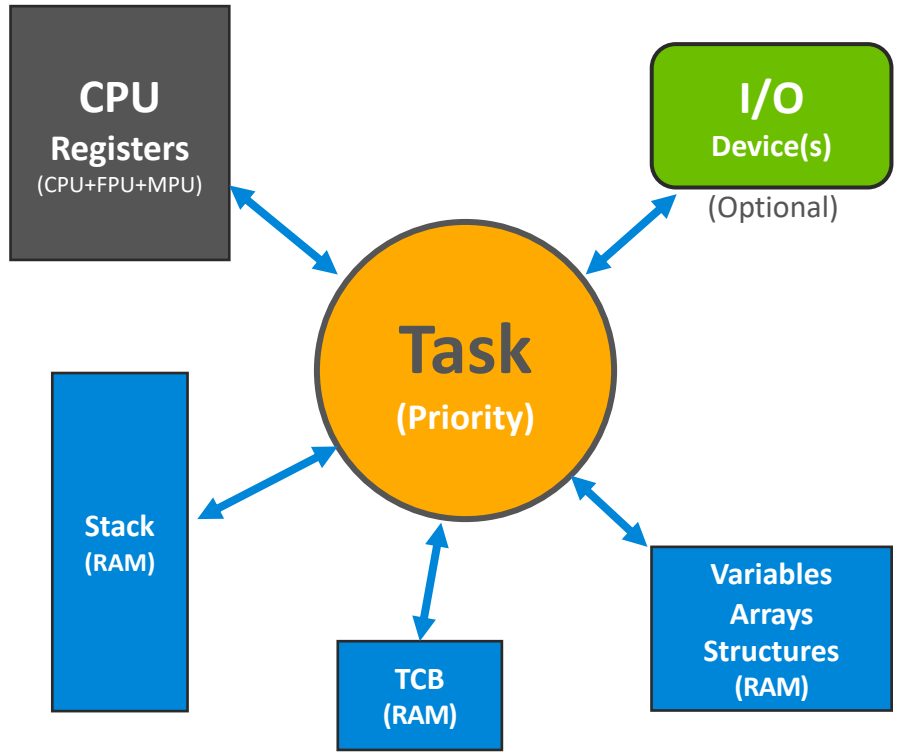


Creating a Task

- You must tell the RTOS about the existence of a task:
  - The RTOS provides a special API: **`OSTaskCreate()`** (or equivalent)

```
void OSTaskCreate (MyTask,              // Address of code
                   &MyTaskStk[0],       // Base of stack
                    MY_TASK_STK_SIZE,// Size of stack
                    MY_TASK_PRIO,       // Task priority
                    :
                    :);
```

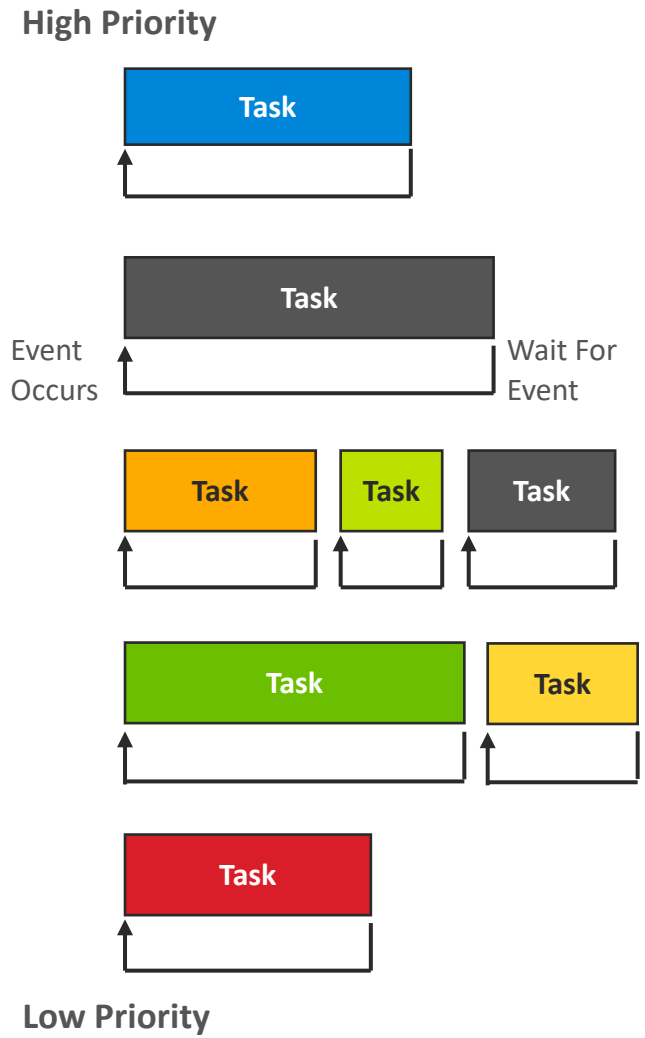
- The RTOS assigns the task:
  - Its own set of ***CPU registers***
  - A Task Control Block (***TCB***)



