**Zephyr Operating System**

**Project Report**

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**OS Project Documentation**

**OS Selected-Zephyr**

**What we were asked to choose?**

An operating system that is Real Time Operating System.

**Aspects of Study**

We had to study the following aspects:

* OS structure
* Kernel
* Thread/Process Handling
* Resource Management
* File Systems
* Booting
* Security
* CPU Scheduling
* Main Memory

**Introduction**

**What is Zephyr**

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**It is a RTOS.**

**RTOS vs OS**

**OS:**

OSes usually gives  a non-deterministic, soft real-time response, in which there is no guarantee as to when each task will be completed, but they  try to stay responsive to the user, for example, the Java virtual machine.

**RTOS:**

RTOS usually provide a hard real time response, which result in providing a fast, highly deterministic reaction to external events for instance-zephyr

Zephyr actually has a small footprint memory. It can work on 8kB too. It was mainly designed for IOT devices due to its small memory and kernel. Also, it is resource constrained. It works best for the embedded systems, LEDs, sensors etc.

Some advantages of Zephyr are:

**Single address-space.**:

It creates a monolithic image that is loaded and executed on a system's hardware by combining application-specific code with a custom kernel. In a single shared address space, both application and kernel code run.

**Highly configurable:**

It enables an application to include only the capabilities it requires at the time it requires them, as well as to specify the quantity and size of those capabilities.

**Compile-time resource definition:**

It enables the definition of system resources at compile time, which reduces code size and improves performance.

**Minimal error checking**:

To reduce code size and improve performance, it provides minimal run-time error checking. To aid in debugging during application development, an optional error-checking infrastructure is provided.

**Extensive suite of services**:

Offers a number of familiar services for development:

1. **Multi-threading Services** for priority-based, non-preemptive and preemptive threads with optional round robin time-slicing.

2**. Interrupt Services for compile-time** registration of interrupt handlers.

3. **Memory Allocation Services** for dynamic allocation and freeing of fixed-size or variable-size memory blocks.

4. **Inter-thread Synchronization Services** for binary semaphores, counting semaphores, and mutex semaphores.

5. **Inter-thread Data Passing Services** for basic message queues, enhanced message queues, and byte streams.

6. **Power Management Services** such as tickless idle and an advanced idling infrastructure.

Zephyr Evolvement:

Zephyr was developed by LINUX foundation and Wind River Systems. It utilizes C programming language which is a high-level language. It is an open-source project.

Need of Zephyr when LINUX existed:

The main feature was of scalability.It was particularly designed for resource-constrained devices. It was actually a very small OS as compared to LINUX, and hence it was unique!

***“Great in cases where Linux is too big! It’s a really small footprint, real-time operating system built with security and safety in mind for highly constrained environments”***

***~Thea Aldrich***

Now let us see the main Structure of OS.

1.Kernel:

![Graphical user interface

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ei6dLOo+9KRtjXgnljwOhr2Pwn8A7GzKXXiq5+2SjB+yw5WMezHqfwx9a9et7aCzt0gtIY4IU+7HEgVV+gHFS1yObZpGkluV7DT7PS7NLXTraK2gQYWOJQo/8A1+9WKKKg1CiiigYUUUhIUZJwPegBajmuI7dN0jAeg9apXWqomVt/nPr2FZMkjyuWkYsfeqUbnJUxCjpHUtXeoyXGVT5E9B1NUqWitErHnSnKbuwooopkhSZoJptIQuc0lFFABRRRQAUUUUAFFFFABRRSUALmkoooAKKKSmAUUUUAFFFFAgoopKBgaaTmgnNJTAKKKKYBmikopATUUlLUgFLmkooAWikpaACiiigAooooAKKKKACiiigB2aWmUtADqKQGlpjCiiigAooooAM0tJRQAtFJmlpgFFFFABRRRQAUZooosAtXLbUZYcK/zp79RVKjNS0XGcou6Oiguorhcxtz6HrU1cwrlWBUlSO4rRttVZflnG4f3h1qHFo76eKT0ka1FRxTxzrujYEVJUHWmnsFFFFAwooooAjnt4bqBobmKOaJxhkkUMpHuDXn3iP4KeF9cLS2Ub6VcH+K35Q/VD/QivRaKd2iXFPc+ZvEHwO8UaTvk05ItUgUZzA2Hxn+4eSfpmvPbywu9OuXt7+2ltpYztZJUKkH0wa+26oaroema7a/Z9YsYLyLnAlQHbn0PUfUVoqj6mTorofFf04qaO8mjOVcn2NfQ+vfAPw/flpNFup9MkOSEP72P6YPI/M15rrnwT8W6Rl7W2j1OIc7rR8n/vk4P5A1vTryg7xdiLVIO8TlbTxJdQcM5I/MfrWxa+LI3wJ0Ge+Dj9DXLXlhd6fM0V9azW0i9UlQqR+BqvXo08yqr4tTWOLqLSWp6NDrNnMB+82H0YY/WriSpIMo6sPUHNeXrK6Y2MR9DVmLUbiI8Nn36V2wzCjL4k0bxxVN76HpVFcLB4muosAu5Hvz/OtKDxb/AM9VQ/mtdUK1GfwyRtGpCWzOoorHh8SWsg+ZWHuCCKtx6vZSdJgP94YrZRb2NLF2iokuYZP9XKjfRgafkUWaCwtFFFIAooooAKKKSgAooooAKKKKCQooooAKKSkJHcigoWioXu7eP788an3YVVk1qyj/AOWpY/7Kmq5WFmy/SGsWbxNbp9yMk/7RArPm8VSHiNUX6AmobjH4mkJtLdnU9OtRy3MMI/eyon1auJuNfupuPNfH1x/KqL3cr98VzzxuHh1v6GLxFKPW52s+vWcQ+UtIfYYFZdx4qfkQqq/juNcyWZvvMT9TTa455p/JH7zCWL/lRo3Os3Nwx3uzfU8flVJ5nfq34CrmmaBq2tTCPSdOubt/SGItj6+leiaF8A/EWoMr6xPb6XDn5lLeZJj1AXj8yK8+rja1T4pGLq1ah5VmtPSfD2r69N5Wj6dc3jjGfJjLBR6k9h719GaB8EvCmjhXvYpNUnGMtcNhM+oUfyJNd9aWVrYW4gsbeG2hByI4Ywij8BXC6glRfU8A8P8A7P8ArN4Vk8Q3sOnR55ij/eyfp8v616r4c+FfhXw3tkt7AXdwvPn3eJCD7DGB+Vdjiis3Js2jCKEAwMDgUtFFSWFFFFABRRRQAUVBPeQ24+dxu/ujk1lXOpyzfLH+7X26mmk2Y1K0IGlc38NsME7n/uise5vpblvmO1f7oqvRWijY8+pXlPToFLRRVHOFFJmkJzSELmkJpKKACiiigAooooAKKKKACiiigAoozSUAFFFFABRRSUxBRRRQMKKKKBBRRSUDCmk5ozSUwCiiimAUlFFIAopM5ooAmooopALmikooAWiiikAuaKSigBaKKKACiiigAooooAKKKKAClpKKAHA0tMpaAHUUmaWmMKKKKACiiigAozRRQAtFJRmmAtFJS0AFFFFABRRRQA5JHjbdGxU+oNaFvqzDAnXP+0KzaKTSZpCpKD0Z0kU8c65jcNUlcwrMjZRip9QcVeg1aVOJh5g9e9Q4PodsMVF/EbNFQQXkE/3HGf7p4NT1mdakpK6CiiigoKKKKACiiigCrf6XYapD5WpWVvdx/wB2eIOP1rjNV+C/gvVBlLCWwctkvaTFSfbDbgB9BXe0U7slxT3PCNW/Z1uVy2h65FJlvuXcRTav+8u7J/AVw+q/CTxppOS+jS3SbiqtaES7vfauWA+or6voqlNmbpR6HxHcWd1ZytFd28sEinDJIhUj8DUGK+3LuxtNQh8q/tYbmP8AuTRhx+RrldS+FPgvU8mXRIYXP8VszRY/AHH6VaqEOj2Z8m5p6zSp92Rh+NfQ2ofs9eHZ0J07Ub+0cn/loVlUD0xgH9a5zUP2dNQjVf7J161uD/ELmFosfTburSNZrZ2J5KkdjyAXkw6tn6irEer3MfRiP91iK7fUPgX40s5Qtrb2t+pH34LlVA/772msG9+G3jKwnMU3h2/kYdTBCZl/76TIrqjjay2mUqlaPUz08R3a/wAcn/fWf51YTxTcr1Yn6qKyrrStRsWZb2xuLdlOCJYmUg/iKq7W9P0rdZlXXVMv6zVW50q+LZu+w/VD/jUq+LT/ABCM/gRXKUVoszqdYor63Psjrh4sXHMaf99GnDxYneJD/wBtMf0rj6KpZpP+VFfW5fyo7H/hLI/+eK/9/P8A61IfFidok/77/wDrVx9FP+1JfyIX1yX8p1zeLR2jT/vomo28WtztWMfgTXK0Uv7Un0ig+ty7I6R/Fc5+6VH0Q1A/ii6bpIw+iisLntS7WPRT+VZvMq3RL7iPrVTojUfX7px/rJP++8fyqrJqdxJ94k/Uk1NY+Hta1NsadpN7dnGcQ27v/IVu6f8ACvxtqSsYPD9zGF6/adsGfpvIzWUswxD+1Yn29Z9Tljdyn+LH4UxpHPVz+del2HwE8X3kBkuWsLBwceXPOWJ9/kDD9a6Gy/ZylaBG1HxCkcufmSC2LqPoxYfyrlniqkvikyf3st2eI0c19J2PwB8KW4Q3c+oXbgfMHlVVJ+gXI/Ouq034c+ENKwbTQLMn+9MnnH/x/NYOog9lJ7nyfp2i6nq83laXp91eSYztghZz+grtNI+CfjLVChns4tOidNwku5QMexVcsD9RX1BHFHDGscKLGijCqgwAPYCnVHtGWqK6niWkfs7QgI+va2zf34rOPH5O3/xNd3o3wn8HaLsaLSVupV/5a3beaT9VPy/pXZUVLk2aKEV0I4LeG1hWK2ijhjXokahQPwFSUUVJYUUUUAFFFFABRRSE4GT0oAWiqlxqUEPAO9vRazZ9TnmyF/dr6L1/OqSbMJ14QNae9ht/vtk/3Ryay7jVZZeIv3a/rVE8nnmirUUjhqYictFoBJJyxJPqaKKKo5gopM0maBC0mfSkopAFFFFABRRRQAUUUUAFFFFABRRRmgApKKKACiiigApKKKYBRRRQAUUUUCCikpCcUDAnFJRSdaYBRRRQAUlFFABSE5oJptABmiiimMsUUUVJIUUUUAFLmkooGLRSUtABS5pKKQC0UlLmgAooooAKKKKACiiigAooooAKWkooAdmim0UAPopuaXNMBaKKKBhRRRQAUUUUAGaM0UUALRSUZpgLRSZooAWiiigAqzDqFxDxu3r6NzVaijRlKUo7M2YdWhc/vQYz+Yq6kiyDKMGHsa5mnJI8bZRmU+oNQ4djqhipL4jpqKxYtVnT/WBZB78GrsWqW8n3yYz7jiocWjrhXpy6l2imq6uMowYeoOadUm17hRRRQMKKKKACiiigAooooAKKKKACqdxo+m3ZJutOtZyepkgVs/mKuUUC0MVvBvhhmLN4b0gk9SbGLn/x2obrwF4TvLdoZvDemBGxkxWqRt1zwygEfga6CindhZHFy/CHwLLjfoEYx/dnlX+TVH/wpvwH/wBAEf8AgXP/APF13FFF2LlRw/8AwpvwH/0AR/4Fz/8AxdH/AApvwH/0AR/4Fz//ABddxRRdhyo4xPhJ4HjXaugREf7U0rfqWrWi8D+FYYljTw3pRVAAC1lGx/EkZP1NbtFF2HKjHj8IeGoW3ReHdJRumVsYwf8A0GtC3sbS0/49LWCD/rlGF/lViigdkFFFFIYUUUUAFFFFABRRRQAUUUUAFFFFABRTJJo4hmR1X6mqU2sRJxErOfXoKdmZyqRjuzQqOW4ihGZHVfYmsWbU7iXgHyx/s1UJLHLEk+pNUos5pYpfZRrTawg4gQt7nis+a7mn/wBY5x/dHSoOlFWo2OOdac92FLSUtMyCikzSZpCFzSZpKKACiiigAooooAKKKKACiiigAooooAKKM0lABRRRQAUUUlMAzRRRQAUUUUCCiiigApKKQmgYE0lJRTAKKKKADNJRRnFABmmk0E0lABRRSUwDNFFFAE4OaWmZpwNIB1FJS0gCiiigQUUUUDFzRSUUALRRmikAUuaSigBaKSlzQAUUUUAFFFFABRRRQAUUUUAFFFFAC0ZpKKAHZpaZS5oAdRSZopgLRRRQMKKKKACiiigAozRRQAZozRRQAtFJRQAtFJRmmA5HaNsoxU+oOKtxapcx/eIcf7QqlmjNKyZcZyjszXj1iNv9bGy/Tmrcd7by/dlXPoTiudzRmp5EdEcVNbnUA56c0tc0k0kf+rdl+hqzHqlyn3mD/wC8KnlZvHFxe6NyistNZ5/eRfipqddVtm6ll+oqbM2Vam+pdoqFLu3f7syfQnFShgehB+lBopJ7MWiiikUFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRTS6r95gPqaBXSHUVXe9tk6yr+BzUD6tbr90M34Yp2ZEqkFuy/RWQ+sv8A8s4lH+8c1Xk1K6f/AJabf90Yp8rMZYmmtjeLBRliAPc1Xk1C2j6yhj6LzWA0jucuxY+pNNquQxli30RrS6yP+WUWfdqpy6jcy5y+wei8VVopqKOeVepLdikknJOTSUUtUY3CikzRn0oELSZpM0lIBc0UlFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFJQAuaSiigAooozQAUZpKKYBRRRQAUUUUCCiikoGGaM0hNJTACc0lFFABiiikpgFFFITSAUmm5opKACiikpgFFFJTGGaKSigCeiiipEKKUGm9KM0APpaZmnA0gFopM0tABRRRQIKKKKBi5opKKAFooopAFLmkooAWikpc0AFFFFABRRRQAUUUUAFFFFABRRRQAUUUUALmjNJRQA7NLTKKAH0U3NGaAHUUmaKYxaKKKACiiigAooooAKKKKACiiigAooooAKKKKADNKHZfukj6UlFA7tEy3lwv3Zn/E1Iup3S9Xz9QKq0UrIpVJrZl9dYnHVIz+BqQa02PmhH4GsyijlRar1F1NUa0O8OP+BU8axF3jcVj0UuVF/Wanc2hrEHdZPyFH9sW/8Adk/75H+NYtFHIg+tVDa/ti2/uyfkP8aP7Xtv7sn5D/GsWijlQfWqhsnWIOySH8BTTrMfaNqyKKOVB9ZqGqdaHaEn/gVMOtOfuxKPqazaKOVE/WKncvHV7g9Ag+gqNtSum/5aY+gFVaKfKiXWqPqStdTv96Vz/wACNREknkmiinoZuTe7EpaKKBBRSUZoAWikzSZoEOpM0maSkA7NJmkooAKKKKACiiigAooooAKKKKACiiigAooooAKKKSgBaTNFFABRRRQAUUmaKYBRRRQAUUUUCCiiigApKKQmgYtNJopM0wCijFFABRSUUAFFGaaTQApNJmkopgFFFJQAUUhpKYxSaSikJpgGaKbRSAs0UgNLUiFopKWgApc0lFADs0tMzS5oAfRTQaWkAtFFFAgooooAKKKKBi5opKKAFoozRSAKXNJRQAtFJRQAtFGaKACiiigAooooAKKKKACiiigAooooAKKKKACiiigBc0ZpKKAFzS5ptFADs0tMooAfRTc0ZNADqKbmjdQA6ikzRmmAtFJkUZoGLRRRQAUUUUAFFFFABRRSUALRRSZoAWikyKM0ALRSZpM0CHUU3NGTQA6kpM0lIB2aM02igBc0ZpKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKM0lAC5pKKKACiiigAopM0UxBmiiigYUUUUCCiiigAopM0UDDNGaTNJTACaSiigAoozSUALRSUZoAKQmgnNNzQAtJRRTAKSiigApDRmkzTGFFJSE0wAmkopKACiiikM/9k=)

