System-Level Programming

4 Software Layers and Abstraction

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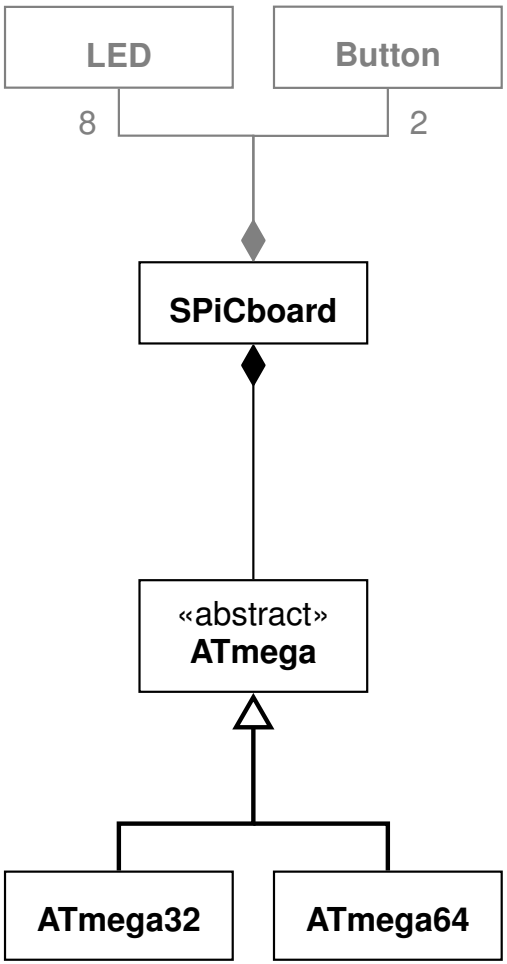
http://sys.cs.fau.de/lehre/ss25

Abstraction by Software Layers: SPiCboard

close to problem — close to machine

Hardware view



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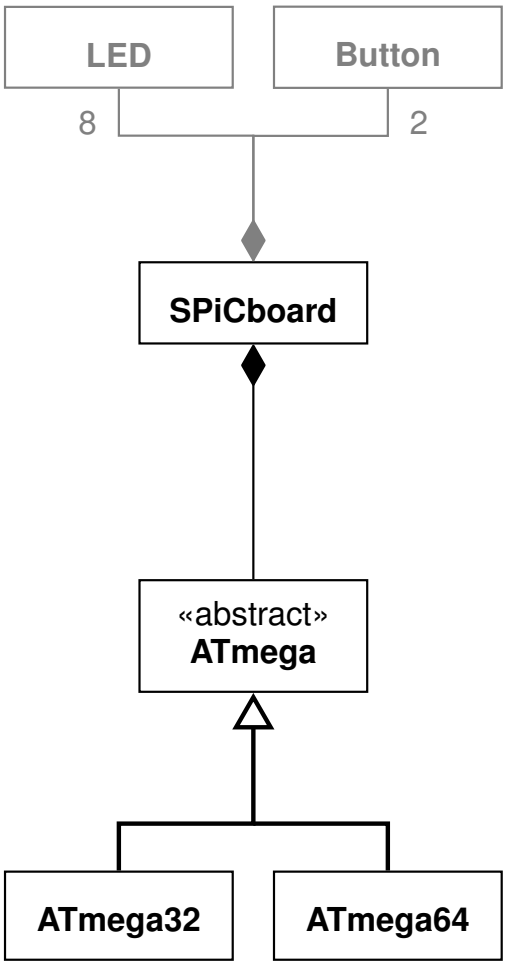
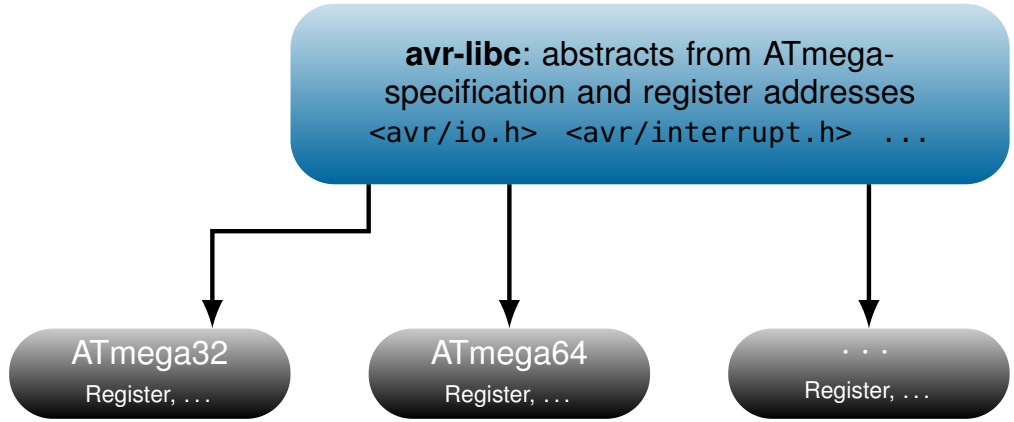