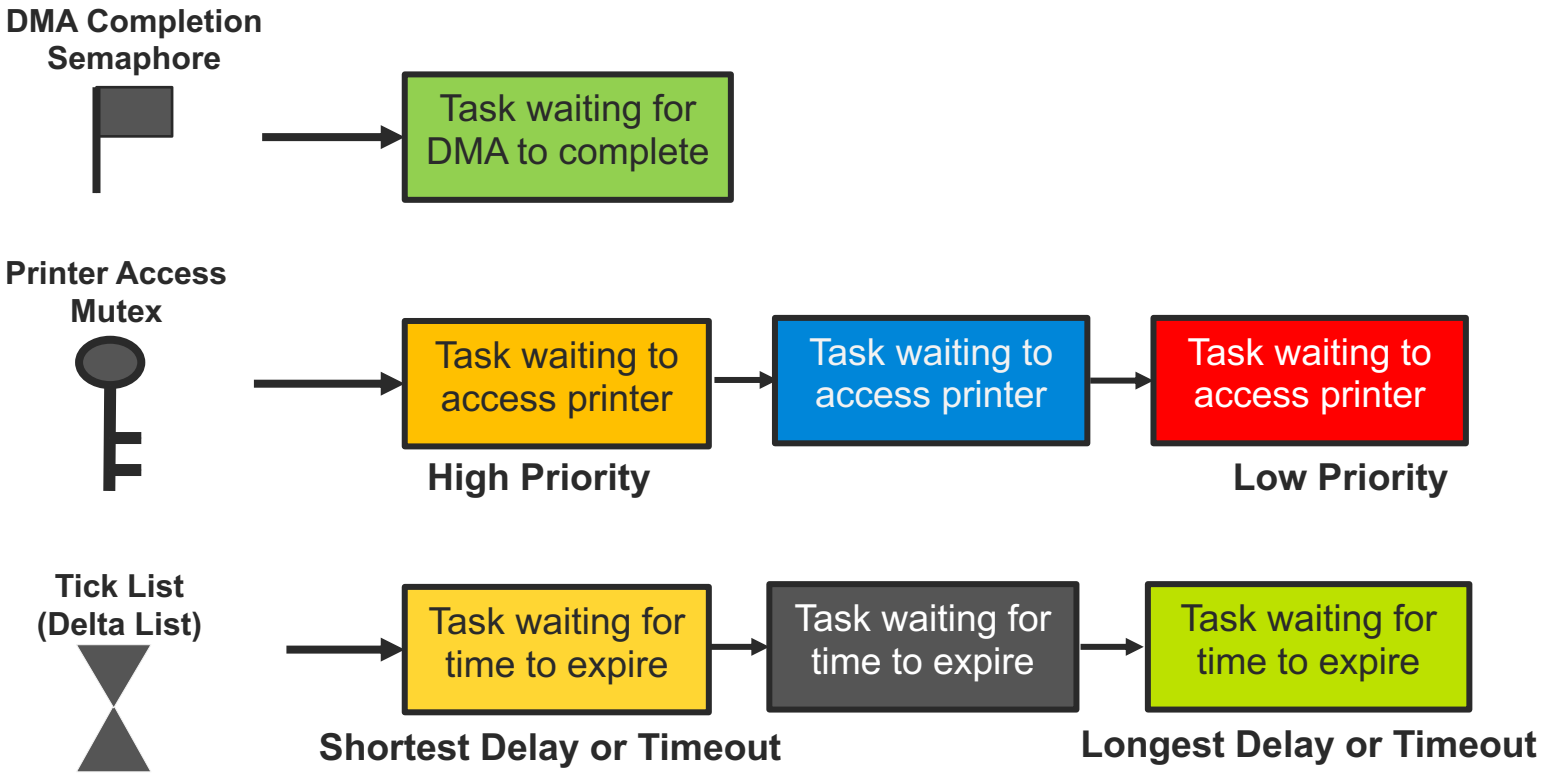
RTOSs Are Event Driven

```
void EachTask (void)
{
  Task initialization;
  while (1) {
    Setup to wait for event;
    Wait for MY event to occur;
    Perform task operation;
  }
}
```

- **Only** the highest-priority Ready task can execute
  - Other tasks will run when the current task decides to **waits for its event**
- Ready tasks are placed in the RTOS's **Ready List**
- Tasks waiting for their event are placed in the **Event Wait List** …



Tasks Waiting for Events Are Placed in a Wait List

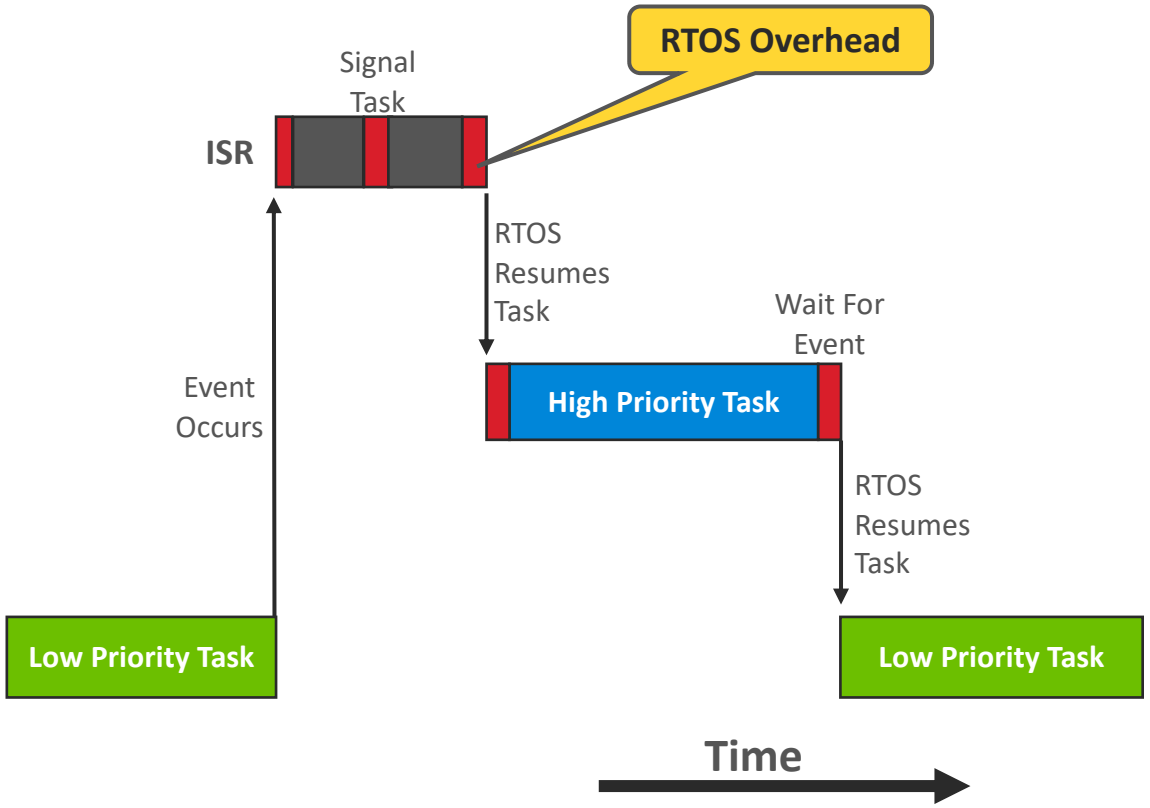


RTOSs Are Preemptive

```
void Low_Prio_Task (void)
{
  Task initialization;
  while (1) {
    Setup to wait for event;
    Wait for event to occur;
    Perform task operation;
  }
}
```

```
void ISR (void)
{
  Entering ISR;
  Perform Work;
  Signal or Send Message to Task;
  Perform Work;  // Optional
  Leaving ISR;
}
```

```
void High_Prio_Task (void)
{
  Task initialization;
  while (1) {
    Setup to wait for event;
    Wait for event to occur;
    Perform task operation;
  }
}
```

