# GetDP

# GetDP Reference Manual

The documentation for GetDP 2.11
A General environment for the treatment of Discrete Problems

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# Obtaining GetDP

The source code and various pre-compiled versions of GetDP (for Windows, Linux and MacOS) can be downloaded from http://getdp.info.

If you use GetDP, we would appreciate that you mention it in your work. References and the latest news about GetDP are always available on http://getdp.info.

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# 1 Overview

GetDP (a "General environment for the treatment of Discrete Problems") is a scientific software environment for the numerical solution of integro-differential equations, open to the coupling of physical problems (electromagnetic, thermal, etc.) as well as of numerical methods (finite element method, integral methods, etc.). It can deal with such problems of various dimensions (1D, 2D or 3D) and time states (static, transient or harmonic).

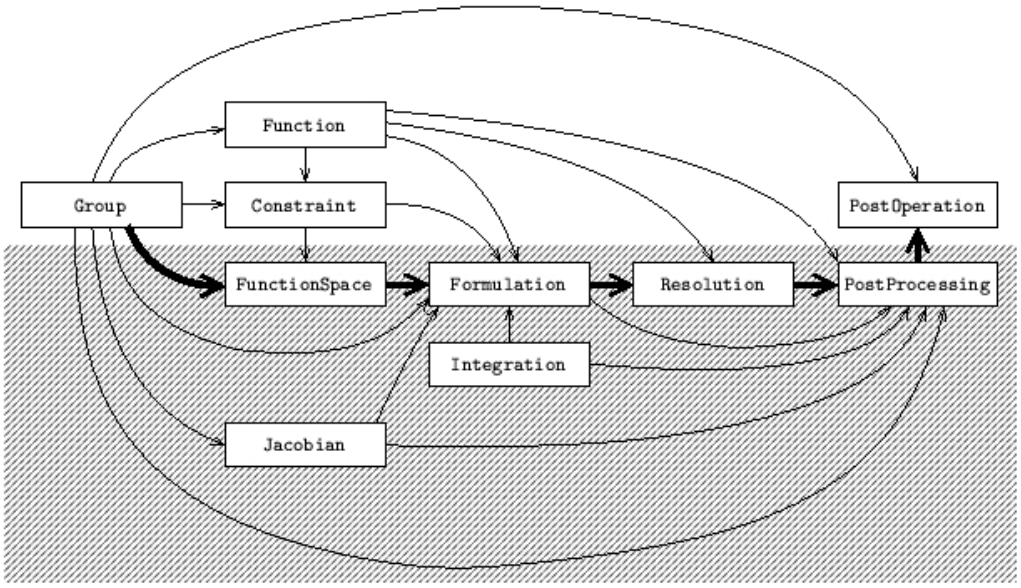
The main feature of GetDP is the closeness between its internal structure (written in C), the organization of data defining discrete problems (written by the user in ASCII data files) and the symbolic mathematical expressions of these problems. Its aim is to be welcoming and of easy use for both development and application levels: it consists of a working environment in which the definition of any problem makes use of a limited number of objects, which makes the environment structured and concise. It therefore gives researchers advanced developing tools and a large freedom in adding new functionalities.

The modeling tools provided by GetDP can be tackled at various levels of complexity: this opens the software to a wide range of activities, such as research, collaboration, education, training and industrial studies.

## 1.1 Numerical tools as objects

An assembly of computational tools (or objects) in GetDP leads to a problem definition structure, which is a transcription of the mathematical expression of the problem, and forms a text data file: the equations describing a phenomenon, written in a mathematical form adapted to a chosen numerical method, directly constitute data for GetDP.

The resolution of a discrete problem with GetDP requires the definition, in a text data file, of the GetDP objects listed (together with their dependencies) in the following figure and table.



```
Group           ---
Function        Group
Constraint      Group, Function, (Resolution)
FunctionSpace   Group, Constraint, (Formulation), (Resolution)
Jacobian        Group
Integration     ---
Formulation     Group, Function, (Constraint), FunctionSpace,
                Jacobian, Integration
Resolution      Function, Formulation
PostProcessing  Group, Function, Jacobian, Integration,
                Formulation, Resolution
PostOperation   Group, PostProcessing
```

The gathering of all these objects constitutes the problem definition structure, which is a copy of the formal mathematical formulation of the problem. Reading the first column of the table from top to bottom pictures the working philosophy and the linking of operations peculiar to GetDP, from group definition to results visualization. The decomposition highlighted in the figure points out the separation between the objects defining the method of resolution, which may be isolated in a "black box" (bottom) and those defining the data peculiar to a given problem (top).

The computational tools which are in the center of a problem definition structure are formulations (`Formulation`) and function spaces (`FunctionSpace`). Formulations define systems of equations that have to be built and solved, while function spaces contain all the quantities, i.e., functions, fields of vectors or covectors, known or not, involved in formulations.

Each object of a problem definition structure must be defined before being referred to by others. A linking which always respects this property is the following: it first contains the objects defining particular data of a problem, such as geometry, physical characteristics and boundary conditions (i.e., `Group`, `Function` and `Constraint`) followed by those defining a resolution method, such as unknowns, equations and related objects (i.e., `Jacobian`, `Integration`, `FunctionSpace`, `Formulation`, `Resolution` and `PostProcessing`). The processing cycle ends with the presentation of the results (i.e., lists of numbers in various formats), defined in `PostOperation` fields. This decomposition points out the possibility of building black boxes, containing objects of the second group, adapted to treatment of general classes of problems that share the same resolution methods.

## 1.2 Which problems can GetDP actually solve?

The preceding explanations may seem very (too) general. Which are the problems that GetDP can actually solve? To answer this question, here is a list of methods that we have considered and coupled until now:

Numerical methods

- finite element method
- boundary element method (experimental, undocumented)
- volume integral methods (experimental, undocumented)

Geometrical models
- one-dimensional models (1D)
- two-dimensional models (2D), plane and axisymmetric
- three-dimensional models (3D)

Time states
- static states
- sinusoidal and harmonic states
- transient states
- eigenvalue problems

These methods have been successfully applied to build coupled physical models involving electromagnetic phenomena (magnetostatics, magnetodynamics, electrostatics, electrokinetics, electrodynamics, wave propagation, lumped electric circuits), acoustic phenomena, thermal phenomena and mechanical phenomena (elasticity, rigid body movement).

As can be guessed from the preceding list, GetDP has been initially developed in the field of computational electromagnetics, which fully uses all the offered coupling features. We believe that this does not interfere with the expected generality of the software because a particular modeling forms a problem definition structure which is totally external to the software: GetDP offers computational tools; the user freely applies them to define and solve his problem.

Nevertheless, specific numerical tools will *always* need to be implemented to solve specific problems in areas other than those mentionned above. If you think the general phisosophy of GetDP is right for you and your problem, but you discover that GetDP lacks the tools necessary to handle it, let us know: we would love to discuss it with you. For example, at the time of this writing, many areas of GetDP would need to be improved to make GetDP as useful for computational mechanics or computational fluid dynamics as it is for computational electromagnetics... So if you have the skills and some free time, feel free to join the project: we gladly accept all code contributions!

## 1.3 Bug reports

If you think you have found a bug in GetDP, you can report it by electronic mail to the GetDP mailing list at `getdp@onelab.info`, or file it directly into our bug tracking system at `http://gitlab.onelab.info/getdp/getdp/issues` (User name and password: `getdp`). Please send as precise a description of the problem as you can, including sample input files that produce the bug (problem definition and mesh files). Don't forget to mention both the version of GetDP and the version of your operation system (see Chapter 3 [Running GetDP], page 11 to see how to get this information).

See Appendix D [Frequently asked questions], page 121, and the bug tracking system to see which problems we already know about.

# 2 How to read this manual

After reading Chapter 1 [Overview], page 5, which depicts the general philosophy of GetDP, you might want to skip Chapter 4 [Expressions], page 15, Chapter 5 [Objects], page 29 and Chapter 6 [Types for objects], page 43 and directly run the demo files bundled in the distribution on your computer (see Chapter 3 [Running GetDP], page 11). You should then open these examples with a text editor and compare their structure with the examples given in Chapter 7 [Short examples], page 75 and Chapter 8 [Complete examples], page 91. For each new syntax element that you fall onto, you can then go back to Chapter 4 [Expressions], page 15, Chapter 5 [Objects], page 29, and Chapter 6 [Types for objects], page 43, and find in these chapters the detailed description of the syntactic rules as well as all the available options.

Indexes for many concepts (see [Concept index], page 139) and for all the syntax elements (see [Syntax index], page 145) are available at the end of this manual.

## 2.1 Syntactic rules used in this document

Here are the rules we tried to follow when writing this user's guide. Note that metasyntactic variable definitions stay valid throughout all the manual (and not only in the sections where the definitions appear). See [Metasyntactic variable index], page 143, for an index of all metasyntactic variables.

