Embedded and Ambient Systems
2023.10.03.

SW architectures of embedded systems

Méréstechnika és
Információs Rendszerek
Tanszék

SW development alternatives

- Resources! (CPU, MEM, Energy)
- Different approach compared to a PC: HW-based programming
- Direct handling of:
  - Polling
  - Interrupt (IT)
- Low level programming (Assembly)
  - To solve less complex tasks
  - Time critical applications
  - Difficult development and debugging
  - Exploiting special peripheral
- High level programming (C, C++, Java?)
  - Less efficient (not always)
    - Some specialties are difficult to understand by humans, e.g. delayed branch, pipeline design…
  - Faster development, reengineering and scalability
  - ASM code parts can be inserted in a C-language environment
- Embedded operation system
- Graphical programming languages, automatic code generation

Services

- Basic tasks
  - Observations
  - Handling peripherals
  - Handling events
  - Timing
  - Communications
  - Data processing
- Problems:
  - Processor: sequential operation
  - Events: occur in an asynchronous manner, overlapped in time
- Various requirements (on program structure):
  - E.g. the program of the microwave oven is finished. Not a critical application, e.g. 1s delay is not even noticed
  - Direction indicator in a car: not that much time critical but safety critical therefore the requirements are more severe
  - Braking system in a car is strongly time- and safety critical (1s delay does matter)
- Handling of tasks has to be planned (process scheduling)

Considerations of program structure used

- Considerations:
  - Resources available / softver-overhead
    - Overhead due to extra computation of process scheduling
  - Memory (storage capacity) available (RAM, ROM)
  - Predictability (planning of the SW system in advance)
  - Scalability, re-engineering
    - Need for extra development due to inserting a new task
  - Time needed for executing a task
  - Reaction time for an external asynchronous event
  - Prioritization of tasks
  - Usage of processor
    - Energy saving operation, how much the resources of the processor is exploited
  - Protection (memory, run time)
  - Recursion, support of function (re)calls
  - Implementation of HW handling
  - Implementation of communications between tasks
  - Application field (e.g. consumer electronics, automotive industry)

Program structuring disciplines

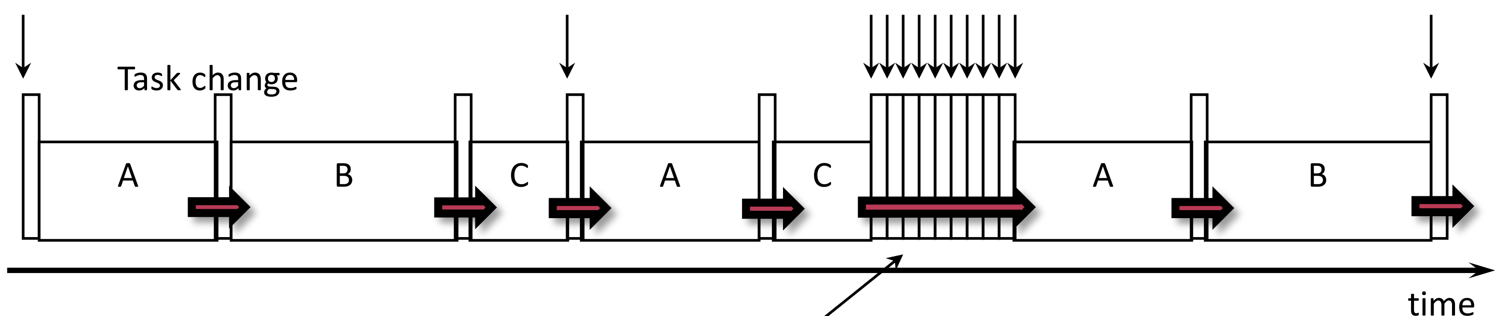
- Cyclic programming
  - Simple cyclic
  - Weighted cyclic
  - Time-controlled cyclic
  - Strict time-controlled cyclic
- Cyclic process scheduling with interrupt (IT)
- Scheduled functions

Simple cyclic program structure

- Tasks are executed one after the other in a cyclic manner (e.g. bicycle computer)

```
void main() {
while (TRUE){
        if (button1_pushed==true) {change_menu() ;}
        if (sensor_state==active) {calculate_speed() ;}
         if (speed_calculated==true) {display_speed();}
        ...
        }
}
```

Border of cycles



Service is not asked for, i.e., no button pushed, etc.

