

Exercises in System Level Programming (SLP) – Summer Term 2026

Exercise 6

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Lehrstuhl für Informatik 4
Systemsoftware



Friedrich-Alexander-Universität
Faculty of Engineering

Presentation Assignment 3

AVR Timer



- Common task for μ Controller programming:
 - Regularly updating an output (e. g. frame rate)
 - Regularly reading of a value (e. g. serial console)
 - Pulse width modulation (PWM)
 - Passive waiting
 - ...

⇒ Implementation using a *timer*



- A timer modifies a counter in every cycle
 - Increment (default)
 - Decrement
 - When a previously configured event occurs, an interrupt is generated
 - Counter reaches a specific value
 - Counter overflows
 - (external event occurs)
 - The ATmega328PB provides 5 different timers:
 - $TIMER\{0, 2\}$: 8-bit counter
 - $TIMER\{1, 3, 4\}$: 16-bit counter
- ⇒ For all exercise tasks: $TIMER0$
- ⇒ Used by the libspicboard: $TIMER\{1, 2, 4\}$



■ How fast does the timer run:

- TCCR0B: TC0 control register B
- CSxx: Clock select bits
- Prescaler: Amount of CPU cycles until the counter is incremented
- What happens when the CPU enters a sleeping state?

CS02	CS01	CS00	Description
0	0	0	Timer off
0	0	1	prescaler 1
0	1	0	prescaler 8
0	1	1	prescaler 64
1	0	0	prescaler 256
1	0	1	prescaler 1024
1	1	0	Ext. clock (falling edge)
1	1	1	Ext. clock (rising edge)



CS02	CS01	CS00	Description
0	0	0	Timer off
0	0	1	prescaler 1
0	1	0	prescaler 8
0	1	1	prescaler 64
1	0	0	prescaler 256
1	0	1	prescaler 1024
1	1	0	Ext. clock (falling edge)
1	1	1	Ext. clock (rising edge)

```
01 static void init(void) {
02     // Activate timer with prescaler 64
03     TCCR0B &= ~(1 << CS02);
04     TCCR0B |= (1 << CS01) | (1 << CS00);
05
06     // [...]
07 }
```



- **When does the timer trigger an interrupt:**
 - **Overflow:** When the counter flows over
 - **Match:** When the counter reaches a specific value
 - ⇒ Register OCR0A (TIMER0 Output Compare Register A)
 - ⇒ Register OCR0B (TIMER0 Output Compare Register B)
 - Interrupts can be unmasked individually
 - TIMSK0: TIMER0 Interrupt Mask Register

Bit	ISR	Description
TOIE0	TIMER0_OVF_vect	TIMER0 Overflow (Interrupt Enable)
OCIE0A	TIMER0_COMPA_vect	TIMER0 Output Compare A (...)
OCIE0B	TIMER0_COMPB_vect	TIMER0 Output Compare B (...)



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```
01 ISR(TIMER0_OVF_vect) {
02     // [...]
03 }
04
05 static void init(void) {
06     // Activate overflow interrupt
07     TIMSK0 |= (1 << TOIE0);
08
09     // [...]
10 }
```



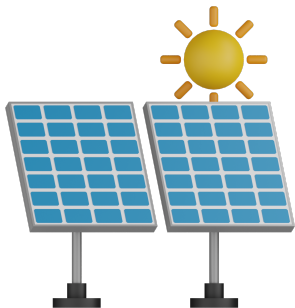
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```
01 ISR(TIMER0_COMPA_vect) { /* [...] */ }
02
03 static void init(void) {
04     // Set comparison value
05     OCR0A = 125 - 1; // Machine starts counting at zero.
06
07     // Set back the counter at 124.
08     TCCR0A = (1<<WGM01);
09
10     // Activate comparison interrupt
11     TIMSK0 |= (1 << OCIE0A);
12
13     /* [...] */ }
```



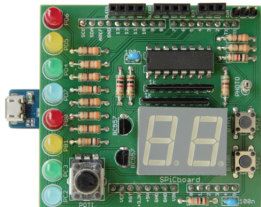
- Reminder: $\text{prescaler} \in \{1, 8, 64, 256, 1024\}$

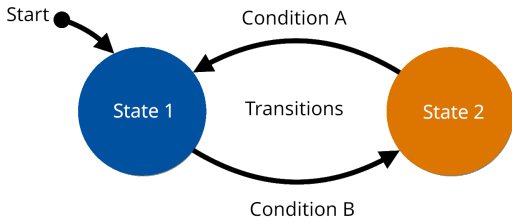
 - **Example:**
 - 8-bit timer with overflow interrupt
 - CPU frequency: 16 MHz (ATmega328PB)
 - Goal: Count with a cycle of length 1 s
- ⇒ Which prescaler is the most resource efficient?
- ⇒ How many overflow interrupts are required until 1 s has passed?
- ⇒ How big is the error that we have to accept?