Software layers



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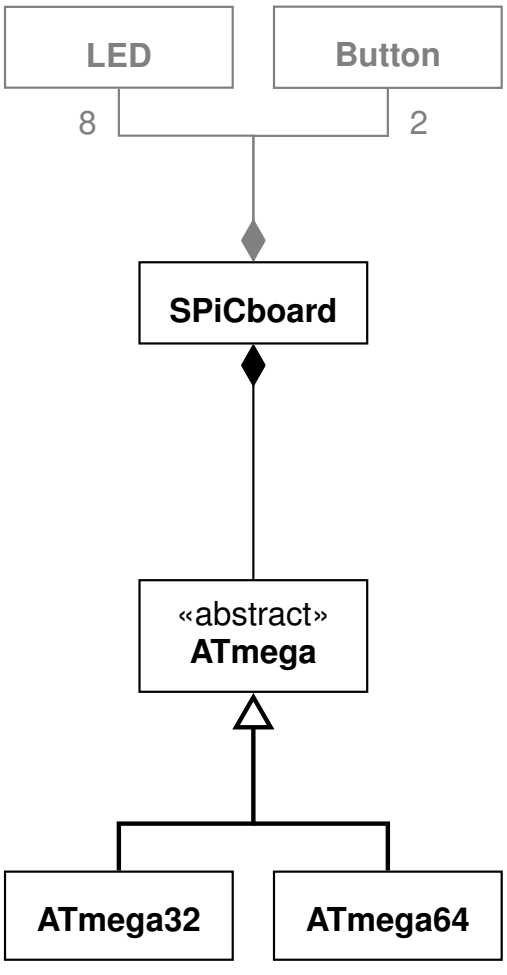