(but the processor runs /checking if a process should be run or not/->not energy friendly!)

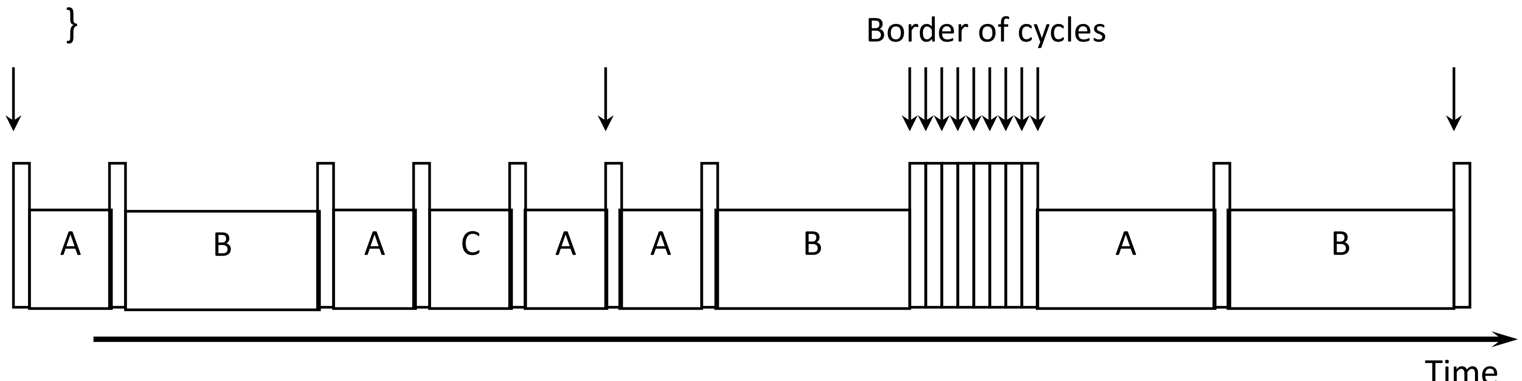
Simple cyclic program structure

- Simple structure
- Communications between tasks:
  - Shared variables, no problem since the are not preemptive: only one task runs at a time (Problem would be: one task reads an other task writes the variable at the "same" time – here this situation cannot happen since tasks cannot be interrupted)
- Scalability:
  - Pros: simple structure, fast development at the beginning
  - Cons: fixed structure
- HW handling: polling (not IT)
- If a new task is inserted the response time is increased
- Not preemptive (only one task runs until it finishes its job and cannot be interrupted)
  - Mutual exclusion is not a problem (more than one process cannot run)
  - A long lasting process can block the running of others
- Applicable only where response time is not critical
- Not energy friendly since the processor operates continuously

Weighted cyclic program structure

- The tasks are executed one after the other in a cyclic manner, but certain tasks are checked more frequently to make it run or not

```
void main() {
while (TRUE){
        if (sensor_state==active) {calculate_speed() ;}
        if (sensor_state==active) {calculate_speed() ;}
        if (button1_pushed==true) {change_menu() ;}
        if (sensor_state==active) {calculate_speed() ;}
        if (sensor_state==active) {calculate_speed() ;}
        if (button1_pushed==true) {change_menu() ;}
         if (speed_calculated==true) {display_speed();}
...
        }
}
```