1. Keywords and literal symbols are printed like `this`.
2. Metasyntactic variables (i.e., text bits that are not part of the syntax, but stand for other text bits) are printed like *this*.
3. A colon (`:`) after a metasyntactic variable separates the variable from its definition.
4. Optional rules are enclosed in `< >` pairs.
5. Multiple choices are separated by `|`.
6. Three dots (`...`) indicate a possible repetition of the preceding rule.
7. For conciseness, the notation *`rule`* `<,` *`rule`* `> ...` is replaced by *`rule`* `<,...>`.
8. The *etc* symbol replaces nonlisted rules.

# 3 Running GetDP

GetDP has no graphical interface[1]. It is a command-line driven program that reads a problem definition file once at the beginning of the processing. This problem definition file is a regular ASCII text file (see Section 1.1 [Numerical tools as objects], page 5), hence created with whatever text editor you like.

If you just type the program name at your shell prompt (without any argument), you will get a short help on how to run GetDP. All GetDP calls look like

```
getdp filename options
```

where *filename* is the ASCII file containing the problem definition, i.e., the structures this user's guide has taught you to create. This file can include other files (see Section 4.2 [Includes], page 15), so that only one problem definition file should always be given on the command line. The input files containing the problem definition structure are usually given the '`.pro`' extension (if so, there is no need to specify the extension on the command line). The name of this file (without the extension) is used as a basis for the creation of intermediate files during the pre-processing and the processing stages.

The *options* are a combination of the following commands (in any order):

`-pre` *resolution-id*

Performs the pre-processing associated with the resolution *resolution-id*. In the pre-processing stage, GetDP creates the geometric database (from the mesh file), identifies the degrees of freedom (the unknowns) of the problem and sets up the constraints on these degrees of freedom. The pre-processing creates a file with a '`.pre`' extension. If *resolution-id* is omitted, the list of available choices is displayed.

`-cal`

Performs the processing. This requires that a pre-processing has been performed previously, or that a `-pre` option is given on the same command line. The performed resolution is the one given as an argument to the `-pre` option. In the processing stage, GetDP executes all the commands given in the `Operation` field of the selected `Resolution` object (such as matrix assemblies, system resolutions, ...).

`-pos` *post-operation-id* ...

Performs the operations in the `PostOperation`(s) selected by the *post-operation-id*(s). This requires that a processing has been performed previously, or that a `-cal` option is given on the same command line. If *post-operation-id* is omitted, the list of available choices is displayed.

`-msh` *filename*

[1] If you are looking for a graphical front-end to GetDP, you may consider using Gmsh (available at `http://gmsh.info`). Gmsh permits to construct geometries, generate meshes, launch computations and visualize results directly from within a user-friendly graphical interface. The file formats used by Gmsh for mesh generation and post-processing are the default file formats accepted by GetDP (see Section A.1 [Input file format], page 111, and Section 6.10 [Types for PostOperation], page 67).

Reads the mesh (in `.msh` format) from *filename* (see Appendix A [File formats], page 111) rather than from the default problem file name (with the '`.msh`' extension appended).

`-gmshread`
*filename ...*

Read gmsh data files (same as GmshRead in `Resolution` operations). Allows to use such datasets outside resolutions (e.g. in pre-processing).

`-split`

Saves processing results in separate files (one for each timestep).

`-res` *filename ...*

Loads processing results from file(s).

`-name` *string*

Uses *string* as the default generic file name for input or output of mesh, pre-processing and processing files.

`-restart`

Restarts processing of a time stepping resolution interrupted before being complete.

`-solve` *resolution-id*

Same as `-pre` *`resolution-id`* `-cal`.

`-solver` *filename*

Specifies a solver option file (whose format varies depending on the linear algebra toolkit used).

`-slepc`

Uses SLEPc instead of Arpack as eigensolver.

`-adapt` *file*

Reads adaptation constraints from file.

`-order` *real*

Specifies the maximum interpolation order.

`-cache`

Caches network computations to disk.

`-bin`

Selects binary format for output files.

`-v2`

Creates mesh-based Gmsh output files when possible.

`-check`

Lets you check the problem structure interactively.

`-v`
`-verbose` *integer*

Sets the verbosity level. A value of 0 means that no information will be displayed during the processing.

`-cpu`

Reports CPU times for all operations.

`-p`
`-progress`

*integer*

Sets the progress update rate. This controls the refreshment rate of the counter indicating the progress of the current computation (in %).

`-onelab` *name* <*address*>

Communicates with OneLab (file or server address)

`-setnumber`

*name value*

Sets constant number *name* to *value*

`-setstring`

*name value*

Sets constant string *name* to *value*

`-info`

Displays the version information.

`-version`

Displays the version number.

`-help`

Displays a message listing basic usage and available options.

# 4 Expressions

This chapter and the next two describe in a rather formal way all the commands that can be used in the ASCII text input files. If you are just beginning to use GetDP, or just want to see what GetDP is all about, you should skip this chapter and the next two for now, have a quick look at Chapter 3 [Running GetDP], page 11, and run the demo problems bundled in the distribution on your computer. You should then open the '`.pro`' files in a text editor and compare their structure with the examples given in Chapter 7 [Short examples], page 75 and Chapter 8 [Complete examples], page 91. Once you have a general idea of how the files are organized, you might want to come back here to learn more about the specific syntax of all the objects, and all the available options.

## 4.1 Comments

Both C and C++ style comments are supported and can be used in the input data files to comment selected text regions:

1. the text region comprised between `/*` and `*/` pairs is ignored;
2. the rest of a line after a double slash `//` is ignored.

Comments cannot be used inside double quotes or inside GetDP keywords.

## 4.2 Includes

An input data file can be included in another input data file by placing one of the following commands (*expression-char* represents a file name) on a separate line, outside the GetDP objects. Any text placed after an include command on the same line is ignored.

```
Include expression-char
#include expression-char
```

See Section 4.4 [Constants], page 16, for the definition of the character expression *expression-char*.

## 4.3 Expressions definition

Expressions are the basic tool of GetDP. They cover a wide range of functional expressions, from constants to formal expressions containing functions (built-in or user-defined, depending on space and time, etc.), arguments, discrete quantities and their associated differential operators, etc. Note that 'white space' (spaces, tabs, new line characters) is ignored inside expressions (as well as inside all GetDP objects).

Expressions are denoted by the metasyntactic variable *expression* (remember the definition of the syntactic rules in Section 2.1 [Syntactic rules], page 9):

```
expression:
  ( expression ) |
  integer |
  real |
  constant-id |
  quantity |
  argument |
```

```
    current-value |
    variable-set |
    variable-get |
    register-set |
    register-get |
    operator-unary expression |
    expression operator-binary expression |
    expression operator-ternary-left expression operator-ternary-right ex-
  pression |
    built-in-function-id [ < expression-list > ] < { expression-cst-list } > |
    function-id [ < expression-list > ] |
    < Real | Complex > [ expression ] |
    Dt [ expression ] |
    AtAnteriorTimeStep [ expression, integer ] |
    Order [ quantity ] |
    Trace [ expression, group-id ] |
    expression ##integer
```

The following sections introduce the quantities that can appear in expressions, i.e., constant terminals (*integer*, *real*) and constant expression identifiers (*constant-id*, *expression-cst-list*), discretized fields (*quantity*), arguments (*argument*), current values (*current-value*), register values (*register-set*, *register-get*), operators (*operator-unary*, *operator-binary*, *operator-ternary-left*, *operator-ternary-right*) and built-in or user-defined functions (*built-in-function-id*, *function-id*). The last seven cases in this definition permit to cast an expression as real or complex, get the time derivative or evaluate an expression at an anterior time step, retrieve the interpolation order of a discretized quantity, evaluate the trace of an expression, and print the value of an expression for debugging purposes.

List of expressions are defined as:

```
expression-list:
  expression <,...>
```

## 4.4 Constants

The three constant types used in GetDP are *integer*, *real* and *string*. These types have the same meaning and syntax as in the C or C++ programming languages. Besides general expressions (*expression*), purely constant expressions, denoted by the metasyntactic variable *expression-cst*, are also used:

```
expression-cst:
  ( expression-cst ) |
  integer |
  real |
  constant-id |
  operator-unary expression-cst |
  expression-cst operator-binary expression-cst |
  expression-cst operator-ternary-left expression-cst operator-ternary-
right
      expression-cst |
```

```
  math-function-id [ < expression-cst-list > ] |
  #constant-id() |
  constant-id(expression-cst) |
  StrFind[ expression-char, expression-char ] |
  StrCmp[ expression-char, expression-char ] |
  StrLen[ expression-char ] |
  StringToName[ expression-char ] | S2N[ expression-char ] |
  Exists[ string ] | FileExists[ string ] |
  GetForced[ string ] | NbrRegions [ string ] |
  GetNumber[ expression-char <, expression-cst> ]
```

`StrFind` searches the first *expression-char* for any occurrence of the second *expression-char*. `StrCmp` compares the two strings (returns an integer greater than, equal to, or less than 0, according as the first string is greater than, equal to, or less than the second string). `StrLen` returns the length of the string. `StringToName` creates a name from the provided string. `Exists` checks for the existence of a constant or a function. `FileExists` checks for the existence of a file. `GetForced` gets the value of a constant (zero if does not exist). `NbrRegions` counts the numbers of elementary regions in a group. `GetNumber` allows to get the value of a ONELAB number variable (the optional second argument specifies the default value returned if the variable does not exist).

