IEC 61131-3: Programming Industrial Automation Systems

Concepts and Programming Languages, Requirements for Programming Systems, Decision-Making Aids

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2 Building Blocks of IEC 61131-3

This chapter explains the meaning and usage of the main language elements of the IEC 61131-3 standard. These are illustrated by several examples from real life, with each example building upon the previous one.

The reader is introduced to the terms and ways of thinking of IEC 61131-3. The basic ideas and concepts are explained clearly and comprehensively without discussing the formal language definitions of the standard itself [IEC 61131-3].

The first section of this chapter gives a compact introduction to the conceptual range of the standard by means of an example containing the most important language elements and providing an overview of the methodology of PLC programming with IEC 61131-3.

The term *"POU" (Program Organisation Unit)* is explained in detail because it is fundamental for a complete understanding of the new language concepts.

As the programming language Instruction List (IL) is already well known to most PLC programmers, it has been chosen as the basis for the examples in this chapter. IL is widespread on the European PLC market and its simple syntax makes it easy to comprehend.

The programming language IL itself is explained in Section 4.1.

2.1 Introduction to the New Standard

IEC 61131-3 not only describes the PLC programming languages themselves, but also offers comprehensive concepts and guidelines for creating PLC projects.

The purpose of this section is to give a short summary of the important terms of the standard without going into details. These terms are illustrated by a simple example. More detailed information will be found in the subsequent sections and chapters.

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2.1.1 Structure of the building blocks

POUs correspond to the *Blocks* in previous (conventional) programming systems. POUs can call each other with or without parameters. As the name implies, POUs are the smallest independent software units of a user program.

There are three types of POUs: *Function (FUN)*, *Function block (FB)* and *Program (PROG)*, in ascending order of functionality. The main difference between functions and function blocks is that functions always produce the same result (function value) when called with the same input parameters, i.e. they have no "memory". Function blocks have their own data record and can therefore "remember" status information (*instantiation*). Programs (PROG) represent the "top" of a PLC user program and have the ability to access the I/Os of the PLC and to make them accessible to other POUs.

IEC 61131-3 predefines the calling interface and the behaviour of frequently needed s*tandard functions (std. FUN)* such as arithmetic or comparison functions, as well as *standard function blocks (std. FB),* such as timers or counters.

Declaration of variables

The IEC 61131-3 standard uses *variables* to store and process information. Variables correspond to (global) flags or bit memories in conventional PLC systems. However, their storage locations no longer need to be defined manually by the user (as absolute or global addresses), but they are managed automatically by the programming system and each possess a fixed *data type*.

IEC 61131-3 specifies several data types (Bool, Byte, Integer, ...). These differ, for example, in the number of bits or the use of signs. It is also possible for the user to define new data types: user-defined data types such as structures and arrays.

Variables can also be assigned to a certain I/O address and can be battery-backed against power failure.

Variables have different forms. They can be defined (declared) outside a POU and used program-wide, they can be declared as interface parameters of a POU, or they can have a local meaning for a POU. For declaration purposes they are therefore divided into different variable types. All variables used by a POU have to be declared in the declaration part of the POU.

The declaration part of a POU can be written in textual form independently of the programming language used. Parts of the declaration (input and output parameters of the POU) can also be represented graphically.

```
VAR_INPUT                          (* Input variable *)
  ValidFlag      : BOOL;           (* Binary value *)
END_VAR
VAR_OUTPUT                         (* Output variable *)
  RevPM          : REAL;           (* Floating-point value *)
END_VAR
VAR RETAIN                         (* Local variable, battery-backed *)
  MotorNr        : INT;            (* Signed integer *)
  MotorName      : STRING [10];    (* String of length 10 *)
  EmStop AT %IX2.0 : BOOL;         (* Input bit 2.0 of I/O *)
END_VAR
```

Example 2.1. Example of typical variable declarations of a POU

Example 2.1 shows the variable declaration part of a POU. A signed integer variable (16 bits incl. sign) with name MotorNr and a text of length 10 with name MotorName are declared. The binary variable EmStop (emergency stop) is assigned to the I/O signal input 2.0 (using the keyword "AT"). These three variables are known only within the corresponding POU, i.e. they are "local". They can only be read and altered by this POU. During a power failure they retain their value, as is indicated by the qualifier "RETAIN". The value for input variable ValidFlag will be set by the calling POU and have the Boolean values TRUE or FALSE. The output parameter returned by the POU in this example is the floating-point value RevPM.

The Boolean values TRUE and FALSE can also be indicated by "1" and "0".

Code part of a POU

The code part, or instruction part, follows the declaration part and contains the instructions to be processed by the PLC.

A POU is programmed using either the textual programming languages Instruction List (IL) and Structured Text (ST) or the graphical languages Ladder Diagram (LD) and Function Block Diagram (FBD). IL is a programming language closer to machine code, whereas ST is a high-level language. LD is suitable for Boolean (binary) logic operations. FBD can be used for programming both Boolean (binary) and arithmetic operations in graphical representation.

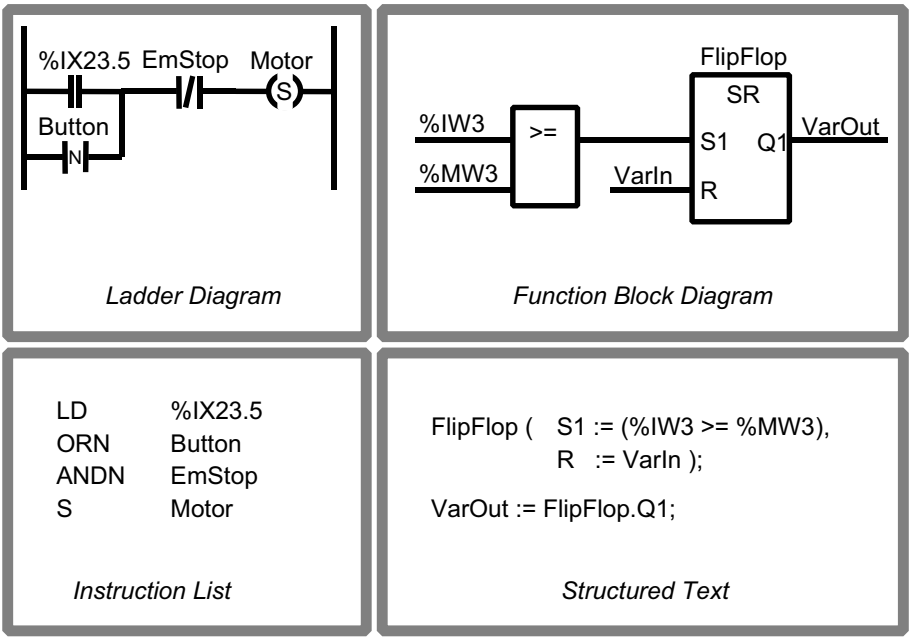


Figure 2.1. Simple examples of the programming languages LD, FBD, IL and ST. The examples in LD and IL are equivalent to one another, as are those in FBD and ST.

Additionally, the description language Sequential Function Chart (SFC) can be used to describe the structure of a PLC program by displaying its sequential and parallel execution. The various subdivisions of the SFC program (steps and transitions) can be programmed independently using any of the IEC 61131-3 programming languages.

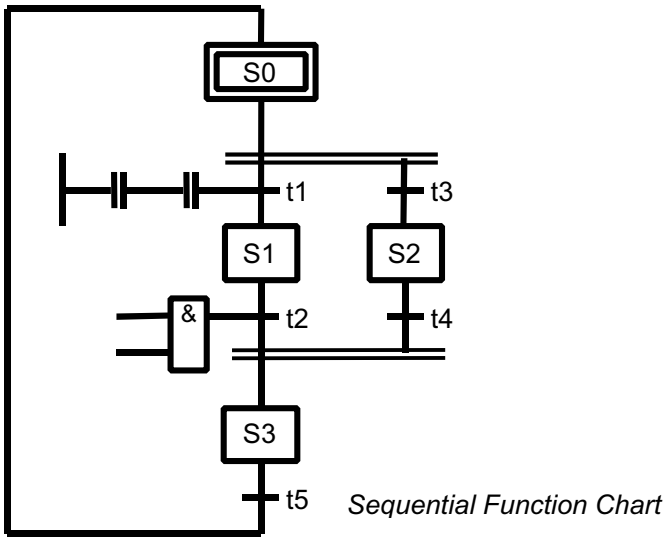


Figure 2.2. Schematic example of structuring using SFC. The execution parts of the steps (S0 to S3) and the transitions (t1 to t5) can be programmed using any other programming language.

Figure 2.2 shows an SFC example: Steps S0, S1 and S3 are processed sequentially. S2 can be executed alternatively to S1. Transitions t1 to t5 are the conditions which must be fulfilled before proceeding from one step to the next.

2.1.2 Introductory example written in IL

An example of an IEC 61131-3 program is presented in this section. Figure 2.3 shows its POU calling hierarchy in tree form.

This example is not formulated as an executable program, but simply serves to demonstrate POU structuring.

