Embedded Operating Systems

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Course Roadmap

Basic Concepts

- Embedded System Design Concepts
- Embedded System Developing Tools and Operating Systems
- Embedded Linux and Android Environment

Core Technology

- Real-Time System Design and Scheduling Algorithms
- System Synchronization Protocols

Real Implementation

- System Initialization and Memory Management
- Power Management Techniques and System Routine
- Embedded Linux Labs and Exercises on Android

Real-Time Operating Systems

Real Time OS

- An RTOS is an abstraction from hardware and software programming
  - Shorter development time
  - Less porting efforts
  - Better reusability
- Choosing an RTOS is important
  - High efforts when porting to a different OS
  - The chosen OS may have a high impact on the amount of resources needed

Soft Real-Time Systems

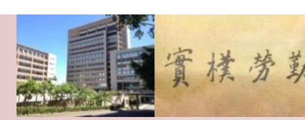
- With Soft Real-Time Systems
  - Missed deadlines are not fatal
  - Often have a human in the loop
- Example:
  - Multimedia applications
    - If the frame-rate of a video clip is lower than 30 frame/sec, the user still can watch the video
  - An automatic teller machine (ATM)
    - If the ATM takes 30 seconds longer than the ideal, the user still won’t walk away

Hard Real-Time Systems

- If the deadline is missed, data is permanently lost or people might get hurt
- Often, these systems are fully autonomous
- Examples:
  - Air bag deployment
  - Anti-lock brake system
  - Nuclear power plant controller

Pure Real-Time OS

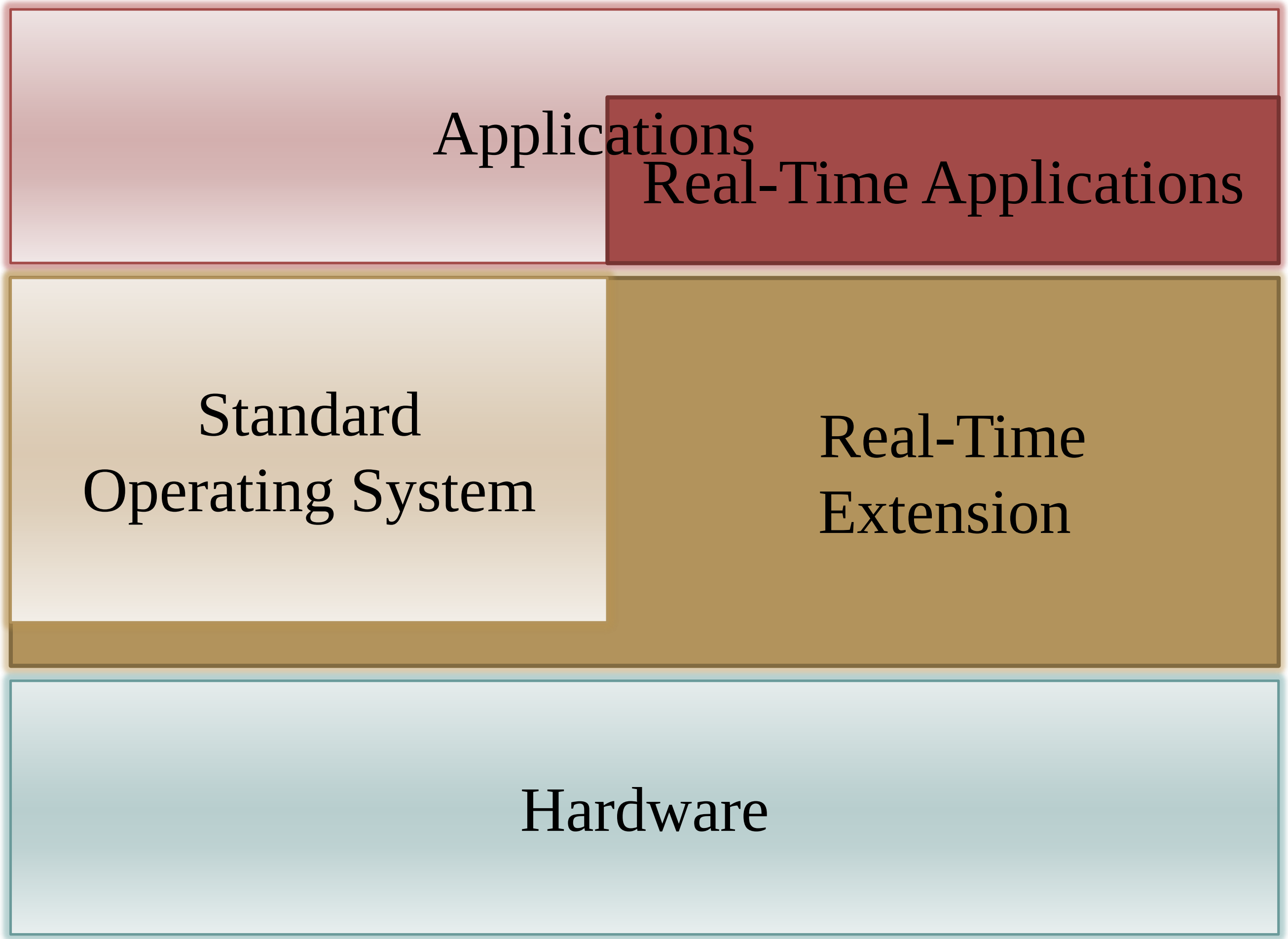
- Especially designed for real-time requirements
- Completely real-time compliant
- Often usable for simple architecture
- Advantage:
  - No or little overhead of computing power and memory
- Disadvantage:
  - Limited functionality
- Examples:
  - eCos, Nucleus, VxWork, QNX, uC/OS II