List of constant expressions are defined as:

```
expression-cst-list:
  expression-cst-list-item <,...>
```

with

```
expression-cst-list-item:
  expression-cst |
  expression-cst : expression-cst |
  expression-cst : expression-cst : expression-cst |
  constant-id () |
  constant-id ( { expression-cst-list } ) |
  List[ constant-id ] |
  List[ expression-cst-list-item ] |
  List[ { expression-cst-list } ] |
  ListAlt[ constant-id, constant-id ] |
  ListAlt[ expression-cst-list-item, expression-cst-list-item ] |
  LinSpace[ expression-cst, expression-cst, expression-cst ] |
  LogSpace[ expression-cst, expression-cst, expression-cst ] |
  - expression-cst-list-item |
  expression-cst * expression-cst-list-item |
  expression-cst-list-item * expression-cst |
  expression-cst / expression-cst-list-item |
  expression-cst-list-item / expression-cst |
  expression-cst-list-item ^ expression-cst |
  expression-cst-list-item + expression-cst-list-item |
  expression-cst-list-item - expression-cst-list-item |
  expression-cst-list-item * expression-cst-list-item |
  expression-cst-list-item / expression-cst-list-item |
```

```
  ListFromFile [ expression-char ]
```

The second case in this last definition permits to create a list containing the range of numbers comprised between the two *expression-cst*, with a unit incrementation step. The third case also permits to create a list containing the range of numbers comprised between the two *expression-cst*, but with a positive or negative incrementation step equal to the third *expression-cst*. The fourth and fifth cases permit to reference constant identifiers (*constant-id*s) of lists of constants and constant identifiers of sublists of constants (see below for the definition of constant identifiers) . The sixth case is a synonym for the fourth. The seventh case permits to create alternate lists: the arguments of `ListAlt` must be *constant-id*s of lists of constants of the same dimension. The result is an alternate list of these constants: first constant of argument 1, first constant of argument 2, second constant of argument 1, etc. These kinds of lists of constants are for example often used for function parameters (see Section 4.6 [Functions], page 22). The next two cases permit to create linear and logarithmic lists of numbers, respectively. The remaining cases permit to apply arithmetic operators item-wise in lists. `ListFromFile` reads a list of numbers from a file.

Contrary to a general *expression* which is evaluated at runtime (thanks to an internal stack mechanism), an *expression-cst* is completely evaluated during the syntactic analysis of the problem (when GetDP reads the '`.pro`' file). The definition of such constants or lists of constants with identifiers can be made outside or inside any GetDP object. The syntax for the definition of constants is:

```
affectation:
  DefineConstant [ constant-id < = expression-cst > <,...> ]; |
  DefineConstant [ constant-id = { expression-cst , onelab-options } <,...> ]; |
  DefineConstant [ string-id < = string-def >  <,...> ]; |
  DefineConstant [ string-id = { string-def , onelab-options } <,...> ]; |
  constant-id <()> = constant-def; |
  constant-id = DefineNumber[ constant-def, onelab-options ];
  string-id <()> = string-def; |
  string-id = DefineString[ string-def, onelab-options ]; |
  Printf [ "string" ] < > | >> string-def >; |
  Printf [ "string", expression-cst-list ] < > | >> string-def >; |
  Read [ constant-id ] ; |
  Read [ constant-id , expression-cst ]; |
  UndefineConstant | Delete [ constant-id ] ;
  UndefineFunction [ constant-id ] ;
  SetNumber[ string , expression-cst ];
  SetString[ string , string-def ];
```

with

```
constant-id:
  string |
  string ( expression-cst-list ) |
  string ~ { expression-cst } <,...>

constant-def:
  expression-cst-list-item |
  { expression-cst-list }
```

```
string-id:
  string |
  string ~ { expression-cst } <,...>

string-def:
  "string" |
  StrCat[ expression-char <,...> ] |
  Str[ expression-char <,...> ]
```

Notes:

1. Five constants are predefined in GetDP: `Pi` (3.1415926535897932), `0D` (0), `1D` (1), `2D` (2) and `3D` (3).
2. When `~{`*expression-cst*`}` is appended to a string *string*, the result is a new string formed by the concatenation of *string*, `_` (an underscore) and the value of the *expression-cst*. This is most useful in loops (see Section 4.11 [Macros loops and conditionals], page 26), where it permits to define unique strings automatically. For example,

   ```
   For i In {1:3}
     x~{i} = i;
   EndFor
   ```

   is the same as

   ```
   x_1 = 1;
   x_2 = 2;
   x_3 = 3;
   ```

3. The assignment in `DefineConstant` (zero if no *expression-cst* is given) is performed only if *constant-id* has not yet been defined. This kind of explicit default definition mechanism is most useful in general problem definition structures making use of a large number of generic constants, functions or groups. When exploiting only a part of a complex problem definition structure, the default definition mechanism allows to define the quantities of interest only, the others being assigned a default value (that will not be used during the processing but that avoids the error messages produced when references to undefined quantities are made).

   When *onelab-options* are provided, the parameter is exchanged with the ONELAB server. See `http://onelab.info/wiki/ONELAB_Syntax_for_Gmsh_and_GetDP` for more information.
4. `DefineNumber` and `DefineString` allow to define a ONELAB parameter. In this case the affectation always takes place. `SetNumber` and `SetString` allow the direct setting of ONELAB parameters without defining local variables.

See Section 7.1 [Constant expression examples], page 75, as well as Section 7.3 [Function examples], page 75, for some examples.

Character expressions are defined as follows:

```
expression-char:
  "string" |
  string-id |
  StrCat[ expression-char <,...> ] |
```

```
Str[ expression-char <,...> ]
StrChoice[ expression, expression-char, expression-char ] |
StrSub[ expression-char, expression, expression ] |
StrSub[ expression-char, expression ] |
UpperCase [ expression-char ] |
Sprintf [ expression-char ] |
Sprintf[ expression-char, expression-cst-list ] |
NameToString ( string ) | N2S ( string ) |
GetString[ expression-char <, expression-char,> ] |
Date | CurrentDirectory | CurrentDir |
AbsolutePath [ expression-char ] |
DirName [ expression-char ] |
OnelabAction
```

`StrCat` and `Str` permit to concatenate character expressions (`Str` adds a newline character after each string except the last) when creating a string. `Str` is also used to create string lists (when *string-id* is followed by `()`). `StrChoice` returns the first or second *expression-char* depending on the value of *expression*. `StrSub` returns the portion of the string that starts at the character position given by the first *expression* and spans the number of characters given by the second *expression* or until the end of the string (whichever comes first; or always if the second *expression* is not provided). `UpperCase` converts the *expression-char* to upper case. `Sprintf` is equivalent to the `sprintf` C function (where *expression-char* is a format string that can contain floating point formatting characters: `%e`, `%g`, etc.). `NameToString` converts a variable name into a string. `GetString` allows to get the value of a ONELAB string variable (the optional second argument specifies the default value returned if the variable does not exist.) `Date` permits to access the current date. `CurrentDirectory` and `CurrentDir` return the directory of the `.pro` file. `AbsolutePath` returns the absolute path of a file. `DirName` returns the directory of a file. `OnelabAction` returns the current ONELAB action (e.g. `check` or `compute`).

List of character expressions are defined as:

```
expression-char-list:
  expression-char <,...>
```

## 4.5 Operators

### 4.5.1 Operator types

The operators in GetDP are similar to the corresponding operators in the C or C++ programming languages.

*operator-unary*:

`-` Unary minus.

`!` Logical not.

*operator-binary*:

`^` Exponentiation. The evaluation of the both arguments must result in a scalar value.

`*` Multiplication or scalar product, depending on the type of the arguments.

`/\` Cross product. The evaluation of both arguments must result in vectors.

`/` Division.

`%` Modulo. The evaluation of the second argument must result in a scalar value.

`+` Addition.

`-` Subtraction.

`==` Equality.

`!=` Inequality.

`>` Greater. The evaluation of both arguments must result in scalar values.

`>=` Greater or equality. The evaluation of both arguments must result in scalar values.

`<` Less. The evaluation of both arguments must result in scalar values.

`<=` Less or equality. The evaluation of both arguments must result in scalar values.

`&&` Logical 'and'. The evaluation of both arguments must result in scalar values.

`||` Logical 'or'. The evaluation of both arguments must result in floating point values. Warning: the logical 'or' always (unlike in C or C++) implies the evaluation of both arguments. That is, the second operand of `||` is evaluated even if the first one is true.

`&` Binary 'and'.

`|` Binary 'or'.

`>>` Bitwise right-shift operator. Shifts the bits of the first argument to the right by the number of bits specified by the second argument.

`<<` Bitwise left-shift operator. Shifts the bits of the first argument to the left by the number of bits specified by the second argument.