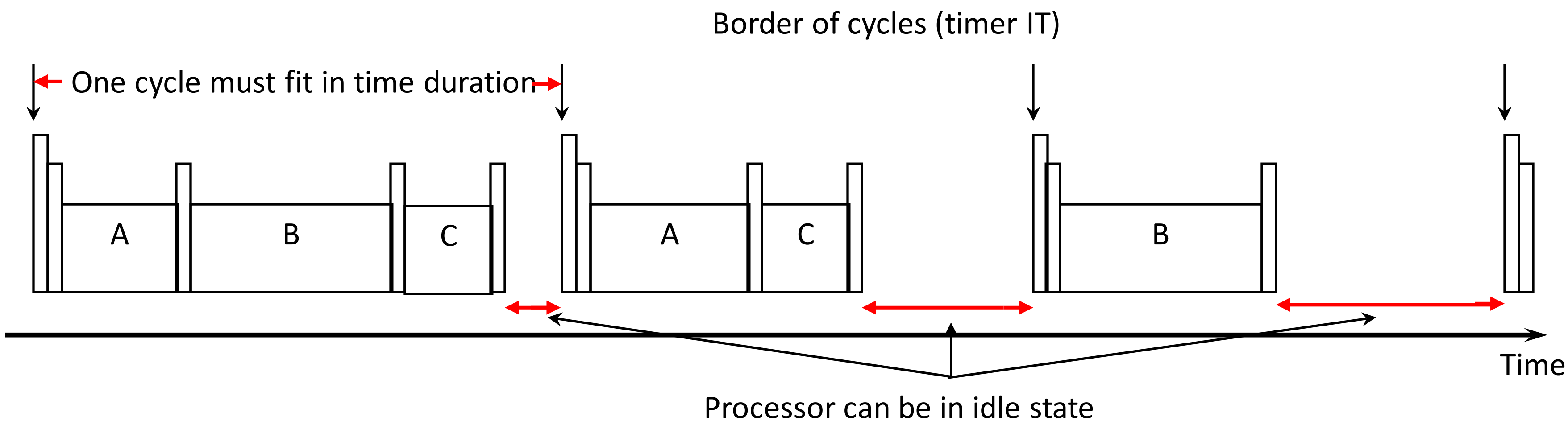
Weighted cyclic program structure

- Simple structure
- Communications between tasks:
  - Shared variables, no problem since the are not preemptive: only one task runs at a time
- Scalability:
  - Pros: simple structure, fast development at the beginning
  - Cons: fixed structure
- HW handling: polling (not IT)
- If a new task is inserted the response time is increased
- Not preemptive (only one task runs until it finishes its job)
  - Mutual exclusion is not a problem (more than one process cannot run)
  - A long lasting process can block the running of others
- Applicable only where response time is not critical
- Not energy friendly since the processor operates continuously
- **A basic level of priority can be assured**

Time-controlled cyclic program structure

- Polling is not continuous but controlled by a timer
- In a time-controlled cycle the structure can be simple cyclic or weighted cyclic

```
TimerITServiceRoutine(){
        if (button1_pushed==true) {change_menu();}
        if (sensor_state==active) {calculate_speed();}
        if (speed_calculated==true) {display_speed();}
}
```

