Exercises in System Level Programming (SLP) – Sommersemester 2024

Exercise 3

Maximilian Ott

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

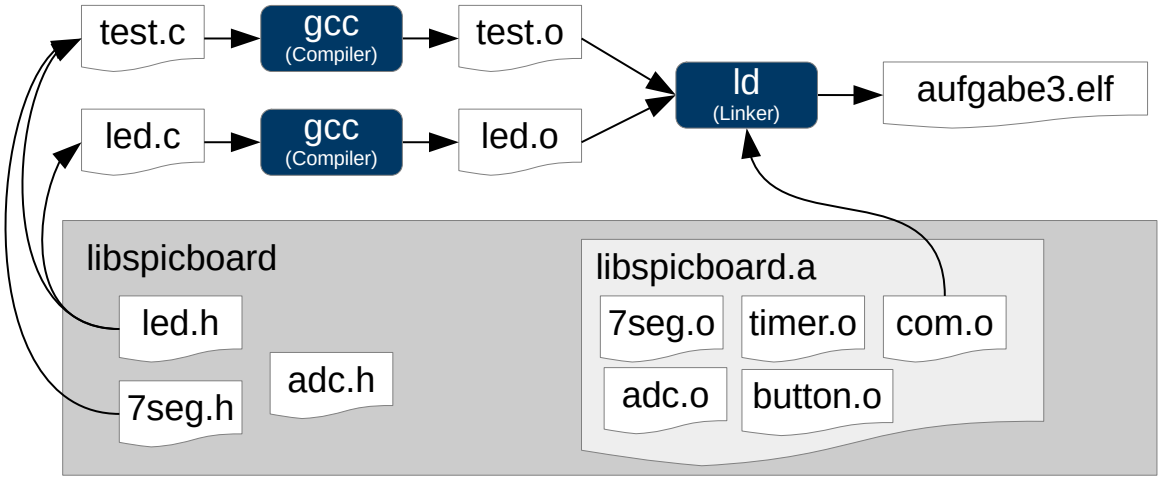
Lehrstuhl für Verteilte Systeme
und Betriebssysteme

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

Presentation Task 1

Modules

Overview: From the Source Code to a Program



1. Preprocessor
2. Compiler
3. Linker
4. Programmer/Flasher

Interface Description (1)

- Header files contain the interface of a module
  - Function declarations
  - Preprocessor macros
  - Type definitions
- Header files can be included multiple times
  - `led.h` includes `avr/io.h`
  - `button.h` includes `avr/io.h`

  ⇝ Functions from `avr/io.h` declared multiple times
- Prevent Multiple inclusions/cycles ⇝ **include-guards**
  - Definition and checking of a preprocessor macro
  - Convention: Macro has the same name as .h-file, '.' replaced by '_'
  - e. g. for `button.h` ⇝ `BUTTON_H`
  - File is only included if the macro has not already been defined
- Attention: Flat name space ⇝ always use unique names

Interface Description (2)

- Creating a .h-file (convention: same name as .c-file)

```
01 #ifndef COM_H
02 #define COM_H
03 /* Include fixed-width data types (used in the header) */
04 #include <stdint.h>
05
06 /* Data Types */
07 typedef enum {
08     ERROR_NO_STOP_BIT, ERROR_PARITY,
09     ERROR_BUFFER_FULL, ERROR_INVALID_POINTER
10 } COM_ERROR_STATUS;
11
12 /* Functions */
13 void sb_com_sendByte(uint8_t data);
14 [...]
15 #endif //COM_H
```

Implementation: Encapsulation

- Internal variables and auxiliary functions not part of the interface
- C has a flat name space
- Unexpected accesses can lead to wrong behaviour

⇒ Encapsulation: Visibility & life span should be restricted

Implementation: Visibility & Life Span (1)

Visibility and Life Span	**not** `static`	`static`
Locale variable	visibility **block** life span **block**	visibility **block** life span **program**
Global variable	visibility **program** life span **program**	visibility **module** life span **program**
Function	visibility **program**	visbility **module**

- Local variables that are **not** declared as `static`:

⇝ `auto` variable (automatically allocated & freed)