*operator-ternary-left*:

`?`

*operator-ternary-right*:

`:` The only ternary operator, formed by *operator-ternary-left* and *operator-ternary-right* is defined as in the C or C++ programming languages. The ternary operator first evaluates its first argument (the *expression-cst* located before the `?`), which must result in a scalar value. If it is true (non-zero) the second argument (located between `?` and `:`) is evaluated and returned; otherwise the third argument (located after `:`) is evaluated and returned.

### 4.5.2 Evaluation order

The evaluation priorities are summarized below (from stronger to weaker, i.e., `^` has the highest evaluation priority). Parentheses `()` may be used anywhere to change the order of evaluation.

```
^

- (unary), !
| &

/\

*, /, %

+, -

<, >, <=, >=, <<, >>
!=, ==

&&, ||

?:
```

## 4.6 Functions

Two types of functions coexist in GetDP: user-defined functions (*function-id*, see Section 5.2 [Function], page 30) and built-in functions (*built-in-function-id*, defined in this section).

Both types of functions are always followed by a pair of brackets `[]` that can possibly contain arguments (see Section 4.8 [Arguments], page 23). This makes it simple to distinguish a *function-id* or a *built-in-function-id* from a *constant-id*. As shown below, built-in functions might also have parameters, given between braces `{}`, and which are completely evaluated during the analysis of the syntax (since they are of *expression-cst-list* type):

```
built-in-function-id [ < expression-list > ] < { expression-cst-list } >
```

with

```
built-in-function-id:
  math-function-id |
  extended-math-function-id |
  green-function-id |
  type-function-id |
  coord-function-id |
  misc-function-id
```

Notes:

1. All possible values for *built-in-function-id* are listed in Section 6.2 [Types for Function], page 44.
2. Classical mathematical functions (see Section 6.2.1 [Math functions], page 44) are the only functions allowed in a constant definition (see the definition of *expression-cst* in Section 4.4 [Constants], page 16).

## 4.7 Current values

Current values return the current floating point value of an internal GetDP variable:

`$Time` Value of the current time. This value is set to zero for non time dependent analyses.

`$DTime` Value of the current time increment used in a time stepping algorithm.

`$Theta` Current theta value in a theta time stepping algorithm.

`$TimeStep`
Number of the current time step in a time stepping algorithm.

`$Breakpoint`
In case of a breakpoint hit in TimeLoopAdaptive it is the number of the current breakpoint. In the other case when $Time corresponds not to a breakpoint the value is -1.

`$Iteration`
Number of the current iteration in a nonlinear loop.

`$EigenvalueReal`
Real part of the current eigenvalue.

`$EigenvalueImag`
Imaginary part of the current eigenvalue.

`$X, $XS` Value of the current (destination or source) X-coordinate.

`$Y, $YS` Value of the current (destination or source) Y-coordinate.

`$Z, $ZS` Value of the current (destination or source) Z-coordinate.

`$A, $B, $C`
Value of the current parametric coordinates used in the parametric `OnGrid PostOperation` (see Section 6.10 [Types for PostOperation], page 67).

Note:

1. The current X, Y and Z coordinates refer to the 'physical world' coordinates, i.e., coordinates in which the mesh is expressed.

Current values are "read-only". User-defined run-time variables, which share the same syntax but whose value can be changed in an *expression*, are defined in Section 4.9 [Run-time variables and registers], page 24.

## 4.8 Arguments

Function arguments can be used in expressions and have the following syntax (*integer* indicates the position of the argument in the *expression-list* of the function, starting from 1):

```
argument :
  $integer
```

See Section 5.2 [Function], page 30, and Section 7.3 [Function examples], page 75, for more details.

## 4.9 Run-time variables and registers

Constant expressions (*expression-csts*) are evaluated only once during the analysis of the problem definition structure, cf. Section 4.4 [Constants], page 16. While this is perfectly fine in most situations, sometimes it is necessary to store and modify variables at run-time. For example, an iteration in a `Resolution` could depend on values computed at run-time. Also, to speed-up the evaluation of *expressions* (which are evaluated at runtime through GetDP's internal stack mechanism), it can be useful to save some results in a temporary variable, at run-time, in order to reuse them later on.

Two mechanisms exit to handle such cases: run-time variables (which follow the same syntax as Section 4.7 [Current values], page 23), and registers.

Run-time variables have the following syntax:

```
variable-set:
  $variable-id = expression

variable-get:
  $variable-id

variable-id:
  string |
  string ~ { expression-cst } <,...>
```

Thus, run-time variables can simply be defined anywhere in an *expression* and be reused later on. Current values can be seen as special cases of run-time variables, which are read-only.

Registers have the following syntax:

```
register-set:
  expression#expression-cst

register-get:
  #expression-cst
```

Thus, to store any expression in the register 5, one should add `#5` directly after the expression. To reuse the value stored in this register, one simply uses `#5` instead of the expression it should replace.

See Section 7.3 [Function examples], page 75, for an example.

## 4.10 Fields

A discretized quantity (defined in a function space, cf. Section 5.4 [FunctionSpace], page 32) is represented between braces `{}`, and can only appear in well-defined expressions in `Formulation` (see Section 5.7 [Formulation], page 36) and `PostProcessing` (see Section 5.9 [PostProcessing], page 39) objects:

```
quantity:
  < quantity-dof > { < quantity-operator > quantity-id } |
  { < quantity-operator > quantity-id } [ expression-cst-list ]
```

with

```
quantity-id:
  string |
  string ~ { expression-cst }
```

and

*quantity-dof*:

`Dof` Defines a vector of discrete quantities (vector of `Degrees of freedom`), to be used only in `Equation` terms of formulations to define (elementary) matrices. Roughly said, the `Dof` symbol in front of a discrete quantity indicates that this quantity is an unknown quantity, and should therefore not be considered as already computed.

An `Equation` term must be linear with respect to the `Dof`. Thus, for example, a nonlinear term like

```
Galerkin { [ f[] * Dof{T}^4 , {T} ]; ... }
```

must first be linearized; and while

```
Galerkin { [ f[] * Dof{T} , {T} ]; ... }
Galerkin { [ -f[] * 12 , {T} ]; ... }
```

is valid, the following, which is affine but not linear, is not:

```
Galerkin { [ f[] * (Dof{T} - 12) , {T} ]; ... }
```

GetDP supports two linearization techniques. The first is functional iteration (or Picard method), where one simply plugs the value obtained at the previous iteration into the nonlinear equation (the previous value is known, and is accessed e.g. with `{T}` instead `Dof{T}`). The second is the Newton-Raphson iteration, where the Jacobian is specified with a `JacNL` equation term.

`BF` Indicates that only a basis function will be used (only valid with basis functions associated with regions).

*quantity-operator*:

`d` Exterior derivative (d): applied to a *p*-form, gives a (*p+1*)-form.

`Grad` Gradient: applied to a scalar field, gives a vector.

`Curl`
`Rot` Curl: applied to a vector field, gives a vector.

`Div` Divergence (div): applied to a vector field, gives a scalar.

`D1` Applies the operator specified in the first argument of `dFunction { basis-function-type, basis-function-type }` (see Section 5.4 [FunctionSpace], page 32). This is currently only used for nodal-interpolated vector fields (interpolated with `BF_Node_X`, `BF_Node_Y`, `BF_Node_Z`)

When the first *basis-function-type* in `dFunction` is set to `BF_NodeX_D1` for component X, `BF_NodeY_D1` for component Y and `BF_NodeZ_D1` for component Z, then `D1` applied to a vector [u_x, u_y, u_z] gives:

$$\left[\frac{\partial u_x}{\partial x}, \frac{\partial u_y}{\partial y}, \frac{\partial u_z}{\partial z}\right]$$

Note that in this case specifying explicitely `dFunction` is not necessary, as `BF_NodeX_D1`, `BF_NodeY_D1` and `BF_NodeZ_D1` are assigned by default as the "`D1` derivatives" of `BF_NodeX`, `BF_NodeY` and `BF_NodeZ`. This also holds for `BF_GroupOfNodes_X`, `BF_GroupOfNodes_Y` and `BF_GroupOfNodes_Z`.

When the first *basis-function-type* in `dFunction` is set to `BF_NodeX_D12` for component X and `BF_NodeY_D12` for component Y, then `D1` applied to a vector [u_x, u_y] gives:

$$\left[\frac{\partial u_x}{\partial x}, \frac{\partial u_y}{\partial y}, \frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right]$$

`D2` Applies the operator specified in the second argument of `dFunction { basis-function-type, basis-function-type }` (see Section 5.4 [FunctionSpace], page 32). This is currently only used for nodal-interpolated vector fields (interpolated with `BF_Node_X`, `BF_Node_Y`, `BF_Node_Z`)

More specifically, when the second *basis-function-type* is to `BF_NodeX_D2` for component X, `BF_NodeY_D2` for component Y and `BF_NodeZ_D2` for component Z, then `D2` applied to a vector [u_x, u_y, u_z] gives:

$$\left[\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}, \frac{\partial u_z}{\partial y} + \frac{\partial u_y}{\partial z}, \frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right]$$

Note that in this case specifying explicitely `dFunction` is not necessary, as `BF_NodeX_D2`, `BF_NodeY_D2` and `BF_NodeZ_D2` are assigned by default as the "`D2` derivatives" of `BF_NodeX`, `BF_NodeY` and `BF_NodeZ`. This also holds for `BF_GroupOfNodes_X`, `BF_GroupOfNodes_Y` and `BF_GroupOfNodes_Z`.