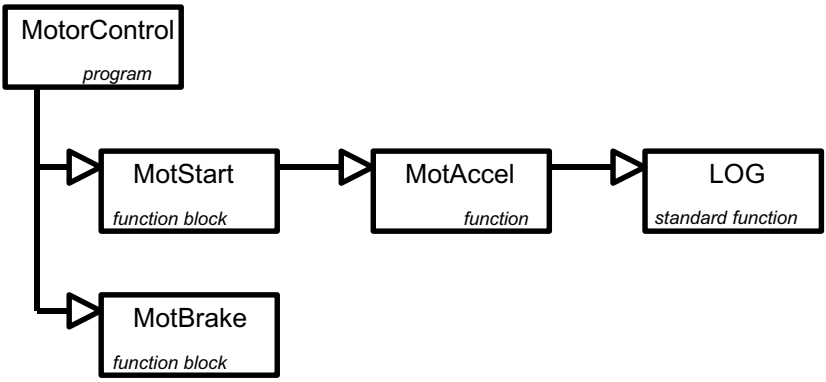
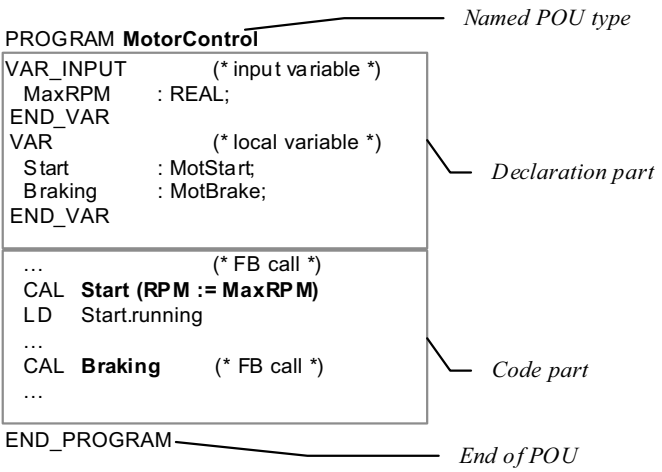


Figure 2.3. Calling hierarchy of POUs in the example

The equivalent IL representation is shown in Example 2.2.



Example 2.2. Declaration of the program MotorControl from Figure 2.3 together with corresponding code parts in IL. Comments are represented by the use of brackets: "(* ... *)".

```
FUNCTION_BLOCK MotStart                          (* function block *)
VAR_INPUT      RPM:      REAL; END_VAR           (* declaration of RPM*)
VAR_OUTPUT     running: BOOL;  END_VAR           (* declaration of running*)
  ...
  LD           RPM
  MotAccel     100.0                             (* function call *)
  ...
END_FUNCTION_BLOCK
```

```
FUNCTION_BLOCK MotBrake                          (* function block *)
...
END_FUNCTION_BLOCK
```

```
FUNCTION MotAccel : REAL                         (* function *)
VAR_INPUT Param1, Param2: REAL; END_VAR           (* declaration of variables*)
  LD    Param2
  LOG                                            (* invoc. of Std. FUN LOG *)
  ...
  ST    MotAccel
END_FUNCTION
```

Example 2.3. The three subprograms of Fig. 2.3 in IL. LOG (logarithm) is predefined standard function of IEC 61131-3.

MotorControl is the main program. When this program is started, the variable RPM is assigned an initial value passed with the call (as will be seen later). This POU then calls the block Start (MotStart). This POU in turn calls the REAL function MotAccel with two input parameters (RPM and 100.0). This then calls LOG – the IEC 61131 *standard function* "Logarithm". After processing Start (MotStart), MotorControl is activated again, evaluates the result running and then calls Braking, (MotBrake).

As shown in Example 2.2, the function blocks MotStart and MotBrake are not called directly using these names, but with the so-called "*instance* names" Start and Braking respectively.

2.1.3 PLC assignment

Each PLC can consist of multiple processing units, such as CPUs or special processors. These are known as *resources* in IEC 61131-3. Several programs can run on one resource. The programs differ in priority or execution type (periodic/cyclic or by interrupt). Each program is associated with a *task*, which makes it into a *run-time program*. Programs may also have multiple associations (*instantiation*).

Before the program described in Examples 2.2 and 2.3 can be loaded into the PLC, more information is required to ensure that the associated task has the desired properties:

- On which PLC type and which resource is the program to run?
- How is the program to be executed and what priority should it have?
- Do variables need to be assigned to physical PLC addresses?
- Are there global or external variable references to other programs to be declared?

This information is stored as the *configuration*, as illustrated textually in Example 2.4 and graphically in Figure 2.4.

```
CONFIGURATION MotorCon
  VAR_GLOBAL Trigger AT %IX2.3 : BOOL;  END_VAR
  RESOURCE Res_1 ON CPU001
    TASK T_1            (INTERVAL := t#80ms,   PRIORITY := 4);
    PROGRAM MotR  WITH T_1 : MotorControl (MaxRPM := 12000);
  END_RESOURCE
  RESOURCE Res_2 ON CPU002
    TASK T_2            (SINGLE := Trigger, PRIORITY := 1);
    PROGRAM MotP  WITH T_2 : MotorProg (...);
  END_RESOURCE
END_CONFIGURATION
```

Example 2.4. Assignment of the programs in Example 2.3 to tasks and resources in a "configuration"

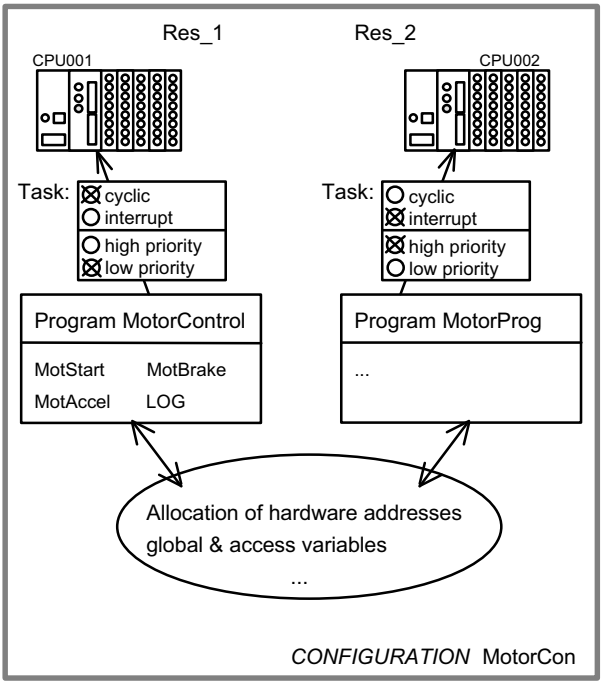


Figure 2.4. Assignment of the programs of a motor control system MotorCon to tasks in the PLC "configuration". The resources (processors) of the PLC system execute the resulting run-time programs.

Figure 2.4 continues Example 2.3. Program MotorControl runs together with its FUNs and FBs on resource CPU001. The associated task specifies that MotorControl should execute cyclically with low priority. Program MotorProg runs here on CPU002, but it could also be executed on CPU001 if this CPU supports multitasking.

The configuration is also used for assigning variables to I/Os and for managing global and communication variables. This is also possible within a PROGRAM.

A PLC project consists of POUs that are either shipped by the PLC manufacturer or created by the user. User programs can be used to build up libraries of tested POUs that can be used again in new projects. IEC 61131-3 supports this aspect of software *re-use* by stipulating that functions and function blocks have to remain "universal", i.e. hardware-independent, as far as possible.

After this short summary, the properties and special features of POUs will now be explained in greater detail in the following sections.

2.2 The Program Organisation Unit (POU)

IEC 61131-3 calls the blocks from which programs and projects are built Program Organisation Units (POUs). POUs correspond to the program blocks, organisation blocks, sequence blocks and function blocks of the conventional PLC programming world.

One very important goal of the standard is to restrict the variety and often implicit meanings of block types and to unify and simplify their usage.

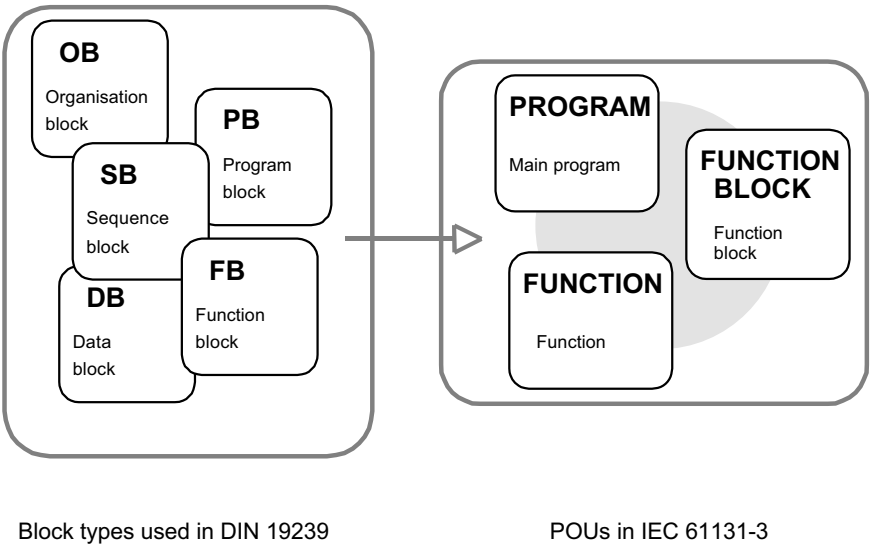


Figure 2.5. Evolution from previous block types (e.g. German DIN 19239) to the POUs of IEC 61131-3

As Figure 2.5 shows, IEC 61131-3 reduces the different block types of PLC manufacturers to three unified basic types. Data blocks are replaced by FB data memories ("instances", see below) or global multi-element variables (see also Chapter 3).

The following three *POU types* or "block types" are defined by the new standard:

POU type	Keyword	Meaning
Program	PROGRAM	Main program including assignment to I/O, global variables and access paths
Function block	FUNCTION_BLOCK	Block with input and output variables; this is the most frequently used POU type
Function	FUNCTION	Block with function value, input and output variables for extension of the basic PLC operation set

Table 2.1. The three POU types of IEC 61131-3 with their meanings

These three POU types differ from each other in certain features:

- **Function (FUN).** POU that can be assigned parameters, but has no static variables (without memory), which, when invoked with the same input parameters, always yields the same result as its function value (output).
- **Function block (FB)**. POU that can be assigned parameters and has static variables (with memory). An FB (for example a counter or timer block), when invoked with the same input parameters, will yield values which also depend on the state of its internal (VAR) and external (VAR_EXTERNAL) variables, which are retained from one execution of the function block to the next.
- **Program (PROG).** This type of POU represents the "main program". All variables of the whole program that are assigned to physical addresses (for example PLC inputs and outputs) must be declared in this POU or above it (Resource, Configuration). In all other respects it behaves like an FB.