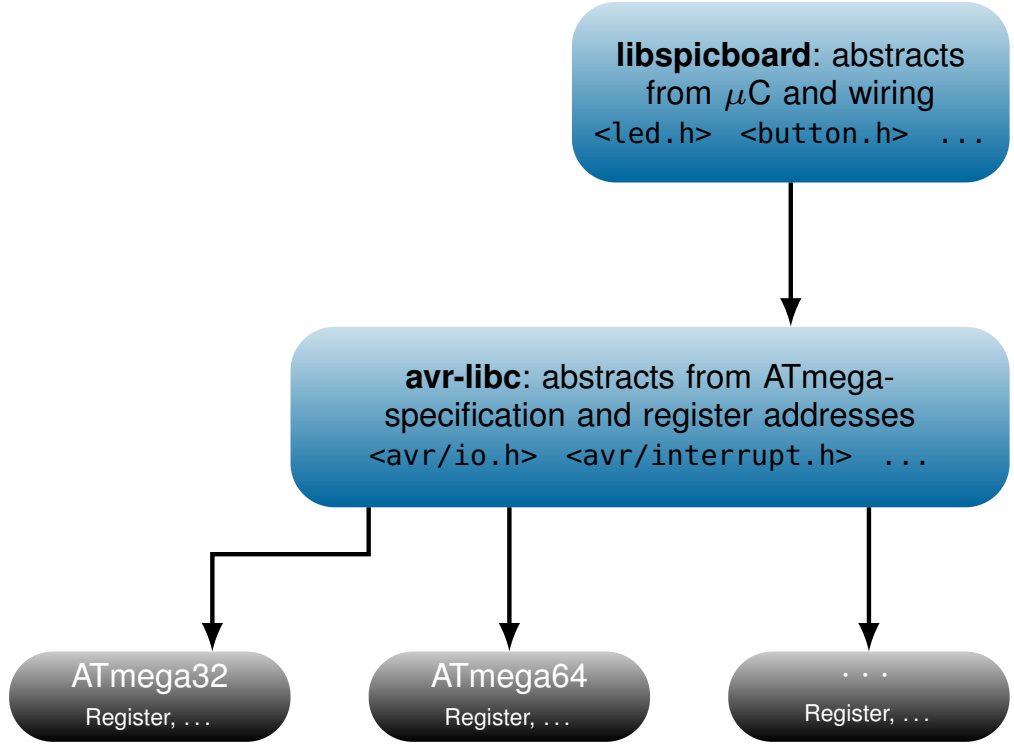
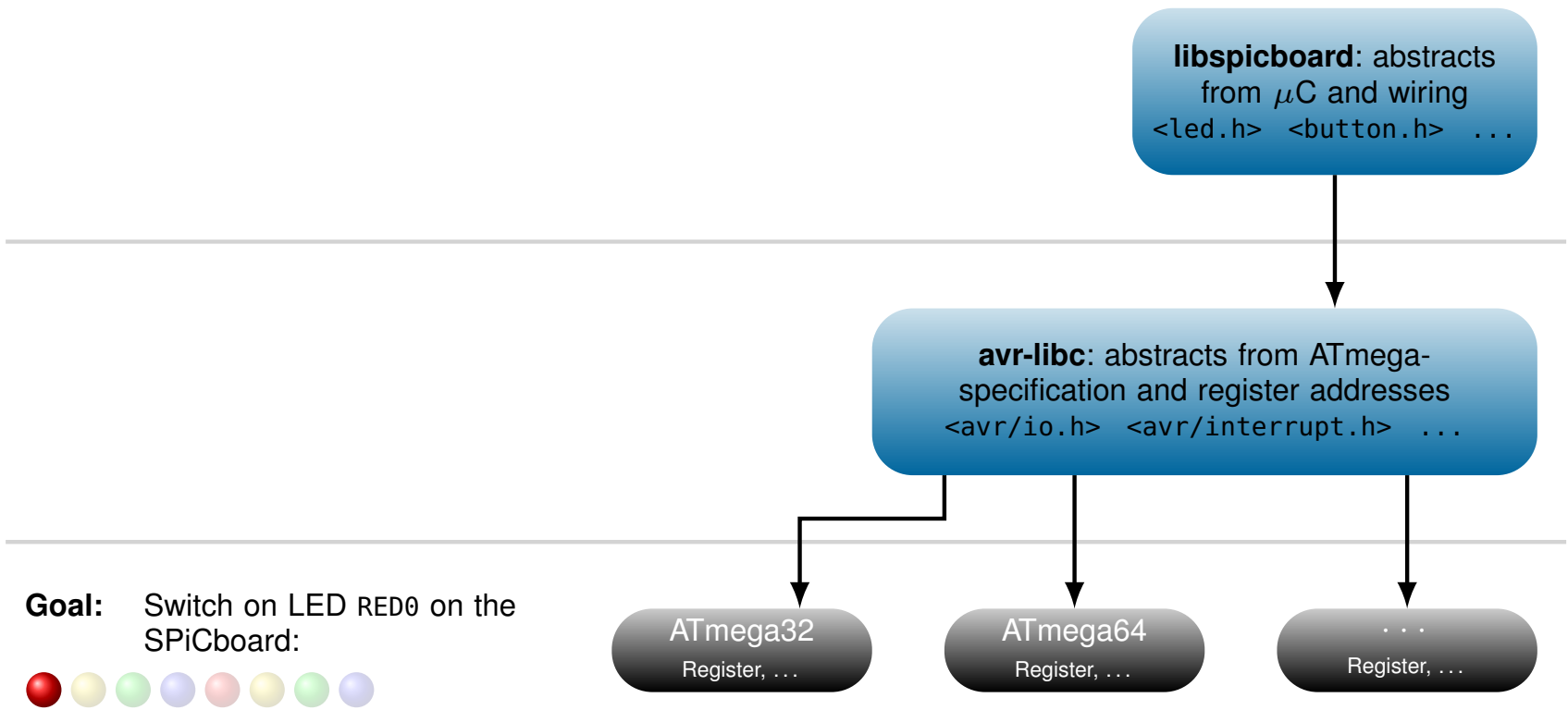