Notes:

1. While the operators `Grad`, `Curl` and `Div` can be applied to 0, 1 and 2-forms respectively, the exterior derivative operator `d` is usually preferred with such fields.
2. The second case permits to evaluate a discretized quantity at a certain position X, Y, Z (when *expression-cst-list* contains three items) or at a specific time, N time steps ago (when *expression-cst-list* contains a single item).

## 4.11 Macros, loops and conditionals

Macros are defined as follows:

`Macro` *`string`* `|` *`expression-char`*

Begins the declaration of a user-defined macro named *string*. The body of the macro starts on the line after '`Macro` *`string`*', and can contain any GetDP command.

`Return` Ends the body of the current user-defined macro. Macro declarations cannot be imbricated, and must be made outside any GetDP object.

Macros, loops and conditionals can be used in any of the following objects: Group, Function, Constraint (as well as in a contraint-case), FunctionSpace, Formulation (as well as in the quantity and equation defintions), Resolution (as well as resolution-term, system defintion and operations), PostProcessing (in the definition of the PostQuantities) and PostOperation (as well as in the operation list).

*loop*:

`Call` *`string`* `|` *`expression-char`* `;`
: Executes the body of a (previously defined) macro named *string*.

`For (` *`expression-cst`* `:` *`expression-cst`* `)`
: Iterates from the value of the first *expression-cst* to the value of the second *expression-cst*, with a unit incrementation step. At each iteration, the commands comprised between '`For (` *`expression-cst`* `:` *`expression-cst`* `)`' and the matching `EndFor` are executed.

`For (` *`expression-cst`* `:` *`expression-cst`* `:` *`expression-cst`* `)`
: Iterates from the value of the first *expression-cst* to the value of the second *expression-cst*, with a positive or negative incrementation step equal to the third *expression-cst*. At each iteration, the commands comprised between '`For (` *`expression-cst`* `:` *`expression-cst`* `:` *`expression-cst`* `)`' and the matching `EndFor` are executed.

`For` *`string`* `In {` *`expression-cst`* `:` *`expression-cst`* `}`
: Iterates from the value of the first *expression-cst* to the value of the second *expression-cst*, with a unit incrementation step. At each iteration, the value of the iterate is affected to an expression named *string*, and the commands comprised between '`For` *`string`* `In {` *`expression-cst`* `:` *`expression-cst`* `}`' and the matching `EndFor` are executed.

`For` *`string`* `In {` *`expression-cst`* `:` *`expression-cst`* `:` *`expression-cst`* `}`
: Iterates from the value of the first *expression-cst* to the value of the second *expression-cst*, with a positive or negative incrementation step equal to the third *expression-cst*. At each iteration, the value of the iterate is affected to an expression named *string*, and the commands comprised between '`For` *`string`* `In {` *`expression-cst`* `:` *`expression-cst`* `:` *`expression-cst`* `}`' and the matching `EndFor` are executed.

`EndFor`
: Ends a matching `For` command.

`If (` *`expression-cst`* `)`
: The body enclosed between '`If (` *`expression-cst`* `)`' and the matching `ElseIf`, `Else` or `EndIf`, is evaluated if *expression-cst* is non-zero.

`ElseIf (` *`expression-cst`* `)`
: The body enclosed between '`ElseIf (` *`expression-cst`* `)`' and the next matching `ElseIf`, `Else` or `EndIf`, is evaluated if *expression-cst* is non-zero and none of the *expression-cst* of the previous matching codes `If` and `ElseIf` were non-zero.

`Else`
: The body enclosed between `Else` and the matching `EndIf` is evaluated if none of the *expression-cst* of the previous matching codes `If` and `ElseIf` were non-zero.

`EndIf`
: Ends a matching `If` command.

`LevelTest`
: Variable equal to the level of imbrication of a body in an `If`-`EndIf` test.

`Parse [` *`expression-char`* `];`
: Parse the given string.

# 5 Objects

This chapter presents the formal definition of the ten GetDP objects mentioned in Chapter 1 [Overview], page 5. To be concise, all the possible parameters for these objects are not given here (cf. the *etc* syntactic rule defined in Section 2.1 [Syntactic rules], page 9). Please refer to Chapter 6 [Types for objects], page 43, for the list of all available options.

## 5.1 `Group`: defining topological entities

Meshes (grids) constitute the input data of GetDP. All that is needed by GetDP as a mesh is a file containing a list of nodes (with their coordinates) and a list of geometrical elements with, for each one, a number characterizing its geometrical type (i.e., line, triangle, quadrangle, tetrahedron, hexahedron, prism, etc.), a number characterizing the physical region to which it belongs and the list of its nodes. This minimal input set should be easy to extract from most of the classical mesh file formats (see Section A.1 [Input file format], page 111, for a complete description of the mesh file format read by GetDP).

Groups of geometrical entities of various types can be considered and are used in many objects. There are region groups, of which the entities are regions, and function groups, with nodes, edges, facets, volumes, groups of nodes, edges of tree, facets of tree, ... of regions.

Amongst region groups, elementary and global groups can be distinguished: elementary groups are relative to single regions (e.g., physical regions in which piecewise defined functions or constraints can be defined) while global groups are relative to sets of regions for which given treatments have to be performed (e.g., domain of integration, support of a function space, etc.).

Groups of function type contain lists of entities built on some region groups (e.g., nodes for nodal elements, edges for edge elements, edges of tree for gauge conditions, groups of nodes for floating potentials, elements on one side of a surface for cuts, etc.).

A definition of initially empty groups can be obtained thanks to a `DefineGroup` command, so that their identifiers exist and can be referred to in other objects, even if these groups are not explicitly defined. This procedure is similar to the `DefineConstant` procedure introduced for constants in Section 4.4 [Constants], page 16.

The syntax for the definition of groups is:

```
Group {
  < DefineGroup [ group-id <{integer}> <,...> ]; > ...
  < group-id = group-def; > ...
  < group-id += group-def; > ...
  < affectation > ...
  < loop > ...
}
```

with

```
group-id:
  string |
  string ~ { expression-cst }
```

```
group-def:
  group-type [ group-list <, group-sub-type group-list > ] |
  group-id <{<integer>}> |
  #group-list

group-type:
  Region | Global | NodesOf | EdgesOf | etc

group-list:
  All | group-list-item | { group-list-item <,...> }

group-list-item:
  integer |
  integer : integer |
  integer : integer : integer |
  group-id <{<integer>}>

group-sub-type:
  Not | StartingOn | OnPositiveSideOf | etc
```

Notes:

1. *integer* as a *group-list-item* is the only interface with the mesh; with each element is associated a region number, being this *integer*, and a geometrical type (see Section A.1 [Input file format], page 111). Ranges of integers can be specified in the same way as ranges of constant expressions in an *expression-cst-list-item* (see Section 4.4 [Constants], page 16). For example, `i:j` replaces the list of consecutive integers *i*, *i*+1, ..., *j*-1, *j*.
2. Array of groups: `DefineGroup[group-id{n}]` defines the empty groups `group-id{i}`, *i*=1, ..., n. Such a definition is optional, i.e., each `group-id{i}` can be separately defined, in any order.
3. `#group-list` is an abbreviation of `Region[group-list]`.

See Section 6.1 [Types for Group], page 43, for the complete list of options and Section 7.2 [Group examples], page 75, for some examples.

## 5.2 `Function`: defining global and piecewise expressions

A user-defined function can be global in space or piecewise defined in region groups. A physical characteristic is an example of a piecewise defined function (e.g., magnetic permeability, electric conductivity, etc.) and can be simply a constant, for linear materials, or a function of one or several arguments for nonlinear materials. Such functions can of course depend on space coordinates or time, which can be needed to express complex constraints.

A definition of initially empty functions can be made thanks to the `DefineFunction` command so that their identifiers exist and can be referred to (but cannot be used) in other objects. The syntax for the definition of functions is:

```
Function {
  < DefineFunction [ function-id <,...> ]; > ...
  < function-id [ < group-def <, group-def > > ] = expression; > ...
```

```
  < affectation > ...
  < loop > ...
}
```

with

```
function-id:
  string
```

Note:

1. The first optional *group-def* in brackets must be of `Region` type, and indicates on which region the (piecewise) function is defined. The second optional *group-def* in brackets, also of `Region` type, defines an association with a second region for mutual contributions. A default piecewise function can be defined with `All` for *group-def*, for all the other non-defined regions. Warning: it is incorrect to write `f[reg1]=1; g[reg2]=f[]+1;` since the domains of definition of `f[]` and `g[]` don't match.
2. One can also define initially empty functions inline by replacing the expression with `***`.