Spaces-Zephyr kernel has only one single address space, just a kernel space and no user space. It is highly configurable and not modular. Moreover, it is library based RTOS.

Graphical user interface, application

Description automatically generated

It is **monolithic** modular.

* Multithreading services, which include priority-based, non-preemptive fibres as well as priority-based, preemptive tasks (with optional round robin time-slicing).
* Interrupt services, which can be written in C or assembly language and include both compile-time and run-time registration of interrupt handlers.
* Binary semaphores, counting semaphores, and mutex semaphores are inter-thread synchronisation services..
* Basic message queues, enhanced message queues, and byte streams are inter-thread data passing services.
* Memory allocation services, including dynamic memory allocation and memory block freeing in fixed and variable sizes.
* Tick-less idle and an advanced idling infrastructure are among the power management services available.
* Highly configurable, allowing an application to include only the capabilities it requires, as well as specifying the quantity and size of those capabilities.
* To reduce code size and improve performance, Zephyr requires that all system resources be defined at compile time.
* Provides minimal run-time error checking to reduce code size and increase performance. An optional error checking infrastructure is provided that can assist in debugging during application development
* Library based RTOS ("kernel-less")

**Kernel-Less:**

There is only one executable that runs in a single address space. To dynamically load applications at run-time, no loader is required. The operating system code is kept to a bare minimum. Function calls are used to implement system calls. When calling an operating system call, no context switches are required. In this case, there is also a lack of security due to hardware memory separation. Threads are used to implement application and operating system calls in the same address space. Bugs in one part of the system can have a large impact on the entire system.

Furthermore, a full context switch with address space changes is often more efficient and time consuming. Furthermore, on small microcontrollers with only one application running, this disadvantage is tolerable.

**Zephyr Nanokernel Overview:**

A multi-threaded, high-performance execution environment with basic set of kernel features. It's perfect for systems with limited memory (the kernel only needs 2 KB!) or simple multi-threading requirements (such as a set of interrupt handlers and a single background task). The most important RTOS services are now available.