PROG and FB can have both input and output parameters. Functions, on the other hand, have input and output parameters and a function value as return value. These properties were previously confined to "function blocks".

The IEC 61131-3 FUNCTION_BLOCK with input **and** output parameters roughly corresponds to the conventional function block. The POU types PROGRAM and FUNCTION do not have direct counterparts in blocks as defined in previous standards, e.g. DIN 19239.

A POU is an encapsulated unit, which can be compiled independently of other program parts. However, the compiler needs information about the calling interfaces of the other POUs that are called in the POU ("prototypes"). Compiled POUs can be linked together later in order to create a complete program.

The name of a POU is known throughout the project and may therefore only be used once. Local subroutines as in some other (high-level) languages are not permitted in IEC 61131-3. Thus, after programming a POU (*declaration*), its name and its calling interface will be known to all other POUs in the project, i.e. the POU name is always global.

This independence of POUs facilitates extensive modularisation of automation tasks as well as the *re-use* of already implemented and tested software units.

In the following sections the common properties of the different types of POUs will first be discussed. The POU types will then be characterised, the calling relationships and other properties will be described, and finally the different types will be summarised and compared.

2.3 Elements of a POU

A POU consists of the elements illustrated in Figure 2.6:

- POU type and name (and data type in the case of functions)
- Declaration part with variable declarations
- POU body with instructions.

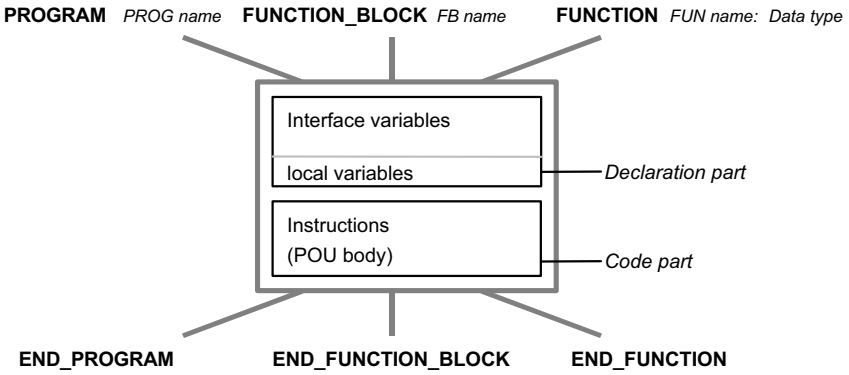


Figure 2.6. The common structure of the three POU types Program (left), Function Block (centre) and Function (right). The declaration part contains interface and local variables.

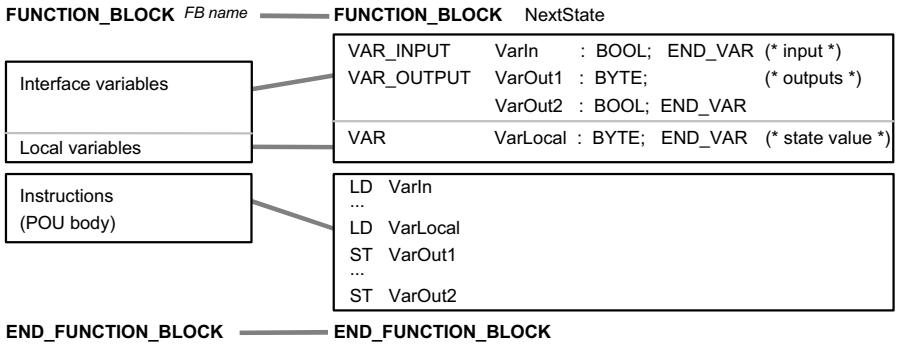
Declarations define all the variables that are to be used within a POU. Here a distinction is made between variables visible from outside the POU (POU interface) and the local variables of the POU. These possibilities will be explained in the next section and in more detail in Chapter 3.

Within the *code part* (body) of a POU the logical circuit or algorithm is programmed using the desired programming language. The languages of IEC 61131-3 are presented and explained in Chapter 4.

Declarations and instructions can be programmed in graphical or textual form.

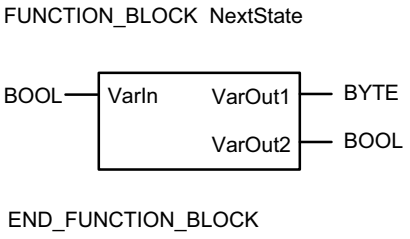
2.3.1 Example

The elements of a POU are illustrated in Example 2.5.



Example 2.5. Elements of a POU (left) and example of a function block in IL (right). The FB contains the input parameter VarIn as well as the two return values VarOut1 and VarOut2. VarLocal is a local variable.

The function block NextState written in IL contains the input parameter VarIn, the two return values VarOut1 and VarOut2 and the local variable VarLocal. In the FB body the IL operators LD (Load) and ST (Store) are used.



Example 2.6. Graphical representation of the calling interface of FB NextState in Example 2.5.

When using the graphical representation of the calling interface, local FB variables such as VarLocal are not visible.

2.3.2 Declaration part

In IEC 61131-3 variables are used for initialising, processing and storing user data. The variables have to be *declared* at the beginning of each POU, i.e. their assignment to a specific *data type* (such as BYTE or REAL) is made known.

Other *attributes* of the variables, such as battery backup, initial values or assignment to physical addresses, can also be defined during declaration.

As shown by Example 2.7, the declaration of POU variables is divided into separate sections for the different *variable types*. Each *declaration block* (VAR_*...END_VAR) corresponds to one variable type and can contain one or more variables. As Example 2.8 shows, the order and number of blocks of the same variable type can be freely determined or can depend on how the variables are used in a particular programming system.

```
(* Local variable *)
VAR             VarLocal : BOOL;   END_VAR    (* local Boolean variable *)
(* Calling interface: input parameters *)
VAR_INPUT       VarIn : REAL;      END_VAR    (* input variable *)
VAR_IN_OUT      VarInOut : UINT;   END_VAR    (* input and output variable *)
(* Return values: output parameters *)
VAR_OUTPUT      VarOut : INT;      END_VAR    (* output variable *)
(* Global interface: global/external variables and access paths *)
VAR_EXTERNAL    VarGlob : WORD;    END_VAR    (* external from other POU *)
VAR_GLOBAL      VarGlob : WORD;    END_VAR    (* global for other POUs *)
VAR_ACCESS      VarPath : WORD;    END_VAR    (* access path of configuration *)
```

Example 2.7. Examples of the declarations of different variable types

```
(* Declaration block 1 *)
VAR          VarLocal1, VarLocal2, VarLocal3: BOOL; END_VAR
(* Declaration block 2 *)
VAR_INPUT    VarIn1 : REAL;                        END_VAR
(* Declaration block 3 *)
VAR_OUTPUT   VarOut : INT;                         END_VAR
(* Declaration block 4 *)
VAR          VarLocal4, VarLocal5 : BOOL;          END_VAR
(* Declaration block 5 *)
VAR_INPUT    VarIn2, VarIn3 : REAL;                END_VAR
(* Declaration block 6 *)
VAR_INPUT    VarIn4 : REAL;                        END_VAR
```

Example 2.8. Examples of declaration blocks: the order and number of the blocks is not specified in IEC 61131-3.

Types of variables in POUs.
As shown by Table 2.2, different types of variables may be used depending on the POU type:

Variable type	**Permitted in:**		
	PROGRAM	*FUNCTION_BLOCK*	*FUNCTION*
VAR	yes	yes	yes
VAR_INPUT	yes	yes	yes
VAR_OUTPUT	yes	yes	yes
VAR_IN_OUT	yes	yes	yes
VAR_EXTERNAL	yes	yes	no
VAR_GLOBAL	yes	no	no
VAR_ACCESS	yes	no	no
VAR_TEMP	yes	yes	no

Table 2.2. Variable types used in the three types of POU

As Table 2.2 shows, all variable types can be used in programs. Function blocks cannot make global variables available to other POUs. This is only permitted in programs, resources and configurations. FBs access global data using the variable type VAR_EXTERNAL.

Functions have the most restrictions because only local and input and output variables are permitted in them. They return their calculation result using the function return value.

Except for local variables, all variable types can be used to import data into and export data from a POU. This makes data exchange between POUs possible. The features of this *POU interface* will be considered in more detail in the next section.

Characteristics of the POU interface
The POU interfaces, as well as the local data area used in the POU, are defined by means of assigning POU variables to variable types in the declaration blocks. The POU interface can be divided into the following sections:

- Calling or invocation interface: formal parameters (input and input/output parameters)
- Return values: output parameters or function return values
- Global interface with global/external variables and access paths.

The calling interface and the return values of a POU can also be represented graphically in the languages LD and FBD.

The variables of the calling interface are also called *formal parameters*. When calling a POU the formal parameters are replaced with *actual parameters*, i.e. assigned actual (variable) values or constants.

In Example 2.3 FB MotStart has only one formal parameter RPM, which is given the value of the actual parameter MaxRPM in Example 2.2, and it also has the output parameter running. The function MotAccel has two formal parameters (one of which is assigned the constant 100.0) and returns its result as the function return value

This is summarised by Table 2.3.

	Variable types	**Remarks**
Calling interface (formal parameters)	VAR_INPUT, VAR_IN_OUT	Input parameters, can also be graphically displayed
Return values	VAR_OUTPUT	Output parameters, can also be graphically displayed
Global interface	VAR_GLOBAL, VAR_EXTERNAL, VAR_ACCESS	Global data
Local values	VAR, VAR_TEMP	POU internal data

Table 2.3. Variable types for interface and local data of a POU. See the comments in Example 2.7.

Formal input parameter (VAR_INPUT): Actual parameters are passed to the POU as *values*, i.e. the variable itself is not used, but only a copy of it. This ensures that this input variable cannot be changed within the called POU. This concept is also known as “call-by-value”.