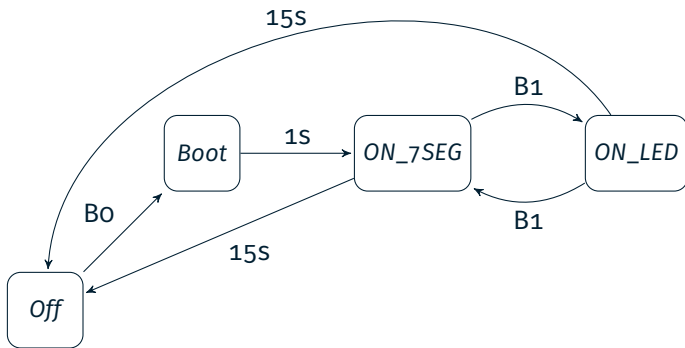
Display for a solar panel

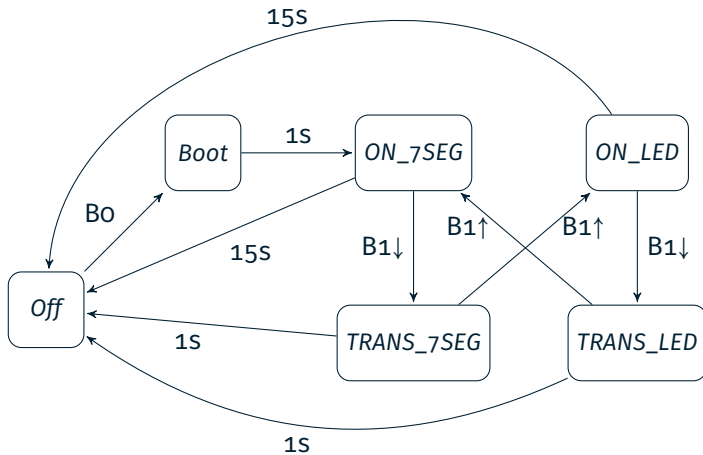
- PHOTO is the panel
- Button0 turns on the display
- Button1 switches between
 1. 7seg shows current power
 2. LEDs show current power
- Button1 hold
 1. Turn off display





- **States** with specific attributes; well-defined initial state
- **Transition** depends on certain conditions







- Using states with hardcoded integer values is prone to errors
 - Hard to memorize
 - Range of value cannot easily be restricted
- Better enum:

```
01 enum state { STATE_OFF, STATE_BOOT, STATE_ON };  
02  
03 enum state my_state = STATE_OFF;
```

- With typedef even more readable:

```
01 typedef enum { STATE_OFF, STATE_BOOT, STATE_ON } state;  
02  
03 state my_state = STATE_OFF;
```



```
01 switch ( my_state ) {
02 case STATE_OFF:
03     ...
04     break;
05 case STATE_BOOT:
06     ...
07     break;
08 case STATE_ON:
09     ...
10     break;
11 default:
12     // maybe invalid state
13     ...
14 }
```

- Avoid any if-else-cascades
- switch-expression has to be an integer (or even better: enum)
- Do not forget the break-instruction!
- Ideal for handling systems with different states
⇒ Implementation of finite state machines



- Each transition is triggered by an interrupt
 - Configure BUTTON0 and BUTTON1 as interrupt inputs
 - ⇒ Which edge should trigger the interrupt?
 - Configure TIMER0 (interval: 1 second)
- Do not use the timer module of the libspicboard when submitting
 - ⇒ However, its use can be helpful for debugging



- We would like to distinguish between different ways of switching states
 - How can we detect whether the button was pressed short or long?
- ⇒ Intermediate states and timer is necessary
- On falling edge: Enter transition state
 - Transition state has two exits, either via a rising edge or via a Timer interrupt