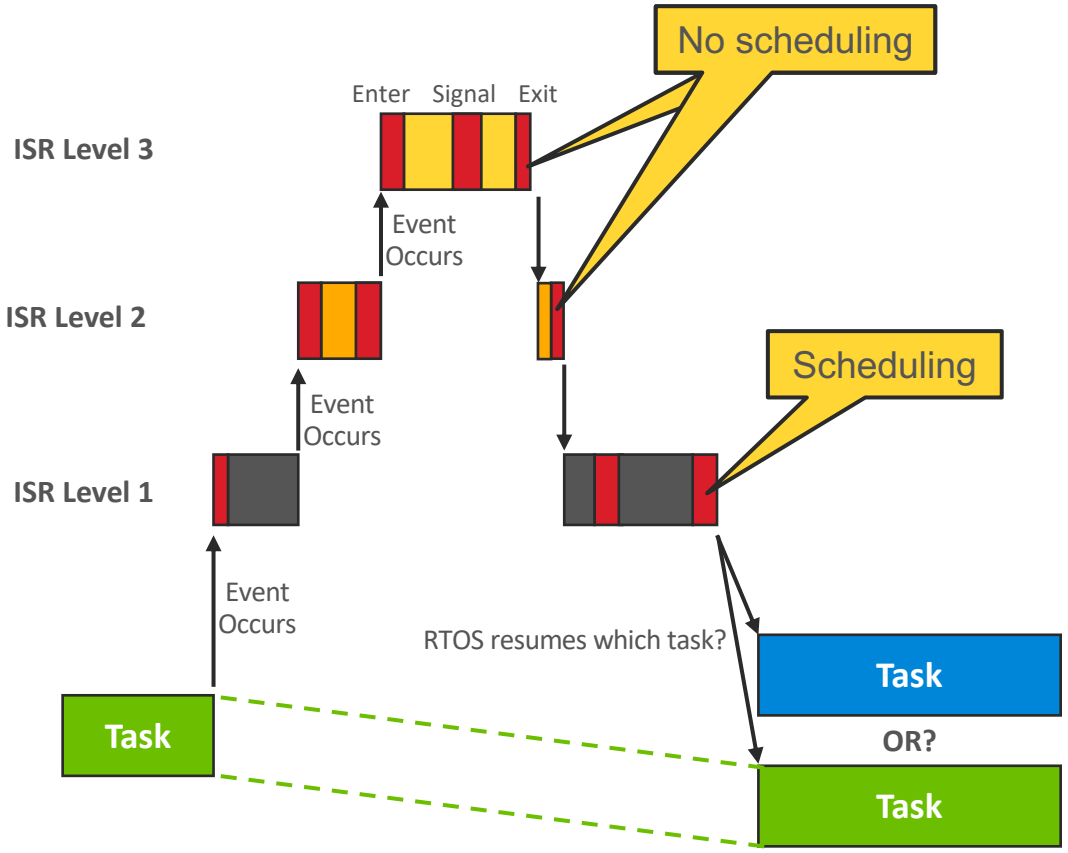


Interrupts Must Notify the RTOS

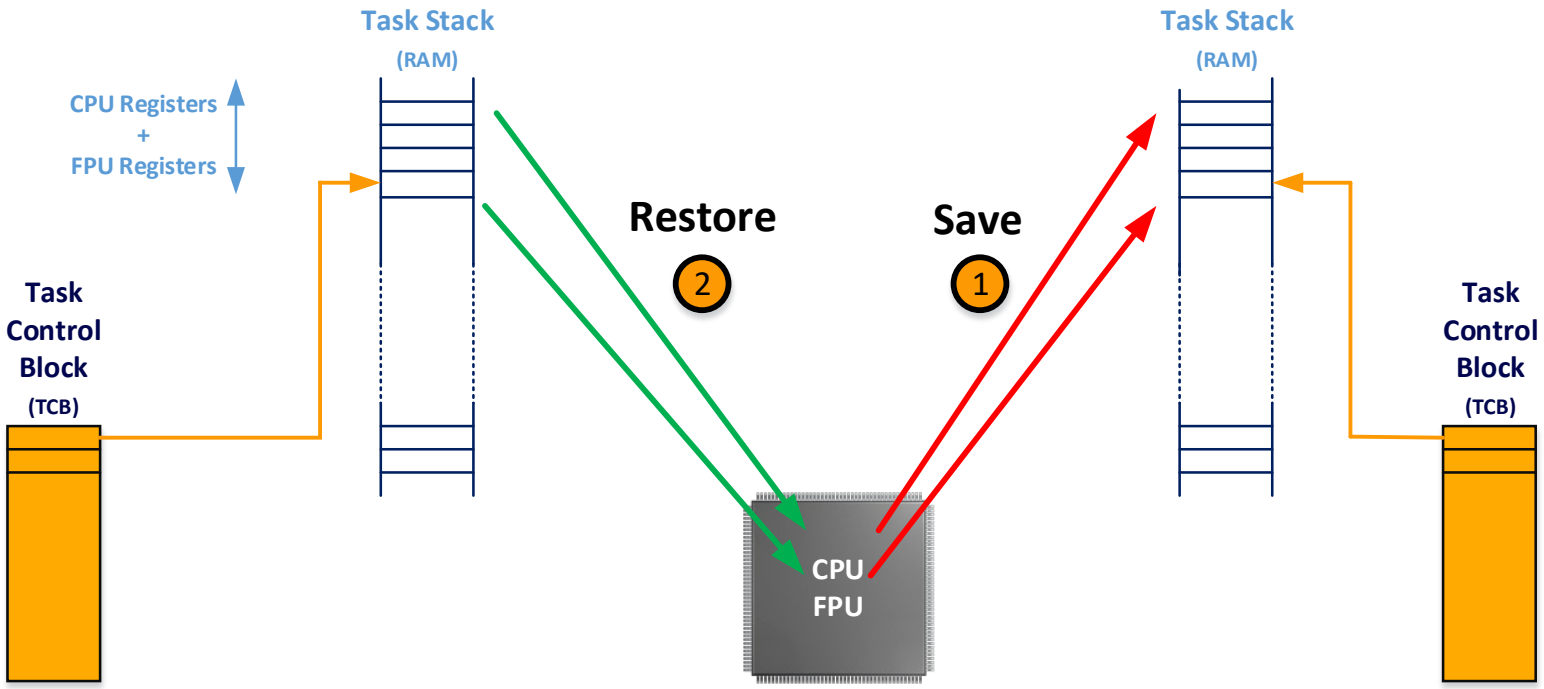
- Oftentimes, interrupts are **events** that tasks are wait for
- Interrupts are **more important** than tasks
  - Assuming, of course, that interrupts are enabled
- **Kernel Aware (KA)** ISRs:
  - Need to notify the RTOS of ISR **entry** and **exit**
    - Allows for nesting ISRs and avoid multiple scheduling

```
void MyISR (void)
{
    Entering ISR;
    :
    Signal or send a message to a MyTask;
    :
    Leaving ISR;
}
```