Formal input/output parameter (VAR_IN_OUT): Actual parameters are passed to the called POU in the form of a pointer to their storage location, i.e. the variable itself is used. It can thus be read and changed by the called POU. Such changes have an automatic effect on the variables declared outside the called POU. This concept is also known as "call-by-reference".

By working with references to storage locations this variable type provides pointers like those used in high-level languages like C for return values from subroutines.

Formal output parameters, return values (VAR_OUTPUT) are not passed to the called POU, but are provided by that POU as values. They are therefore not part of the calling interface. They appear together with VAR_INPUT and VAR_IN_OUT in graphical representation, but in textual languages such as IL or ST their **values** are read **after** calling the POU.

The method of passing to the calling POU is also "return-by-value", allowing the values to be read by the calling instance (FB or PROG). This ensures that the output parameters of a POU are protected against changes by a calling POU. When a POU of type PROGRAM is called, the output parameters are provided together with the actual parameters by the resource and assigned to appropriate variables for further processing (see examples in Chapter 6).

If a POU call uses complex arrays or data structures as variables, the use of VAR_IN_OUT results in more efficient programs, as it is not the variables themselves (VAR_INPUT and VAR_OUTPUT) that have to be copied at run time, but only their respective pointers. However such variables are not protected against (unwelcome) manipulation by the called POU.

External and internal access to POU variables

Formal parameters and return values have the special property of being **visible** outside their POU: the calling POU can (but need not) use their names explicitly for setting input values.

This makes it easier to document the POU calling interface and parameters may be omitted and/or their sequence may be altered. In this context input and output variables are also protected against unauthorised reading and writing.

Table 2.4 summarises all variable types and their meaning. Access rights are given for each variable type, indicating whether the variable:

- is visible to the calling POU ("external") and can be read or written to there
- can be read or written to within the POU ("internal") in which it is defined.

Variable type	Access rights[a] external	internal	Explanation
VAR, VAR_TEMP *Local Variables*	-	RW	A local variable is only visible within its POU and can be processed only there.
VAR_INPUT *Input Variables*	W[b]	R	An input variable is visible to the calling POU and may be written to (changed) there. It may not be changed within its own POU.
VAR_OUTPUT *Output Variables*	R	RW	An output variable is visible to the calling POU and may only be read there. It can be read and written to within its own POU.
VAR_IN_OUT *Input and Output Variables*	RW	RW	An input/output variable possesses the combined features of VAR_INPUT and VAR_OUTPUT: it is visible and may be read or changed within or outside its POU.
VAR_EXTERNAL *External Variables*	RW	RW	An external variable is required to enable read and write access from within a POU to a global variable of another POU. It is visible only to POUs that list this global variable under VAR_EXTERNAL; all other POUs have no access to this global variable. Identifier and type of a variable under VAR_EXTERNAL must coincide with the corresponding VAR_GLOBAL declaration in PROGRAM.
VAR_GLOBAL *Global Variables*	RW	RW	A variable declared as GLOBAL may be read and written to by several POUs. For this purpose, the variable must be listed with identical name and type under VAR-EXTERNAL in the other POUs.
VAR_ACCESS *Access Paths*	RW	RW	Global variable of configurations as communication channel between components (resources) of configurations (see also Chapter 6). It can be used like a global variable within a POU.

a W=Write, R=Read, RW=Read and Write
b can be written to only as formal parameter during invocation

Table 2.4. The meaning of the variable types. The left-hand column contains the keyword of each variable type in bold letters. In the "Access rights" column the read/write rights are indicated for the calling POU (external) and within the POU (internal) respectively.

IEC 61131-3 provides extensive access protection for input and output variables, as shown in Table 2.4 for VAR_INPUT and VAR_OUTPUT: input variables may not be changed within their POU, and output parameters may not be changed outside.

The special relevance of the declaration part to function blocks will be discussed again in Section 2.4.1 when explaining FB instantiation.

The following examples show both external (calling the POU) and internal (within the POU) access to formal parameters and return values of POUs:

```
FUNCTION_BLOCK FBTwo
VAR_INPUT
  VarIn     : BYTE;
END_VAR
VAR_OUTPUT
  VarOut    : BYTE;
END_VAR
VAR
  VarLocal : BYTE;
END_VAR
...
LD    VarIn
AND   VarLocal
ST    VarOut
...

END_FUNCTION_BLOCK
```

```
FUNCTION_BLOCK FBOne
VAR ExampleFB : FBTwo; END_VAR

...
LD    44
ST    ExampleFB.VarIn
CAL   ExampleFB        (* FB call *)
LD    ExampleFB.VarOut
...
END_FUNCTION_BLOCK
```

Example 2.9. Internal access (on the left) and external access (on the right) to the formal parameters VarIn and VarOut.

In Example 2.9 FBOne calls block ExampleFB (described by FBTwo). The input variable VarIn is assigned the constant 44 as actual parameter, i.e. this input variable is visible and initialised in FBOne. VarOut is also visible here and can be read by FBOne. Within FBTwo VarIn can be read (e.g. by LD) and VarOut can be written to (e.g. using the instruction ST).

Further features and specialities of variables and variable types will be explained in Section 3.4**.**

2.3.3 Code part

The instruction or code part (body) of a POU immediately follows the declaration part and contains the instructions to be executed by the PLC. IEC 61131-3 provides five programming languages (three of which have graphical representation) for application-oriented formulation of the control task.

As the method of programming differs strongly between these languages, they are suitable for different control tasks and application areas.

Here is a general guide to the languages:

SFC	*Sequential Function Chart*: For breaking down the control task into parts which can be executed sequentially and in parallel, as well as for controlling their overall execution. SFC very clearly describes the program flow by defining which actions of the controlled process will be enabled, disabled or terminated at any one time. IEC 61131-3 emphasises the importance of SFC as an *Aid for Structuring* PLC programs.
LD	*Ladder Diagram*: Graphical connection ("circuit diagram") of Boolean variables (contacts and coils), geometrical view of a circuit similar to earlier relay controls. POUs written in LD are divided into sections known as *networks*.
FBD	*Function Block Diagram*: Graphical connection of arithmetic, Boolean or other functional elements and function blocks. POUs written in FBD are divided into *networks* like those in LD. *Boolean* FBD networks can often be represented in LD and vice versa.
IL	*Instruction List*: Low-level machine-oriented language offered by most of the programming systems
ST	*Structured Text*: High-level language (similar to PASCAL) for control tasks as well as complex (mathematical) calculations.

Table 2.5. Features of the programming languages of IEC 61131-3

In addition, the standard explicitly allows the use of other programming languages (e.g. C or BASIC), which fulfil the following basic requirements of PLC programming:

- The use of variables must be implemented in the same way as in the other programming languages of IEC 61131-3, i.e. compliant with the declaration part of a POU.
- Calls of functions and function blocks must adhere to the standard, especially calls of standard functions and standard function blocks.
- There must be no inconsistencies with the other programming languages or with the structuring aid SFC.

Details of these standard programming languages, their individual usage and their representation are given in Chapter 4.

2.4 The Function Block

Function blocks are the main building blocks for structuring PLC programs. They are called by programs and FBs and can themselves call functions as well as other FBs.

In this section the basic features of function blocks will be explained. A detailed example of an FB can be found in Appendix C.

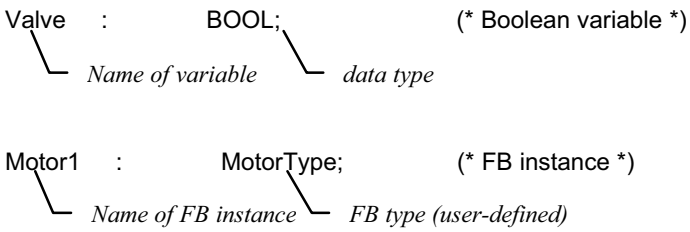
The concept of the "instantiation of FBs" is of great importance in IEC 61131-3 and is an essential distinguishing criterion between the three POU types. This concept will therefore be introduced before explaining the other features of POUs.

2.4.1 Instances of function blocks

What is an "instance"?

The creation of variables by the programmer by specifying the variable's name and data type in the declaration is called *instantiation*.

In the following Example 2.10 the variable Valve is an *instance* of data type BOOL:



Example 2.10. Declaration of a variable as an "instance of a data type" (top). Declaration of an FB "variable" as an "instance of a user-defined FB type" (bottom).

Function blocks also are instantiated like variables: In Example 2.10 the FB instance Motor1 is declared as an instance of the user-defined function block (FB type) MotorType in the declaration part of a POU. After instantiation an FB can be used (as an instance) and called within the POU in which it is declared.

This principle of instantiation may appear unusual at first sight but, in fact, it is nothing new.

Up until now, for example, function blocks for counting or timing, known for short as counters and timers respectively, were mostly defined by their type (such

as direction of counting or timing behaviour) and by a number given by the user, e.g. Counter "C19".

Instead of this absolute number the standard IEC 61131-3 requires a (symbolic) variable name combined with the specification of the desired timer or counter type. This has to be declared in the declaration part of the POU. The programming system can automatically generate internal, absolute numbers for these FB variables when compiling the POU into machine code for the PLC.

With the aid of these variable names the PLC programmer can use different timers or counters of the same type in a transparent manner and without the need to check name conflicts.

By means of instantiation IEC 61131-3 unifies the usage of manufacturer-dependent FBs (typically timers and counters) and user-defined FBs. Instance names correspond to the symbolic names or so-called *symbols* used by many PLC programming systems. Similarly, an FB type corresponds to its calling interface. In fact, FB instances provide much more than this: "Structure" and "Memory" for FBs will be explained in the next two subsections.

The term "function block" is often used with two slightly different meanings: it serves as a synonym for the FB instance name as well as for the FB type (= name of the FB itself). In this book "function block" means *FB type,* while an FB instance will always be explicitly indicated as an instance name.