Software layers



Abstraction by Software Layers: *LED* → *on* Compared



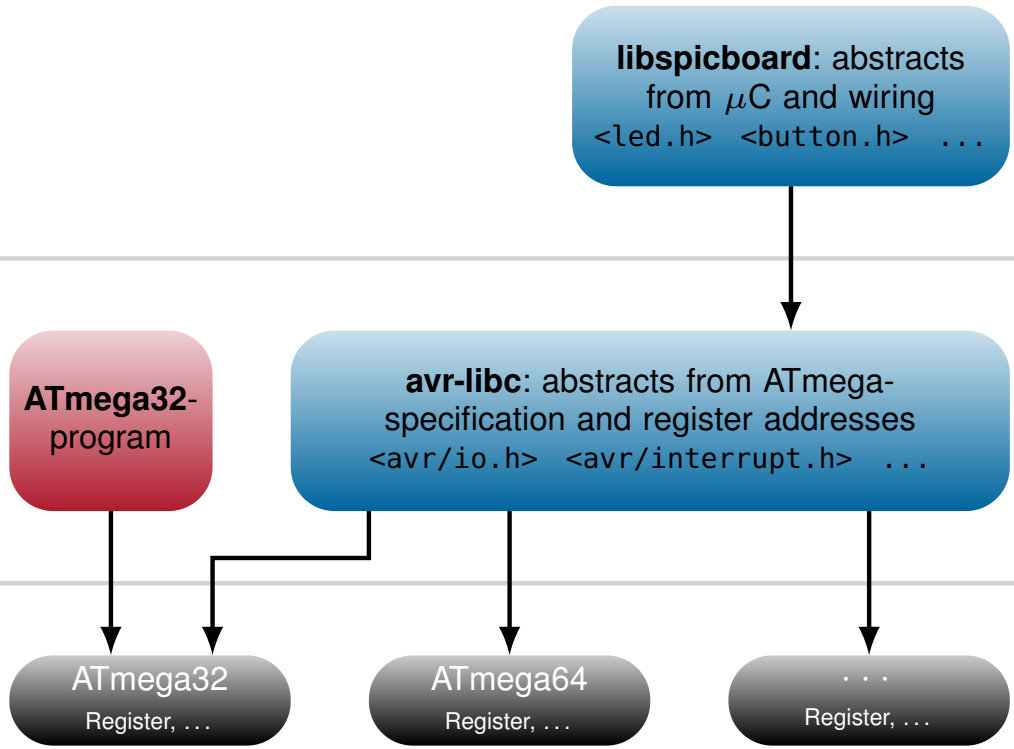
Goal: Switch on LED `RED0` on the SPiCboard:

Abstraction by Software Layers: *LED* → *on* Compared

Program only runs on **ATmega32**. It uses register addresses specific to the **ATmega32** (like `0x12`) and characteristics:

```
...
(*(unsigned char*)(0x11)) |= (1<<7);
(*(unsigned char*)(0x12)) &= ~(1<<7);
```

Goal: Switch on LED `RED0` on the SPiCboard:



Abstraction by Software Layers: *LED* → *on* Compared

Program runs on **each** μC of the ATmega-series. It uses **symbolic register names** of the **avr-libc** (like `PORTD`) and general characteristics:

```
#include <avr/io.h>
...
DDRD |= (1<<7);
PORTD &= ~(1<<7);
```

