Programming Directive, 2011 Version 1.1

The Programming Directive describes the *organizational procedures* and the *rules to be observed* when programming methods as part of FVV research projects. The goal of this Directive is to ensure that the methods developed can be widely used and are of high quality.

Contents

Preamble

FVV research projects help to improve the store of scientific knowledge, which often leads to new models, equations or procedures. In most cases there is merit in documenting this gain in knowledge (i.e. models, equations, etc.) not only in the final report but also in the form of unambiguous source code. For this reason, this source code is also referred to as a “method carrier”. It is not “software” in the sense of a product that is easy for end users to use. Rather, it constitutes unambiguous documentation and a description of the findings that are obtained in the form of programmed source text.

On the one hand, this creates less of a burden for the research institutes, since they do not have to develop software in the sense of a product (i.e. no user interface development, it has to be guaranteed to run only on a base platform, etc.); on the other, this means that the demands on the quality of the source code have to be high, to ensure that member companies can incorporate it into commercial products or in-house software without difficulty. Source code almost always has to be adapted to enable integration into in-house software in this way. It therefore has to be programmed in such a way that, once the project is completed, software developers working for an FVV member who have previously not been involved in the research project can understand the code without difficulty, incorporate it into their own software, and validate the results against reference results from the FVV project.

The on-going research projects within FVV are too varied and different for any general, binding regulation regarding the base platform, i.e. the programming language in particular, to be of any practical value. The base platform, including the programming language, must be determined by the discussion group for every project individually. Account must be taken in this regard of the specific project requirements, previous FVV tasks, synergy effects with on-going FVV tasks, ability of the method carrier to be used long-term, and also the level of technical advance in the software development itself.

0. Area of application

The Programming Directive must be used if the specific objective of the research project is to develop method carriers.

Even if the development of the method carrier is only one key step toward achieving the objective of the project, or if it only becomes clear after the project has started that a method carrier is being developed, it is still compulsory to use the Programming Directive. The project committee and the research institute(s) may decide independently, but in consultation with each other, regarding the boundary conditions for method development in the context of the Programming Directive.

1. Objectives

The objectives of this Directive are to guarantee a defined quality standard and to improve the usability of the method carrier.

The quality standard is defined by the following:

- Absence of errors in code
- Safeguarding the ability of the method carrier to run on the base platform(s) agreed upon with the project committee
- Portability of the method carrier code to other base platforms
- Existence of an input and output description, and/or user guide
- Integrated review of input data
- Sufficient code commentary
- Observance of all other requirements of the Programming Directive

2. Organizational procedure

The method carriers created while working on a research subject form a part of the results of the research. These are drawn up by the research institute that is responsible for the following:

- The underlying physical and mathematical model and its coding
- The general program sequence
- The completeness of the method carrier, including the validation dataset (inputs and outputs) and documentation

The FVV office shall assist the chairman and research institute in interpreting the Directive.

The task of the chairman is to coordinate the activities of the research institute, in consultation with the project committee. No later than six months prior to the end of a project, the research institute should submit an advance status report for the method carriers in existence as of that point to the competent project-monitoring committee. The purpose of this advance version of the method carrier is to enable agreement in principle as to whether the research institute is on the right path in terms of programming style and documentation. At this point the project committee must give the research institute feedback regarding observance of the Programming Directive and the scope of the method carrier.

The project committee chairman shall declare the project successfully concluded only when the project committee has declared the achieved status of the method carrier, including the validation dataset and documentation, to be satisfactory.

3. Scope of results to be submitted regarding the method carrier

The methods developed in the research project must be submitted to the project committee and FVV to the extent shown below:

- Method carriers
  - Complete source code
  - Version capable of running
- Validation data (input and associated result data in machine-readable form)
- Handover workshop
- Program documentation, incl. interface definition (see Chapter 5)
- Description of development environment, including compiler settings (where relevant)
- Description of base platform (version and configuration)
- User Manual

The project committee is responsible for reviewing and approving documents and results. Following conclusion of the project, the results will be made available on the FVV platform, together with the final report. The research institute gives its assurance that the method carrier is free of third-party rights.

4. Programming requirements

The competent FVV committees shall set down the rules that apply to the coding of new method carriers. Such rules are set down in this Directive.

The rules are broken down into requirements for the following:

- Scope of programming
- Program structure
- Running properties of the program
- Ability of the program to be implemented on other base platforms
- Code readability
- Details of coding
- Any use of third-party library subroutines
- Freedom from third-party rights
- Nature and scope of documentation
- Any special features of the task

The research institute and the competent “project committee” are jointly responsible for observing the rules. If, in an isolated instance, a problem should arise that is not covered by the regulations, the research institute and the “project committee”, headed by the chairman, shall agree on a solution. In such cases, the FVV office and the relevant FVV committees must be advised about problems with the Programming Directive and the agreed solutions.

The following points must be noted in this regard, in particular:

- It must be possible to import programs (method carriers) into another base platform without significant additional action as a matter of course (requirements in terms of implementation capability).
- The programs (method carriers) must be structured in such a way that users can replace or remove entire program sequences (program structure requirements).
- The program must be written in a way that is easy to understand, so that details can be clarified or amended with no need to contact the programmer (code readability requirements).
- In this context, the use of English comments and identifiers in the source text is recommended, so as to make the results of the research accessible to the international members of FVV. The language to be used shall be decided at the beginning of the project by agreement between the chairman, project committee and research institute.
- Every method carrier that is developed as part of an FVV research task must be sufficiently documented.

  This includes the following:

  - Short description of program (see Section 5.1)
  - User guide
  - Source program
  - Program documentation

- Implementation notes
- Research report containing a presentation of the physical and technical principles, and also the mathematical methods.

4.1 Base platform

Definition:

- The base platform is both necessary and sufficient for the implementation of the method carrier, i.e. it enables it to be executed and makes available all of the necessary prerequisites for work on the method carrier.
- The base platform is in place from the start of the project. This does not rule out the possibility of a later change to a newer version of the base platform by agreement between the project committee and the research institute.
- Availability must be assured, preferably for research institutes and all FVV members, or for members of the project committee as a minimum. If, in a given case, the base platform is not available to all members of the project committee, the possibility of supporting another base platform in parallel must be examined. At the same time, this ensures the portability of the method carrier.
- Everything that is not a base platform is a method carrier, and must be supplied as source code.

Examples of base platforms:

- Compiler, interpreter, linker, libraries
- Software package with standard language programming interface (e.g. to create submodels)
- Software package with visual programming interface (e.g. to develop functions for engine control units or to represent a physical connection in this graphic representation)

The base platform is determined in conjunction with the discussion group [“DG”] or the project committee before the project begins. The following must be considered in the selection process:

- That the base platform supports the achievement of the project objectives. This also implies that no undefined interactions between the base platform and the method carrier are expected.
- Those synergies with current and/or completed projects are drawn upon. FVV programs were previously programmed in Fortran and ANSI C. It is preferable that any extensions to these programs be programmed in these languages.
- That the long-term usability of the method carrier is assured (i.e. robustness in the face of version changes).
- That account is taken of technical advances in programming.

If Fortran or C is chosen as programming languages at the beginning of the project, programming should be done using Fortran 95 or ANSI C in accordance with ISO/IEC 9899. Programs must be coded in accordance with applicable ANSI standards regardless of the standard language in which they are programmed as a matter of course.

Program function and user interface must be kept separate in all cases.

Library modules that the research institute requires to guarantee the ability of the method carrier to run shall either count as part of the base platform and be subject to the same quality demands, or must be provided in the source code as part of the method carrier. If these library modules are meant to count as part of the base platform, this must be established within the DG before the project is awarded and documented in the Supplement.

4.2 Requirements in terms of method carrier running properties

- Prior to Processing, the input data shall be checked for completeness, plausibility, and possible violation of fixed array memory dimensions.
- The program must be secured against crashes caused by undefined operations (e.g. dividing by zero, square root of a negative number).
- Iterative loops are terminated not only by way of accuracy bounds but also by way of a counter. The bounds and counter can be defined in the software and/or be varied using inputs. A system must be in place to notify users when the iteration limit is reached with no convergence.
- During normal program operation, no interactions (notifications or switch queries) or pauses are permitted.
- Data transfer between different programs in a software package is admissible if formatted or in binary form. If binary files are used, a binary to 7-bit ASCII format converter must be included in the software package.
- Result data that is required in addition for further processing (e.g. charts) must be output as a binary or 7-bit ASCII file, at the programmer’s option.
- The elimination of graphics software must not compromise the function of the calculation program.