- ISRs can be written directly in C on Cortex-M CPUs



A Context Switch Occurs When the RTOS Decides to Run Another Task

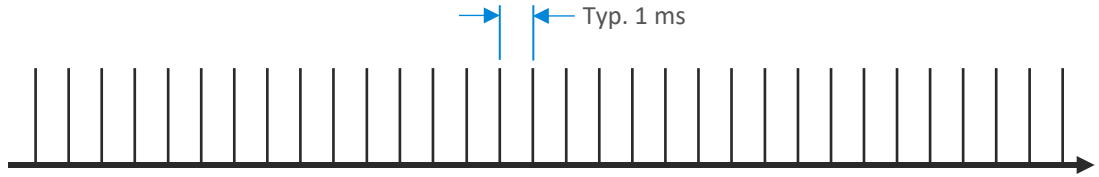


Context Switch

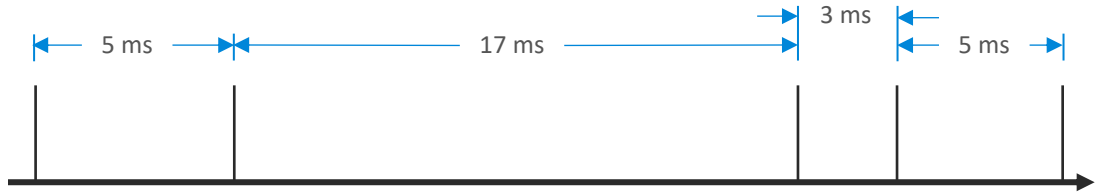
Example using Cortex-M4

Most RTOSs Have a Periodic Time Source

- Most RTOS have a time-based interrupt
  - Called the **System Tick** or **Clock Tick**
  - Requires a hardware timer
- The System Tick is used to provide **coarse**:
  - Delay (or sleep)
  - Timeouts on **Wait for Event** RTOS APIs
- A System Tick is **not** mandatory!
  - If you don't need time delays or timeouts you can remove it
- Typically interrupts at regular intervals
  - Not power-efficient
  - Dynamic tick (a.k.a. tick suppression) is more efficient
    - Requires reconfiguring the tick timer at each interrupt