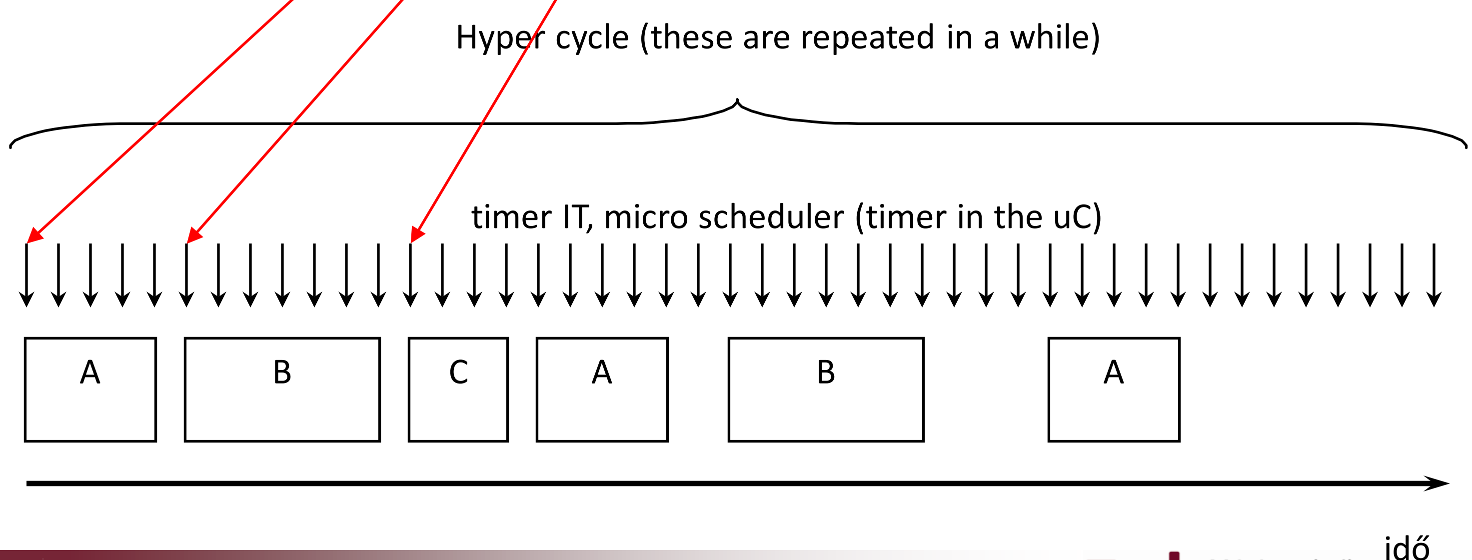


Time-controlled cyclic program structure

- During one cycle the properties of simple cyclic and weighted cyclic structures are valid here
- Good choice for systems using scheduled control, e.g., sampled signal processing systems
- Cycle time must be less than the required response time
  - Run time of a cycle must fit between two timer IT
- Advantage over simple cyclic and weighted cyclic structures is energy friendly operation
  - Processor can be in idle state between the executed tasks and next timer IT

Strict time-controlled cyclic structure

- The execution of each task starts at a scheduled time in a strict sense
- Administration:
  - In a table: time instants and function references (in hyper cycle)
  - The operating system or scheduler supervise the time instants and starts the "tasks"



Strict time-controlled cyclic structure

- Scalability:
  - Pros: start of running can be calculated precisely
  - Cons: inserting a new task requires re-scheduling every other tasks
- HW handling: polling
- Non-preemptive: one task runs at a time
  - No problem with shared variables
- Every task must fit in its assigned time slot
  - The run time of every task must be known (at least its possible worst case runtime)
- Good for real-time systems: strict timings

Cyclic process scheduling with interrupt (IT)

```
FLAG        button, sensor;
void interrupt Button_IT_Handler() { Button_fast_A(); button=TRUE; }
void interrupt Sensor_IT_Handler() { Sensor_fast(); sensor=TRUE; }
void main() {
 while (TRUE){
            if (button)  {button=FALSE; Service_button(); }
            if (sensor)  {sensor =FALSE; Service_ sensor(); }
             display_speed();}
            ...
            }
}
```