Example 2.11 shows a comparison between the declarations of function blocks (here only standard FBs) and variables:

```
VAR
  FillLevel     : UINT;     (* unsigned integer variable *)
  EmStop        : BOOL;     (* Boolean variable *)
  Time9         : TON;      (* timer of type on-delay *)
  Time13        : TON;      (* timer of type on-delay *)
  CountDown     : CTD;      (* down-counter *)
  GenCounter    : CTUD;     (* up-down counter *)
END_VAR
```

Example 2.11. Examples of variable declaration and instantiation of standard function blocks (bold).

Although in this example Time9 and Time13 are based on the same FB type (TON) of a timer FB (on-delay), they are independent timer blocks which can be separately called as instances and are treated independently of each other, i.e. they represent two different "timers".

FB instances are visible and can be used within the POU in which they are declared. If they are declared as global, all other POUs can use them as well (with VAR_EXTERNAL).

Functions, on the other hand, are always visible project-wide and can be called from any POU without any further need of declaration. Similarly FB **types** are known project-wide and can be used in any POU for the declaration of instances.

The declaration and calling of standard FBs will be described in detail in Chapter 5. Their usage in the different programming languages is explained in Chapter 4.

Instance means "structure".

The concept of instantiation, as applied in the examples of timer or counter FBs, results in **structured** variables, which:

- describe the FB calling interface like a data structure,
- contain the actual status of a timer or counter,
- represent a method for calling FBs.

This allows flexible parameter assignment when calling an FB, as can be seen below in the example of an up/down counter:

```
VAR
  Counter :   CTUD;      (* up/down counter *)
END_VAR
```

Example 2.12. Declaration of an up/down counter with IEC 61131-3

After this declaration the inputs and outputs of this counter can be accessed using a data structure defined implicitly by IEC 61131-3. In order to clarify this structure Example 2.13 shows it in an alternative representation.

```
TYPE CTUD :    (* data structure of an FB instance of FB type CTUD *)
  STRUCT
    (* inputs *)
    CU :        BOOL;    (* count up *)
    CD :        BOOL;    (* count down *)
    R  :        BOOL;    (* reset *)
    LD :        BOOL;    (* load *)
    PV :        INT;     (* preset value *)
    (* outputs *)
    QU :        BOOL;    (* output up *)
    QD :        BOOL;    (* output down *)
    CV :        INT;     (* current value *)
  END_STRUCT;
END_TYPE
```

Example 2.13. Alternative representation of the data structure of the up/down counter (standard FB) in Example 2.12

The data structure in Example 2.13 shows the formal parameters (calling interface) and return values of the standard FB CTUD. It represents the caller's view of the FB. Local or external variables of the POU are kept hidden.

This data structure is managed automatically by the programming or run-time system and is easy to use for assigning parameters to FBs, as shown in Example 2.14 in the programming language IL:

```
LD    34
ST    Counter.PV     (* preset count value *)
LD    %IX7.1
ST    Counter.CU     (* count up *)
LD    %M3.4
ST    Counter.R      (* reset counter *)
CAL   Counter        (* invocation of FB with actual parameters *)
LD    Counter.CV     (* get current count value *)
```

Example 2.14. Parameterisation and invocation of the up/down counter in Example 2.12

In this example the instance Counter is assigned the parameters 34, %IX7.1 and %M3.4, before Counter is called by means of the instruction CAL (shown here in bold type). The current counter value can then be read.

As seen in Example 2.14, the inputs and outputs of the FB are accessed using the FB instance name and a separating period. This procedure is also used for structure elements (see Section 3.5.2).

Unused input or output parameters are given initial values that can be defined within the FB itself.

In Section. 4.1.4 further methods of calling FBs in IL by means of their instance names are shown.

Instance means "memory".
When several variable names are declared for the same FB type a sort of "FB data copy" is created for each instance in the PLC memory. These copies contain the values of the local (VAR) and the input or output variables (VAR_INPUT, VAR_OUTPUT), but not the values for VAR_IN_OUT (these are only pointers to variables, not the values themselves) or VAR_EXTERNAL (these are global variables).

This means that the instance can store local data values and input and output parameters over several invocations, i.e. it has a kind of "memory". Such a memory is important for FBs such as flip-flops or counters, as their behaviour is dependent on the current **status** of their flags and counter values respectively.

All variables of this memory are stored in a memory area which is **firmly** assigned to this one FB instance (by declaration). This memory area must therefore be **static**. This also means that the stack cannot be used in the usual way to manage local **temporary** variables!

Particularly in the case of function blocks which handle large data areas such as tables or arrays, this can lead to (unnecessarily) large static memory requirements for FB instances.

IEC 61131-3 has therefore defined variable type VAR_TEMP. A value of a variable that does **not** have to be maintained between calls is defined with the VAR_TEMP declaration. In this case the programming system uses a dynamic area or stack to create memory space that is valid only while the instance is executed.

Furthermore, large numbers of input and output parameters can lead to memory-consuming FB instances. The use of VAR_IN_OUT instead of VAR_INPUT and VAR_OUTPUT respectively can help reduce memory requirements.

In Section 2.3.2 the read/write restrictions on the input and output variables of POUs were detailed. This is of particular importance for FB instances:

- Input parameters (formal parameters) of an FB instance maintain their values until the next invocation. If the called FB could change its own input variables, these values would be incorrect at the next call of the FB instance, and this would not be detected by the calling POU.
- Similarly, output parameters (return values) of an FB instance maintain their values between calls. Allowing the calling POU to alter these values would result in the called FB making incorrect assumptions about the status of its own outputs.

Like normal variables, FB instances can also be made retentive by using the keyword RETAIN, i.e. they maintain their local status information and the values of their calling interface during power failure.

Finally, the relationship between FB instances and conventional data blocks (DB) will be explained.

Relationship between FB instances and data blocks.

Before calling a conventional FB, which has no local data memory (besides formal parameters), it is common practice to activate a data block containing, for example, recipe or FB-specific data. Within the FB the data block can also serve as a local data memory area. This means that programmers can use a conventional FB with individual "instance data", but have to ensure the unambiguous assignment of the data to the FB themselves. This data is also retained between FB calls, because the data block is a global "shared memory area", as shown in Example 2.15:

```
JU      DB 14     (* global DB *)
JU      FB 14     (* FB call *)
...
```

a) Conventional DB/FB pair

```
VAR_GLOBAL
  FB_14 : FB_Ex;   (* global instance *)
END_VAR
CAL   FB_14        (* invocation of FB instance*)
...
```

b) FB instance in IEC 61131-3

Example 2.15. The use of a conventional DB/FB pair is similar to an FB instance as defined in IEC 61131-3. This topic will be discussed in more detail in Section 7.7.

This type of instantiation is restricted to function blocks and is not applicable to functions (FUNCTION).

Programs are similarly instantiated and called as instances in the Configuration as the highest level of the POU hierarchy. But this (more powerful) kind of instance differs from that for FBs, in that it leads to the creation of run-time programs by association with different tasks. This will be described in Chapter 6.

2.4.2 Re-usable and object-oriented FBs

Function blocks are subject to certain restrictions, which make them re-usable in PLC programs:

- The declaration of variables with fixed assignment to PLC hardware addresses (see also Chapter 3: "directly represented variables": %Q, %I, %M) as "local" variables is not permitted in function blocks. This ensures that FBs are independent of specific hardware. The usage of PLC addresses as global variables in VAR_EXTERNAL is, however, not affected.
- The declaration of access paths of variable type VAR_ACCESS (see also Chapter 3) or global variables with VAR_GLOBAL is also not permitted within FBs. Global data, and thus indirectly access paths, can be accessed by means of VAR_EXTERNAL.

- External data can only be passed to the FB by means of the POU interface using parameters and external variables. There is no “inheritance”, as in some other programming languages.

As a result of these features, function blocks are also referred to as *encapsulated*, which indicates that they can be used universally and are free from unwelcome side effects during execution - an important property for parts of PLC programs. Local FB data and therefore the FB function do not directly rely on global variables, I/O or system-wide communication paths. FBs can manipulate such data areas only indirectly via their (well-documented) interface.

The FB instance model with the properties of “structure” and “memory” was introduced in the previous section. Together with the property of encapsulation for re-usability a very new view of function blocks appears. This can be summarised as follows:

> “A function block is an independent, encapsulated data structure with a defined algorithm working on this data.”

The algorithm is represented by the code part of the FB. The data structure corresponds to the FB instance and can be “called”, something which is not possible with normal data structures. From each FB type any number of instances can be derived, each independent of the other. Each instance has a unique name with its own data area.

Because of this, IEC 61131-3 considers function blocks to be “object-oriented”. These features should not, however, be confused with those of today’s modern “object-oriented programming languages (→OOP)” such as, for example, C# with its class hierarchy!

To summarise, FBs work on their **own** data area containing input, output and local variables. In previous PLC programming systems FBs usually worked on global data areas such as flags, shared memory, I/O and data blocks.

2.4.3 Types of variables in FBs

A function block can have any number of input and output parameters, or even none at all, and can use local as well as external variables.

In addition or as an alternative to making a whole FB instance retentive, local or output variables can also be declared as retentive **within** the declaration part of the FB.

Unlike the FB instance itself which can be declared retentive using RETAIN, the values of input or input/output parameters cannot be declared retentive in the FB declaration part (RETAIN) as these are passed by the calling POU and have to be declared retentive there.

For VAR_IN_OUT it should be noted that the **pointers** to variables can be declared retentive in an instance using the qualifier RETAIN. The corresponding

values themselves can, however, be lost if they are not also declared as retentive in the calling POU.

Due to the necessary hardware-independence, directly represented variables (I/Os) may not be declared as local variables in FBs, such variables may only be "imported" as global variables using VAR_EXTERNAL.

One special feature of variable declaration in IEC 61131-3 are the so-called edge-triggered parameters. The standard provides the standard FBs R_TRIG and F_TRIG for rising and falling edge detection (see also Chapter 5).