- Global variables and functions declared as `static`, if no export is necessary

Implementation: Visibility & Life Span (2)

```c
static uint8_t state; // global static
uint8_t event_counter; // global

static void f(uint8_t a) {
  static uint8_t call_counter = 0; // local static
  uint8_t num_leds; // local (auto)
  /* ... */
}

void main(void) {
  /* ... */
}
```

- Visibility & life span should be chosen as **restricted** as possible

⇝ If possible: `static` for global variables and functions

Implementation: Initialization of a Module (1)

- Modules have to perform an initialization
  - For example: Configuring ports
  - **Java:** Possible with class constructors
  - **C:** No such concepts
- *Workaround:* Modules have to initialize themself upon the first function call
  - Remember completion of initialization
  - Prevent multiple initialization
- Creating an `initDone`-variable
  - Call of the `init` function in each function
  - `initDone`-variable initially set to `0`
  - After initialization it is set to `1`

Implementation: Initialization of a Module (2)

- `initDone` is initially set to `0`
- Is set to 1 after initialization

⇝ Initialization only performed once

```
01 static void init(void) {
02     static uint8_t initDone = 0;
03     if (initDone == 0) {
04       initDone = 1;
05       ...
06     }
07 }
08
09 void mod_func(void) {
10     init();
11     ...
12 }
```


In- & Output via Pins

General Purpose Input/Output (GPIO)

- Microcontroller interact with their environment
- Besides some predefined protocols: Arbitrary (digital) signals
- Many pins can be configured as an input or an output

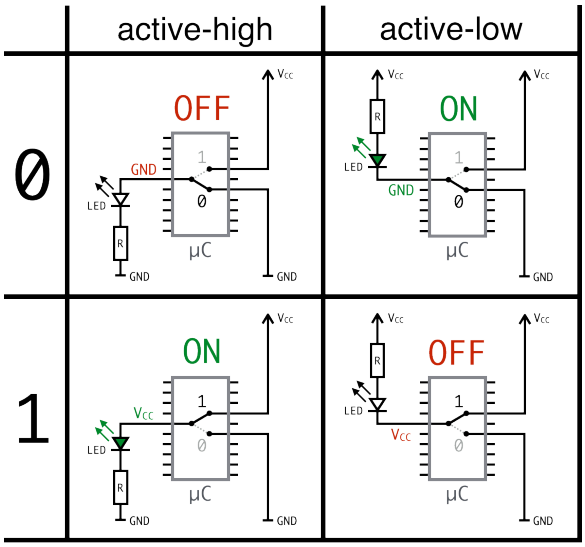
⇝ General Purpose Input/Output (GPIO)

Output: Active-high & Active-low

Output dependent on wiring:

active-high: high-level (logically 1; V_{cc} at Pin) → LED is on

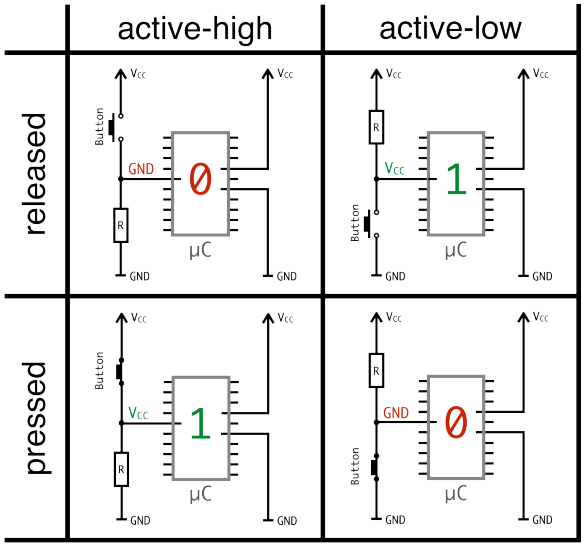
active-low: low-level (logically 0; *GND* at Pin) → LED is on



Input: Active-high & Active-low

Input dependent on wiring:

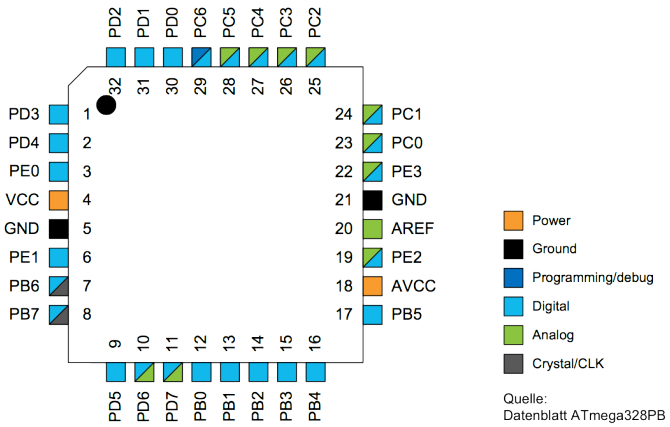
active-high: Button pressed → high-level (logically 1; V_{CC} at Pin)
active-low: Button pressed → low-level (logically 0; *GND* at Pin)



Inputs are of high impedance, a well defined level has to be present

⇝ Use pull-down or (internal) pull-up resistors

Configuration of the Pins



- Eight pins are combined to an I/O port for the AVR
- Each I/O port of the AVR is controlled by three 8-bit registers

  DDRx Data Direction Register
  PORTx Port Output Register
  PINx Port Input Register

- Every pin of a port has exactly one bit in each of the three register

I/O-Port-Register (1)

DDRx: Data Direction Register configures pin `i` as an in- or output

- `Bit i = 1` → Pin `i` used as an output
- `Bit i = 0` → Pin `i` used as an input

Example:

```
01 DDRC |= (1 << PC3);  // PC3 as output (Pin 3 at Port C)
02 DDRD &= ~(1 << PD2); // PD2 as input (Pin 2 at Port D)
```


I/O-Port-Register (2)

PORTx: Port Output Register depends on DDRx register

- If **output**: Sets level to high or low at pin `i`
  - `Bit i = 1` → high-level at pin `i`
  - `Bit i = 0` → low-level at pin `i`
- If **input**: Sets the state of the internal pull-up resistor at pin `i`
  - `Bit i = 1` → activates pull-up resistor for pin `i`
  - `Bit i = 0` → deactivates pull-up resistor for pin `i`

Example:

```
01 PORTC |= (1 << PC3);  // Pulls PC3 to high (LED off)
02 PORTC &= ~(1 << PC3); // Pulls PC3 to low (LED on)
03
04 PORTD |= (1 << PD2);  // Activates internal pull up for PD2
05 PORTD &= ~(1 << PD2); // Deactivates internal pull up for PD2
```

PINx: Port Input Register (read only) current value of pin `i`

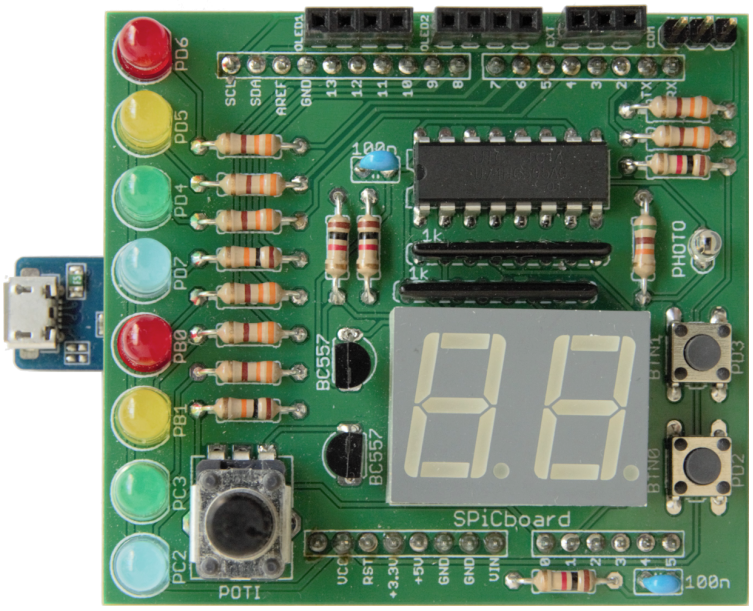
- If **input**: poll what level is set from outside
- If **output**: poll whether high or low is put out