Low-level events are handled by interrupts
E.g. magnetic sensor position

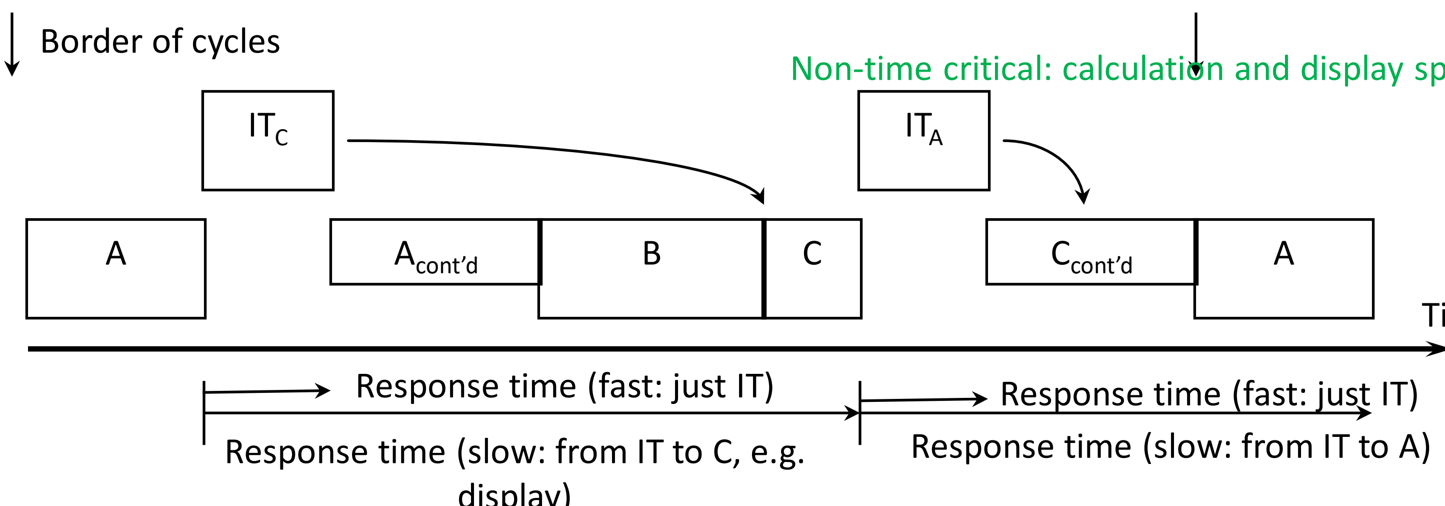
Time-stamp of sensor becomes known and saved

Simple cyclic

Calculation of speed based on time-stamp can happen later

Time critical: time instant when the magnet passed the sensor

Non-time critical: calculation and display speed



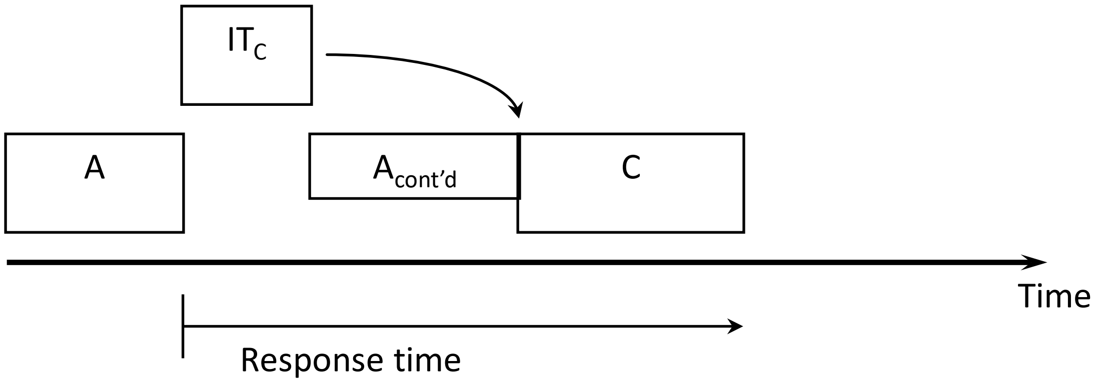
Cyclic process scheduling with interrupt (IT)

- IT (interrupt) is needed when polling is not appropriate since the application is time-critical
  - Independently, certain peripherals can be handled by polling
- Deterministic behavior is not true any more
  - IT may happen any time and program have to tolerate it
- Mutual exclusion must be assured for interrupts
  - Not to overwrite a variable being used during interrupt
- Response time is increased by duration of interrupts
- Frequently applied solution (expected in many cases)
- Inserting a new task increases response time
- IT routine: execute only the most important tasks, further processing can be done later

