System-Level Programming

9 Functions

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What is a Function?

**Function** ::= subprogram
- program piece (block) that has an **identifier**
- **parameter** can be passed when calling the function
- a **return value** can be passed after finishing

Functions are elementary program pieces
- structure extensive tasks in smaller, manageable components
- enable a simple reuse of components
- enable a simple exchange of components
- hide implementation details: **black-box** principle
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**function** $\mapsto$ **abstraction**

- Identifier and parameters **abstract**
  - from the actual program piece
  - from the representation and usage of data
- Enables a step-by-step abstraction and refinement
Example

Function (abstraction) `sb_led_setMask()`

```c
#include <led.h>
void main(void) {
    sb_led_setMask(0xaa);
    while(1) {}  
}
```

Implementation in libspiciboard

```c
void sb_led_setMask(uint8_t setting) {
    uint8_t i = 0;
    for (i = 0; i < 8; i++) {
        if ((setting >> i) & 1) {
            sb_led_on(i);
        } else {
            sb_led_off(i);
        }
    }
}
```
Example

Function (abstraction) \texttt{sb\_led\_setMask()}

```c
#include <led.h>
void main(void) {
    sb\_led\_setMask(0xaa);
    while(1) {}
}
```

Implementation in \texttt{libspicboard}

```c
void \texttt{sb\_led\_setMask(uint8\_t setting)}
{
    \texttt{uint8\_t} \texttt{i} = 0;
    for (\texttt{i} = 0; \texttt{i} < 8; \texttt{i}++) {
        \texttt{if ((setting} \gg \texttt{i}) \& 1) { \texttt{sb\_led\_on(i);}}
        \texttt{else} { \texttt{sb\_led\_off(i);}}
    }
}
```
Function Definitions

Syntax:  
\[
\text{type identifier ( formalParam\text{opt} ) \{block\}}
\]

- **type**: type of the returned value, \texttt{void} if nothing is returned
- **identifier**: name of the function, which is used for calling it
- **formalParam\text{opt}**: list of formal parameters:
  \[
  \text{type}_1 \, \text{id}_1\text{opt}, \ldots, \text{type}_n \, \text{id}_n\text{opt}
  \]
  (parameter identifiers are optional)
- **{block}**: implementation; formal parameters can be used as local variables

Examples:

\[
\begin{align*}
\text{int max(int a, int b) \{} \\
&\quad \text{if (a > b) return a;} \\
&\quad \text{return b;} \\
\text{\{} 
\end{align*}
\]

\[
\begin{align*}
\text{void wait(void) \{} \\
&\quad \text{volatile uint16_t w;} \\
&\quad \text{for (w = 0; w < 0xffff; w++) \{} \\
&\quad \quad \text{\{} \\
&\quad \quad \text{\}} \\
&\quad \text{\}}
\end{align*}
\]
Function Calls

Syntax:  \texttt{identifier ( actParam )}

- \texttt{identifier}  
  name of the function to be jumped into

- \texttt{actParam}  
  list of actual parameters (passed values, have to be compatible in type and count to the list of formal parameters)

Examples:

\begin{verbatim}
int x = max(47, 11);
char text[] = "Hello, World";
int x = max(47, text);
max(48, 12);
\end{verbatim}

Call of the \texttt{max()} function. 47 and 11 are the actual parameters, which are mapped to the formal parameters \(a\) and \(b\) of the \texttt{max()}-function (\texttt{\rightarrow 9-4}).

\textbf{Error:} text is not promotable to type \texttt{int}

actual parameter 2 does not match definition of formal parameter \(b\) (\texttt{\leftrightarrow 9-4})

The returned value can be ignored (even though it makes no sense here).
General types of parameter passing

- **call by value**
  
  Formal parameters are copies of the actual parameters. Changes made to the formal parameters are lost when the function is exited.
  
  *This is the standard case in C.*

- **call by reference**
  
  Formal parameters are references to the actual parameters. Changes made to the formal parameters directly affect the actual parameters as well.
  
  *In C possible with the help of pointers.*

Note:

- arrays are always passed *by reference*

- the order in which parameters are evaluated is *undefined!*
Functions can call themselves (recursion)

```java
int fak(int n) {
    if (n > 1)
        return n * fak(n - 1);
    return 1;
}
```

Recursive definition of the factorial function.

