

Exercises in System Level Programming (SLP) – Summer Term 2024

Exercise 7

Maximilian Ott

Lehrstuhl für Informatik 4
Friedrich-Alexander-Universität Erlangen-Nürnberg



Chair in Distributed Systems
and Operating Systems



FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

FACULTY OF ENGINEERING

Presentation Assignment 3

AVR Timer

Timer: Motivation



- 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: $TIMER\{1, 2, 4\}$

2

Timer: Configuration (Timer clock speed)



- **How fast does the timer run:**
 - $TCCR0B$: $TC0$ control register B
 - CS_{xx} : 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)

3



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 (...)



- **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 (...)

4



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 (...)

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

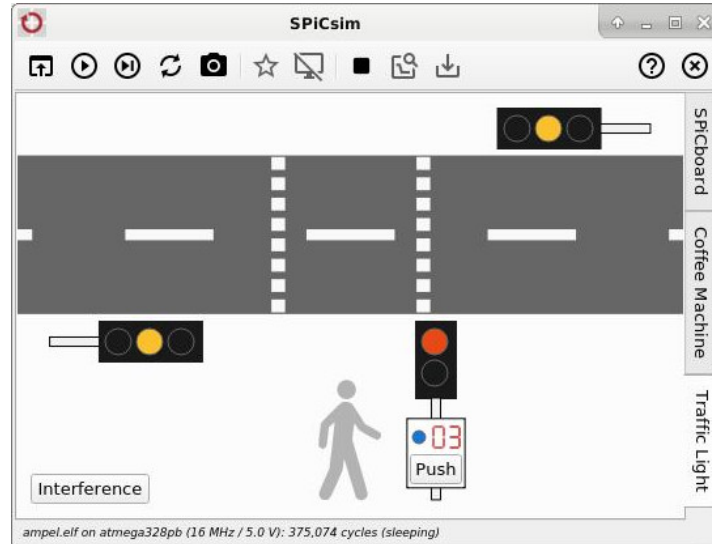
4



- 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?

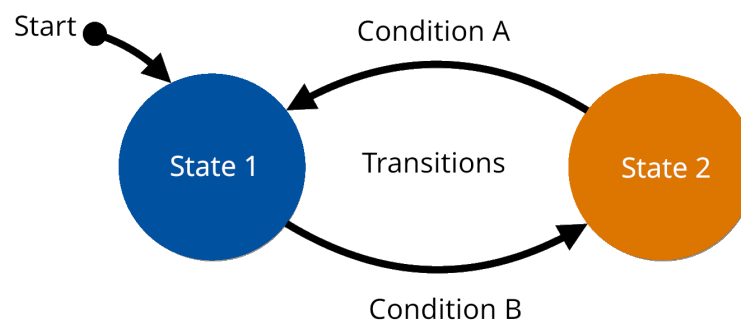
Task: Traffic Light



- Implementation of a (pedestrian) traffic light with waiting-time display

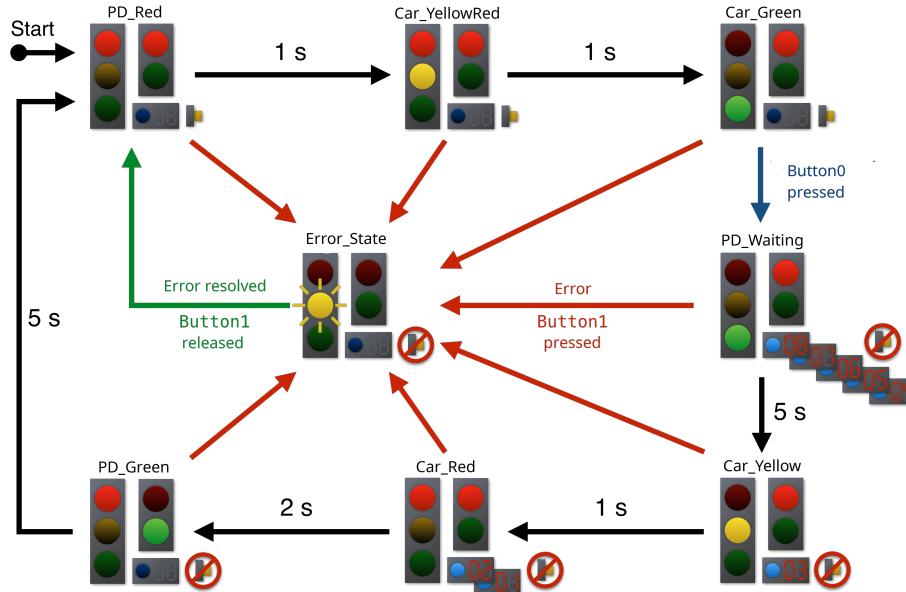
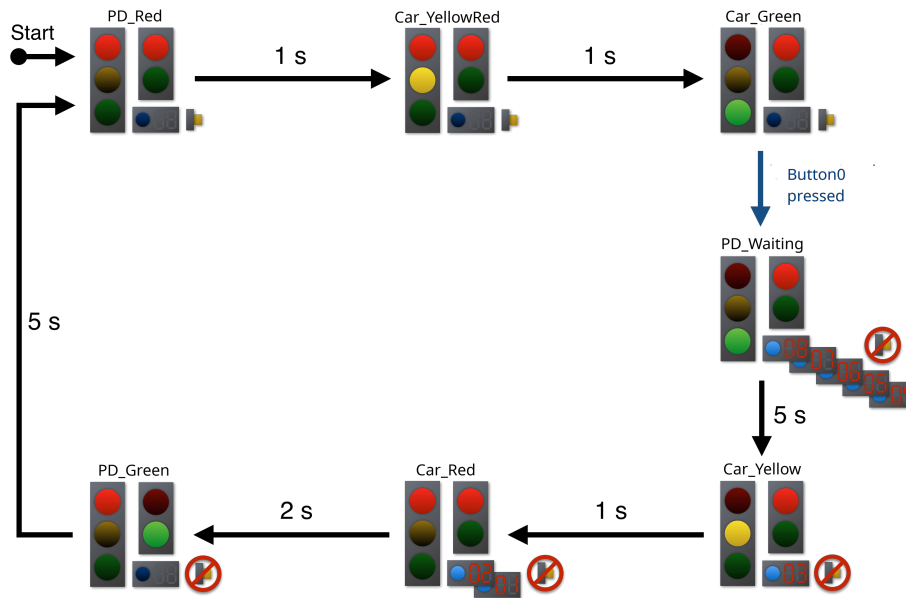
6