Example:

```
01 if((PIND & (1 << PD2)) == 0) { // Testing whether Pin PD2 is low
02   // low-level --> button is pressed
03   [...]
04 }
05
06 if((PIND & (1 << PD2)) != 0) { // Testing whether Pin PD2 is high
07   // high-level --> button is not pressed
08   [...]
09 }
```

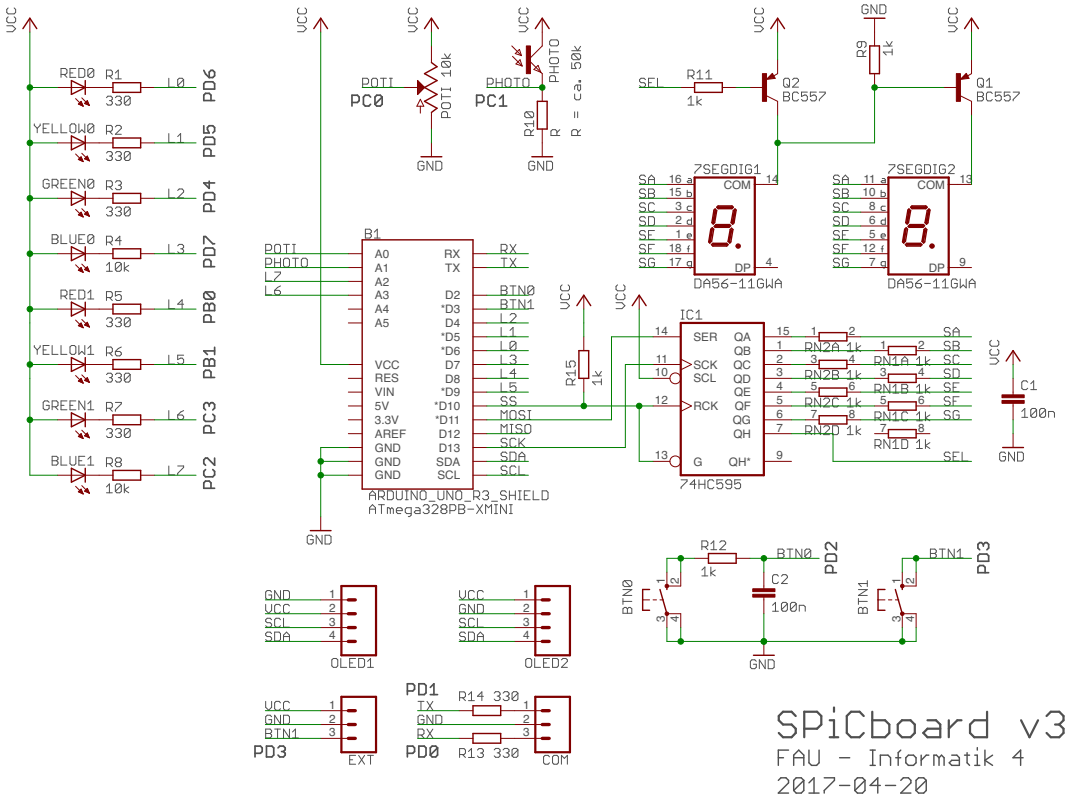

Task: LED Module

LED Module – Overview



- LED 0 (RED0) ⇒ PD6 ⇒ Port D, Pin 6 ⇒ Bit 6 at PORTD and DDRD
- …
- LED 7 (BLUE1) ⇒ PC2 ⇒ Port C, Pin 2 ⇒ Bit 2 at PORTC and DDRC