4.3 Requirements in terms of program implementation

- All arithmetic expressions must be coded only in one mode (i.e. only ‘real’ or ‘integer’). The standardized conversion functions must be used for type conversions (e.g. ‘real’ _ ‘Integer’).
- All variables should be available as SI units wherever possible. Deviations must be highlighted within variable names (e.g. p_Zyl_bar) or using comments.
- In the case of Fortran, all variables must be declared using IMPLICIT NONE
- All variables must be specified within the range of values that can be displayed and in terms of resolution.
- Parameters for accessing subroutines must be kept strictly separate, by ‘input’ and ‘output’.
- Data field sizes must be easy to change at a central point in the program; the goal must be to achieve dynamic memory management.

4.4 Program structure requirements

- The main program essentially contains only subroutine accesses. Global data structures must be avoided as much as possible.
- If compiler-specific functions have to be used in exceptional situations, they must be summarized and documented in a module of the software package. The same applies to function accesses, e.g. differential equation solvers from commercial software packages that are used as a base platform.

- Individual subroutines should contain no more than 200 executable instructions, as far as possible.
- Wide use must be made of opportunities to structure programs in an easy-to-follow manner and to transfer data between program components using structured data types.
- Inputs, outputs and graphic accesses must be executed in separate subroutines in each case.
- Error messages contain a short description of the error and the name of the subroutine that caused it.
- The possibility of parallelization must be taken into consideration when drafting the program structure.
- Depending on the area of application (e.g. FEM, CFD), efforts should be made to implement the program using 64-bit addressing from the outset.
- The following applies as a matter of course with regard to Fortran:
    - Languages superseded with effect from Fortran 95 are no longer admissible. As with the above statement regarding the use of global data structures, COMMON blocks are admissible in Fortran only in specially justified exceptional cases and in consultation with the project committee. Filling of COMMON blocks must be performed on a standardized basis using an INCLUDE instruction in all affected subroutines.
    - The objective must be to achieve linear program operation. The use of BLOCK IF instructions or SELECT CASE constructs is preferred. Assigned GOTO, computed GOTO und arithmetic IF instructions are not admissible.
    - In Fortran, named loops of the “DO … END DO” structure must be used.

4.5 Requirements in terms of source code and readability

Programs must be coded in self-documenting form, i.e. they must be structured in such a way and with enough comments that third-party readers familiar with the report and literature can find their way around without further aids and without asking the programmer.

4.5.1 Naming

Correct naming is the most decisive element when writing source code. Meaningful and self-evident names are essential to an intuitive understanding of the source code. A good choice of name is a creative process that cannot be standardized in this document because it must always be adapted to suit the context.

This Directive will not set down a naming convention, but it is important that a standardized, meaningful naming process that will be understood at a general level is followed within the project. The following convention is intended as a proposal for the research institute. If the research institute wishes to use a different naming convention, it must advise the project committee accordingly at one of the first sessions and document its own convention in writing.

Hungarian notation (type prefix) is not used. The names of pointers form an exception to this rule.

Compound identifiers are written using “camel hump” notation, i.e. the individual words within the compound word each start with a capital letter. (E.g. getnextsample is written as getNextSample). Separate rules apply to the use of upper and lower case letters for the first letter of the identifier (see below).

As an alternative to camel hump notation, underscores may be used to represent subscripts, based on TEX notation.

Naming of methods

Names of methods and functions always start with a verb. The first letter is therefore written in lower case (based on German language usage). No prefix is put first (e.g.: getNextSample()).

Method names must state precisely what the method does. Therefore, the initial verb must be followed by a second part that describes what the "doing" relates to. This can be achieved only if every method deals with precisely one task and not two, three or more.

Naming of constants

Names of constants are written entirely in upper case. Because visual word division using "camel hump" notation is not possible in this case, the word elements must be separated using a "_" (underline) symbol (e.g.: MAX_CYLINDER_COUNT).

Naming of variables

Names of variables / instances / objects normally begin with a noun. The first letter is therefore written in upper case (based on German language usage). It must therefore be ensured that the variable name offers precise information about the content or purpose of the variable. Variable names such as "i", "j" or "k" are admissible as loop indices.

Boolean variables must be labeled in such a way that readers automatically interpret structures correctly.

Variables representing physical values and for which a standard symbol exists (e.g. pressure p, temperature T), or for which a symbol has been introduced in the final project report, should be identified using that symbol. This makes it easier to read formulae and also simplifies the parallel reading of the final report and the source code. Upper and lower-case conventions for these symbols must be strictly observed (e.g. pressure p and power P; time t and temperature T). Standard symbols such as these should not be used incorrectly. To ensure better readability, indices should be separated from the symbols, most of which consist of a single letter, with an underscore (e.g. T_unburned, p_CylMotored). Non-SI units must be labeled as part of the variable name, e.g. p_bar.

Example:

Declaration: bool **Is**Valid;
bool **Has**NewValuesReceived;
real*8 p_CylinderMaxFired; /* max. cylinder pressure during combustion in Pa*/
real*8 p_CylinderMaxMotored; /* max. cylinder pressure w/o combustion in Pa*/
real*8 FiringPressureRatio; /* pressure ratio fired/motored */

in code: if(IsValid) {....}

if(HasNewValuesReceived) {....}

FiringPressureRatio= p_CylinderMaxFired/ p_CylinderMaxMotored;

4.5.2 Comments

- Programs must be coded in self-documenting form, i.e. they must contain enough comments that third-party readers familiar with the report and literature can find their way around without further aids.

- Every program module contains the standardized program heading in accordance with the “Standard program heading” form (see Annex 3, examples for FORTRAN and C in Annexes 4 and 5) as well as a “history” list that provides information about changes in the code.
- The meaning / use of all variables and the physical unit must be stated as a comment in the declaration.
- The use of documentation systems such as Doxygen is generally recommended. In this case deviations from the form in which the variable declaration is documented, as shown in the “Standard program heading” form template, are admissible. It must then be assured that the declaration of variables in comments includes the appropriate information for automatic inclusion in the documentation.

4.5.3 Readability

- Efforts must be made to achieve a structured (indented) layout in the source code. Empty spaces in the structure must be generated using spaces rather than tabs.
- Lines of code must not exceed 80 characters as a matter of course. This enables lines to be output on terminals or on paper without being cut off. Lines may be longer if this results in improved readability.
- Program source code must use 7-bit ASCII. German accented or special characters are not permitted (e.g. Ä = Ae; Ö= Oe; Ü = Ue; ß = ss). This also applies to comments in the source text and data sets, if these are text files.

4.6 Quality Assurance

All methods should be implemented in the source code without error; in particular, there should be no inconsistencies in the final report and source code. The research institute is free to choose the methods that it uses for quality assurance. At the start of the project, the research institute must advise the working group of the measures that it would like to use for quality assurance, and when. Code reviews and version control systems are recommended. When code reviews are used, it must be documented in all source code when the review was performed, and by whom.

5. Documentation of method carriers

All of the following documentation must be stored on the Prometa server as separate files together with the final documentation.

5.1 Short program description

The short description must enable users to learn whether the program is fundamentally suited to resolving the problem in their subject area. The description must be written on a form in accordance with the attached example (see form “Short Program Description”, Annex 8).

5.2 User documentation (User Manual)

The appropriate FVV templates must be used to document the method carrier (e.g. the “Short Description”, see above). The user documentation contains all important information that is needed to use a program or method carrier. The following in particular form part of the user documentation:

a) Hints on installation and about the base platform

b) Input

- Input form, if formatted text input datasets are imported from older FVV programs
- Clarification of input variables
- Physical variables with a description of units and value range
- Actuating variables with details of their function
- Details of admissible input data ranges
- Definitions and conventions regarding metrics and how to prepare them.