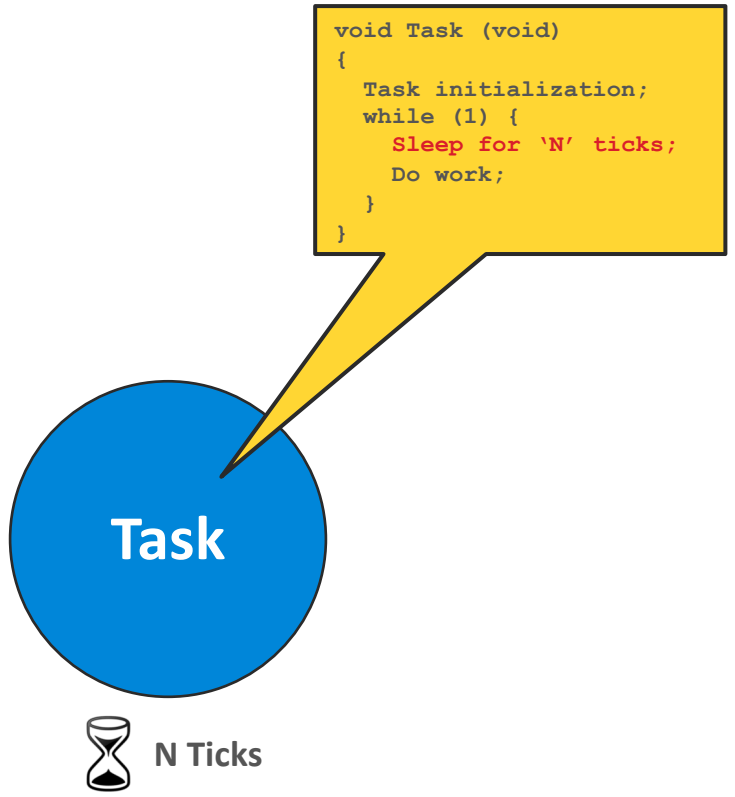
Typical RTOS Tick



Dynamic RTOS Tick

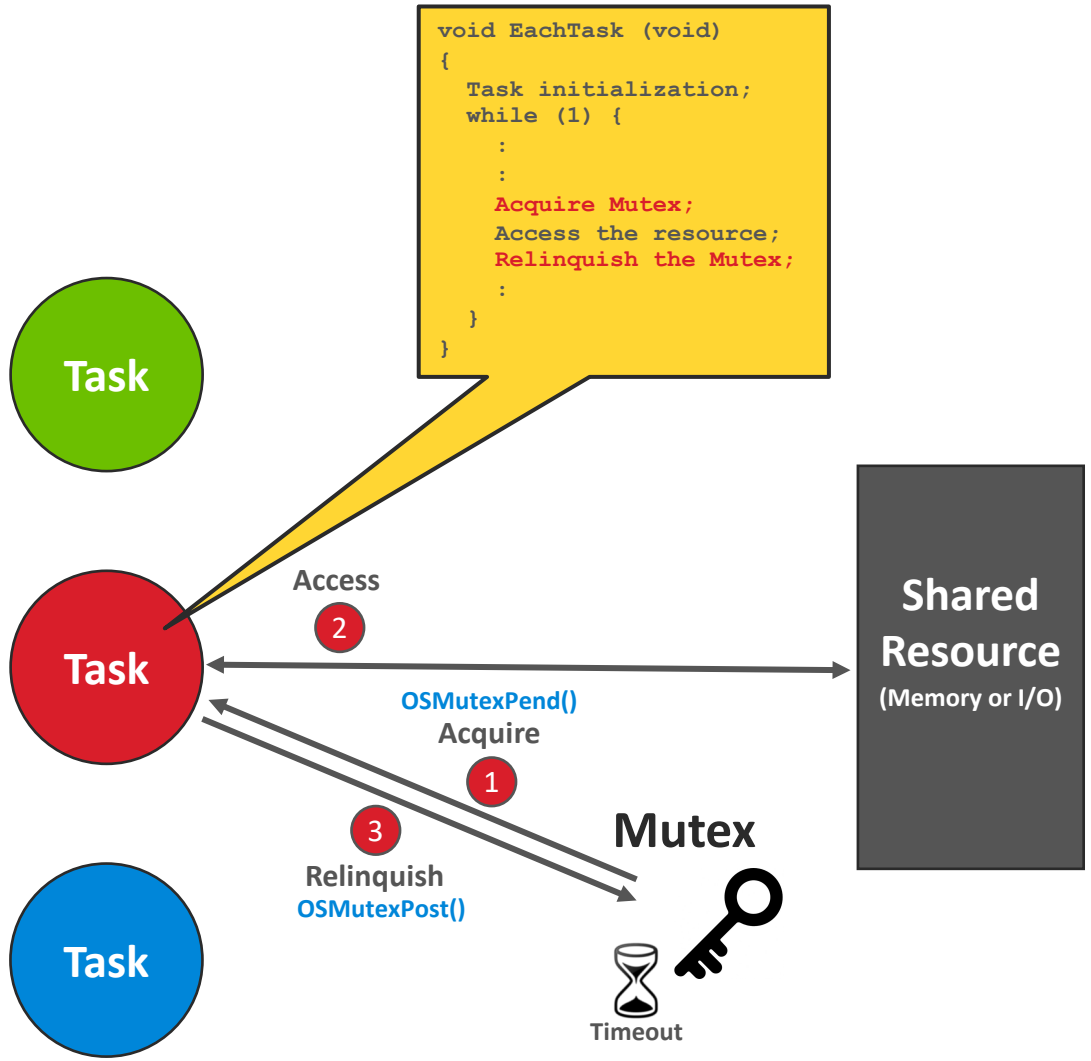
RTOS Services – Time Delays (i.e. Sleep)

- A task can put itself to **sleep** by calling RTOS APIs:
  - **OSTimeDly()** // Delay for N ticks
  - **OSTimeDlyHMSM()** // Delay for Hours, Minutes, Seconds, Milliseconds
- Can be used to **wake up** a task at regular intervals
  - Control loops
  - Updating a display
  - Scanning a keyboard
  - Letting other tasks a chance to run
  - Etc.



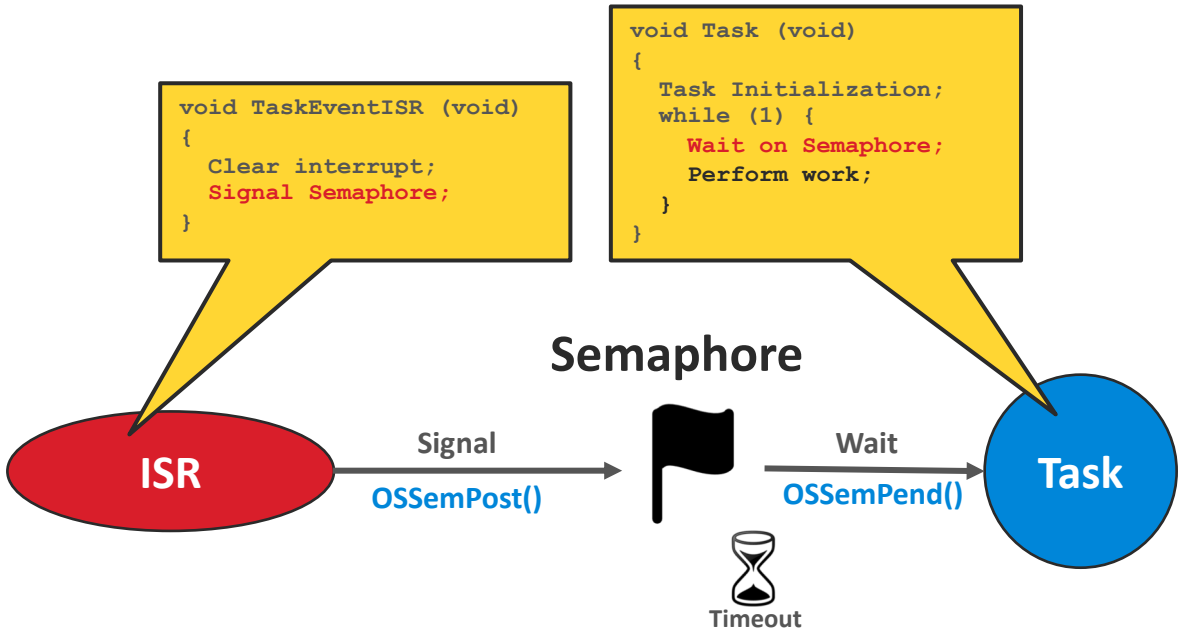
RTOS Services – Sharing a Resource Using a Mutex

- What is a resource?
  - Shared memory, variables, arrays, structures
  - I/O devices
- RTOSs typically provide resource sharing APIs
  - Mutex have built-in **priority inheritance**
    - Eliminates unbounded priority inversions
  - There could be multiple mutexes in a system
    - Each protecting access to a different resource