Recursion leads to a significant runtime and memory cost! For each recursion step:

- Memory has to be provided for: return address, parameters and all local variables
- Parameter are copied, and a function call is performed

Rule: When possible, avoid any recursion when writing system-level code!
Functions can call themselves (recursion)

```java
int fak(int n) {
    if (n > 1)
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Recursive definition of the factorial function.

A descriptive but really bad example for the use of recursion!
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Recursion leads to a significant runtime and memory cost!
For each recursion step:
- Memory has to be provided for: return address, parameters and all local variables
- Parameter are copied, and a function call is performed

**Rule:** When possible, avoid any recursion when writing system-level code!
Function Declaration

- Functions have to be declared (made known) in the source code prior to being used.
  - When defining a function upfront, this definition serves as declaration.
  - Otherwise, (if the function is implemented “further below” in the source code or is defined in another module) it has to be declared explicitly.

Syntax: `type identifier ( formalParam );`

Example:

```java
// declaration by definition
int max(int a, int b) {
    if (a > b) return a;
    return b;
}

void main(void) {
    int z = max(47, 11);
}

// explicit declaration
int max(int, int);

void main(void) {
    int z = max(47, 11);
}

int max(int a, int b) {
    if (a > b) return a;
    return b;
}
```
Functions shall **should** be **declared** in the code prior to being used.
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**Attention:** C does not enforce this!

- Possibility to call functions that are **not declared**
  (← implicit declaration)
- Such calls are however **not type-safe**
  - the compiler does not know the list of formal parameters
  - it cannot verify whether the actual parameters match
  - Possibility to pass **anything**
- Modern compilers at least generate a **warning**
  - Always take compiler warnings seriously!
Functions shall **should** be **declared** in the code prior to being used.

**Example:**

```c
#include <stdio.h>

int main(void) {
    double d = 47.11;
    foo(d);
    return 0;
}

void foo(int a, int b) {
    printf("foo: a:%d, b:%d\n", a, b);
}
```
Functions shall **should** be declared in the code prior to being used.

**Example:**

```c
#include <stdio.h>

int main(void) {
    double d = 47.11;
    foo(d);
    return 0;
}

void foo(int a, int b) {
    printf("foo: a:%d, b:%d\n", a, b);
}
```

Function `foo()` is not declared; the compiler **warns** but accepts any actual parameters.
Functions shall **should** be declared in the code prior to being used.

**Example:**

```c
#include <stdio.h>

int main(void) {
    double d = 47.11;
    foo(d);
    return 0;
}

void foo(int a, int b) {
    printf("foo: a:%d, b:%d\n", a, b);
}
```

foo() is defined with formal parameters (int, int). Everything that is passed as actual parameters will be interpreted as int!
Functions should be declared in the code prior to being used.

Example:

```c
#include <stdio.h>

int main(void) {
    double d = 47.11;
    foo(d);
    return 0;
}

void foo(int a, int b) {
    printf("foo: a:%d, b:%d\n", a, b);
}
```

What will be printed?
Functions shall **should** be declared in the code prior to being used.

- Functions that are declared with an empty list of formal parameters will also accept any parameter ➔ **no type safety**
- The compiler does **not** warn in this case. The problems remain!
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- Functions that are declared with an empty list of formal parameters will also accept any parameter → no type safety
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**Example:**

```c
#include <stdio.h>

void foo(); // "open" declaration

int main(void) {
    double d = 47.11;
    foo(d);
    return 0;
}

void foo(int a, int b) {
    printf("foo: a:%d, b:%d\n", a, b);
}
```

Function `foo()` has been declared with empty list of formal parameters → this is a formally **valid call!**
Functions shall **should** be declared in the code prior to being used.

- Functions that are declared with an empty list of formal parameters will also accept any parameter → **no type safety**
- The compiler does **not** warn in this case. The problems remain!

**Attention: Risk of confusion**

- In Java, `void foo()` would define a **parameterless** method
  - In C, one has to explicitly write `void foo(void)`
  - In C, `void foo()` declares an **open** function
    - This is only useful in (rare) cases!
    - Generally it is considered bad style → point deduction in exam!

**Rule:** Functions always need to be **declared completely**!