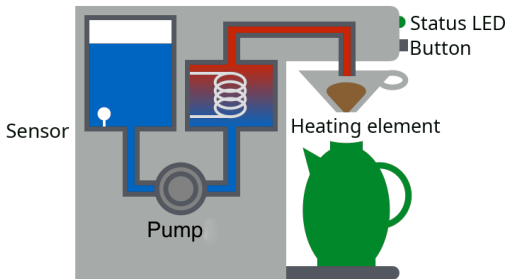


■ Hints:

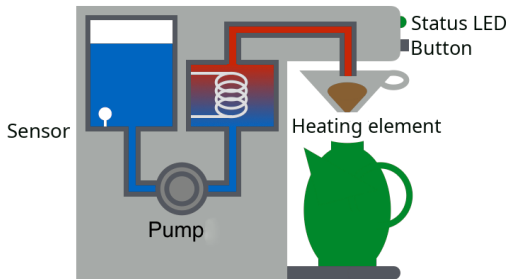
- Implement each function exactly as specified in the description (reference implementation available)
- Model presses of the buttons and alarms as events
- Wait passively for all interrupts
- “Deactivate” the button by simply ignoring its interrupt (It is not necessary to modify the interrupt configuration)
- Mapping to a finite state machine can be useful
- Usage of `volatile` always needs a reason

Hands-on: Coffee Machine

Screencast: <https://www.video.uni-erlangen.de/clip/id/17647>



- Learning goals:
 - Finite state machines
 - Timers and alarms
 - Interrupts & sleep modes



■ Wiring:

- Pump & heating: Port D, Pin 5 (active-low)
- Button: INT0 an Port D, Pin 2 (active-low)
- Sensor: INT1 an Port D, Pin 3 (water: high; no water: low)
- State LED:
 - BLUE0: **STANDBY**
 - GREEN0: **ACTIVE**
 - RED0: **NO_WATER**



STANDBY

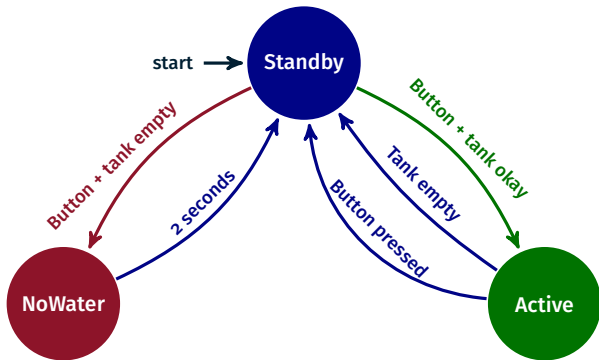
- Machine is switched off
- Pump and heating are off
- User can start making coffee by pressing the button
- Initial state

ACTIVE

- Machine is switched on
- Pump and heating are on
- Water tank is not empty
- User can stop the machine by pressing the button

NO_WATER

- Coffee machine shows that not enough water is in the tank
- Pump and heating are off
- Time period: 2 seconds



■ Hints:

- Pressed button & change of water level by interrupts
- State LED: `void setLEDState(state_t state)`
- Waiting phases can be implemented using the single-shot alarms
- During waiting phases always enter a power-saving mode



DDRx Configuration of pin i of port x as in-/output

- Bit $i = 1 \rightarrow$ Pin i as output
- Bit $i = 0 \rightarrow$ Pin i as input

PORTx Mode of operation **depends on DDRx**:

- If pin i is **configured as output**, then bit i in the PORTx register controls whether a high level or a low level has to be generated at pin i
 - Bit $i = 1 \rightarrow$ high level at pin i
 - Bit $i = 0 \rightarrow$ low level a pin i
- If pin i is **configured as input**, then the internal pull-up resistor can be activated
 - Bit $i = 1 \rightarrow$ pull-up resistor at pin i (level is pulled high)
 - Bit $i = 0 \rightarrow$ pin i configured as tri-state

PINx Bit i returns the current level of pin i at port x (read only)



- Interrupt sense control (ISC) bits of the ATmega328PB are located at the external interrupt control register A (EICRA)
- Position of the ISC-bits inside the register defined by macros

Interrupt INT0		Interrupt on	Interrupt INT1	
ISC01	ISC00		ISC11	ISC10
0	0	low level	0	0
0	1	either edge	0	1
1	0	falling edge	1	0
1	1	rising edge	1	1

- ATmega328PB: External interrupt mask register (EIMSK)
- The position of the bits in this register is also defined by macros INTn