As appropriate, reference must be made to an appropriate explanation in the research report or program manual.

c) Output

Explanation of output, e.g. for screen, storage media and, as appropriate, further processing in the base platform (see Chapter 5.4), as well as the structure and content of any potential result file. The output values must be documented in this regard in terms of their meaning and the technical units used.

d) Error messages, re-start

- Explanation of error messages
- Description of corrective measures
- Information on restarting following a premature program termination

e) Files

The nature, size and structure of the files used must be specified.

f) Test examples

Input and output must be illustrated using one or more practical instances of application.
This includes the following:

- Computer-specific details (hardware, operating system, base platform and, as appropriate, compiler plus options)
- Input data sets and result files

- Screen or printer output and/or graphic program output
- Computing times, stating the hardware used
- Memory requirement (internal / external)

5.3 Source program

The full source program for the method carrier, including any library modules to be supplied by the research institute, must be stored on the FVV Prometa server immediately following the conclusion of the research project, and be capable of retrieval at any time. FVV is responsible for administration of the entire method carrier.

5.4 Program documentation

The program documentation must be maintained in such a way that errors can be corrected and additions and alterations can be made to the program without particular difficulty. It must be considered as a supplement to the user documentation and the final report.

This includes the following:

- Rough block diagram (Annex 1)
- Structure diagram (see Annex 6)
- Short description of individual subroutines, similar to the program heading (see Annex 3 and/or Annexes 4 or 5)
- Explanation of all agreed variables
- Data flow charts, in the case of software packages

All interfaces to base platforms (i.e. third-party programs, libraries) must be documented in such a way that they can be ported to any other desired base platforms.

This includes the following:

- Details of the functions of the base platform that are used
- List of arguments
    - Units and admissible value ranges for input and output variables
    - Interpretation of variables transmitted via the interface
- Time and type of interactions between base platform and method carrier
- Peculiarities of the base platform used (e.g. workarounds in the case of compiler errors)
- As appropriate, criteria that led to the selection of the base platform
- As appropriate, in the case of mathematical procedures, a description of the mathematical procedure within the base platform, if known and/or published
- As appropriate, references in the literature to the base platform

Libraries that are not part of the base platform must be distributed as part of the method carrier in the source code. They must be documented in the same way as the method carrier.

In addition, documentation must also be drawn up for every physical model or subroutine, which may be done as part of the final project report.

- Written preparation
- Mathematical derivation and digital execution
- Validity ranges and boundary conditions
- Sample application examples (verification samples)
- Model structure plan, i.e. overview of additional submodels

6. Real-time programs

The use of ANSI C (ISO/IEC 9899) is recommended when programming real-time-capable programs. Because of the different structure of such software solutions, hardware-specific expansions are needed and must therefore be co-ordinated precisely with the project committee in each case.

Each program code to be programmed manually must be implemented in accordance with "MISRA-C:2004 Guidelines for the Use of the C Language in Critical Systems". This is based on standard ISO/IEC 9899: Programming languages - C.

The following standards must be taken into consideration in the case of autocoding:

- MISRA AC AGC - Guidelines for the application of MISRA-C:2004 in the context of automatic code generation
- MISRA AC GMG - Generic modelling design and style Guidelines
- MISRA AC SLSF - Modelling design and style Guidelines for the application of Simulink and Stateflow
- And, as appropriate, MISRA AC TL - Modelling style Guidelines for the application of TargetLink in the context of automatic code generation

Observance of MISRA standards must be checked automatically, where possible. The appropriate tools must be selected by the project committee based on the project in question. Because it is not possible for all MISRA rules to be checked by algorithms that run automatically, some of these rules must be checked "manually".

To ensure a clear allocation, a *compliance matrix* must be drawn up at the start of each new project, which establishes which rule is to be checked using which method. If not all rules are checked, this must be clearly noted in the matrix.

The program must be compiled in accordance with the rules in the attached Style Guide (see Annex 9). The program structure must be modular. Modularization must follow the rules of the Style Guide. Comments must also be provided in a modular fashion.

The above rules for documentation also remain valid for real-time-capable programs; in addition, all functions must be shown in time flow charts (see Annex 7).

If the C code is generated using a process of automatic code generation, other types of diagram may be used to document the C code, such as signal flow diagrams, state transition diagrams and flow charts.

7. Abbreviations

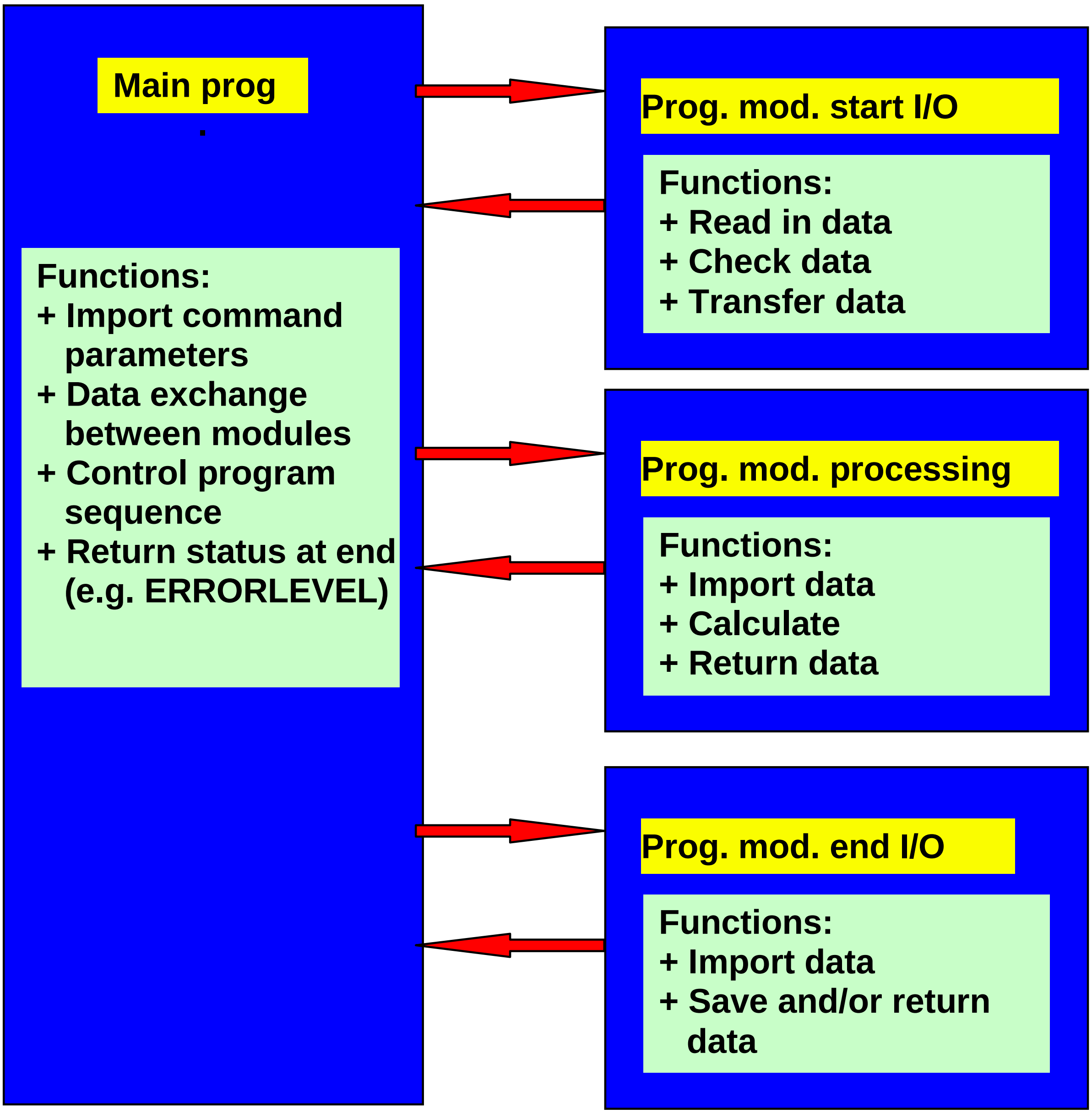
DG	Discussion group

8. Glossary

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>Method</td><td>Abstract procedure / algorithm
Also a novel combination of proven techniques
Parameter derivation and/or identification from trial results</td></tr>
<tr><td>Method carrier</td><td>Sample application
Documented core implementation of method (no GUI, etc.) on a defined base platform</td></tr>
<tr><td>Base platform</td><td>The base platform is necessary and sufficient to enable execution of the method carrier
The base platform exists from the start of the project
It is available for research institutes and all FVV members, or for members of the project committee as a minimum
Examples of base platforms are: Excel, MATLAB, higher programming languages, CAE software, etc.
Everything that is not a base platform is a method carrier, and must be supplied as source code.</td></tr>
<tr><td>Software product</td><td>Generally applicable, parameterized overall application, including the following:
– Method
– Data model structure
– User interface (e.g. pre-/postprocessor)
– Product documentation
– Version check
– Error handling methods
– Porting
– Regression tests
– Installation program
– Integration with other software products, as appropriate
– Certification
– …</td></tr>
<tr><td>Software maintenance</td><td>– Further development and maintenance regarding the following:
– State of the art in terms of method
– Software performance
– Stability
– General quality (bug fixing)
– Adaptation to changeable hardware and OS requirements</td></tr>
<tr><td>Software commercialization</td><td>Commercial retail and service worldwide, without exception, subject to legal boundary conditions</td></tr>
</table>