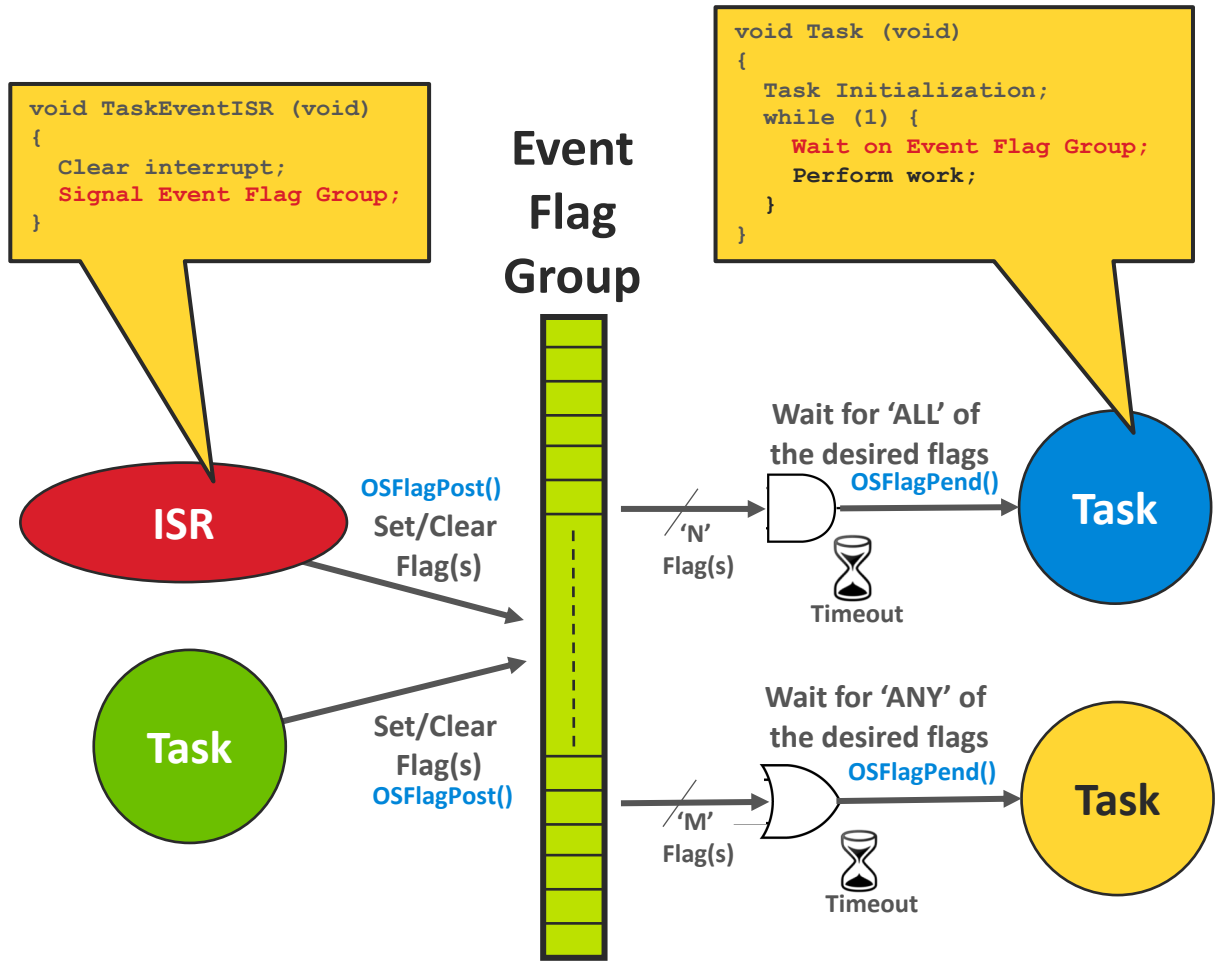
RTOS Services – Signaling a Task Using a Semaphore

- Semaphores can be used to **signal** a task
  - Called from ISR or Task
  - Does not contain data



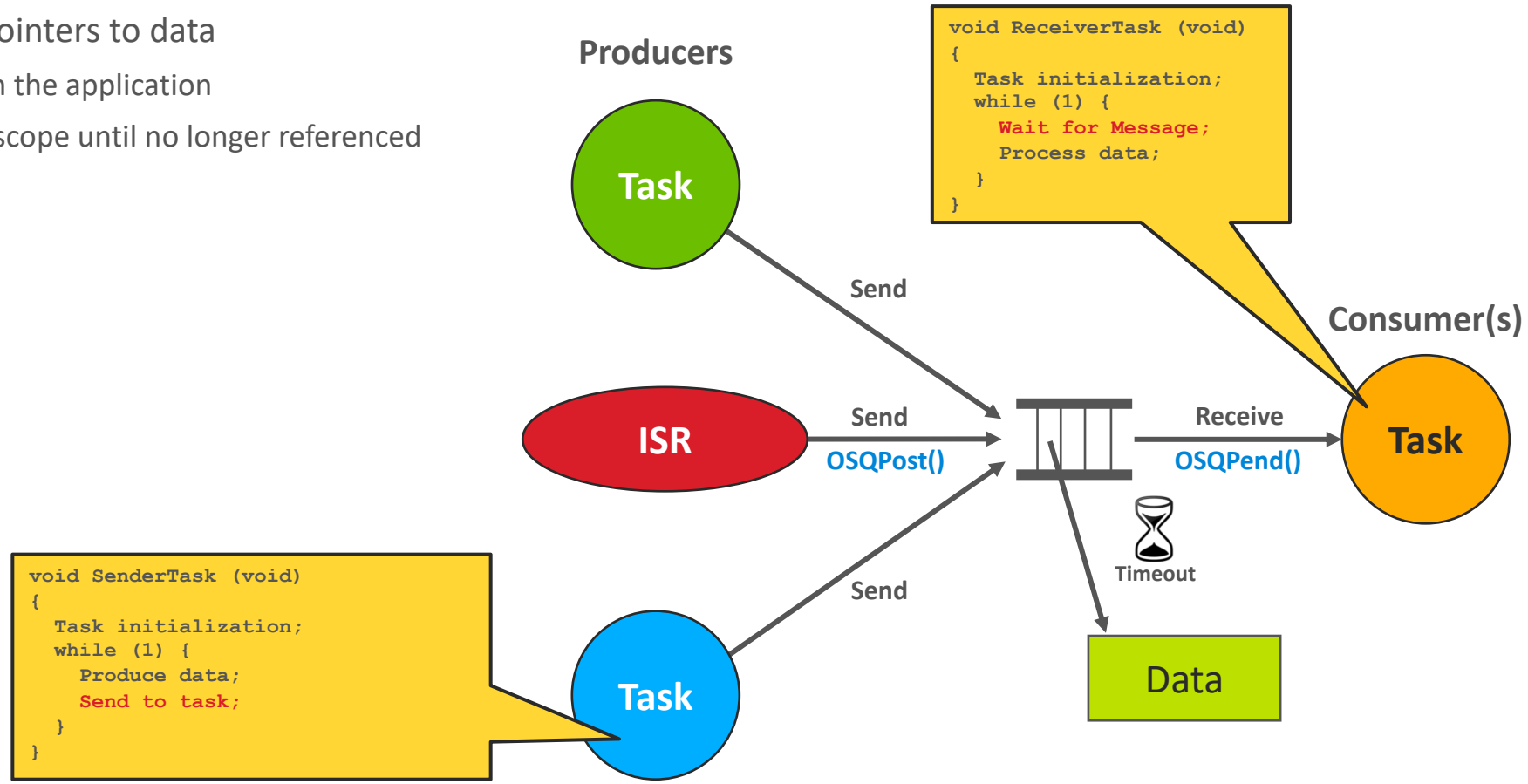
RTOS Services – Signaling Task(s) Using Event Flags