Some example of these systems are:

* + embedded sensor hubs
  + environmental sensors
  + simple LED wearables
  + store inventory tags

A picture containing chart

Description automatically generated

**Nanokernel Scheduling and Objects:**

Nanokernel is cooperatively scheduled. It is run until they yield or call a blocking API. It is marked as not runnable. After that, next highest priority fiber is then run. This kernel is typically used for device drivers and performance-critical work.

**Zephyr Microkernel Overview:**

It actually supplements the capabilities of the nanokernel to provide a richer set of kernel features. This module of kernel is suitable for systems with

* + heftier memory (50 to 900 KB)
  + multiple communication devices (like Wi-Fi and Bluetooth® Low Energy)
  + and multiple data processing tasks

Examples of such systems include:

* + Fitness wearables
  + Smart watches
  + IoT wireless gateways

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**Microkernel Scheduling and Objects:**

When no fibres are runnable, a task is scheduled in microkernel. The tasks are avoidable. The task with the highest priority is completed first. Round-robin time-slicing between tasks of equal priority is also available. Additionally, it is utilized for data processing. A server file in the nanokernel schedules tasks that are running in the microkernel. High-priority tasks should be run within the nanokernel, and interrupts should be allowed to run freely within the nanokernel. When all of the fibres have completed a task, the server fibre will send the nanokernel the next most important task. If two tasks are tied, the one that has spent the most time in the microkernel will be chosen. The two kernel system's goal is to keep memory stacks small and assign processes to the cloud whenever possible.

**Supported Platforms for Zephyr Kernel:**

Graphical user interface, website

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**2. Process/Thread Handling:**

Threads:

A thread is a kernel object that is used to process applications that are too long or complex for an ISR to handle. An application can define any number of threads (limited only by available RAM). Each thread has its own thread id, which is assigned when the thread is created.

Life Cycle of a thread:

It constitutes of many stages like:

1.Thread creation

2.Thread Abortion

3.Thread Suspension

4.Thread Resuming

5.Thread Termination

Properties of Stacks:

**Stack Area:**

It's a memory location where the thread's stack is kept. The size of the stack area can be adjusted to fit the thread's processing requirements. To create and work with stack memory regions, special macros are available.

**Thread control block**:

It is used for private kernel bookkeeping of the thread’s metadata. This is an instance of type **[k\_thread](https://docs.zephyrproject.org/latest/reference/kernel/threads/index.html" \l "c.k_thread" \t "_blank)**.

**Entry point function**:

When the thread is started, this function is called. This function accepts up to three argument values.

**Scheduling priority**:

which instructs the kernel’s scheduler how to allocate CPU time to the thread.

**Thread options:**

A set of thread options that allow the kernel to treat the thread differently depending on the circumstances.

**Start delay**:

It gives the specifics to the kernel about how long to wait before starting the thread.

**Thread Creation:**

firstly before a thread can be used, it must  be created. The thread control block and one end of the stack portion are both initialised by the kernel. The thread's stack is usually left uninitialized for the rest of its life.

The K\_NO\_WAIT start delay instructs the kernel to begin thread execution immediately. Alternatively, by specifying a timeout value, the kernel can be told to delay the thread's execution – for example, to allow device hardware used by the thread to become available.

Before the thread begins to execute, the kernel allows a delayed start to be cancelled. If the thread has already begun, a cancellation request has no effect. Before a thread can be used, it must be re-spawned after its delayed start was successfully cancelled.

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**Thread Suspension:**

If a thread is suspended, it will not be able to execute for an indefinite period of time. Any thread, including the calling thread, can be suspended using the  k\_thread\_ suspend() function. Suspending an already suspended thread has no additional effect.

Once a thread has been suspended, it cannot be scheduled until another thread calls k\_thread\_resume() to un-suspend it.

**Thread Aborting:**

By aborting, a thread can asynchronously end its execution. If a thread encounters a fatal error condition, such as dereferencing a null pointer, the kernel aborts it automatically.

By calling k\_thread\_abort, a thread can be aborted by another thread (or by itself) (). However, rather than aborting a thread, it is usually preferable to signal it to end gracefully.

The kernel does not reclaim shared resources owned by an aborted thread, as it does with thread termination.

**Thread Termination:**

When a thread is started, it usually runs indefinitely. A thread, on the other hand, can end its execution synchronously by returning from its entry point function. Termination is the term for this.

Because the kernel does not automatically reclaim shared resources (such as mutexes and dynamically allocated memory), a thread that terminates is responsible for releasing any shared resources it may own before returning..