Annex 1

Example of modular program structure



Annex 2

Example of arrangement of DO loop labels in Fortran:

```
DO L=1,LMAX
  DO J=1,JMAX
    A=Y(J,L)
    DO I=1,IMAX
      X(I,J,L)=Z(L)*A
    END DO
    DO I=1,IMAX
      T(I,J,L)=X(I,J,L)**2-A
    END DO
  END DO
  DO J=1,JMAX
    B=Y(J,L)**2
    C(J,L)=PI*B
    D(J,L)=28.5*(B-5.)
  END DO
END DO
```

Annex 3

Model for comments on program / subroutine headers

Explanation of program function in one sentence	
Author	J. Smith
Institution	Institute of Applied Computer Science
University	Podunk University
Date	11.11.2011
Language	Fortran 95
Project	Crankcase lighting
FVV no.	4711

Code Review	Reviewer	Date
Review I	Dr. X. Troubleshooter	16.02.1999
Review II	Prof. Head	28.02.1999

Variable name	**Type**	**On/Off**	**Unit**	**Explanation of variable**
A	Real*4	On	m**2	Heat-transferring surface of piston head
R	Real*4	On	KJ/kg K	Gas constant
X	Real*4	Off	m	Piston stroke

History:			
Version	Date	Author	Comment
V 1.0	2004-07-07	J. Smith	Document created
V2.0	2007-11-30	Mrs F. Smith, IACS, Podunk University	Formal revision in FVV M815
…			

Implementation based on:
- MERKER, Günter; SCHWARZ, Christian; STIESCH, Gunnar; OTTO, Frank: Verbrennungsmotoren. Simulation der Verbrennung u. Schadstoffbildung. 2nd ed. Stuttgart: Teubner, 2004
- PISCHINGER, R. ; KLELL, M. ; SAMS, T.: Thermodynamik der Verbrennungskraftmaschine. 2nd ed. Vienna: Springer, 2002.

Annex 4

Example of a program in Fortran 95

```
!
! Subroutine to calculate heat transfer based on Woschni
!
! Author:          J. Smith
! Institution:     Institute of Applied Computer Science
! University:      Podunk University
! Date:            2004-07-07
! Language:        Fortran 95
! Project:         Crankcase lighting
! FVV no.:         4711
! -------------------------------------------------------------------------
! Review I:        Dr. X. Troubleshooter, 2004-07-09
! Review II:       Prof. Head, 2004-12-10
! -------------------------------------------------------------------------
! Amended:         Mrs. F. Smith
! Date:            2009-11-18
! Institution:     Institute of Applied Computer Science
! University:      Podunk University
! Project:         Crankcase lighting
! FVV no.:         4711
!

! -------------------------------------------------------------------------
! Variable       Type    Input/Output Unit Description
! -------------------------------------------------------------------------
! p              real*8    I     (Pa)      Pressure in cylinder
! T              real*8    I     (K)       Mean temp. in cylinder
! p_ES           real*8    I     (Pa)      Pressure in cylinder with
!                                          inlet closing (ES)
! T_ES           real*8    I     (K)       Temp. in cylinder with ES
! V_ES           real*8    I     (m^3)     Vol. in cylinder with ES
! V_Hub          real*8    I     (m^3)     Cylinder displacement
! d_Zyl          real*8    I     (m)       Cylinder diameter
! c_m            real*8    I     (m/sec)   Mean piston speed
! c_u_Drall      real*8    I     (m/sec)   Swirl velocity
! p_Schlepp      real*8    I     (Pa)      motored pressure profile
!                                          without combustion
! isGasExchange  logical   I     (-)       Indicates whether charge exchange
!                                          present or not
!
! alpha          real*8    O     (W/m^2/K) Heat transfer coefficient
! isValid        logical   O               Error flag  0: Error 1: OK
!

! History:
! --------
! Version   Date        Name       Description
!  V 1.0    20040707    Smith      Document created
!  V 1.1    20040709    Smith      Huber activated only for whole engine
cycles
```

```
!  V 1.2    20041210    Smith       alpha_uv no longer calculated for empty
!                                   areas
!  V 1.45   20070615    Smith       Minor internal redesign (DataMain%geo)
!  V 1.52   20081216    Smith       Improved oscillation control in response
to !                                turning Huber expansion on or off
!  V 1.54   20091001    Smith       Clean error message if alpha = NaN
!  V 1.55   20091118    Smith       No further crashes caused by extreme
!                                   combustion term


! Implementation based on:
!   - MERKER, Günter; SCHWARZ, Christian; STIESCH, Gunnar; OTTO, Frank:
!     Verbrennungsmotoren. Simulation der Verbrennung u. Schadstoffbildung.
!     2nd ed. Stuttgart: Teubner, 2004
!   - PISCHINGER, R. ; KLELL, M. ; SAMS, T.: Thermodynamik der
!     Verbrennungskraftmaschine. 2nd ed. Vienna: Springer, 2002.


subroutine calcAlphaWoschni( p, T, p_ES, T_ES, V_ES, V_Hub, d_Zyl, c_m,
                             c_u_Drall, p_Schlepp, isGasExchange, alpha,
                             isValid )

implicit none

! Arguments
real*8, intent(in)    :: p               ! (Pa) Pressure in cylinder
real*8, intent (in)   :: T               ! (K) Mean temp. in cylinder
real*8, intent (in)   :: p_ES            ! (Pa) Pressure in cylinder with ES
real*8, intent (in)   :: T_ES            ! (K)  Temp. in cylinder with ES
real*8, intent (in)   :: V_ES            ! (m^3) Vol. in cylinder with ES
real*8, intent (in)   :: V_Hub           ! (m^3) Cylinder displacement
real*8, intent (in)   :: d_Zyl           ! (m)  Cylinder diameter
real*8, intent (in)   :: c_m             ! (m/s) Mean piston speed
real*8, intent (in)   :: c_u_Drall       ! (m/s) Swirl speed
real*8, intent (in)   :: p_Schlepp       ! (Pa) motored pressure profile
logical, intent (in) :: isGasExchange    ! Indicates whether in charge
                                           exchange
real*8, intent (out) :: alpha       ! (W/m^2/K) Heat transfer coefficient
logical, intent (out):: isValid     ! Error flag 0: Error 1: OK

! Internal variables:
real*8 :: C1, C2                          ! Constants based on Woschni
real*8 :: p_bar, p_ES_bar, p_Schlepp_bar  ! (bar) converted pressures
real*8 :: delta_p_bar                     ! (bar) pressure differential,
fired
real*8 :: zh1, zh2                        ! Auxiliary variables


if (p > 0.0 .and. p_ES > 0.0) then  ! valid pressure?
  C2=3.24*0.001               ! Constant  C2
  if (isGasExchange) then
    C1=6.18+0.417*(c_u_Drall / c_m)   ! Constant  C1 for charge exchange
  else
    C1=2.28+0.308*(c_u_Drall / c_m)   ! Constant  C1 for high pressure phase
  end if

  ! Variables with non-SI compliant units must be
  ! clearly labeled
  p_bar = p*1e-5
  p_ES_bar = p_ES*1e-5
  p_Schlepp_bar = p_Schlepp*1e-5

  zh1 = 130.0 * (d**(-0.2))*(p_bar**0.8)*(T**(-0.53))
```

```
  delta_p_bar = p_bar - p_Schlepp_bar
  if (delta_p_bar > 0.0) then      ! must not be negative
    ! Calculate combustion term based on Woschni:
    zh2 = ( C1 * c_m + C2 * ((V_Hub * T_ES) / (p_ES_bar * V_ES)) *
                                                  delta_p_bar)**0.8
  else
    zh2 = ( C1 * c_m )**0.8
  endif

  alpha=zh1*zh2         ! (W/m^2/K) Heat transfer coefficient

  isValid = .true.

else
  alpha = 0.0
  isValid = .false.          ! Error invalid pressure
end if

end subroutine calcAlphaWoschni
```