Real-Time Extension of General OS

- Extension of an OS by real-time components
- Cooperation between RT-and non-RT parts
- Advantages:
  - Rich functionality
- Disadvantage:
  - No general real-time ability
  - Need more computing and memory resources
- Example:
  - RT-Linux, Solaris

Picture of Real-Time Extension

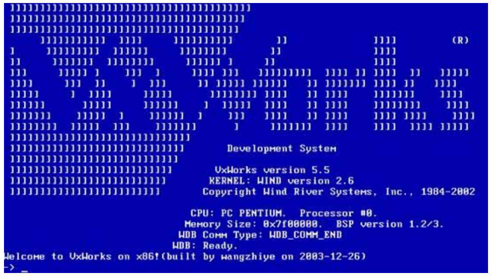


Components of a RTOS

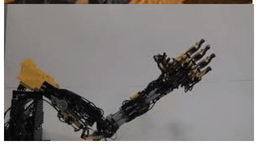
- Process Management
  - Real-Time Scheduler
  - Synchronization Mechanism
    - Inter-Process Communication (IPC)
    - Semaphores
- Memory Management
- Interrupt Service Mechanism
- I/O Management
- Development Environments

Case Studies of RTOS

Introduction of VxWorks



- Manufacturer: Wind River System
  - Largest player on the market
  - Proprietary software
- Target Platforms:
  - x86, MIPS, PowerPC, SPARC, ARM, …
- Application Examples:
  - Transport systems: Airbus A400M, AH-64 Apache, BMW iDrive
  - Spacecraft: Phoenix Mars Lander (2008), Curiosity Rover (2012), Yutu Rover (2013)
  - Robots and programmable controllers, networking and communication components, printers, copiers, and image processing



Writing C Code on VxWorks

- VxWorks consists of threads (called "tasks")
  - VxWorks does not start at a main function
  - Every global function can be called from the shell
- Every global function or variable is global to the whole system
- Every function can access to every memory location
  - Every other global function and variable can be accessed
  - Writing to a NULL pointer can corrupt the interrupt table
  - Stack overflow can crash the system

Introduction of Real-Time Linux

- What is RTLinux
  - It is a hard real-time RTOS microkernel
  - It runs the entire Linux operating system as a fully preemptive process
- The Key Ideas
  - To be hard real-time, the execution time of each component should be deterministic
  - Each real-time task can use only the device drivers with real-time support
  - Other tasks can use the whole functions of Linux and can not lock device without the monitoring of RTLinux

Modules of Real-Time Linux

- A priority scheduler that supports both a "lite POSIX" interface and the RTLinux API
- A timer which controls the processor clocks and exports an abstract interface for connecting handlers to clocks
- A module supports POSIX read/write/open interface to device drivers
- A module connects real-time tasks and interrupt handlers to Linux processes through a device layer so that Linux processes can read/write to RT components
- A package of semaphore which is used among real-time tasks
- A module shares memory between real-time components and Linux processes

Introduction of μC/OS-II (1/2)

- The name is from micro-controller operating system, version 2
- μC/OS-II is certified in an avionics product by FAA in July 2000 and is also used in the Mars Curiosity Rover
- It is a very small real-time kernel
  - Memory footprint is about 20KB for a fully functional kernel
  - Source code is about 5,500 lines, mostly in ANSI C
  - It's source is open but not free for commercial usages
- Preemptible priority-driven real-time scheduling
  - 64 priority levels (max 64 tasks)
  - 8 reserved for μC/OS-II
  - Each task is an infinite loop

Introduction of μC/OS-II (2/2)

- Deterministic execution times for most μC/OS-II functions and services
- Nested interrupts could go up to 256 levels
- Supports of various 8-bit to 64-bit platforms: x86, 68x, MIPS, 8051, etc.
- Easy for development: Borland C++ compiler and DOS (optional)
- However, uC/OS-II still lacks of the following features:
  - Resource synchronization protocol
  - Soft-real-time support

The μC/OS-II File Structure

Application Code (Your Code!)