In some cases a thread may want to sleep until another thread terminates. This can be accomplished with the **[k\_thread\_join()](https://docs.zephyrproject.org/latest/reference/kernel/threads/index.html" \l "c.k_thread_join" \t "_blank)** API. This will block the calling thread until either the timeout expires, the target thread self-exits, or the target thread aborts (either due to a k\_thread\_abort() call or triggering a fatal error).

Once a thread has terminated, the kernel guarantees that no use will be made of the thread struct. The memory of such a struct can then be re-used for any purpose, including spawning a new thread. Note that the thread must be fully terminated, which presents race conditions where a thread’s own logic signals completion which is seen by another thread before the kernel processing is complete. Under normal circumstances, application code should use **[k\_thread\_join()](https://docs.zephyrproject.org/latest/reference/kernel/threads/index.html" \l "c.k_thread_join" \t "_blank)** or **[k\_thread\_abort()](https://docs.zephyrproject.org/latest/reference/kernel/threads/index.html" \l "c.k_thread_abort" \t "_blank)** to synchronize on thread termination state and not rely on signaling from within application logic.

**Thread Definition:**

A thread is defined on run time. It is different from thread creation.

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**Thread States:**

Ready and Unready queues are present before memory. When a thread is ready, it is place in ready queue as it has all the execution features and can be executed anytime.

Following are the factors that makes the thread unready:

* The thread is not started.
* The thread is waiting for a kernel object to complete the operation. (e.g. the thread is taking a semaphore that is unavailable.)
* The thread is waiting for a timeout to occur.
* The thread has been suspended.
* The thread has terminated or aborted.

Thread Diagram:

Diagram

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**Thread Priority:**

The low numerical in priority terms is the higher priority.

There are two kinds of priorities

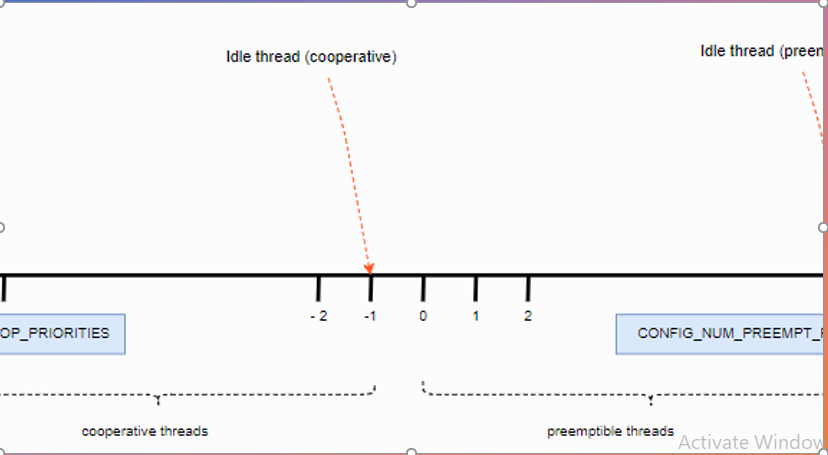
1. Cooperative thread
2. Preemptive Thread

**Cooperative Thread:**

It has a negative thread value. Once it becomes the current thread, a cooperative thread remains the current thread until it performs an action that makes it unready.

**Preemptive Thread:**

A *preemptible thread* has a non-negative priority value. Once it becomes the current thread, a preemptible thread may be supplanted at any time if a cooperative thread, or a preemptible thread of higher or equal priority, becomes ready.



**Thread Scheduling:**

The scheduler determines which thread is allowed to execute at any point in time; this thread is known as the current thread. Whenever the scheduler changes the identity of the current thread, or when execution of the current thread is supplanted by an ISR, the kernel first saves the current thread’s CPU register values. These register values get restored when the thread later resumes execution.

There are many algorithms on which threads work in zephyr. Some are:

* Cooperative and Preemptive Scheduling
* Earliest Deadline First (EDF)
* Meta IRQ scheduling implementing “interrupt bottom half” or “tasklet” behavior
* Timeslicing: Enables time slicing between preemptible threads of equal priority

Multiple queuing strategies:

* Simple linked-list ready queue
* Red/black tree ready queue
* Traditional multi-queue ready queue

**Cooperative Time Slicing:**

If a cooperative thread performs lengthy computations, it may cause an unacceptable delay in the scheduling of other threads, including those of higher priority and equal priority.

Solution to this could be:

* Calling **k\_yeild()** puts the thread at the back of the scheduler’s prioritized list of ready threads, and then invokes the scheduler
* Calling **k\_sleep()** makes the thread unready for a specified time period

**Preemptive Time Slicing:**

Once a preemptive thread becomes the current thread, it remains the current thread until a higher priority thread becomes ready, or until the thread performs an action that makes it unready.