Finite State Machines



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

7





- 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_RED, STATE_YELLOW, STATE_GREEN };  
02  
03 enum state my_state = STATE_RED;
```

- With typedef even more readable:

```
01 typedef enum { STATE_RED, STATE_YELLOW, STATE_GREEN } state;  
02  
03 state my_state = STATE_RED;
```

10

Choosing States: switch-case Instruction



```
01 switch ( my_state ) {  
02 case STATE_RED:  
03     ...  
04     break;  
05 case STATE_YELLOW:  
06     ...  
07     break;  
08 case STATE_GREEN:  
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

11



- 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

12

Hints



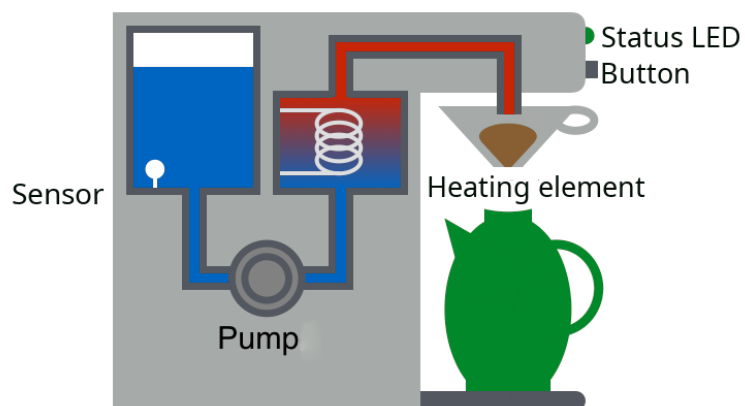
- Hints:
 - Implement each function exactly as specified in the description (reference implementation available)
 - Model presses of the buttons and alarms as events
 - Wait passively for all interrupts
 - “Deactivate” the button by simply ignoring its interrupt (It is not necessary to modify the interrupt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

13

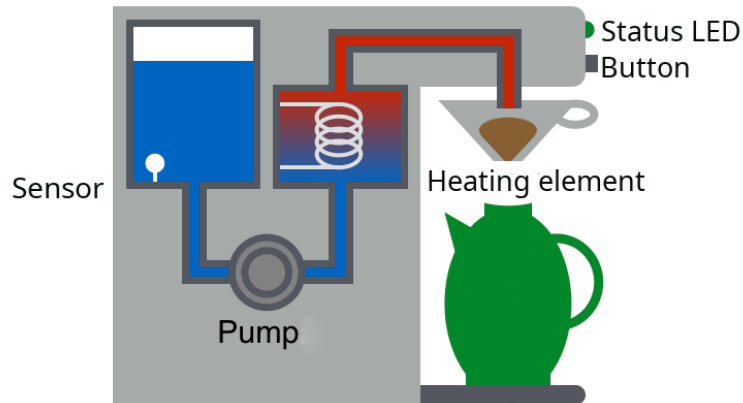
Hands-on: Coffee Machine

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

Hands-on: Coffee Machine (1)



- 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**

15

Hands-on: Coffee Machine (2)



STANDBY

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

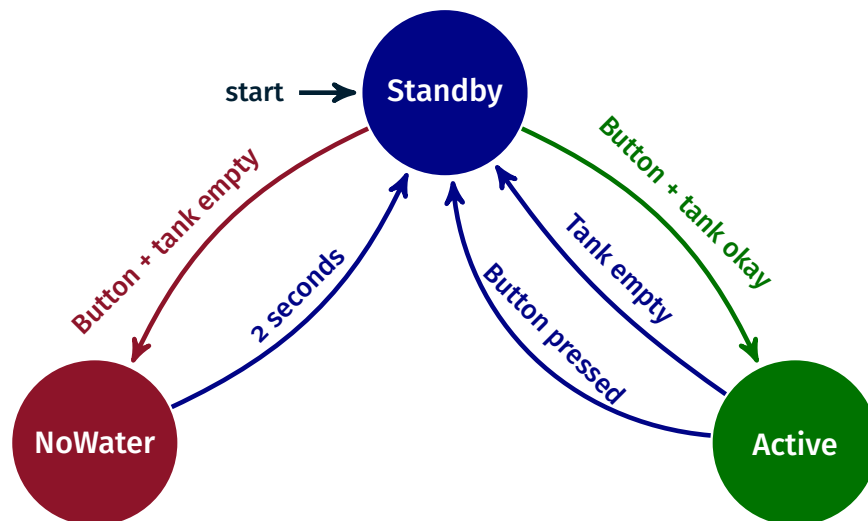
ACTIVE

- 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

16



■ 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

17

Hands-on: Coffee Machine (3)



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)

18



- 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