See Section 6.2 [Types for Function], page 44, for the complete list of built-in functions and Section 7.3 [Function examples], page 75, for some examples.

## 5.3 `Constraint`: specifying constraints on function spaces and formulations

Constraints can be referred to in `FunctionSpace` objects to be used for boundary conditions, to impose global quantities or to initialize quantities. These constraints can be expressed with functions or be imposed by the pre-resolution of another discrete problem. Other constraints can also be defined, e.g., constraints of network type for the definition of circuit connections, to be used in `Formulation` objects.

The syntax for the definition of constraints is:

```
Constraint {
  { < Append < expression-cst >; >
    Name constraint-id; Type constraint-type;
    Case {
      { Region group-def; < Type constraint-type; >
        < SubRegion group-def; > < TimeFunction expression; >
        < RegionRef group-def; > < SubRegionRef group-def; >
        < Coefficient expression; > < Function expression; >
        < Filter expression; >
        constraint-val; } ...
      < loop > ...
    }
  | Case constraint-case-id {
      { Region group-def; < Type constraint-type; >
        constraint-case-val; } ...
      < loop > ...
    } ...
  } ...
```

```
    < affectation > ...
    < loop > ...
  }
```

with

```
  constraint-id:
  constraint-case-id:
    string |
    string ~ { expression-cst }

  constraint-type:
    Assign | Init | Network | Link | etc

  constraint-val:
    Value expression | NameOfResolution resolution-id | etc

  constraint-case-val:
    Branch { integer, integer } | etc
```

Notes:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `Constraint` of the same `Name` with additional `Case`s.
2. The constraint type *constraint-type* defined outside the `Case` fields is applied to all the cases of the constraint, unless other types are explicitly given in these cases. The default type is `Assign`.
3. The region type `Region` *group-def* will be the main *group-list* argument of the *group-def* to be built for the constraints of `FunctionSpace`s. The optional region type `SubRegion` *group-def* will be the argument of the associated *group-sub-type*.
4. *expression* in `Value` of *constraint-val* cannot be time dependent (`$Time`) because it is evaluated only once during the pre-processing (for efficiency reasons). Time dependences must be defined in `TimeFunction` *expression*.

See Section 6.3 [Types for Constraint], page 53, for the complete list of options and Section 7.4 [Constraint examples], page 77, for some examples.

## 5.4 FunctionSpace: building function spaces

A `FunctionSpace` is characterized by the type of its interpolated fields, one or several basis functions and optional constraints (in space and time). Subspaces of a function space can be defined (e.g., for the use with hierarchical elements), as well as direct associations of global quantities (e.g., floating potential, electric charge, current, voltage, magnetomotive force, etc.).

A key point is that basis functions are defined by any number of subsets of functions, being added. Each subset is characterized by associated built-in functions for evaluation, a support of definition and a set of associated supporting geometrical entities (e.g., nodes, edges, facets, volumes, groups of nodes, edges incident to a node, etc.). The freedom in defining various kinds of basis functions associated with different geometrical entities to

interpolate a field permits to build made-to-measure function spaces adapted to a wide variety of field approximations (see Section 7.5 [FunctionSpace examples], page 78).

The syntax for the definition of function spaces is:

```
FunctionSpace {
  { < Append < expression-cst >; >
    Name function-space-id;
    Type function-space-type;
    BasisFunction {
     { Name basis-function-id; NameOfCoef coef-id;
       Function basis-function-type
         < { Quantity quantity-id;
             Formulation formulation-id { expression-cst };
             Group group-def;
             Resolution resolution-id { expression-cst } } >;
       < dFunction { basis-function-type, basis-function-type } ; >
       Support group-def; Entity group-def; } ...
    }
  < SubSpace {
     { < Append < expression-cst >; >
       Name sub-space-id;
       NameOfBasisFunction basis-function-list; } ...
    } >
  < GlobalQuantity {
     { Name global-quantity-id; Type global-quantity-type;
       NameOfCoef coef-id; } ...
    } >
  < Constraint {
     { NameOfCoef coef-id;
       EntityType Auto | group-type; < EntitySubType group-sub-type; >
       NameOfConstraint constraint-id <{}>; } ...
    } >
  } ...
  < affectation > ...
  < loop > ...
}
```

with

```
function-space-id:
formulation-id:
resolution-id:
  string |
  string ~ { expression-cst }

basis-function-id:
coef-id:
sub-space-id:
global-quantity-id:
```

```
    string

function-space-type:
  Scalar | Vector | Form0 | Form1 | etc

basis-function-type:
  BF_Node | BF_Edge | etc

basis-function-list:
  basis-function-id | { basis-function-id <,...> }

global-quantity-type:
  AliasOf | AssociatedWith
```

Notes:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive; its omission fixes it to a top value) permits to append an existing `FunctionSpace` of the same `Name` with additional `BasisFunction`s, `SubSpace`s, `GlobalQuantity`'s and `Constraint`s, or an existing `SubSpace` of the same `Name` with additional `NameOfBasisFunction`'s. If the `Append FunctionSpace` level is 2, the `Append SubSpace` level is automatically 1 if omitted.
2. When the definition region of a function type group used as an `Entity` of a `BasisFunction` is the same as that of the associated `Support`, it is replaced by `All` for more efficient treatments during the computation process (this prevents the construction and the analysis of a list of geometrical entities).
3. The same `Name` for several `BasisFunction` fields permits to define piecewise basis functions; separate `NameOfCoef`s must be defined for those fields.
4. A constraint is associated with geometrical entities defined by an automatically created `Group` of type *group-type* (`Auto` automatically fixes it as the `Entity` *group-def* type of the related `BasisFunction`), using the `Region` defined in a `Constraint` object as its main argument, and the optional `SubRegion` in the same object as a *group-sub-type* argument.
5. A global basis function (`BF_Global` or `BF_dGlobal`) needs parameters, i.e., it is given by the quantity (*quantity-id*) pre-computed from multiresolutions performed on multiformulations.
6. Explicit derivatives of the basis functions can be specified using `dFunction { basis-function-type , basis-function-type }`. These derivates can be accessed using the special `D1` and `D2` operators (see Section 4.10 [Fields], page 24).

See Section 6.4 [Types for FunctionSpace], page 54, for the complete list of options and Section 7.5 [FunctionSpace examples], page 78, for some examples.

## 5.5 `Jacobian`: defining jacobian methods

Jacobian methods can be referred to in `Formulation` and `PostProcessing` objects to be used in the computation of integral terms and for changes of coordinates. They are based on

`Group` objects and define the geometrical transformations applied to the reference elements (i.e., lines, triangles, quadrangles, tetrahedra, prisms, hexahedra, etc.). Besides the classical lineic, surfacic and volume Jacobians, the `Jacobian` object allows the construction of various transformation methods (e.g., infinite transformations for unbounded domains) thanks to dedicated jacobian methods.

The syntax for the definition of Jacobian methods is:

```
Jacobian {
  { < Append < expression-cst >; >
    Name jacobian-id;
    Case {
      { Region group-def | All;
        Jacobian jacobian-type < { expression-cst-list } >; } ...
    }
  } ...
}
```

with

```
jacobian-id:
  string

jacobian-type:
  Vol | Sur | VolAxi | etc
```

Note:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `Jacobian` of the same `Name` with additional `Case`s.
2. The default case of a `Jacobian` object is defined by `Region All` and must follow all the other cases.

See Section 6.5 [Types for Jacobian], page 56, for the complete list of options and Section 7.6 [Jacobian examples], page 82, for some examples.

## 5.6 `Integration`: defining integration methods

Various numerical or analytical integration methods can be referred to in `Formulation` and `PostProcessing` objects to be used in the computation of integral terms, each with a set of particular options (number of integration points for quadrature methods—which can be linked to an error criterion for adaptative methods, definition of transformations for singular integrations, etc.). Moreover, a choice can be made between several integration methods according to a criterion (e.g., on the proximity between the source and computation points in integral formulations).

The syntax for the definition of integration methods is:

```
Integration {
  { < Append < expression-cst >; >
    Name integration-id; < Criterion expression; >
    Case {
    < { Type integration-type;
```

```
            Case {
              { GeoElement element-type; NumberOfPoints expression-cst } ...
            }
          } ... >
        < { Type Analytic; } ... >
        }
      } ...
    }
```

with

```
    integration-id:
      string

    integration-type:
      Gauss | etc

    element-type:
      Line | Triangle | Tetrahedron etc
```

Note:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `Integration` of the same `Name` with additional `Case`s.

See Section 6.6 [Types for Integration], page 57, for the complete list of options and Section 7.7 [Integration examples], page 83, for some examples.

## 5.7 `Formulation`: building equations

The `Formulation` tool permits to deal with volume, surface and line integrals with many kinds of densities to integrate, written in a form that is similar to their symbolic expressions (it uses the same *expression* syntax as elsewhere in GetDP), which therefore permits to directly take into account various kinds of elementary matrices (e.g., with scalar or cross products, anisotropies, nonlinearities, time derivatives, various test functions, etc.). In case nonlinear physical characteristics are considered, arguments are used for associated functions. In that way, many formulations can be directly written in the data file, as they are written symbolically. Fields involved in each formulation are declared as belonging to beforehand defined function spaces. The uncoupling between formulations and function spaces allows to maintain a generality in both their definitions.