Annex 5

Example of a program in C

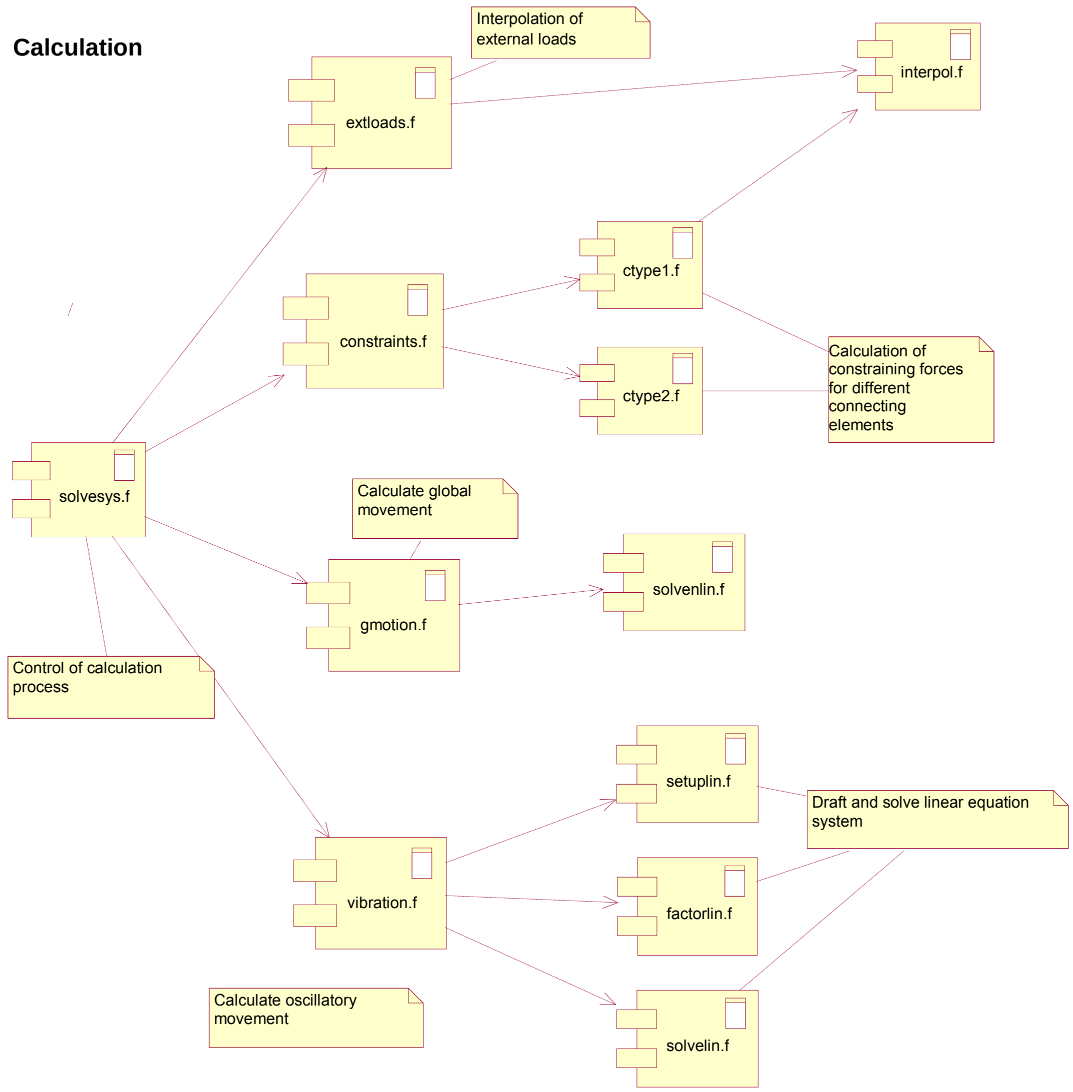
```
/*
 -----------------------------------------------------------------------

 Subroutine to calculate heat transfer based on Woschni

 -----------------------------------------------------------------------

 Author:          J. Smith
 Institution:     Institute of Applied Computer Science
 University:      Podunk University
 Date:            2007-07-07
 Language:        ANSI C
 Project:         Crankcase lighting
 FVV no.:         4711
 -----------------------------------------------------------------------
 Review I:        Dr. X. Troubleshooter, 2004-07-09
 Review II:       Prof. Head, 2004-12-10
 -----------------------------------------------------------------------
 Amended:         Mrs. F. Smith
 Date:            2009-11-18
 Institution:     Institute of Applied Computer Science
 University:      Technical Podunk University
 Project:         Crankcase lighting
 FVV no.:         4711


 -----------------------------------------------------------------------
 Variable Type    Input/Output Unit Description
 -----------------------------------------------------------------------
 p               real*8    I     (Pa)      Pressure in cylinder
 T               real*8    I     (K)       Mean temp. in cylinder
 p_ES            real*8    I     (Pa)      Pressure in cylinder with
                                           inlet closing (ES)
 T_ES            real*8    I     (K)       Temp. in cylinder with ES
 V_ES            real*8    I     (m^3)     Vol. in cylinder with ES
 V_Hub           real*8    I     (m^3)     Cylinder displacement
 d_Zyl           real*8    I     (m)       Cylinder diameter
 c_m             real*8    I     (m/sec)   Mean piston speed
 c_u_Drall       real*8    I     (m/sec)   Swirl velocity
 p_Schlepp       real*8    I     (Pa)      Working gas pressure
                                     without combustion
 isGasExchange   logical   I     (-)       Indicates whether charge exchange
                                           present or not

 isValid         logical   O               Error flag 0: Error 1: OK
```

```
 History:
 --------
 Version    Date        Name        Description
  V 1.0     20040707    Smith       Document created
  V 1.1     20040709    Smith       Huber activated only for whole engine
cycles
  V 1.2     20041210    Smith       alpha_uv no longer calculated for empty
                                    areas
  V 1.45    20070615    Smith       Minor internal redesign (DataMain%geo)
  V 1.52    20081216    Smith       Improved oscillation control in response
                                    to turning Huber expansion on or off
  V 1.54    20091001    Smith       Clean error message if alpha = NaN
  V 1.55    20091118    Smith       No further crashes caused by extreme
                                    combustion term


 Implementation based on:
   - MERKER, Günter; SCHWARZ, Christian; STIESCH, Gunnar; OTTO, Frank:
     Verbrennungsmotoren. Simulation der Verbrennung u. Schadstoffbildung.
     2nd ed. Stuttgart: Teubner, 2004
   - PISCHINGER, R.; KLELL, M. ; SAMS, T.: Thermodynamik der
     Verbrennungskraftmaschine. 2nd ed. Vienna: Springer, 2002.


*/

double calcAlphaWoschni( p, T, p_ES, T_ES, V_ES, V_Hub, d_Zyl, c_m,
                         c_u_Drall, p_Schlepp, isGasExchange,
                         isValid )

{

//Internal variables:
double C1, C2;                               // Constants based on Woschni
double p_bar, p_ES_bar, p_Schlepp_bar;       // (bar) converted pressures
double delta_p_bar;                          // (bar) pressure differential,
fired
double zh1, zh2;                             // Auxiliary variables
double alpha;                                // (W/m^2/K Heat transfer
coefficient
```

```
if (p > 0.0 && p_ES > 0.0)    // valid pressure?
{
  C2=3.24*0.001;              // Const.  C2
  if (isGasExchange)
    /* Const. C1 for charge exchange */
    C1=6.18+0.417*(c_u_Drall / c_m);
  else
    /* Const. C1 for high pressure phase */
    C1=2.28+0.308*(c_u_Drall / c_m);

  /* Variables with non-SI compliant units must be
     clearly labeled */
  p_bar = p*1e-5;
  p_ES_bar = p_ES*1e-5;
  p_Schlepp_bar = p_Schlepp*1e-5;

  zh1 = 130.0 * pow(d,-0.2) * pow(p_bar,0.8) * pow(T, -0.53);

  delta_p_bar = p_bar - p_Schlepp_bar;
  if (delta_p_bar > 0.0)       /* must not be negative */
  {
    /* Calculate combustion term based on Woschni: */
    zh2 = pow( C1 * c_m + C2 * ((V_Hub * T_ES) / (p_ES_bar * V_ES)) *
                                                 delta_p_bar, 0.8 );
  }
  else
  {
    zh2 = pow( C1 * c_m, 0.8);
  }

  alpha=zh1*zh2;        /* (W/m^2/K) Heat transfer coefficient */

  isValid = true;

}
else
{
  alpha = 0.0;
  isValid = false;            /* Error invalid pressure */
}

return alpha ;

}
```