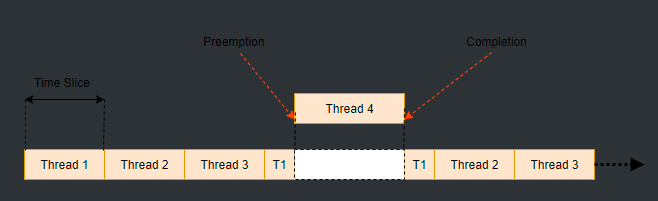
Solution to this could be:

**Scheduler Locking:**

A preemptible thread that does not wish to be preempted while performing a critical operation can instruct the scheduler to temporarily treat it as a cooperative thread by calling k\_sched\_lock().It is restored when the critical section is over. It is unlocked by k\_sched\_unlcok().

**Responsiveness:**

By following multiple scheduling algorithms zephyr meets the deadlines and is a hard time operating system. Below figure shows how tasks are scheduled and rescheduled time to time to meet nearest deadlines.



**Synchronization in Zephyr:**

There are two solution for the synchronization purposes :

1.Semaphores

2. Mutexes

**Semaphores:**

A semaphore is a kernel object that implements a traditional counting semaphore.

**Defining a Semaphore**:

A semaphore is defined using a variable of type **struct k\_sem**. It must then be initialized by calling k\_sem\_init().

The following code defines a semaphore, then configures it as a binary semaphore by setting its count to 0 and its limit to 1.

**struct k\_sem my\_sem;**

**k\_sem\_init(&my\_sem, 0, 1);**

**Giving a Semaphore**

A semaphore is given by calling **k\_sem\_give().** The following shows it.

**void input\_data\_interrupt\_handler(void \*arg)**

**{**

**/\* notify thread that data is available \*/**

**k\_sem\_give(&my\_sem); ...**

**}**

**2. Mutexes:**

A mutex is a kernel object that implements a traditional reentrant mutex. A mutex allows multiple threads to safely share an associated hardware or software resource by ensuring mutually exclusive access to the resource.

A mutex has the following key properties:

• A lock count that indicates the number of times the mutex has be locked by the thread that has locked it. A count of zero indicates that the mutex is unlocked.

• An owning thread that identifies the thread that has locked the mutex, when it is locked.

A thread that needs to use a shared resource must first gain exclusive rights to access it by locking the associated mutex. If the mutex is already locked by another thread, the requesting thread may choose to wait for the mutex to be unlocked. After locking a mutex, the thread may safely use the associated resource for as long as needed;

**Defining a Mutex:**

A mutex is defined using a variable of type struct k\_mutex.

**struct k\_mutex my\_mutex;**

**k\_mutex\_init(&my\_mutex);**

**Locking a Mutex:**

A mutex is locked by calling k\_mutex\_lock().

**CLASSICAL EXAMPLE:**

A simple application that demonstrates basic sanity of the kernel. Two threads (A and B) take turns printing a greeting message to the console, and use sleep requests and semaphores to control the rate at which messages are generated

Text

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**3.Resource Management:**

Resources are well managed by zephyr.

**Memory Slabs:**

A memory slab is a kernel object that allows memory blocks to be dynamically allocated from a designated memory region. All memory blocks in a memory slab have a single fixed size, allowing them to be allocated and released efficiently and avoiding memory fragmentation concerns.

The block size of each block, measured in bytes. It must be at least 4N bytes long, where N is greater than 0.

• The number of blocks available for allocation. It must be greater than zero.

• A buffer that provides the memory for the memory slab’s blocks. It must be at least “block size” times “number of blocks” bytes long.

**Defining a Memory Slab:**

A memory slab is a kernel object that allows memory blocks to be dynamically allocated from a designated memory region. All memory blocks in a memory slab have a single fixed size, allowing them to be allocated and released efficiently and avoiding memory fragmentation concerns.

A memory slab is defined using a variable of type struct k\_mem\_slab

The following code defines and initializes a memory slab that has 6 blocks that are 400 bytes long, each of which is aligned to a 4-byte boundary..

**struct k\_mem\_slab my\_slab;**

**char \_\_aligned(4) my\_slab\_buffer[6 \* 400];**

**k\_mem\_slab\_init(&my\_slab, my\_slab\_buffer, 400, 6);**

**Allocating a Memory Block:**

A memory block is allocated by calling k\_mem\_slab\_alloc().

The following code builds on the example above, and waits up to 100 milliseconds for a memory block to become available, then fills it with zeroes. A warning is printed if a suitable block is not obtained.

**char \*block\_ptr;**

**if (k\_mem\_slab\_alloc(&my\_slab, &block\_ptr, 100) == 0)) {**

**memset(block\_ptr, 0, 400);**

**...**

**} else {**

**printf("Memory allocation time-out");**

**}**

**Releasing a Memory Block:**

A memory block is released by calling k\_mem\_slab\_free().