SPiCboard Block Circuit Diagram

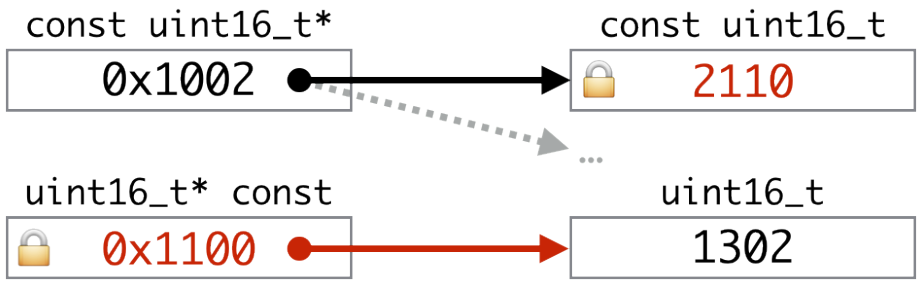


LED Module – Task

- Implement the LED module of the libspicboard
  - Same behaviour as the original
  - Description:
    `https://sys.cs.fau.de/lehre/SS24/spic/uebung/spicboard/libapi/extern/group__LED.html`
- Testing of the module
  - Link your own module with a test program (`test-led.c`)
  - Other parts of the library can be used for testing
- LEDs of the SPiCboard
  - Connections and names of the single LEDs can be extracted from the overview pictures
  - All LEDs are **active-low**
    i.e. they are switched on if a low-level is applied
  - PD6 = Port D, Pin 6

Excursion: const uint8_t* vs. uint8_t* const

- `const uint8_t*`
  - Pointer to a **constant** `uint8_t`-**value**
  - **Value** cannot be modified via the pointer
- `uint8_t* const`
  - **Constant pointer** to an (arbitrary) `uint8_t`-value
  - **Pointer** is not allowed to point at a different memory address



Port- and Pin-Array (1)

- Address operator: &
- Reference operator: *
- Definitions for ports and pins (in `avr/io.h`)

```
01 #define PORTD (* (volatile uint8_t *) 0x2B)
02 ...
03 #define PD0     0
04 ...
```

- Macro replaces `PORTD` by `(* (volatile uint8_t *) 0x2B)`
  1. Takes the integer `0x2B` (address of PORTD)
  2. Casts it into a `(volatile uint8_t *)` pointer
  3. Dereferences pointer `*` (⇒PORTD is accessing the register contents)
  4. Brackets `(...)` enforce correct order of operations (Attention, macro!)

Port- and Pin-Array (2)

- Port array:

```
01 static volatile uint8_t * const ports[8] = { &PORTD,
02                                              ...,
03                                              &PORTC };
```

  - Reverses the dereferencing of the address operator
    - ⇒ Elements of `ports` are addresses in the form of `uint8_t` pointers
- Pin array:

```
01 static uint8_t const pins[8] = { PD6, ..., PC2 };
```

- Access:

```
01 * (ports[0]) &= ~(1 << pins[0]);
```

Compiler Settings

- Create project as usual
  - Initial source file: `test-led.c`
  - Then add second source file `led.c`
- When compiling, functions from your own module are used
- Additional parts of the library are included if required
- Code can be temporarily deactivated for testing the original functions:

```
01 #if 0
02   ....
03 #endif
```

⇒ Does the compiler see this “comment”?
⇒ How can we comment in the code again?

Testing of the Module

```
01 void main(void){
02   ...
03   // 1.) Testing with valid LED-ID
04   int8_t result = sb_led_on(RED0);
05   if(result != 0){
06     // Test failed
07     // Output e.g. with 7-Segment display
08   }
09   // wait some seconds
10
11   // 2.) Testing with invalid LED-ID
12   ...
13 }
```

- Pay close attention to the interface description (incl. return values)
- Testing of **all possible return values**
- Give an error if the returned value is different from the specification

Hands-on: Statistics Module

Screencast: https://www.video.uni-erlangen.de/clip/id/16328

Hands-on: Statistics Module

- Statistics module and test program
- Functionality of the module (interface):

```
01 // Interface
02 uint8_t avgArray(uint16_t *a, size_t s, uint16_t *avg);
03 uint8_t minArray(uint16_t *a, size_t s, uint16_t *min);
04 uint8_t maxArray(uint16_t *a, size_t s, uint16_t *max);
05
06 // Internal auxiliary functions
07 uint16_t getMin(uint16_t a, uint16_t b);
08 uint16_t getMax(uint16_t a, uint16_t b);
```

- Return value:
  - 0: OK
  - 1: Error
- How to proceed:
  - Header file with module interface (and include guards)
  - Implementation of the module (consider visibility)
  - Testing of the module in the main program (incl. errors)