The use of edge detection as an attribute of variable types is only possible for input variables (see Section 3.5.4).

FBs are required for the implementation of some typical basic PLC functions, such as timers and counters, as these must maintain their status information (instance data). IEC 61131-3 defines several standard FBs that will be described in more detail and with examples in Chapter 5

2.5 The Function

The basic idea of a function (FUN) as defined by IEC 61131-3 is that the instructions in the body of a function that are performed on the values of the input variables result in an **unambiguous** function value (free from *side effects*). In this sense functions can be seen as manufacturer- or application-specific extensions of the PLC's set of operations.

The following simple rule is valid for functions: the same input values always result in the same output values and function (return) value. This is independent of how often or at what time the function is called. Unlike FBs, functions do not have a memory.

Functions can be used as IL operators (instructions) as well as operands in ST expressions. Like FB types, but unlike FB instances, functions are also accessible project-wide, i.e. known to all POUs of a PLC project.

For the purpose of simplifying and unifying the basic functionality of a PLC system, IEC 61131-3 predefines a set of frequently used standard functions, whose features, run-time behaviour and calling interface are standardised (see also Chapter 5).

With the help of user-defined functions this collection can be extended to include device-specific extensions or application-specific libraries.

A detailed example of a function can be found in Appendix C. Functions have several restrictions in comparison to other POU types. These restrictions are necessary to ensure that the functions are truly independent (free of any side

effects) and to allow for the use of functions within expressions, e.g. in ST. This will be dealt with in detail in the following section.

2.5.1 Types of variables in functions and the function value

Functions have any number of input and output parameters and **exactly** one function (return) value.

The function value can be of any data type, including derived data types. Thus a simple Boolean value or a floating-point double word is just as valid as an array or a complex data structure consisting of several data elements (multi-element variable), as described in Chapter 3.

Each programming language of IEC 61131-3 uses the function name as a special variable within the function body in order to explicitly assign a function value.

As functions always return the same result when provided with the same input parameters, they may not store temporary results, status information or internal data between their invocations, i.e. they operate “without memory”.

Functions can use local variables for intermediate results, but these will be lost when terminating the function. Local variables can therefore not be declared as retentive.

Functions may not call function blocks such as timers, counters or edge detectors. Furthermore, the use of global variables within functions is not permitted.

The standard does not stipulate how a PLC system should treat functions and the current values of their variables after a power failure. The POU that calls the function is therefore responsible for backing up variables where necessary. In any case it makes sense to use FBs instead of functions if important data is being processed.

Furthermore, in functions (as in FBs) the declaration of directly represented variables (I/O addresses) is not permitted.

How a function for root calculation is declared and called is shown in Example 2.16: return parameters include the extracted root as well as the error flag indicating an invalid root with a negative number.

```
FUNCTION   SquareRoot : INT      (* square root calculation *)
                                 (* start of declaration part *)
VAR_INPUT                        (* Input parameter *)
  VarIn     :    REAL;           (* input variable *)
END_VAR
VAR_TEMP                         (* temporary values *)
  Result    :    REAL;           (* local variable *)
END_VAR
VAR_OUTPUT                       (* output parameter *)
  Error     :    BOOL;           (* flag for root from neg. number *)
END_VAR
                                 (* start of instruction part *)
LD        VarIn                  (* load input variable *)
LT        0                      (* negative number? *)
JMPC      M_error                (* error case *)
LD        VarIn                  (* load input variable *)
SQRT                             (* calculate square root *)
ST        Result                 (* result is ok *)
LD        FALSE                  (* logical "0" for error flag: reset *)
ST        Error                  (* reset error flag *)
JMP       M_end                  (* done, jump to FUN end *)
M_error:                         (* handling of error "negative number" *)
LD        0                      (* zero, because of invalid result in case of error *)
ST        Result                 (* reset result *)
LD        TRUE                   (* logical "1" for error flag: set *)
ST        Error                  (* set error flag *)
M_end:
LD        Result                 (* result will be in function value! *)
RET
                                 (* FUN end *)
END_FUNCTION
```

Example 2.16. Declaration and call of a function "Square root calculation with error" in IL.

2.6 The Program

Functions and function blocks constitute "subroutines", whereas POUs of type PROGRAM build the PLC's "main program". On multitasking-capable controller hardware several main programs can be executed simultaneously. Therefore PROGRAMs have special features compared to FBs. These features will be explained in this section.

In addition to the features of FBs, a PLC programmer can use the following features in a PROGRAM:

- Declaration of directly represented variables to access the physical I/O addresses of the PLC (%Q, %I, %M) is allowed,
- Usage of VAR_ACCESS or VAR_GLOBAL is possible,
- A PROGRAM is associated with a task within the configuration, in order to form a run-time program, i.e. programs are not called explicitly by other POUs.

Variables can be assigned to the PLC I/Os in a PROGRAM by using directly represented or symbolic variables as global or POU parameters.

Furthermore programs describe the mechanisms by which communication and global data exchange to other programs take place (inside and outside the configuration). The variable type VAR_ACCESS is used for this purpose.

These features can also be used at the resource and configuration levels. This is, in fact, to be recommended for complex PLC projects.

Because of the wide functionality of the POU PROGRAM it is possible, in smaller projects, to work without a configuration definition: the PROGRAM takes over the task of assigning the program to PLC hardware.

Such possibilities depend on the functionality of a programming system and will not be dealt with any further here.

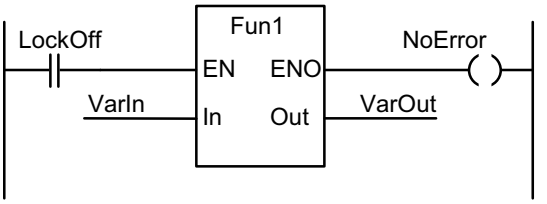
A detailed example of a PROGRAM can be found in Appendix C.

The run-time properties and special treatment of a PROGRAM in the CPU are expressed by associating the PROGRAM with TASKs. The program is instantiated, allowing it to be assigned to more than one task and to be executed several times simultaneously within the PLC. This instantiation differs, however from that for FB instances.

The assignment of programs to tasks is done in the CONFIGURATION and is explained in Chapter 6.

2.7 The Execution control with EN and ENO

In the ladder diagram LD, functions have a special feature not used in the other programming languages of IEC 61131-3: here the functions possess an additional input and output. These are the Boolean input EN (Enable In) and the Boolean output ENO (Enable Out).



Example 2.17. Graphical invocation of a function with EN/ENO in LD

Example 2.17 shows the graphical representation for calling function Fun1 with EN and ENO in LD. In this example Fun1 will only be executed if input EN has the value logical "1" (TRUE), i.e. contact Lockoff is closed. After error-free execution of the POU the output ENO is similarly "1" (TRUE) and the variable NoError remains set.

With the aid of the EN/ENO pair it is possible to at least partially integrate any function, even those whose inputs or function value are not Boolean, like Fun1 in Example 2.17, into the "power flow". The meaning of EN/ENO based on this concept is summarised in Table 2.6:

EN	Explanation[a]	ENO
EN = FALSE	If EN is FALSE when calling the POU, the code-part of the function may **not** be executed. In this case output ENO will be set to FALSE upon exiting the unexecuted POU call in order to indicate that the POU has not been executed. **Note for FB**: Assignments to inputs are implementation independent in FB. The FB instance's values of the previous call are retained. This is irrelevant in FUN (no memory).	ENO = FALSE
EN = TRUE	If EN is TRUE when calling POU , the code-part of the POU can be executed normally. In this case ENO will initially be set to TRUE **before** starting the execution.	ENO = TRUE
	ENO can afterwards be set to TRUE or FALSE by instructions executed within the POU body.	ENO = individual value
	If a program or system error (as described in Appendix E) occurs while executing the function ENO will be reset to FALSE by the PLC.	ENO = FALSE (error occurred)

a TRUE = logical "1", FALSE = logical "0"

Table 2.6. Meaning of EN and ENO within functions

As can been seen from Table 2.6, EN and ENO determine the **control flow** in a graphical network by means of conditional function execution and error handling in case of abnormal termination. EN can be connected not only to a single contact as in Example 2.17, but also with a sub-network of several contacts, thus setting a complex precondition. ENO can be similarly be evaluated by a more complex sub-network (e.g. contacts, coils and functions). These control flow operations should however be logically distinguished from other LD/FBD operations that represent the **data flow** of the PLC program.

These special inputs/outputs EN and ENO are not treated as normal function inputs and outputs by IEC 61131-3, but are reserved only for the tasks described above. Timers or counters are typical examples of function blocks in this context.

The use of these additional inputs and outputs is not included in the other IEC 61131-3 programming languages. In FBD the representation of EN/ENO is allowed as an additional feature.

The function call in Example 2.17 can be represented in IL if the programming system supports EN/ENO as implicit system variables.

If a programming system supports the usage of EN and ENO, it is difficult to convert POUs programmed with these into textual form. In order to make this possible, EN/ENO would also have to be keywords in IL or ST and would need to be automatically generated there, as they are in LD/FBD. Then a function called in LD could be written in IL and could, for example, set the ENO flag in case of an

error. Otherwise only functions written in LD/FBD can be used in LD/FBD programs. The standard, however, does not make any statement about how to use EN and ENO as keywords and graphical elements in LD/FBD in order to set and reset them.

On the other hand, it is questionable whether the usage of EN and ENO is advantageous in comparison functions (std. FUN, see also Appendix A). A comparison function then has two Boolean outputs, each of which can be connected with a coil. If this comparison is used within a parallel branch of an LD network, ENO and the output Q have to be connected separately: ENO continues the parallel branch while Q, in a sense, opens a new sub-network.