- **Event Flags** are a grouping of bits used to signal the occurrence of more than one events
  - Signals from ISRs or Tasks
  - Only tasks can wait for events

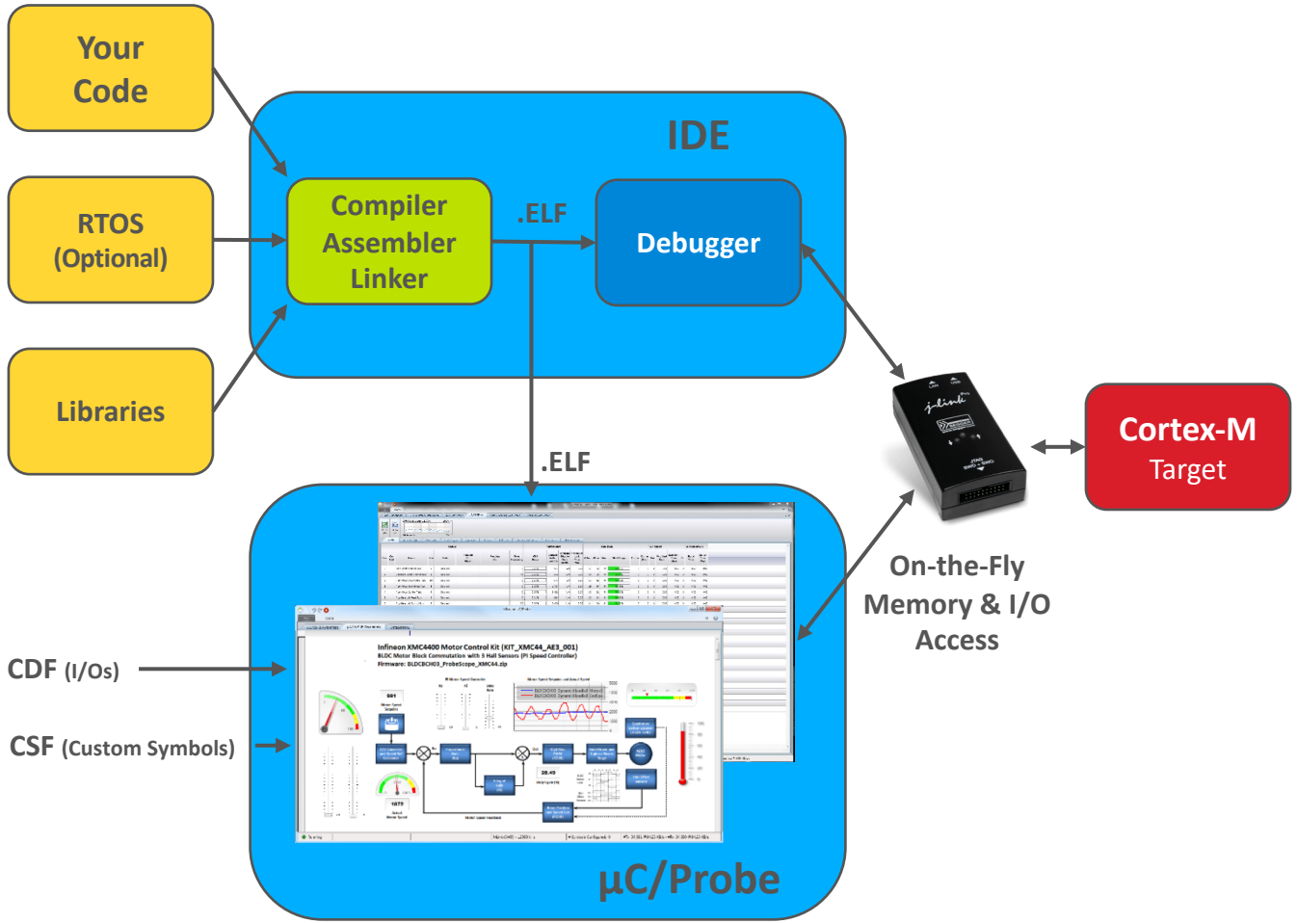


RTOS Services – Sending Messages to Task(s)

- Messages can be sent from an ISR or a task to other task(s)
- Messages are typically pointers to data
  - The data sent depends on the application
  - The data must remain in scope until no longer referenced