Program only runs on **ATmega32**. It uses register addresses specific to the **ATmega32** (like `0x12`) and characteristics:

```
...
(*(unsigned char*)(0x11)) |= (1<<7);
(*(unsigned char*)(0x12)) &= ~(1<<7);
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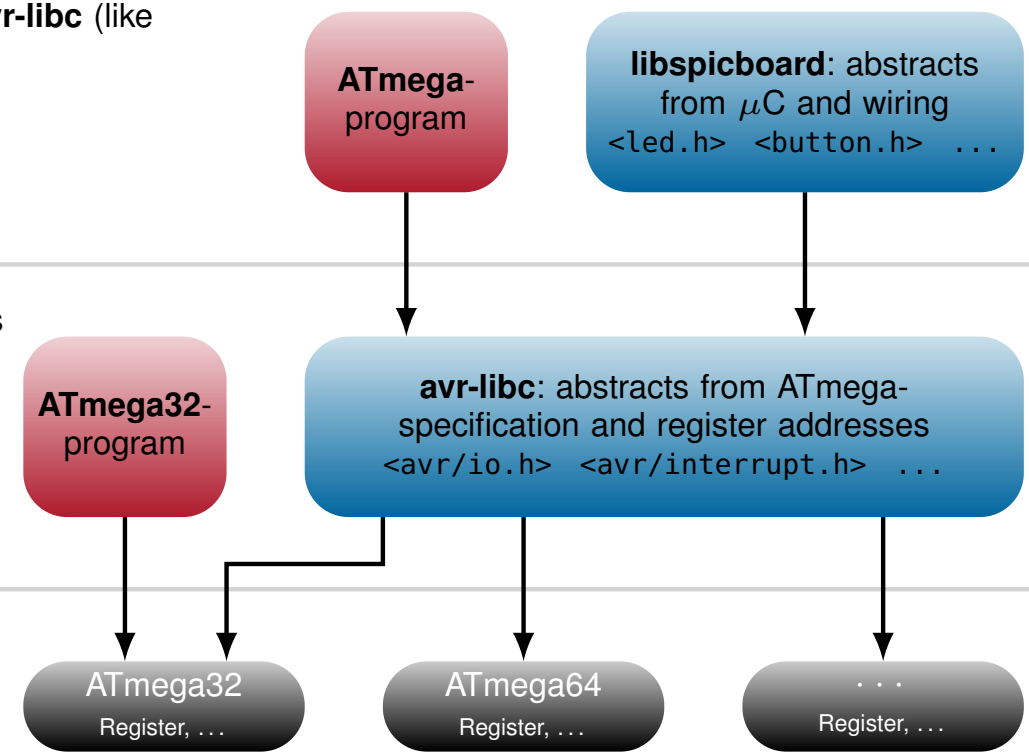
Goal: Switch on LED `RED0` on the SPiCboard:



Abstraction by Software Layers: *LED → on* Compared

Program only runs on the **SPiCboard**. It uses functions (like `sb_led_on()`) and constants (like `RED0`) of the **libspicboard** that represent concrete wiring of LEDs, buttons, etc. with the μC:

```
#include <led.h>
...
sb_led_on(RED0);
```

Program runs on **each** μC of the ATmega-series. It uses **symbolic register names** of the **avr-libc** (like `PORTD`) and general characteristics:

```
#include <avr/io.h>
...
DDRD |= (1<<7);
PORTD &= ~(1<<7);
```

Program only runs on **ATmega32**. It uses register addresses specific to the **ATmega32** (like `0x12`) and characteristics:

```
...
(*(unsigned char*)(0x11)) |= (1<<7);
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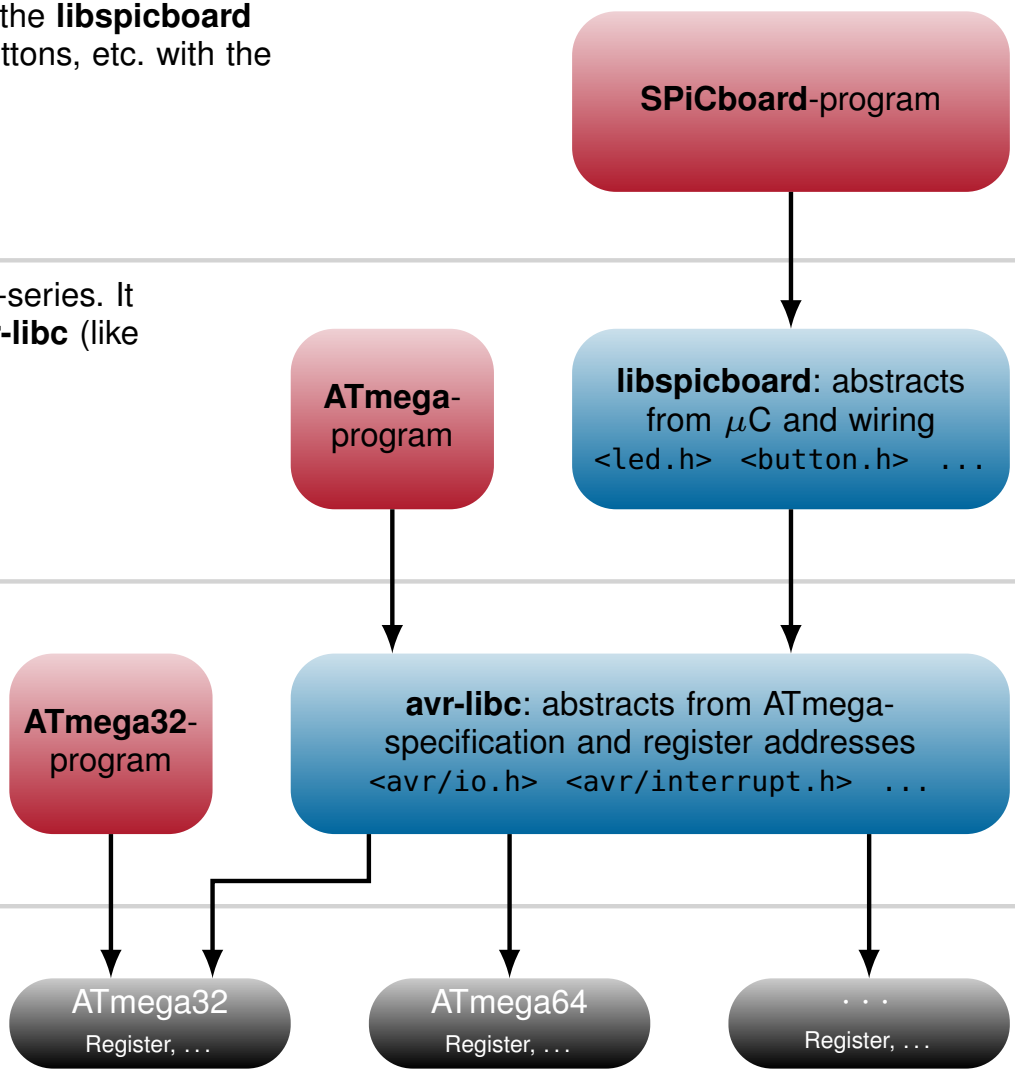
Goal: Switch on LED `RED0` on the SPiCboard:



close to problem — close to machine

Abstraction by Software Layers: Complete Example

Until now: development with avr-libc

```
#include <avr/io.h>

void main(void) {
  // initialize hardware

  // button0 on PD2
  DDRD  &= ~(1 << 2);
  PORTD |=  (1 << 2);
  // LED on PD6
  DDRD  |= (1 << 6);
  PORTD |= (1 << 6);

  // wait until PD2: low --> (button0 pressed)
  while ((PIND >> 2) & 1) {
  }

  // greet user (red LED)
  PORTD &= ~(1 << 6); // PD6: low --> LED is on

  // wait forever
  while (1) {
  }
}
```

(ref. ↪ 3–11)

Now: development with libspicboard

```
#include <led.h>
#include <button.h>

void main(void) {

  // wait until Button0 is pressed
  while (sb_button_getState(BUTTON0)
                        != PRESSED) {
  }

  // greet user
  sb_led_on(RED0);

  // wait forever
  while (1) {
  }
}
```

Abstraction by Software Layers: Complete Example

Until now: development with avr-libc

```
#include <avr/io.h>

void main(void) {
  // initialize hardware

  // button0 on PD2
  DDRD  &= ~(1 << 2);
  PORTD |=  (1 << 2);
  // LED on PD6
  DDRD  |= (1 << 6);
  PORTD |= (1 << 6);

  // wait until PD2: low --> (button0 pressed)
  while ((PIND >> 2) & 1) {
  }

  // greet user (red LED)
  PORTD &= ~(1 << 6); // PD6: low --> LED is on

  // wait forever
  while (1) {
  }
}
```