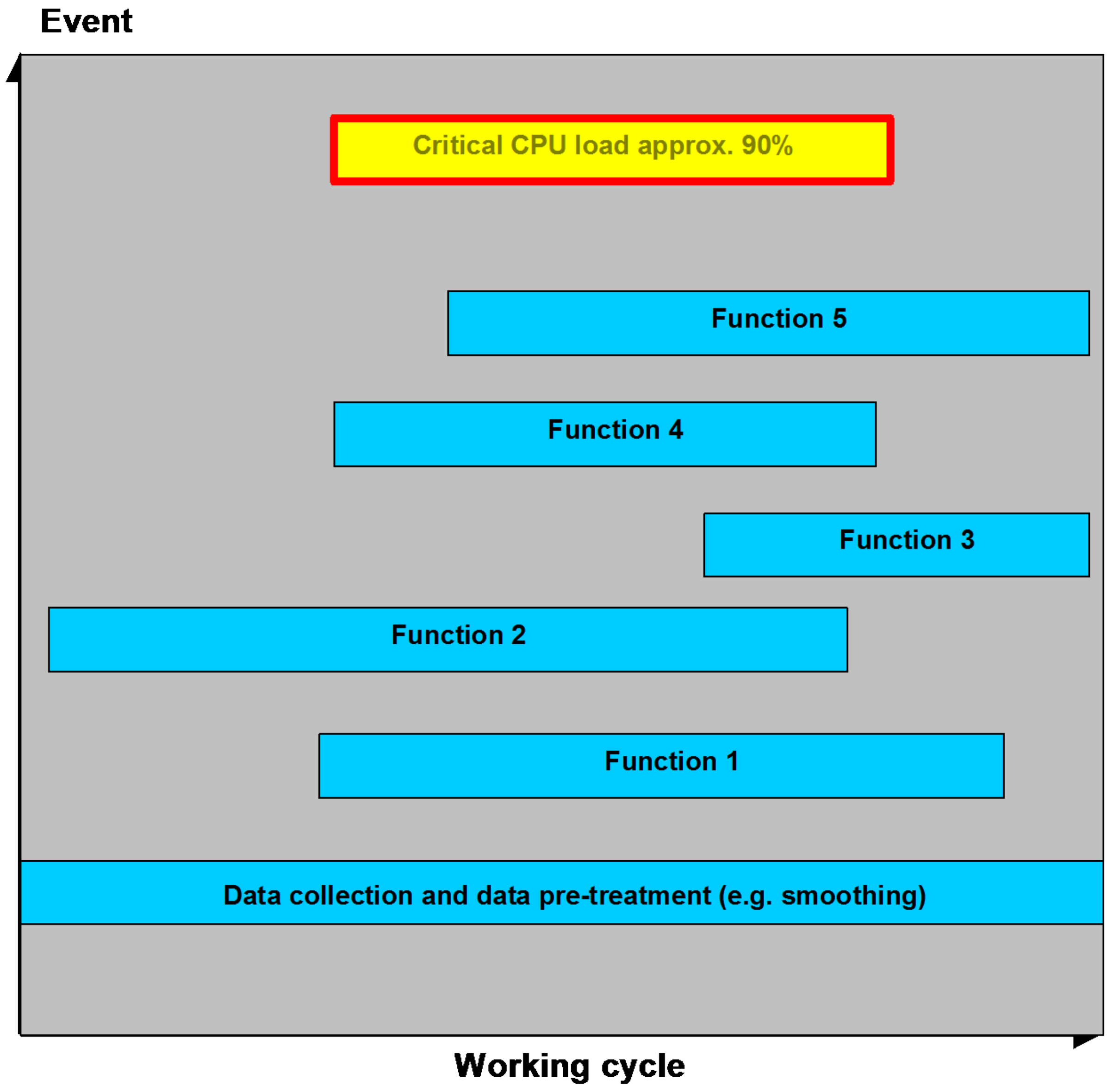
Annex 6

Example of program structure plan



Annex 7

Example of a time plan



Annex 8

Short program description

Name of program	
Short project title	
Project no.	
Research institute	
Head of research institute	
Authors	
Date created	
Version	
Revised by	
Purpose of method	
Keywords	
Programming language	
Requirements in terms of:	
System environment	
Available interfaces	
Important notes	

Annex 9

Real-time programs

Explanation of term – Real-time programs

1.1 Group

A software design unit with clearly delimited functionality and defined interfaces; it may consist of multiple components (e.g. the COM group contains all communications components).

1.2 Component

A software design unit with clearly delimited functionality and defined interfaces within a group (e.g. CCP, KWP).

1.3 Module

In the programming sense, a file (also known as a Source File) that may consist of a series of operations (functions), type declarations, variables and constants. Every module is physically stored under a specific name that describes the content of the module as precisely as possible. Each module is thus the smallest compilable programming unit (see Annex A on module structure).
To achieve better software quality in terms of ease of maintenance and readability, the whole of the source code for a given program must be structured in modular form, i.e. comprising, where possible, several modules (program files) that can be individually compiled, each describing a specific situation. Module names must reflect the overall task performed by all operations contained in the module in question. Some examples are listed below (modules are C files).

Example:

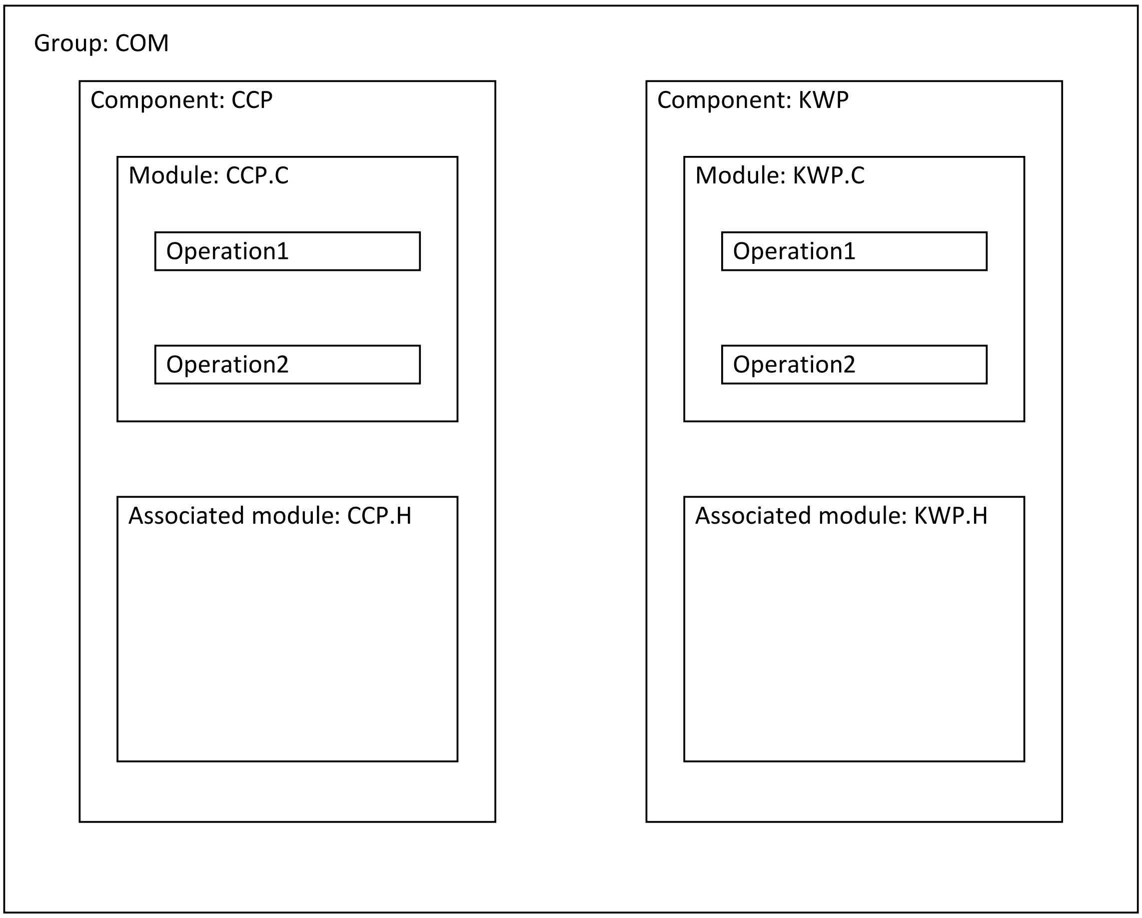
CCP.C
KWP.C

Notes:

- Components are abbreviated in all names for non-local objects
- Show the memory class in names (`_var` vs. `var` vs. `var_` for module-global, local, persistent-local, for example)
- Mandatory and comprehensive use of `const`
- Mandatory use of module-global, not externally visible operations wherever possible
    - Use `static`
    - Omit module abbreviation
    - Position in source text ahead of global, externally visible operations
- The same applies to data objects

1.4 Operation (function)

This is part of a module, consisting of the operation name and a sequence of instructions. An operation has a defined input and output.



This arrangement can be simplified as required (if a group contains only one component) or refined.

Style Guide – real-time programs (ref. Chapter 4)

1.5 Style Guide

The MISRA standard "Guidelines For The Use Of The C Language In Vehicle Based Software" makes available a series of rules that are intended to support the programming of correct C programs. These rules relate mainly to the details of the programming language C and say nothing about the programming style (i.e. a style guide). For this reason, this chapter should be considered as a supplement to the MISRA standard insofar as it provides a definition of the Style Guide.

Note: (MISRA: R111) identifies MISRA rule 111 as reference.

1.5.1 Data types

1.5.1.1 Basic data types

The data types to be used must be defined as a matter of course via "compiler switches" for different processors or compilers. The basic data types listed in the following table must be used so as to exclude differing interpretations of data types on different systems. The data types offered by the compiler must be converted into the following basic data types.

ECU designation	**Data width**	**ANSI data type (e.g. MPC 565)**
bool	**8 bit**	
s8	8 Bit	signed char
u8	8 Bit	unsigned char
s16	16 Bit	signed int
u16	16 Bit	
s32	32 Bit	
u32	32 Bit	
s64	64 Bit	
u64	64 Bit	
f32	32 Bit	
f64	64 Bit	
f128	128 Bit	

1.5.1.2 Derived data types

Further data types can now be derived from the basic data types. These are labeled with a suffixed "**_t**".

1.5.1.3 Structures / bit variables

The data types used in the bit variables must be declared using ANSI-C. Derived "typedefs" are compiler-dependent and lead to errors.

```
typedef struct
{
 unsigned int    bit1_b:1
 unsigned int    bit2_b:1
 unsigned int    bit3_b:1
.
.
.
}bitword_t
```

(MISRA: R111-R113)

1.5.1.4 Type conversion

Type conversion must be done only explicitly. By doing so, the user shows that the conversion was intentional. Implicit type conversions are compiler-dependent. This means that the program is not portable and the data types are not predictable.

(MISRA: R43-R45)

1.5.1.5 Pre-processor arithmetic

Pre-processor constants that are used for pre-processor arithmetic must be declared by stating the data type “double” or “float”. The desired data type must then be stated explicitly (as “cast”).

(MISRA: R87-R100)

Examples:

```
#define ADC_LOOP_TIME_C     ( (f64) 1000 )
#define ADC_FACTOR_C        ( (f64)  0.01 )
#define ADC_VALUE_C         ( (u16) ADC_LOOP_TIME_C * ADC_FACTOR_C  )
```

1.5.1.6 Declaring data masks (masks)

Data masks must be declared using compiler switches, since the bit structure and byte arrangement are processor-dependent. “Else branches” need to be defined.
The control flow of instructions must be made clear using indents.

Examples:

```
#ifdef INTEL
  #define MASK 0x0001
#elif MOTOROLA
  #define MASK 0x0100
#else
  #error message_no_processor
#endif
```

1.5.2 Naming conventions

Clarity, ease of maintenance and compatibility (within a programming team) are guaranteed if meaningful names and a standardized writing format are adopted for variables, constants, structures, etc. Because one objective is to ensure that the existing software can be re-used, the names for the language elements listed above should be, and remain, non-project-dependent. Names must communicate meaning and not be made too short. In extreme cases they should be abbreviated in a way that still reflects their sense. It must be ensured in this regard that the designation chosen does not conflict with the reserved names in the programming environment (compiler, linker, programming language etc.).
All identifiers belonging to a functional module must begin with a defined abbreviation. Where possible, the abbreviation should be limited to three letters.

1.5.2.1 Names of variables

Names of variables are structured as shown below:

[abbreviation]_DescriptionOfVariables]_[variabletype]

abbreviation	-	Name of the associated components, in lower case
DescriptionOfVariables	-	Logical description of the variables, with no separation of individual words with an underscore, but identified instead using upper and lower case letters
variabletype	-	s8, u8, s16, u16, s32, u32, s64, u64, f32, f64, f128

Examples:

```
adc_BatteryVoltage_u16      /* Analog value for battery voltage */

can_ReceiveBuffer_u8[8]     /* CAN receive buffer */
```

There is no need to use the component description with local variables (within the operations).

1.5.2.1.1 Pointer

Pointer names are formed in accordance with the requirements for variable names, with the difference that the variable type is replaced by the character sequence "**_p**" (pointer).

[abbreviation]_[DescriptionOfVariables]_p

Examples:

```
can_TransmitBuffer_p        /* CAN transmit buffer */
```

1.5.2.1.2 Structure variables

Structure variables are formed in accordance with the requirements for variable names, with the difference that the variable type is replaced by the character sequence "**_st**" (structure).

[abbreviation]_[DescriptionOfVariable]_st

Examples:

```
can_Bitfeld_t  can_ErrorStatus_st    /* CAN Status */
```

1.5.2.2 Applicable values

Applicable values (characteristic values, characteristic curves, characteristic diagrams) are described as follows:

[abbreviation]_[Description]_[identifier]

abbreviation	-	Name of the associated components, in lower case
Description	-	Logical description of the variables, with no separation of individual words with an underscore, but identified instead using upper case letters
identifier		kw, kl, kf, kr (no data type specified) kw – characteristic value kl – characteristic curve kf – characteristic map (kr – characteristic volume)

Examples:

```
adc_TempSensor_kl                 /* Sensor characteristic curve */

adc_TempSensorThreshold_kw        /* Sensor threshold value */
```

1.5.2.3 Names of operations

Names of operations are structured in the same way as names of variables, with the following difference:

- The variable type describes the return value of the operation; if the operation does not produce a value (i.e. if it is void), this description is not used.

