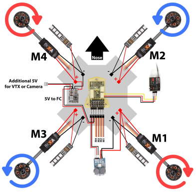

Embedded Software Architectures

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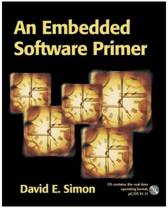
Readings

- Read Chap 5 of Simon, D. E. (1999). An Embedded Software Primer
- Skip section 5.3 on Function queue scheduling



[1] Readings are based on Simon, D. E. (1999). An Embedded Software Primer (Pap/Cdr ed.). Addison-Wesley Professional.
[2] Bold reading section are mandatory. Other sections are suggested but not required readings

Introduction

- This lecture will discuss various architectures for embedded software—the basic structures that are used to put together an embedded system software.
- The best architecture depends on several factors:
  - Real-time requirements of the application (absolute response time)
  - Available hardware (speed, features)
  - Number and complexity of different software features
  - Number and complexity of different peripherals
  - Relative priority of features
- Thus, each software architecture is tradeoff between complexity and control over response and priority

Choosing the best software architecture

- When designing an embedded software, what is the most optimum software architecture to use for a given system?
- The best architecture depends on several factors
  - Real-time requirements of the application (absolute response time)
  - Available hardware (speed, features)
  - Number and complexity of different software features
  - Number and complexity of different peripherals
  - Relative priority of features
- The decision is based on the tradeoff between complexity and control over response and priority:
  - Systems that require little control and poor response can be done with simple architectures
  - Rapid response systems will require more complex program design to be successful.

Example 1 —Air conditioning

- This system can be written with a very simple software architecture.
- The response time can be within a number of tens of seconds.
- The major function is to monitor the temperature readings and turn on and off the air conditioner.
- A timer may be needed to provide the turn-on and turn-off time.

Example 2 —Office telephone with Speaker

Consider a digital telephone answering machine with speech compression. It performs the following operations

- Records about 30 minutes of total voice sampled at 8kHz
- The software design for the answering machine
  - It must respond rapidly to many different events.
  - It has restrictive and various processing requirements.
  - It has different deadlines and different priorities

Example 2 —Office telephone with Speaker

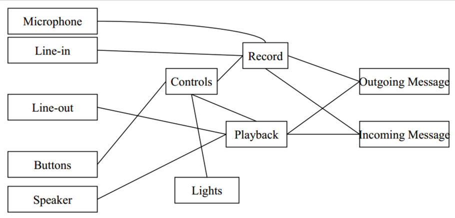
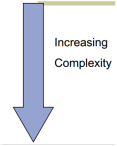


FIG 1. Simplified class diagram of the office telephone

Basic RT software architectures

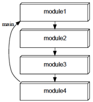
- Round-Robin
- Round-Robin with Interrupts
- Real-Time Operating System



Round Robin

Round Robin

- Simplest architecture
- No interrupts
- Main loop checks each device one at a time, and service whichever needs to be serviced.
- Service order depends on position in the loop.
- No priorities
- No shared data
- No latency issues (other than waiting for other devices to be serviced




```
void main(void) {
  while (TRUE) {
    module1();
    module2();
    module3();
    module4();
  }
}
```

FIG 2. Round Robin[1]

[1] Baier, M. (2014). Embedded software development in research environment: A

Round Robin Architecture

```
void main(void) {
  while (true) {
    if (Device_A_needs_service()){
      //Service device A
    }
    if (Device_B_needs_service()){
      //Service device B
    }
    if (Device_C_needs_service()){
      //Service device C
    }
    // Etc...
  }
}
```

LISTING 1: Round Robin Architecture

Round-Robin architecture—Pros and cons

Advantages:

- Simple solution, but sufficient for some applications.
- Exchanging data between tasks is easy.

Drawbacks:

- The worst-case latency of an external request is equal to the execution time of the entire main loop.
  - Architecture fails if any one device requires a shorter response time
  - Most I/O needs fast response time (buttons, serial ports, etc.)
- Implementing additional features can adversely affect the correctness of a system, by increasing latencies beyond acceptable bounds.
- Architecture is fragile to added functionality: adding one more device to the loop may break everything

Example —A digital multimeter

- This uses a round-robin works well for this system because:
  - only 3 I/O devices
  - no lengthy processing
  - no tight response requirements
  - small delays in switch position changes will go unnoticed
- No emergency control
  - No such requirements
  - Users are unlikely to notice the few fractions of a second it takes for the microprocessor to get around the loop
- Adequate because it is a SIMPLE system!
  - Simple devices such as watches, simple microwave ovens, toys, vending machine etc
  - Devices where operations are all user initiated and process quickly
  - Anything where the processor has plenty of time to get around the loop, and the user won't notice the delay

Example —digital multimeter

```c
void vDigitalMultiMeterMain (void)
{
    enum {0HMS_1, 0HMS_10 V0LTS_100} eSwitchPosition;
    while (TRUE)
    {
        eSwitchPosition = // Read the position of the switch;
        switch (eSwitchPosition)
        {
            case 0HMS_1:
                  // Read hardware to measure ohms Format result
            break;
            case 0HMS_10:
                 //Read hardware to measure ohms
                 // Format result
            break;
            case V0LTS_100:
                  //Read hardware to measure volts
                  // Format result
            break;
        }
        // Write result to display
    }
}
```

FIG 3. Digital multi-meter—It is possible to use a round-robin architecture because its users cannot expect faster response than they can move their hands and the probes

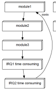
Summary —Round robin architecture

- This is the simplest architecture devoid of interrupts or shared-data concerns
- However several problems arise from its simplicity:
  - If a device has a response time constraints this architecture has problems (e.g. if in the example device Z has a deadline of 15 ms and A and B take 10 ms each.)
  - If any one of the cases at the worst take 5 seconds, the system would have a max. response time of 5 seconds, which would make it less appealing.
  - Architecture is not robust. Addition of a single device might cause all deadlines to be missed.