(ref. ↪ 3–11)

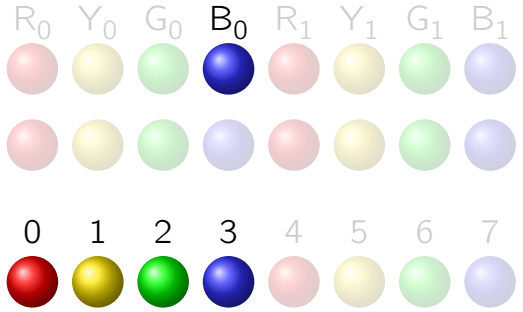
Now: development with libspicboard

```
#include <led.h>
#include <button.h>

void main(void) {

  // wait until Button0 is pressed
  while (sb_button_getState(BUTTON0)
                        != PRESSED) {
  }

  // greet user
  sb_led_on(RED0);

  // wait forever
  while (1) {
  }
}
```

- Hardware initialization not needed anymore
- Program simpler to understand due to **problem-specific abstraction**
  - setting bit 6 in `PORTD` ↦ `sb_led_on(RED0)`
  - reading bit 2 in `PORTD` ↦ `sb_button_getState(BUTTON0)`

Abstraction of the libspicboard: Short Overview

- Output abstractions (selection)
  - LED module (`#include <led.h>`)
    - switch LED on: `sb_led_on(BLUE0)` ⇝
    - switch LED off: `sb_led_off(BLUE0)` ⇝
    - switching all LEDs on or off: `sb_led_setMask(0x0f)` ⇝