Processor Independent Implementations

- Scheduling policy
- Event flags
- Semaphores
- Mailboxes
- Event queues
- Task management
- Time management
- Memory management

Application Specific Configurations

- OS_CFG.H
- Max # of tasks
- Max Queue length
- …

uC/OS-II Port for Processor Specific Codes

Software

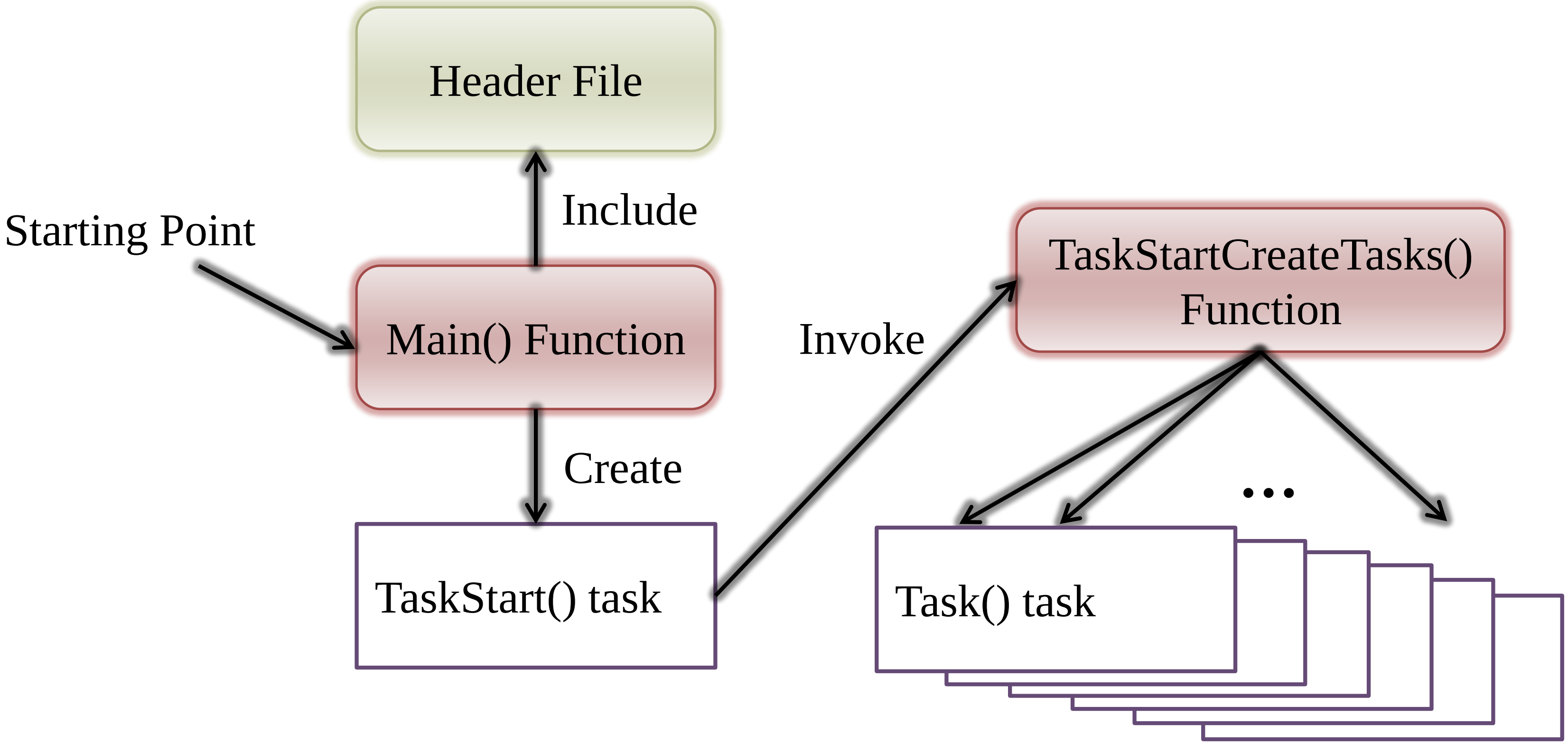
Hardware

CPU | Timer

An Example on µC/OS-II: Multitasking

- Three System Tasks
- Ten Application Tasks Randomly Print Its Number

Multitasking: Workflow



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Multitasking: Header File

```
#include "includes.h"
/*
*************************************************************************
CONSTANTS
*************************************************************************
*/
#define TASK_STK_SIZE 512
#define N_TASKS 10
/*
*************************************************************************
VARIABLES
*************************************************************************
*/
OS_STK TaskStk[N_TASKS][TASK_STK_SIZE];
OS_STK TaskStartStk[TASK_STK_SIZE];
char TaskData[N_TASKS];
OS_EVENT *RandomSem;
```