Debugging RTOS-Based Systems – µC/Probe, Graphical Live Watch®



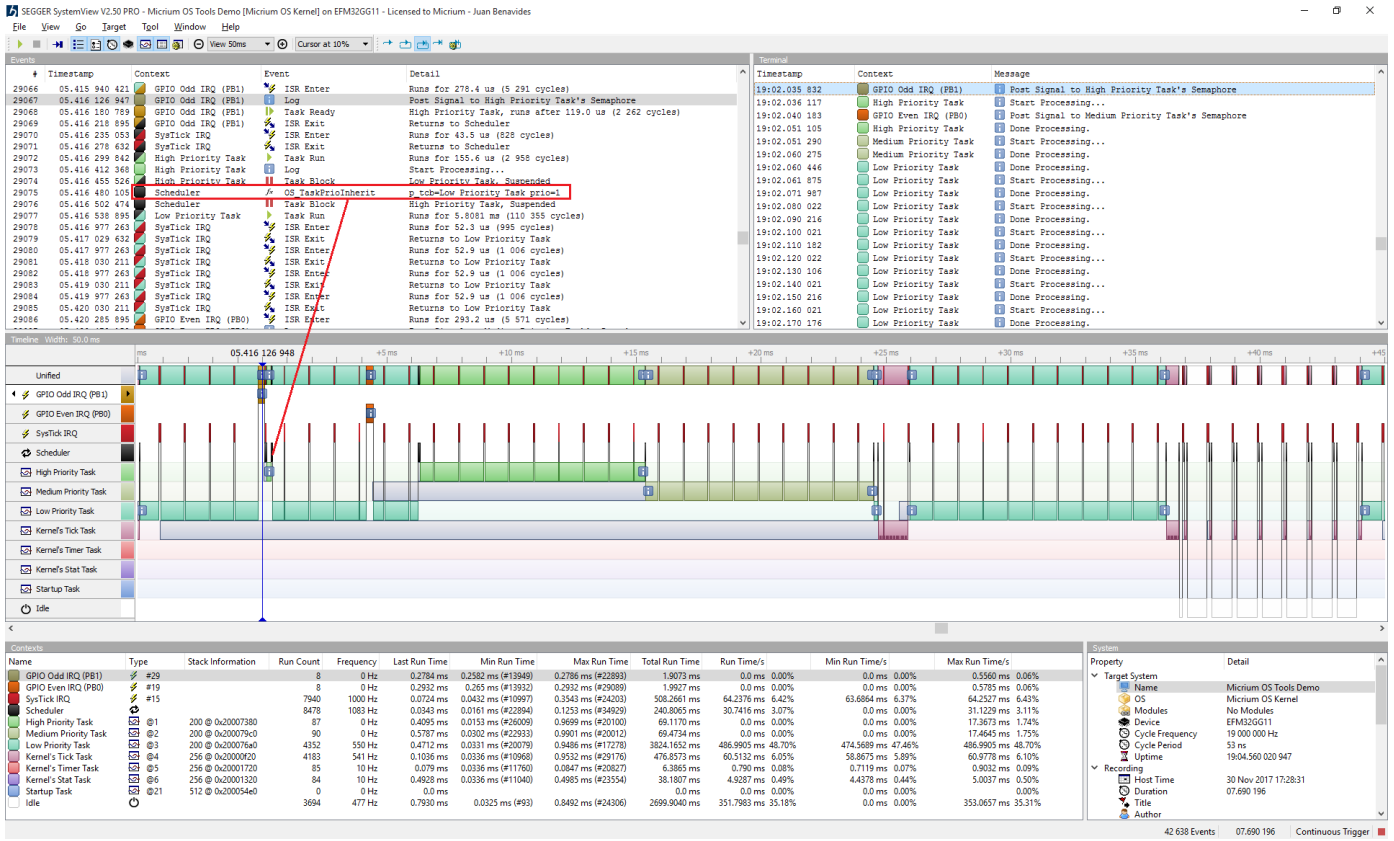
- Seeing inside an embedded system
  - Non-intrusive
- Display or change **ANY** values numerically or graphically
- A universal **tool** that interfaces to any target:
  - 8-, 16-, 32-, 64-bit and DSPs
  - No CPU intervention with Cortex-M
  - Requires target resident code if not using the debug port:
    - RS232C
    - TCP/IP
    - USB
- For **bare metal** or **RTOS**-Based applications
  - Micrium's RTOS and TCP/IP awareness

Debugging RTOS-Based Systems – µC/Probe, Graphical Live Watch®

Micrium's µC/Probe™

- **RTOS awareness**
  - Task state stack usage
  - CPU usage
  - Run counters
  - Interrupt disable time
  - Kernel objects
  - Etc.
- Built-in 8 channel **oscilloscope**
- Display live data in Microsoft **Excel**
- Scripting
- Joystick Interface
- Multimedia support
- Etc.

Debugging RTOS-Based Systems – Segger's SystemView



- Displays the execution profile of RTOS-based systems
  - Displayed **live**
    - Trigger on any task or ISR
  - Visualizing the execution profile of an application
  - Helps confirm the expected behavior of your system
- Measures CPU usage on a per-task basis
  - Min/Max/Avg task run time
  - Counts the number of task executions
- Display the occurrence of 'events' in your code
- Traces can be saved for post-analysis or record keeping

Do You Need an RTOS?

- Do you have some **real-time requirements**?
- Do you have **independent tasks**?
  - User interface, control loops, communications, etc.
- Do you have tasks that could **starve other tasks**?
  - e.g. updating a graphics display, receiving an Ethernet frame, encryption, etc.
- Do you have **multiple programmers** working on different portions of your project?
- Is **portability and reuse** important?
- Does your product need **additional middleware** components?
  - TCP/IP stack, USB stack, GUI, File System, Bluetooth, etc.
- Do you have **enough RAM** to support multiple tasks?
  - Flash memory is rarely a concern because most embedded systems have more Flash than RAM
- Are you using a **32-bit CPU**?
  - You should consider using an RTOS

Development Tools and Books

- Silicon Labs Integrated Development Environment (FREE):
  - https://www.silabs.com/products/development-tools/software/simplicity-studio
- Silicon Labs Development Boards:
  - https://www.silabs.com/products/development-tools/mcu
- Silicon Labs / Micrium OS Kernel (FREE when using Silicon Labs chips):
  - https://www.silabs.com/products/development-tools/software/micrium-os
- Micrium's µC/Probe, Graphical Live Watch® (FREE Educational Version):
  - https://www.micrium.com/ucprobe/trial/
- Segger's SystemView (FREE Evaluation Version):
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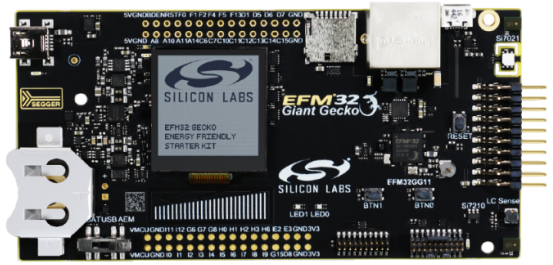

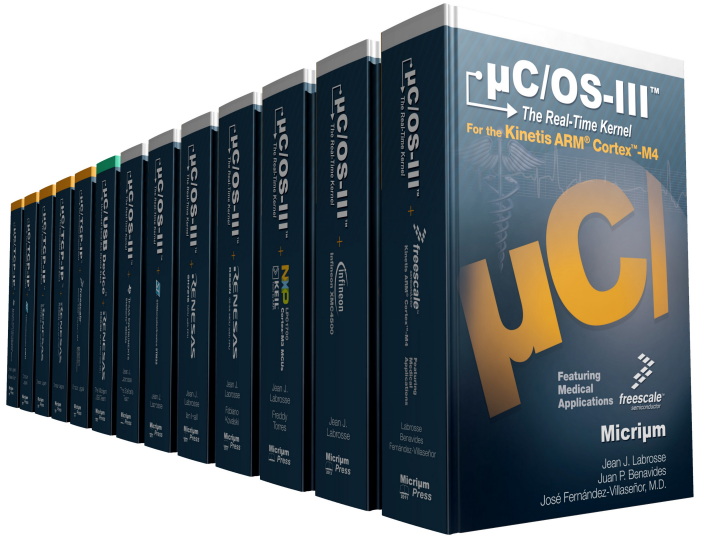

Thank you!

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