[abbreviation]_[DescriptionOfOperation]_[variabletype]( )

abbreviation	-	Name of the associated components, in lower case
DescriptionOfOperation	-	Logical description of the operation, with no separation of individual words with an underscore,

but identified instead using upper case letters

variabletype	-	s8, u8, s16, u16, s32, u32, s64, u64, f32, f64, f128

Examples:

```
u8 can_TransmitData_u8 ()
void can_BusOff ()
```

1.5.2.4 Constants by defines

Constants are written in upper case, with the attached character string "**_C**", as shown below:

[ABBREVIATION]_[DESCRIPTION_OF_CONSTANTS]_C

ABBREVIATION	-	Name of the associated components, in upper case
DESCRIPTION_OF_CONSTANTS	-	Logical description of the operation, with individual words separated with an underscore

- Constants must be enclosed in parentheses.
- They must be explicitly defined by data type.

Examples:

```
#define CAN_RECEIVE_BUFFER_LENGTH_C         ( (u8)8 )
```

1.5.2.5 Macros

Macros are written in upper case. The name of the macro is followed immediately by a pair of parentheses "()".

[ABBREVIATION]_[DESCRIPTION_OF_MACRO]( )

ABBREVIATION	-	Name of the associated components, in upper case
DESCRIPTION_OF_MACRO	-	Logical description of the macro, with individual words separated with an underscore

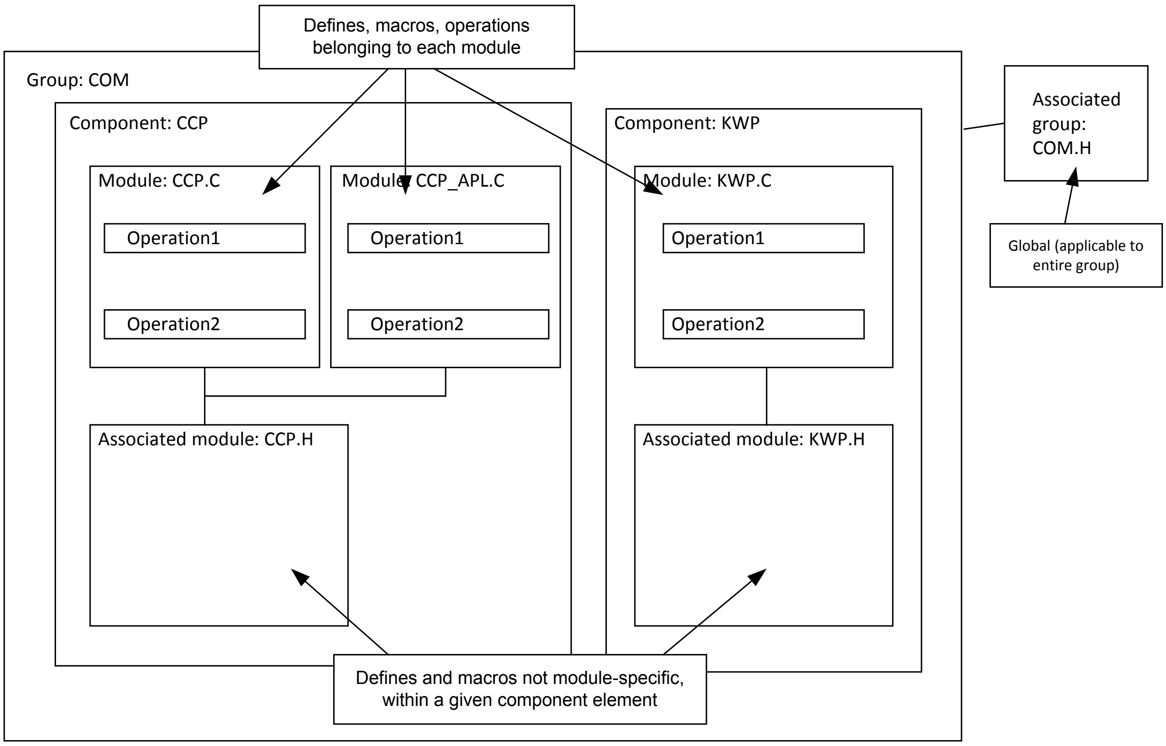
Examples:

```
CAN_NEWDAT_SET()
```

(MISRA: R90-R96)

1.5.2.6 Header files

The names of header files must be described using the abbreviations that signal attribution to a given component. This encourages clarity, attribution and ease of maintenance of the software. The illustration below shows the principle to be followed when creating header files.



Modules may have their own header files.

1.5.3 Project files

1.5.3.1 Fundamental properties

- No tabs must be used.
- Indent: 3 spaces
- Line length must not exceed 120 characters.
- Brackets belonging together must be positioned above each other.

```
if( )
{

}
else
{

}
```

- Accented and other special characters such as ä, ö, ü and ß are not permitted.
- Blank spaces must be placed between operators: x + y

1.5.3.2 Module structure

To ensure that the code is consistent and readable, a module header (see Annex A) must be included in every program file. An operation header (see Annex B) must be created for each operation.

1.5.4 Predefined compiler macros and data types

Predefined data types and macros must not be used, since these are entirely dependent on the compilers used.

1.5.5 Return instruction

A maximum of one return instruction may be used within an operation as the last instruction.

(MISRA: R79-R86)

1.5.6 Comments

Comments must explain “what” is done and “why”, but not “how”. Comments must not be nested. Program codes must not be repeated in words.

1.5.7 Program code

1.5.7.1 Conditional compiling

In principle, provision must be made for conditional compiling for different processors or hardware variants, etc., even if only one processor is used. This makes expansion or portability possible. The “else branch” is used for error handling and must be provided. The control flow must be made clear using indents.

Examples:

```
#ifdef INTEL
  ....
#elif MOTOROLA
  .....
#else
  #error message_no_processor
#endif
```

1.5.7.2 Change documentation for program code

Program code changes are documented by way of the appropriate entries in the program version control system (PVCS).

Annex A – Structure of a C file (module)

The C file is a collection of operations that are linked with each other either logically or functionally. This file is called a module. Each file contains only one module header at the start of the file. The structure and content are shown below.

```
/*****************************************************************
PROJECT:            MSP0208
                    $Header:   $
NAME:               $Workfile: $
CREATE DATE:       2002-09-24
CODING STANDARD:
DESCRIPTION:
REVISION:           $Revision: $
                    $Author:   $
                    $Date:     $
LIST OF CHANGES:
$Log:$
*****************************************************************/

/*---------------------------------------------------------------
    Header files (#include)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Global variables
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Global constants (const)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Globally applicable parameters (const)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Type definitions within the module (typedef)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Constants within the module by Define (#define)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Macros within the module (#define, inline)
---------------------------------------------------------------*/

/*---------------------------------------------------------------
    Variables within the module (static)
---------------------------------------------------------------*/
```

```
/*-----------------------------------------------------------------
    Constants within the module (static const)
-----------------------------------------------------------------*/

/*-----------------------------------------------------------------
    Parameters applicable within the module (const)
-----------------------------------------------------------------*/

/*-----------------------------------------------------------------
    Operation prototypes within the module (static)
-----------------------------------------------------------------*/
```

Annex B – Structure of an operation

The following shows the basic structure to be used for each operation.

```
/****************************************************************
NAME OF OPERATION:   NameOfOperation
DESCRIPTION:
INPUTS:
OUTPUTS:
AUTHOR/DATE:
****************************************************************/

void NameOfOperation(void)
{


} /* End NameOfOperation */
```

Note:

All variables (parameters, global variables) that are read or described must be listed and described under INPUTS / OUTPUTS.

Annex C – Structure of a header file

```
/*****************************************************************
PROJECT:            MSP0208
                    $Header:   $
NAME:               $Workfile: $
CREATE DATE:        2002-09-24
CODING STANDARD:
DESCRIPTION:
REVISION:           $Revision: $
                    $Author:   $
                    $Date:     $
LIST OF CHANGES:
$Log:$
*****************************************************************/

#ifndef header_h
#define header_h

/*----------------------------------------------------------------
    Global type definitions (typedef)
----------------------------------------------------------------*/

/*----------------------------------------------------------------
    Global constants by Define (#define)
----------------------------------------------------------------*/

/*----------------------------------------------------------------
    External definitions of global variables
----------------------------------------------------------------*/

/*----------------------------------------------------------------
    External definitions of global constants
----------------------------------------------------------------*/

/*----------------------------------------------------------------
    External definitions of operation prototypes
----------------------------------------------------------------*/

/*----------------------------------------------------------------
    Global macros (#define)
----------------------------------------------------------------*/
```