Because of this complexity only some of today's IEC programming systems use EN/ENO. Instead of **dictating** the Boolean pair EN/ENO in LD/FBD there are other conceivable alternatives:

- EN and ENO can be used both implicitly and explicitly in all programming languages,
- Each function which can be called in LD/FBD must have at least one binary input and output respectively,
- Only standard functions have an EN/ENO pair (for error handling within the PLC system). This pair may not be used for user-defined functions.

The third alternative is the nearest to the definition in IEC 61131-3. This would, however, mean that EN and ENO are PLC system variables, which cannot be manipulated by the PLC programmer.

2.8 Calling Functions and Function Blocks

In this section we will deal with the special features which have to be considered when calling functions and function blocks. These features apply to standard as well as user-defined functions and function blocks.

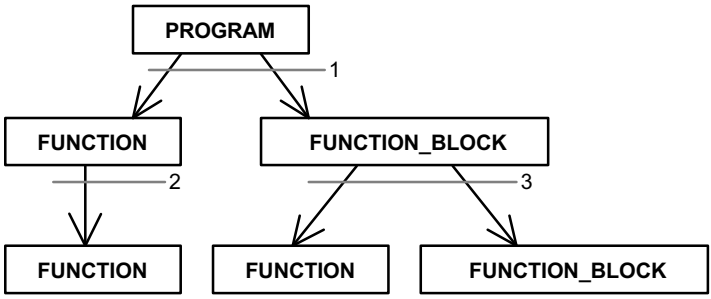
The following examples will be given in IL. The use of ST and graphical representation in LD and FBD are topics of Chapter 4.

2.8.1 Mutual calls of POUs

The following rules, visualised in Figure 2.7, can be applied to the mutual calling of POU types:

- PROGRAM may call FUNCTION_BLOCK and FUNCTION, but not the other way round,
- FUNCTION_BLOCK may call FUNCTION_BLOCK,
- FUNCTION_BLOCK may call FUNCTION, but not the other way round,

- Calls of POUs may not be recursive, i.e. a POU may not call (an instance of) itself either directly or indirectly.



1 Program calls function or function block

2 Function calls function

3 Function block calls function or function block

Figure 2.7. The three possible ways of invocation among the POU types

Programs and FB instances may call FB instances. Functions, on the other hand, may not call FB instances, as otherwise the independence (freedom from side effects) of functions could not be guaranteed.

Programs (PROGRAM) are instantiated to form run-time programs within the Configuration by association with a TASK. They are then called by the Resource.

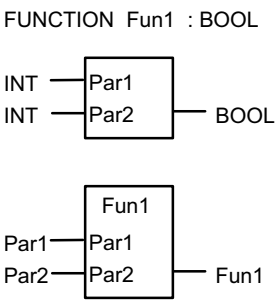
2.8.2 Recursive calls are invalid

IEC 1131-3 clearly defines that POUs may not call themselves ("recursion") either directly or indirectly, i.e. a POU may not call a POU instance of the same type and/or name. This would mean that a POU could "define itself" by using its own name in its declaration or calling itself within its own body. Recursion is, however, usually permitted in other programming languages in the PC world.

If recursion were allowed, it would not be possible for the programming system to calculate the maximum memory space needed by a recursive PLC program at run time.

Recursion can always be replaced by corresponding iterative constructs, i.e. by building program loops.

Both the following figures show examples of invalid calls:




```
FUNCTION  Fun1  : BOOL
VAR_INPUT
  Par1, Par2  :  INT;
END_VAR

LD     Par1
Fun1   Par2
ST     Fun1

END_FUNCTION
```

Example 2.18. Invalid recursive call of a function in graphical and IL representation: nested invocation.

In Example 2.18 the same function is called again within function Fun1.

The top half of this example shows the declaration part of the function (input variables Par1 and Par2 of data type INT and function value of type BOOL).

In the bottom part, this function is called with the same input variables so that there would be an endless (recursive) chain of calls at run time.

```
FUNCTION_BLOCK  FunBlk
VAR_INPUT
  In1    :    DINT;                    (* input variable *)
END_VAR
VAR
  InstFunBlk    :  FunBlk;              (* improper instance of the same type *)
  Var1  :    DINT;                    (* local variable *)
END_VAR
...
  CALC   InstFunBlk (In1 := Var1);     (* invalid recursive invocation! *)
...
END_FUNCTION_BLOCK
```

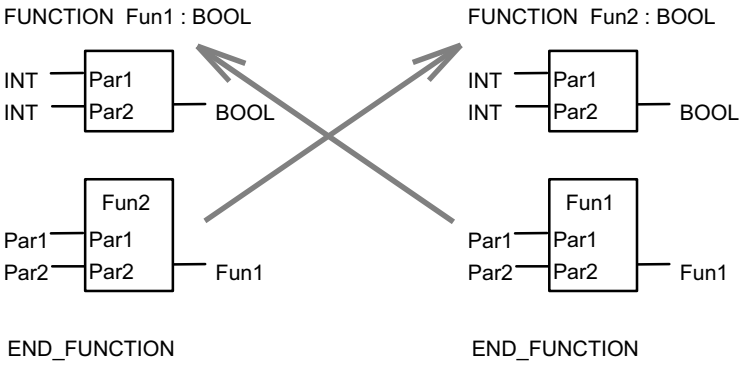
Example 2.19. Invalid recursive call of an FB in IL: nesting already in declaration part.

Example 2.19 shows function block FunBst, in whose local variable declaration (VAR) an instance InstFunBlk of its own type (FunBst) is declared. This instance is called in the function body. This would result in endlessly deep nesting when instantiating the FB in the declaration, and the memory space required for the instance at run time would be impossible to determine.

Programmers themselves or the programming/PLC system must check whether unintentional recursive calling exists in the PLC program.

This checking can be carried out when creating the program by means of a POU calling tree, as the invalid use of recursion applies to FB types and not to their instance names. This is even possible if FB instance names are used as input parameters (see also Section 2.8.6).

The following example shows how recursive calls can occur even if a function or FB instance does not directly call itself. It suffices if they mutually call each other.



Example 2.20. Recursion by mutual invocation in graphical representation

Such types of recursion are, on principle, not permitted in IEC 61131-3. The calling condition may be defined as follows: if a POU is called by POU A, that POU and all the POUs below it in the calling hierarchy may not use the name of POU A (FB instance or function name).

Unlike most of the modern high-level languages (such as C), recursion is therefore prohibited by IEC 61131-3. This helps protect PLC programs against program errors caused by unintentional recursion.

2.8.3 Extendibility and overloading

Standard functions such as additions may have more than two input parameters. This is called input *extension* and will make use of the same function for multiple input parameters clearer. A standard function or a standard function block type is *overloaded* if these POUs can work with input data elements of various data types. These concepts are described in detail in Section 5.1.1.

2.8.4 Calling with formal parameters

When a FUN/FB is called, the input parameters are passed to the POU's input variables. These input variables are also called *formal parameters*, i.e. they are placeholders. The input parameters are known as *actual parameters* in order to express that they contain actual input values.

When calling a POU, the formal parameters may or may not be explicitly specified. This depends on the POU type (FUN or FB) and the programming language used for the POU call (see also Chapter 4).

Table 2.7 gives a summary of which POU types can be called, in textual and graphical representation, with or without giving the formal parameter names (without also called "non-formal").

Language	Function	Function block	Program
IL	with or without	with [a]	with
ST	with or without [b]	with	with
LD and FBD	with [b]	with	with

a possible in three different ways, see Section 4.1.4
b with std. FUN: if a parameter name exists; EN will always come first.

Table 2.7. Possible explicit specification of formal parameters ("with" or "without") in POU calls

In FBs and PROGs the formal parameters must always be specified explicitly, independently of the programming language. In IL there are different ways of doing this (see Section 4.1.4).

In ST functions can be called with or without specifying the names of the formal parameters.

Many formal parameters of standard functions do not have a name (see Appendix A.2). Therefore these cannot be displayed in graphical representation and cannot be explicitly specified in textual languages.

IEC 61131-3 does not state whether the names of formal parameters can be specified when calling user-defined functions in IL. However, in order to keep such function calls consistent with those of standard functions, it is assumed that the names of formal parameters may **not** be used with function calls in IL.

The same rules are valid for the calling of standard functions and standard function blocks. Example 2.21 shows examples for each POU type.

FB declaration:

```
FUNCTION_BLOCK FBlk
VAR_INPUT
  Par1 :   TIME;
  Par2 :   WORD;
  Par3 :   INT;
END_VAR
... (*instructions *)
END_FUNCTION_BLOCK
```

FUN declaration:

```
FUNCTION Fctn : INT
VAR_INPUT
  Par1 :   TIME;
  Par2 :   WORD;
  Par3 :   INT;
END_VAR
... (*instructions *)
END_FUNCTION
```

PROG declaration:

```
PROGRAM Prgrm
  VAR_GLOBAL
    FunBlk   : FBlk;
    VarGlob  : INT;
    AT %IW4 : WORD;
END_VAR
  ... (* instructions *)
  END_PROGRAM
```

```
(* 1. Invocations in IL *)
LD          t#20:12
Fctn        %IW4, VarGlob                                  (* function call *)
CAL FunBlk  (Par1 := t#20:12, Par2 := %IW4, Par3 := VarGlob)  (* FB call *)
```

```
(* 2. Invocations in ST *)
Fctn        (t#20:12, %IW4, VarGlob)                       (* function call *)
Fctn        (Par1 := t#20:12, Par2 := %IW4, Par3 := VarGlob); (* function call *)
FunBlk      (Par1 := t#20:12, Par2 := %IW4, Par3 := VarGlob); (* FB call *)
```

Example 2.21. Equivalent function and function block calls with and without explicit formal parameters in the textual languages IL and ST. In both cases the invocation (calling) is done in the program Prgrm.

In IL the first actual parameter is loaded as the current result (CR) before the invocation instruction (CAL) is given, as can be seen from the call of function Fctn in Example 2.21. When calling the function the other two parameters are specified separated by commas, the names of these formal parameters may not be included.