Round-robin with interrupts

Round-robin with interrupts

- Allows some control of software execution
- Gives more control over priorities.
- Based on Round Robin, but interrupts deal with urgent timing requirements.
- Interrupts a) service hardware and b) set flags
- Main routine checks flags and does any lower priority follow-up processing.




```
void main(void) {
  while (TRUE) {
    module1();
    module2();
    module3();
    if (irq1 do calc) irq1AddCalc();
    if (irq2 do calc) irq2AddCalc();
  }
}
void IRQ1_ISR(void) {
   …
   irq1 do calc = true;
}
```

FIG 4. Round robin with interrupts

[1] Bajer, M. (2014). Embedded software development in research environment: A practical guide for non-experts. Proceedings - 2014 3rd Mediterranean

Round-robin with interrupts

Principles: Tasks are invoked in round-robin fashion, but interrupt routines take care of urgent operations

- A little bit more control
  - In this architecture, interrupt service routines (ISR) deal with the very urgent needs of the hardware and set corresponding flags
  - Interrupt routines set flags to indicate the interrupt happened
  - main while loop polls the status of the interrupt flags and does any follow-up processing required by a set flag.
- ISR can get good response
- All of the processing that you put into the ISR has a higher priority than the task code

Round-robin with interrupts

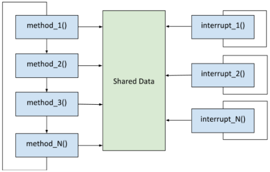
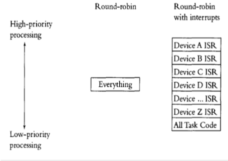


FIG 5. Round Robin with Interrupts[1]

[1] Automaticaddison, A. (2019, May 6). Round-Robin vs Function-Queue-Scheduling. Automatic Addison. https://automaticaddison.com/round-robin-vs-function-queue-scheduling-embedded-software-architecture/#round_robin

Round-robin with interrupts

```
bool fDeviceA = false, fDeviceB =false, fDeviceZ= false;
void interrupt vHandieDeviceA (void){
    // Take care of I/O Device A
    fDeviceA =true;
}
void interrupt vHandleDeviceB (void){
    // Take care of I/O Device B
    fDeviceB =true;
}
void interrupt vHandleDeviceZ (void){
    // Take care of I/O Device Z
    fDeviceZ = true;
}
void main (void){
    while (TRUE){
        if (fDeviceA){
            fDeviceA =false;
            // Handle data to or from I/O Device A
        }
        if (fDeviceB){
            fDeviceB =false;
            // Handle data to or from I/O Device B
        }
        if (fDeviceZ){
            fDeviceZ = false;
            //Handle data to or from I/O Device Z
        }
    }
}
```



Round-robin with interrupts—Pro and cons

Advantages

- Still relatively simple
- Hardware timing requirements better met

Drawbacks

- All task code still executes at same priority
- Maximum delay unchanged
- Worst case response time = sum all other execution times + execution times of any other interrupts that occur

Possible improvements

- Change order flags are checked (e.g., A,B,A,B,A,D)
  - Improves response of A
  - Increases latency of other tasks
- Move some task code to interrupt
  - Decreases response time of lower priority interrupts
  - May not be able to ensure lower priority interrupt code

Real Time Operating System

Real Time Operating System Architecture

- Most complex
- Interrupts signal the need for follow-up tasks
- Instead of a loop deciding what to do next the RTOS decides.
- Interrupts handle urgent operations, then signal that there is more work to do for task code
- One follow-up task can be suspended by the RTOS in favoring of performing a higher priority task.
- Differences with previous architectures
  - We don't write signaling flags (RTOS takes care of it)
  - No loop in our code decides what is executed next (RTOS does this)
  - RTOS knows relative task priorities and controls what is executed next
  - RTOS can suspend a task in the middle to execute code of higher priority

RTOS—Pros and cons

Advantages

- Task do not disturb others —This is actually remarkably hard otherwise
- Provices a standard way for memory protection —if a process tries to access memory that isn't its own, it fails. This is probably a fault and it makes debugging a lot easier.
- Built in priority-based scheduling, abstracting timing information
- Maintainability and

Disadvantages

- An RTOS itself needs some processing time, throughput is affected.
- An RTOS used lot of system resources which is not as good
- Very few tasks run at the same time and their concentration is restricted to few applications to avoid errors
- Quality and industrial-level RTOS are expensive

Conclusion—Architecture Selection

- Select the simplest architecture that will meet your response requirements.
- If your response requirements might necessitate using a real-time operating system then that should probably be your choice.
- Things rarely get smaller/simpler and its a lot easier to start on a more complicated architecture than to migrate to it later when things grew to hairy
- If it makes sense create hybrids

TAB 1. Characteristics of various software architectures

	Priorities available	Worse response time for task code	Code maintainablity	Simplicity
Round-robin	None	Sum of all task code	Poor	Very simple
Round-robin with interrupts	Interrupt routines in priority order, then all task code at the same time	Total of execution time for all task code (plus execution time for interrupt routines)	Good for interrupt routines. Poor for task code	Must deal with data shared between interrup routines and task code
	then task code in priority order	routines)		the OS itself and is usually hidden to the programmers/user)

The end