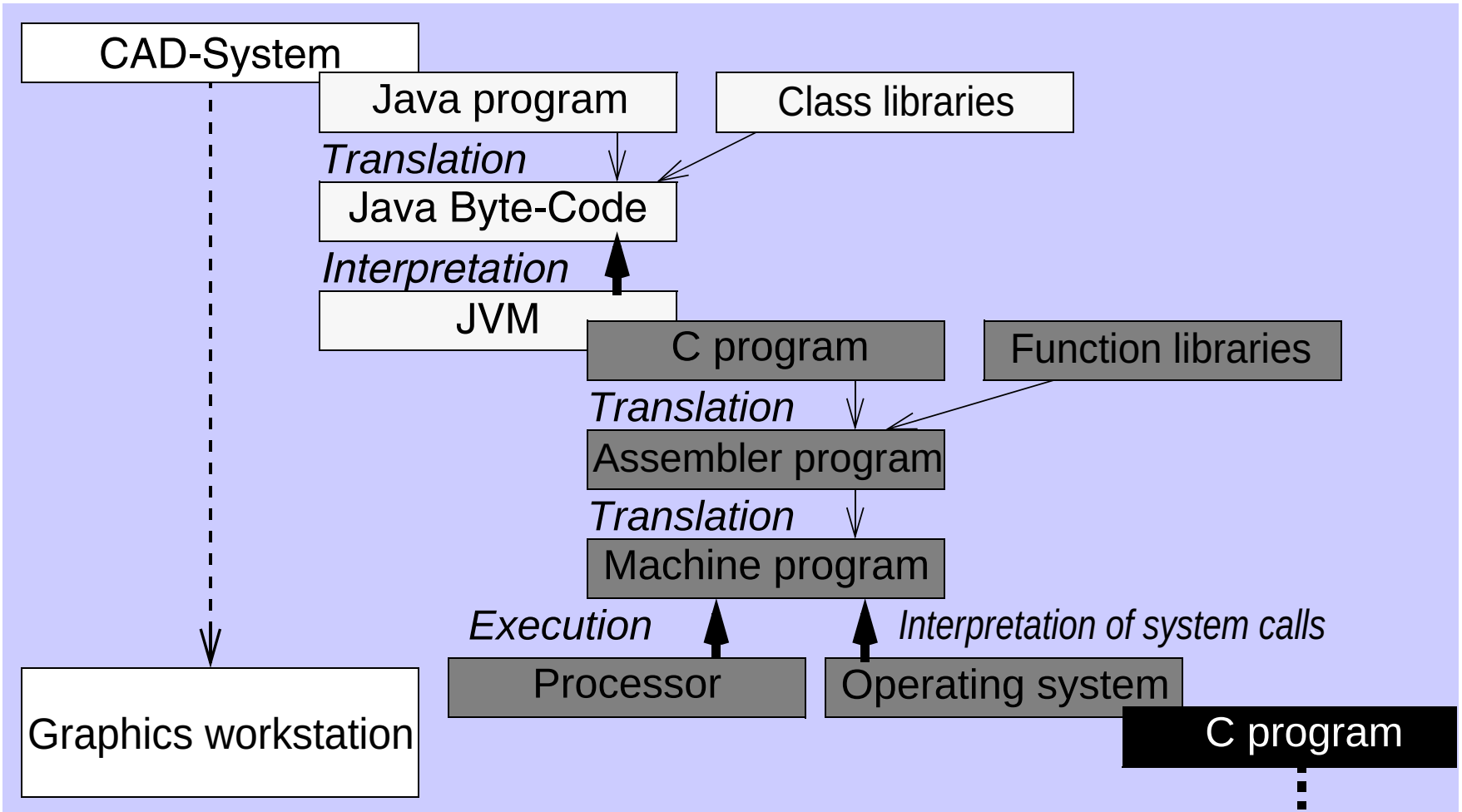


  - 7 segment module (`#include <7seg.h>`)
    - showing an integer $n \in \{-9 \ldots 99\}$: `sb_7seg_showNumber(47)` ⇝

- Input abstractions (selection)
  - Button module (`#include <button.h>`)
    - reading the button state: `sb_button_getState(BUTTON0)` ↦ `BUTTONSTATE_{PRESSED,RELEASED}`
  - ADC module (`#include <adc.h>`)
    - reading the value of the potentiometer: `sb_adc_read(POTI)` ↦ $\{0 \ldots 1023\}$

Software Layers in General

Discrepancy: application problem $\longleftrightarrow$ hardware processes



Goal: executable machine code

close to problem — close to machine

The Role of the Operating System

- **User view:** Environment for starting, controlling, and combining of applications
  - Shell, graphical user interface
    - e. g., bash, Windows
  - Communication between applications and users
    - e. g., with files
- **Application view:** Function libraries with abstractions for easier software development
  - Generic in-/output of data
    - e. g., on printers, serial interfaces, in files
  - Persistent storage and transfer of data
    - e. g., by the file system, over TCP/IP sockets
  - Management of memory and other resources
    - e. g., execution time on CPU

The Role of the Operating System (continued)

- **System view:** Software layers for multiplexing of the hardware ($\hookrightarrow$ multi-user mode)
  - Parallel handling of program instances with **process concepts**
    - virtual memory $\hookrightarrow$ own 32-/64-bit address space
    - virtual processor $\hookrightarrow$ scheduled/preempted transparently
    - virtual in/output devices $\hookrightarrow$ can be piped in files, sockets, ...
  - Isolation of program instances with **process concepts**
    - automatic garbage collection at the end of process life
    - detection/prevention of memory access to other processes
  - **Partial protection** from critical programming errors
    - detection of *some* invalid memory accesses (e. g., access to address `0`)
    - detection of *some* invalid operations (e. g., `div/0`)

µC programming without operating system platform $\rightsquigarrow$ **no protection**

- Operating system **protects programmer less** from bugs compared to e. g., Python.
- For the µC programming, we even have to **give up this protection**.
- 8/16-bit µC often have **no hardware support** for protection.

Example: Error Detection by the Operating System

Linux: Division by 0

```
1  #include <stdio.h>
2
3
4  int main(int argc, char **argv) {
5    int a = 23;
6    int b;
7
8    b = 4711 / (a - 23);
9    printf("Result: %d\n", b);
10
11   return 0;
12 }
```

Compilation and execution yields:

```
gcc error-linux.c -o error-linux
./error-linux
Floating point exception
```

⇝ program gets **terminated**.

SPiCboard: Division by 0

```
#include <7seg.h>
#include <avr/interrupt.h>

void main(void) {
  int a = 23;
  int b;
  sei();
  b = 4711 / (a - 23);
  sb_7seg_showNumber(b);

  while (1) {}
}
```

Execution yields:

⇝ Program continues computation with **wrong data**.