The following code builds on the example above, and allocates a memory block, then releases it once it is no longer needed.

**char \*block\_ptr;**

**k\_mem\_slab\_alloc(&my\_slab, &block\_ptr, K\_FOREVER);**

**... /\* use memory block pointed at by block\_ptr \*/**

**k\_mem\_slab\_free(&my\_slab, &block\_ptr);**

**Heap Memory Pool:**

The heap memory pool is a predefined memory pool object that allows threads to dynamically allocate memory from a common memory region in a malloc()-like manner.

**Allocating Memory:**

**char \*mem\_ptr;**

**mem\_ptr = k\_malloc(200);**

**if (mem\_ptr != NULL)) {**

**memset(mem\_ptr, 0, 200);**

**...**

**} else {**

**printf("Memory not allocated");**

**}**

**Deallocating Memory:**

Memory is deallocated by calling free().

**char \*mem\_ptr;**

**mem\_ptr = k\_malloc(75);**

**... /\* use memory block \*/**

**k\_free(mem\_ptr);**

1. **Memory Management:**

**Demand paging:**

Demand paging provides a mechanism where data is only brought into physical memory as required by current execution context

There are functions where paging in and out can be invoked manually using **k\_mem\_page\_in()** and **k\_mem\_page\_out().**

**k\_mem\_page\_in()**:

k\_mem\_page\_in() can be used to page in data pages in anticipation that they are required in the near future. This is used to minimize number of page faults as these data pages are already in physical memory, and thus minimizing latency.

**k\_mem\_page\_out():**

k\_mem\_page\_out() can be used to page out data pages where they are not going to be accessed for a considerable amount of time.

**Paging Statistics:**

Paging statistics can be viewed as:

• Overall statistics via k\_mem\_paging\_stats\_get()

• Per-thread statistics via k\_mem\_paging\_thread\_stats\_get()

• xecution time histogram of backing store doing page-in via **k\_mem\_paging\_histogram\_backing\_store\_page\_in\_get()**

**PAGING ALGORITHM:**

• Not recently used algorithm (NRU)

• The paging algorithm is used to determine which data page and its corresponding page frame can be paged out to free up a page frame for the next page in operation. There are two functions which are called from the kernel paging code

• **k\_mem\_paging\_eviction\_init()** is called to initialize the paging algorithm.

• **k\_mem\_paging\_eviction\_select()** is called to select a data page to evict.

**4.File Systems:**

**FILE SYSTEM:**

**FILE:**

Zephyr RTOS Virtual Filesystem Switch (VFS) allows applications to mount multiple file systems at different mount points (e.g., /fatfs and /lfs). The mount point data structure contains all the necessary information required to instantiate, mount, and operate on a file system

**MULTIPLE INSTANCES:**

Zephyr RTOS supports multiple instances of a file system by making use of the mount point as the disk volume name, which is used by the file system library while formatting or mounting a disk

**FILE CREATION:**

A file system is declared as:

**static struct fs\_mount\_t mp =**

**{**

**.type = FS\_FATFS,**

**.mnt\_point = FATFS\_MNTP,**

**.fs\_data = &fat\_fs,**

**};**

where

• ***FS\_FATFS*** is the file system type like FATFS or LittleFS.

• ***FATFS\_MNTP*** is the mount point where the file system will be mounted.

• ***fat\_fs*** is the file system data which will be used by fs\_mount() API.

**FILE OPERATIONS:**

**FS\_O\_READ:**

It is used to open for reading file.

**FS\_O\_WRITE:**

It is used to open for writing file.

**FS\_O\_CREATE:**

It is used to create file if does not exist.

**FS\_TRUNCATE:**

It is used to truncates a file to a given size.

Graphical user interface, application

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**4.User Security:**

**Cryptographic techniques:**

The security functionality in Zephyr hinges mainly on the inclusion of cryptographic algorithms, and on its monolithic system design.The cryptographic features are provided through a set of cryptographic libraries. Applications can choose TinyCrypt2 or mbedTLS based on their needs.

**Monolithic design:**

The security architecture is based on a monolithic design where the Zephyr kernel and all applications are compiled into a single static binary. System calls are implemented as function calls without requiring context switches. Static linking eliminates the potential for dynamically loading malicious code

**Stack protection:**

Stack protection mechanisms are provided to protect against stack overruns. In addition, applications can take advantage of thread separation features to split the system into privileged and unprivileged execution environments. Memory protection features provide the capability to partition system resources.

**Memory Separation:**

Memory will be partitioned into regions and assigned attributes based on the owner of that region of memory.

**Separation of Privileges:**

Separation of privilege is the principle that two conditions or more need to be satisfied before access is granted. In the context of the Zephyr project, this could encompass split keys.

Timeline

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