The two equivalent calls in ST can be written with or without the names of formal parameters. The input parameters are enclosed in brackets each time.

In the call of FB instance FunBlk in this example all three formal parameters are specified in full in both IL and ST.

The usage of formal and actual parameters in graphical representation is shown in Example 3.19.

2.8.5 Calls with input parameters omitted or in a different order

Functions and function blocks can be called even if the input parameter list is incomplete or not every parameter is assigned a value.

If input parameters are **omitted**, the names of the formal parameters that are used must be specified explicitly. This ensures that the programming system can assign the actual parameters to the correct formal parameters.

If the **order** of the parameters in a FUN/FB call is to be changed, it is also necessary to specify the formal parameter names explicitly. These situations are shown, as an example in IL, in Example 2.22.

```
(* 1.   complete FB call *)
CAL   FunBlk (Par1 := t#20:12, Par2 := %IW4, Par3 := VarGlob);

(* 2.   complete FB call with parameters in a changed order *)
CAL   FunBlk (Par2 := %IW4, Par1 := t#20:12, Par3 := VarGlob);

(* 3.   incomplete FB call *)
CAL   FunBlk (Par2 := %IW4);

(* 4.   incomplete FB call with parameters in a changed order *)
CAL   FunBlk (Par3 := VarGlob, Par1 := t#20:12);
```

Example 2.22. Examples of the FB call from Example 2.21 with parameters omitted and in a different order, written in IL

This means that either all formal parameters must be specified, and the parameter order is not relevant, or no formal parameters are used and the entries must appear in the correct order. The formal parameters always have to be specified when calling FBs, for functions this is, however, language-dependent (see Table 2.7).

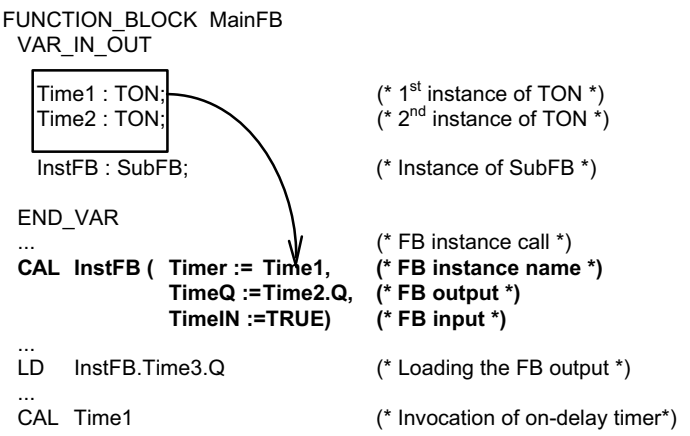
Assignments to input variables can be omitted if the input variables are "initialised" in the declaration part of the POU. Instead of the actual parameter that is missing the initial value will then be used. If there is no user-defined initial value the default value for the standard data types of IEC 61131-3 will be used. This ensures that input variables **always** have values.

For FBs initialisation is performed only for the first call of an instance. After this the values from the last call still exist, because instance data (including input variables) is retained.

2.8.6 FB instances as actual FB parameters

This section describes the use of FB instance names as well as their inputs and outputs as actual parameters in the calling of other function blocks.

Using Example 2.23 this section explains what facilities IEC 61131-3 offers for indirect calling or indirect parameter assignment of FB instances.



Example 2.23. Using the FB instance name Time1 and the output parameter Time2.Q as actual parameters of another FB. The timers Time1 and Time2 are instances of the standard FB TON (on-delay, see Chapter 5). SubFB will be declared in Example 2.24.

Instance names and the inputs and outputs of instances can be used as the actual parameters for input or input/output variables. Table 2.8 shows the cases where this is allowed (in table: "yes") and not allowed ("no").

		As actual parameter for SubFB		Return value, External variable
Instance	Example	VAR_INPUT	VAR_IN_OUT (pointer)	VAR_EXTERNAL VAR_OUTPUT
Instance name	Time1	yes [a]	yes [b]	yes [c]
-input	Time2.IN	-	-	-
-output	Time2.Q	yes	no [d]	-

a Instance may not be called within SubFB (indirect FB call not possible)
b Indirect FB call is possible, output of instance may not be changed within SubFB
c Direct FB call, output of instance may not be changed within MainFB
d The function (return) value of a function cannot be used either

Table 2.8. Possible cases for using or indirectly calling FB instances as actual parameters of FBs. The "Example" column refers to Example 2.23. The last column shows that FB instances may also be used as external variables or as return values. Time2.IN may not be used for read access and cannot therefore be passed as a parameter.

As this summary shows, only certain combinations of function block instance names and their inputs and outputs can be passed as actual parameters to function blocks for each of the variable types.

VAR_INPUT: FB instances and their outputs cannot be called or altered within SubFB if they are passed as VAR_INPUT. They may, however, be read.

VAR_IN_OUT: The output of an FB instance, whose pointer would be used here, is not allowed as a parameter for this variable type. An erroneous manipulation of this output can thus be prevented. Similarly, a pointer to the function value of a function is **not** allowed as a parameter for a VAR_IN_OUT variable.

The instance passed as a parameter can then be called, thereby implementing an **indirect** FB call.

The outputs of the FB instance that has been passed may not be written to. FB instance inputs may, however, be freely accessed.

VAR_EXTERNAL, VAR_OUTPUT: FB instances are called directly, their inputs and outputs may only be read by the calling POU.

Example of an indirect FB call.
Example 2.24 shows (together with Example 2.23) the use of some cases permitted in Table 2.8 within function block SubFB.

```
FUNCTION_BLOCK  SubFB
  VAR_INPUT
    TimeIN :  BOOL;        (* Boolean input variable *)
    TimeQ  :  BOOL;        (* Boolean input variable *)
  END_VAR
  VAR_IN_OUT
    Timer  :  TON;         (* pointer to instance Time1 of TON – input/output variable *)
  END_VAR
  VAR_OUTPUT
    Time3  :  TON;         (* 3rd instance of TON *)
  END_VAR
  VAR
    Start : BOOL := TRUE; (* local Boolean variable *)
  END_VAR
...
(* Indirect call of Time1 setting/checking the actual parameter values using Timer *)
LD    Start
ST    Timer.IN          (* starting of Timer Time1 *)
CAL   Timer             (* calling the on-delay timer Time 1 indirectly *)
LD    Timer.Q           (* checking the output of Time1 *)
...
(* Direct call of Time3; indirect access to Time2 *)
LD    TimeIN            (*indirect checking of the input of Time2 is not possible *)
ST    Time3.IN          (* starting the timer using Time3.IN *)
CAL   Time3             (* calling the on-delay timer Time3 directly *)
LD    Time3.Q           (*checking the output using Time3.Q *)
...
LD    TimeQ             (*indirectly checking the output of Time 2 *)
...
END_FUNCTION_BLOCK
```

Example 2.24. Alternative ways of calling the on-delay FB Time1 from Example 2.23 indirectly and usage of its inputs and outputs

This example shows the *indirect call* of FB Time1, whose instance name was passed to FB SubFB as an input/output variable in Example 2.23. The function block SubFB is only assigned the FB instance name Time1 at the run time of MainFB. In SubFB Time1 (as input variable Timer) is provided with the parameter Timer.IN and then called.

As shown with Example 2.24, it is also possible to access the inputs and outputs of an FB passed as an instance name. Here the instance inputs (Timer.IN) can be read and written to, whereas the outputs (as Timer.Q) can only be read.

The FB instance Time3 in this example serves as a comparison between the treatment of input parameters and of the return values of an FB as output variables.

FB instance names as actual parameters of functions.
Instance names (such as Time1) and components of an FB instance (such as Time2.Q) can also be used as actual parameters for functions. Initially this appears to be inconsistent with the requirement that functions have to produce the same result when supplied with the same inputs and that they may not call FBs.

This is, however, not as contradictory as it seems: the FB instance passed as a parameter is not **called**, but its input and output variables are treated like elements of a normal data structure, see also Section 2.4.1.

Function values as actual parameters.
Functions and function values may also be used as actual parameters for functions and function blocks. The input variables have the same data type as the function and are assigned the function value when called.

IEC 61131-3 does not give any explicit instructions about this possibility, thus making it implementation-dependent.

Initialisation of FB instances.
Instances of function blocks store the status of input, output and internal variables. This was called "memory" above. FB instances can also be initialised, as shown in example 2.25.

```
VAR Instance_Ex :
        FunBlk (Par3 := 55, Par1 := t#20:12);
END_VAR
```

Example 2.25. Example of FB call from example 2.21 with parameters omitted and in a different order, written in IL

2.9 Summary of POU Features

The following table summarises all essential POU features that have been presented and discussed in this chapter.

Feature	Function	Function Block	Program
Input parameter	yes	yes	yes
Output parameter	yes	yes	yes
Input/output parameter	yes	yes	yes
Function value	yes	no	no
Invocation of functions	yes	yes	yes
Invocation of function blocks	no	yes	yes
Invocation of programs	no	no	no
Declaration of global variables	no	no	yes
Access to external variables	no	yes	yes
Declaration of directly represented variables [a]	no	no	yes
Declaration of local variables	yes	yes	yes
Declaration of FB instances	no	yes	yes
Overloading [b]	yes	yes	no
Extension [c]	yes	no	no
Edge detection possible	no	yes	yes
Usage of EN/ENO [c]	yes	yes	no
Retention of local and output variables	no	yes	yes
Indirect FB call	no	yes	yes
Initialisation of FB instances	no	yes	no
Usage of function values as input parameters [d]	yes	yes	yes
Usage of FB instances as input parameters	yes	yes	yes
Recursive invocation	no	no	no

a for function blocks only with VAR_EXTERNAL
b for standard functions
c for standard functions and standard function blocks
d not in IL, otherwise: implementation-dependent

Table 2.9. An overview of the POU features summarising the important topics of this chapter. The entries “yes” or “no” mean “permitted” and “not permitted” for the corresponding POU type respectively.