Multitasking: Main()

```
void main (void)
{
        PC_DispClrScr(DISP_FGND_WHITE + ISP_BGND_BLACK);
        OSInit();
        PC_DOSSaveReturn();
        PC_VectSet(uCOS, OSCtxSw);
        RandomSem = OSSemCreate(1);
        OSTaskCreate( TaskStart,
                      (void *)0,
                      (void *)&TaskStartStk[TASK_STK_SIZE-1],
                      0);
        OSStart();
}
```

- TaskStart: Entry point of the task (a pointer to function)
- (void *)0: User-specified data
- (void *)&TaskStartStk[TASK_STK_SIZE-1]: Top of stack
- 0: Priority (0=hightest)

Multitasking: TaskStart()

```
void TaskStart (void *pdata)
{
        /*skip the details of setting*/
        OSStatInit();
        TaskStartCreateTasks();
        for (;;)
        {
                if (PC_GetKey(&key) == TRUE)
                {
                        if (key == 0x1B) { PC_DOSReturn(); }
                }
                OSTimeDlyHMSM(0, 0, 1, 0);
        }
}
```

Call the function to create the other tasks

See if the ESCAPE key has been pressed

Wait one second

Multitasking: TaskStartCreateTasks()

```
static void TaskStartCreateTasks (void)
{
        INT8U i;
        for (i = 0; i < N_TASKS; i++)
        {
                TaskData[i] = '0' + i;
                OSTaskCreate(
                        Task,
                        (void *)&TaskData[i],
                        &TaskStk[i][TASK_STK_SIZE - 1],
                        i + 1 );
        }
}
```

Entry point of the task (a pointer to function)

Argument: character to print

Top of stack

Priority

Multitasking: Task()

```
void Task (void *pdata)
{
        INT8U x;
        INT8U y;
        INT8U err;
        for (;;)
        {
            OSSemPend(RandomSem, 0, &err);
            /* Acquire semaphore to perform random numbers */
            x = random(80);
            /* Find X position where task number will appear */
            y = random(16);
            /* Find Y position where task number will appear */
            OSSemPost(RandomSem);
            /* Release semaphore */
            PC_DispChar(x, y + 5, *(char *)pdata, DISP_FGND_BLACK +DISP_BGND_LIGHT_GRAY);
            /* Display the task number on the screen */
            OSTimeDly(1);
            /* Delay 1 clock tick */
        }
}
```

Randomly pick up the position to print its data

Print & delay

OSinit()
(\SOFTWARE\uCOS-II\EX1_x86L\BC45\SOURCE\OS_CORE.C)

- Initialize the internal structures of μC/OS-II and MUST be called before any services
- Internal structures of μC/OS-2
  - Task ready list
  - Priority table
  - Task control blocks (TCB)
  - Free pool
- Create housekeeping tasks
  - The idle task
  - The statistics task

PC_DOSSaveReturn()

(\SOFTWARE\BLOCKS\PC\BC45\PC.C)

- Save the current status of DOS for the future restoration
  - Interrupt vectors and the RTC tick rate
- Set a global returning point by calling setjump()
  - µC/OS-II can come back here when it terminates.
  - PC_DOSReturn()

PC_VectSet(uCOS,OSCtxSw)
(\SOFTWARE\BLOCKS\PC\BC45\PC.C)

- Install the context switch handler
- Interrupt 0x08 (timer) under 80x86 family
  - Invoked by INT instruction

OSStart()
(SOFTWARE\uCOS-II\EX1_x86L\BC45\SOURCE\CORE.C)

- Start multitasking of µC/OS-2
- It never returns to main()
- µC/OS-II is terminated if PC_DOSReturn() is called

Conclusion of μC/OS-II

- Operating System Contents
  - Data structure of each OS component
  - Basic functions of task scheduling and resource management
  - Other fundamental supports of OS
- Application Format
  - Each task is an infinite loop
  - Ready tasks execute according to their priorities
- Porting Efforts
  - CPU and timer setting
  - Interrupt handler