Scheduled functions

- Every task is implemented in a function
- In case of an event (like interrupt) to execute the function, <u>the function is put in a function queue</u>
- If a function to be executed exists then the scheduler calls that from the queue
- Uniform function format is used

```
void interrupt Button_IT_Handler() { Button_fast_A(); PutFunction(Service_button))}
void interrupt Sensor_IT_Handler() { Sensor_fast(); PutFunction(Service_sensor)}
void interrupt Display_timer_IT_Handler() {PutFunction(Service_display_timer)}
void Service_button();
void Service_sensor();
void Service_display_timer();
void main() {
  while (TRUE){
     while (IsFunctionQueueEmpty()) ;
     CallFirstFromQueue();
   }
}
```



Scheduled functions

- HW handling: interrupt
- Communications between tasks:
  - Task – task : no problem
  - Task – IT: mutual exclusion must be assured: take care of shared variables
- Scalability:
  - Inserting a new task is easy
  - The running environment requires extra care
- Calling from the function queue:
  - FIFO
  - Based on priority
- Operation is similar to embedded operation systems

Implementation of scheduled functions

- A possible implementation

```
typedef void (*fp)(void);
fp functionToCall;
#define N_FN 8
#define N_FN_MASK (N_FN-1)
fp fnArray[N_FN];
uint16_t fnArray_top=0;
uint16_t fnArray_bott=0;

void putFn(void (*func)(void)){
      fnArray[fnArray_top] = func;
      fnArray_top = (fnArray_top+1)&(N_FN_MASK);
}

int32_t getFn(){
      int32_t retVal;
      fp functionToCall;
      if (fnArray_top == fnArray_bott){
            retVal = -1;
      } else {
            retVal = fnArray_bott;
            fnArray_bott = (fnArray_bott+1)&(N_FN_MASK);
            functionToCall = fnArray[retVal];
            functionToCall();
      }
      return (retVal);
}
```

Function pointer

Array of function pointers

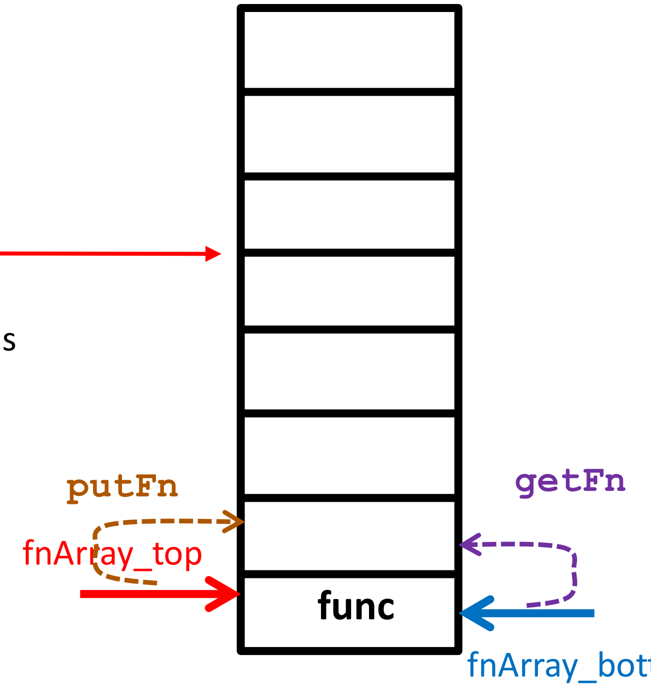
Pointer of new function is placed in the array

Check if new function exists or not

No new function

New function exists

Function is called



Considerations

- Choose the simplest scheduling method that is still able to meet the requirements
- Task scheduling has to be planned carefully since change of concept or even inserting a new task may lead to huge extra work