A `Formulation` is characterized by its type, the involved quantities (of local, global or integral type) and a list of equation terms. Global equations can also be considered, e.g., for the coupling with network relations.

The syntax for the definition of formulations is:

```
Formulation {
  { < Append < expression-cst >; >
    Name formulation-id; Type formulation-type;
    Quantity {
      { Name quantity-id; Type quantity-type;
```

```
            NameOfSpace function-space-id <{}>
                      < [ sub-space-id | global-quantity-id ] >;
            < Symmetry expression-cst; >
            < [ expression ]; In group-def;
              Jacobian jacobian-id; Integration integration-id; >
            < IndexOfSystem integer; >  } ...
        }
        Equation {
         < local-term-type
             { < term-op-type > [ expression, expression ];
               In group-def; Jacobian jacobian-id;
               Integration integration-id; } > ...
         < GlobalTerm
             { < term-op-type > [ expression, expression ];
               In group-def; < SubType equation-term-sub-type; > } > ...
         < GlobalEquation
             { Type Network; NameOfConstraint constraint-id;
               { Node expression; Loop expression; Equation expression;
                 In group-def; } ...
             } > ...
         < affectation > ...
         < loop > ...
        }
      } ...
      < affectation > ...
      < loop > ...
    }
```

with

```
    formulation-id:
      string |
      string ~ { expression-cst }

    formulation-type:
      FemEquation | etc

    local-term-type:
      Galerkin | deRham

    equation-term-sub-type:
      Self (default) | Mutual | SelfAndMutual

    quantity-type:
      Local | Global | Integral

    term-op-type:
      DtDof | DtDtDof | JacNL | etc
```

Note:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `Formulation` of the same `Name` with additional `Quantity`'s and `Equation`s.
2. `IndexOfSystem` permits to resolve ambiguous cases when several quantities belong to the same function space, but to different systems of equations. The *integer* parameter then specifies the index in the list of an `OriginSystem` command (see Section 5.8 [Resolution], page 38).
3. A `GlobalTerm` defines a term to be assembled in an equation associated with a global quantity. This equation is a finite element equation if that global quantity is linked with local quantities. The optional associated `SubType` defines either self (default) or mutual contributions, or both. Mutual contributions need piecewise functions defined on pairs or regions.
4. A `GlobalEquation` defines a global equation to be assembled in the matrix of the system.

See Section 6.7 [Types for Formulation], page 57, for the complete list of options and Section 7.8 [Formulation examples], page 83, for some examples.

## 5.8 `Resolution`: solving systems of equations

The operations available in a `Resolution` include: the generation of a linear system, its solving with various kinds of linear solvers, the saving of the solution or its transfer to another system, the definition of various time stepping methods, the construction of iterative loops for nonlinear problems (Newton-Raphson and fixed point methods), etc. Multi-harmonic resolutions, coupled problems (e.g., magneto-thermal) or linked problems (e.g., pre-computations of source fields) are thus easily defined in GetDP.

The `Resolution` object is characterized by a list of systems to build and their associated formulations, using time or frequency domain, and a list of elementary operations:

```
Resolution {
  { < Append < expression-cst >; >
    Name resolution-id; < Hidden expression-cst; >
    System {
      { Name system-id; NameOfFormulation formulation-list;
        < Type system-type; >
        < Frequency expression-cst-list-item |
          Frequency { expression-cst-list }; >
        < DestinationSystem system-id; >
        < OriginSystem system-id; | OriginSystem { system-id <,...> }; >
        < NameOfMesh expression-char > < Solver expression-char >
        < loop > } ...
      < loop > ...
    }
    Operation {
      < resolution-op; > ...
      < loop > ...
    }
```

```
    } ...
    < affectation > ...
    < loop > ...
  }
```

with

```
  resolution-id:
  system-id:
    string |
    string ~ { expression-cst }

  formulation-list:
    formulation-id <{}> | { formulation-id <{}> <,...> }

  system-type:
    Real | Complex

  resolution-op:
    Generate[system-id] | Solve[system-id] | etc
```

Notes:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `Resolution` of the same `Name` with additional `Systems` and `Operations`.
2. The default type for a system of equations is `Real`. A frequency domain analysis is defined through the definition of one or several frequencies (`Frequency` *expression-cst-list-item* | `Frequency { expression-cst-list }`). Complex systems of equations with no predefined list of frequencies (e.g., in modal analyses) can be explicitely defined with `Type Complex`.
3. `NameOfMesh` permits to explicitely specify the mesh to be used for the construction of the system of equations.
4. `Solver` permits to explicitely specify the name of the solver parameter file to use for the solving of the system of equations. This is ony valid if GetDP was compiled against the default solver library (it is the case if you downloaded a pre-compiled copy of GetDP from the internet).
5. `DestinationSystem` permits to specify the destination system of a `TransferSolution` operation (see Section 6.8 [Types for Resolution], page 58).
6. `OriginSystem` permits to specify the systems from which ambiguous quantity definitions can be solved (see Section 5.7 [Formulation], page 36).

See Section 6.8 [Types for Resolution], page 58, for the complete list of options and Section 7.9 [Resolution examples], page 85, for some examples.

## 5.9 `PostProcessing`: exploiting computational results

The `PostProcessing` object is based on the quantities defined in a `Formulation` and permits the construction (thanks to the *expression* syntax) of any useful piecewise defined quantity of interest:

```
PostProcessing {
  { < Append < expression-cst >; >
    Name post-processing-id;
    NameOfFormulation formulation-id <{}>; < NameOfSystem system-id; >
    Quantity {
      { < Append < expression-cst >; >
        Name post-quantity-id; Value { post-value ... } } ...
      < loop > ...
    }
  } ...
  < affectation > ...
  < loop > ...
}
```

with

```
post-processing-id:
post-quantity-id:
  string |
  string ~ { expression-cst }

post-value:
  Local { local-value } | Integral { integral-value }

local-value:
  [ expression ]; In group-def; Jacobian jacobian-id;

integral-value:
  [ expression ]; In group-def;
  Integration integration-id; Jacobian jacobian-id;
```

Notes:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive; its omission fixes it to a top value) permits to append an existing `PostProcessing` of the same `Name` with additional `Value`s, or an existing `Quantity` of the same `Name` with additional `Quantity`'s. If the `Append PostProcessing` level is 2, the `Append Quantity` level is automatically 1 if omitted. Fixing the `Append Quantity` level to *-n* suppresses the *n* lastly defined `Quantity`'s before appending.
2. The quantity defined with *integral-value* is piecewise defined over the elements of the mesh of *group-def*, and takes, in each element, the value of the integration of *expression* over this element. The global integral of *expression* over a whole region (being either *group-def* or a subset of *group-def*) has to be defined in the `PostOperation` with the *post-quantity-id*`[`*group-def*`]` command (see Section 5.10 [PostOperation], page 41).
3. If `NameOfSystem` *system-id* is not given, the system is automatically selected as the one to which the first quantity listed in the `Quantity` field of *formulation-id* is associated.

See Section 6.9 [Types for PostProcessing], page 66, for the complete list of options and Section 7.10 [PostProcessing examples], page 88, for some examples.

## 5.10 PostOperation: exporting results

The PostOperation is the bridge between results obtained with GetDP and the external world. It defines several elementary operations on PostProcessing quantities (e.g., plot on a region, section on a user-defined plane, etc.), and outputs the results in several file formats.

```
PostOperation {
  { < Append < expression-cst >; >
    Name post-operation-id; NameOfPostProcessing post-processing-id;
    < Hidden expression-cst; >
    < Format post-operation-fmt; >
    < TimeValue expression-cst-list; > < TimeImagValue expression-cst-list; >
    < LastTimeStepOnly < expression-cst >; >
    < OverrideTimeStepValue expression-cst; >
    < NoMesh expression-cst; > < AppendToExistingFile expression-cst; >
    < ResampleTime[expression-cst, expression-cst, expression-cst]; >
    Operation {
      < post-operation-op; > ...
    }
  } ...
  < affectation > ...
  < loop > ...
} |
PostOperation < (Append < expression-cst >) > post-operation-id UsingPost post-
processing-id {
  < post-operation-op; > ...
} ...
```

with

```
post-operation-id:
  string |
  string ~ { expression-cst }

post-operation-op:
  Print[ post-quantity-id <[group-def]>, print-support <,print-option> ... ] |
  Print[ "string", expression <,print-option> ... ] |
  Print[ "string", Str[ expression-char ] <,print-option> ... ] |
  Echo[ "string" <,print-option> ... ] |
  PrintGroup[ group-id, print-support <,print-option> ... ] |
  SendMergeFileRequest[ expression-char ] |
  < loop > ...
  etc

print-support:
  OnElementsOf group-def | OnRegion group-def | OnGlobal | etc
```

```
print-option:
  File expression-char | Format post-operation-fmt | etc

post-operation-fmt:
  Table | TimeTable | etc
```

Notes:

1. The optional `Append < expression-cst >` (when the optional level *expression-cst* is strictly positive) permits to append an existing `PostOperation` of the same `Name` with additional `Operations`.
2. Both `PostOperation` syntaxes are equivalent. The first one conforms to the overall interface, but the second one is more concise.
3. The format *post-operation-fmt* defined outside the `Operation` field is applied to all the post-processing operations, unless other formats are explicitly given in these operations with the `Format` option (see Section 6.10 [Types for PostOperation], page 67). The default format is `Gmsh`.
4. The `ResampleTime` option allows equidistant resampling of the time steps by a spline interpolation. The parameters are: start time, stop time, time step.
5. The optional argument `[group-def]` of the *post-quantity-id* can only be used when this quantity has been defined as an *integral-value* (see Section 5.9 [PostProcessing], page 39). In this case, the sum of all elementary integrals is performed over the region *group-def*.

See Section 6.10 [Types for PostOperation], page 67, for the complete list of options and Section 7.11 [PostOperation examples], page 88, for some examples.

# 6 Types for objects

This chapter presents the complete list of choices associated with metasyntactic variables introduced for the ten GetDP objects.

## 6.1 Types for `Group`

Types in

*group-type* `[` *R1* `<,` *group-sub-type R2* `<,` *group-sub-type-2 R3* `> > ]`

*group-type* `<` *group-sub-type* `<` *group-sub-type-2* `> >`:

`Region` Regions in *R1*.

`Global` Regions in *R1* (variant of `Region` used with global `BasisFunctions` `BF_Global` and `BF_dGlobal`).

`NodesOf` Nodes of elements of *R1*

`< Not`: but not those of *R2* `>`.

`EdgesOf` Edges of elements of *R1*

`< Not`: but not those of *R2* `>`.

`FacetsOf` Facets of elements of *R1*

`< Not`: but not those of *R2* `>`.

`VolumesOf`

Volumes of elements of *R1*

`< Not`: but not those of *R2* `>`.

`ElementsOf`

Elements of regions in *R1*

`< OnOneSideOf`: only elements on one side of *R2* (non-automatic, i.e., both sides if both in *R1*) `> | < OnPositiveSideOf`: only elements on positive (normal) side of *R2* `< , Not`: but not those touching only its skin *R3* (mandatory for free skins for correct separation of side layers) `> >`.

`GroupsOfNodesOf`

Groups of nodes of elements of *R1* (a group is associated with each region).

`GroupsOfEdgesOf`

Groups of edges of elements of *R1* (a group is associated with each region).

`< InSupport`: in a support *R2* being a group of type `ElementOf`, i.e., containing elements `>`.

`GroupsOfEdgesOnNodesOf`

Groups of edges incident to nodes of elements of *R1* (a group is associated with each node).

`< Not`: but not those of *R2*) `>`.

`GroupOfRegionsOf`

Single group of elements of regions in *R1* (with basis function BF_Region just one DOF is created for all elements of *R1*).

`EdgesOfTreeIn`
: Edges of a tree of edges of *R1*

  `< StartingOn`: a complete tree is first built on *R2* `>`.

`FacetsOfTreeIn`
: Facets of a tree of facets of *R1*

  `< StartingOn`: a complete tree is first built on *R2* `>`.

`DualNodesOf`
: Dual nodes of elements of *R1*.

`DualEdgesOf`
: Dual edges of elements of *R1*.

`DualFacetsOf`
: Dual facets of elements of *R1*.

`DualVolumesOf`
: Dual volumes of elements of *R1*.

## 6.2 Types for `Function`

### 6.2.1 Math functions

The following functions are the equivalent of the functions of the C or C++ math library. Unless indicated otherwise, arguments to these functions can be real or complex valued when used in *expression*s. When used in constant expressions (*expression-cst*, see Section 4.4 [Constants], page 16), only real-valued arguments are accepted.

*math-function-id*:

`Exp` `[`*expression*`]`
: Exponential function: e^*expression*.

`Log` `[`*expression*`]`
: Natural logarithm: ln(*expression*), *expression*>0.

`Log10` `[`*expression*`]`
: Base 10 logarithm: log10(*expression*), *expression*>0.

`Sqrt` `[`*expression*`]`
: Square root, *expression*>=0.

`Sin` `[`*expression*`]`
: Sine of *expression*.

`Asin` `[`*expression*`]`
: Arc sine (inverse sine) of *expression* in [-Pi/2,Pi/2], *expression* in [-1,1] (real valued only).

`Cos` `[`*expression*`]`
: Cosine of *expression*.

`Acos` `[expression]`

Arc cosine (inverse cosine) of *expression* in [0,Pi], *expression* in [-1,1] (real valued only).

`Tan` `[expression]`

Tangent of *expression*.

`Atan` `[expression]`

Arc tangent (inverse tangent) of *expression* in [-Pi/2,Pi/2] (real valued only).

`Atan2` `[expression,expression]`

Arc tangent (inverse tangent) of the first *expression* divided by the second, in [-Pi,Pi] (real valued only).

`Sinh` `[expression]`

Hyperbolic sine of *expression*.

`Cosh` `[expression]`

Hyperbolic cosine of *expression*.

`Tanh` `[expression]`

Hyperbolic tangent of the real valued *expression*.

`TanhC2` `[expression]`

Hyperbolic tangent of a complex valued *expression*.

`Fabs` `[expression]`

Absolute value of *expression* (real valued only).

`Abs` `[expression]`

Absolute value of *expression*.

`Floor` `[expression]`

Rounds downwards to the nearest integer that is not greater than *expression* (real valued only).

`Ceil` `[expression]`

Rounds upwards to the nearest integer that is not less than *expression* (real valued only).

`Fmod` `[expression,expression]`

Remainder of the division of the first *expression* by the second, with the sign of the first (real valued only).

`Min` `[expression,expression]`

Minimum of the two (scalar) expressions (real valued only).

`Max` `[expression,expression]`

Maximum of the two (scalar) expressions (real valued only).

`Sign` `[expression]`

-1 for *expression* less than zero and 1 otherwise (real valued only).

`Jn` `[expression]`

Returns the Bessel function of the first kind of order given by the first *expression* for the value of the second *expression* (real valued only).

`dJn` `[expression]`

Returns the derivative of the Bessel function of the first kind of order given by the first *expression* for the value of the second *expression* (real valued only).

`Yn` `[expression]`

Returns the Bessel function of the second kind of order given by the first *expression* for the value of the second *expression* (real valued only).

`dYn` `[expression]`

Returns the derivative of the Bessel function of the second kind of order given by the first *expression* for the value of the second *expression* (real valued only).

### 6.2.2 Extended math functions

*extended-math-function-id*:

`Cross` `[expression,expression]`

Cross product of the two arguments; *expression* must be a vector.

`Hypot` `[expression,expression]`

Square root of the sum of the squares of its arguments.

`Norm` `[expression]`

Absolute value if *expression* is a scalar; euclidian norm if *expression* is a vector.

`SquNorm` `[expression]`

Square norm: `Norm[expression]^2`.

`Unit` `[expression]`

Normalization: `expression/Norm[expression]`. Returns 0 if the norm is smaller than 1.e-30.

`Transpose`
`[expression]`

Transposition; *expression* must be a tensor.

`Inv` `[expression]`

Inverse of the tensor *expression*.

`Det` `[expression]`

Determinant of the tensor *expression*.

`Rotate` `[expression,expression,expression,expression]`

Rotation of a vector or tensor given by the first *expression* by the angles in radians given by the last three *expression* values around the x-, y- and z-axis.

`TTrace` `[expression]`

Trace; *expression* must be a tensor.

`Cos_wt_p` `[]{`*expression-cst*`,`*expression-cst*`}`

The first parameter represents the angular frequency and the second represents the phase. If the type of the current system is `Real`, `F_Cos_wt_p[]{w,p}` is identical to `Cos[w*$Time+p]`. If the type of the current system is `Complex`, it is identical to `Complex[Cos[p],Sin[p]]`.

`Sin_wt_p` `[]{`*expression-cst*`,`*expression-cst*`}`

The first parameter represents the angular frequency and the second represents the phase. If the type of the current system is `Real`, `F_Sin_wt_p[]{w,p}` is identical to `Sin[w*$Time+p]`. If the type of the current system is `Complex`, it is identical to `Complex[Sin[p],-Cos[p]]`.

`Period` `[`*expression*`]{`*expression-cst*`}`

`Fmod[`*expression*`,`*expression-cst*`] + (`*expression*`<0 ? `*expression-cst*` : 0)`; the result is always in [0,*expression-cst*[.

`Interval` `[`*expression*`,`*expression*`,`*expression*`]{`*expression-cst*`, `*expression-cst*`,`*expression-cst*`}`

Not documented yet.

### 6.2.3 Green functions

The Green functions are only used in integral quantities (see Section 5.7 [Formulation], page 36). The first parameter represents the dimension of the problem:

- `1D`: `r = Fabs[$X-$XS]`
- `2D`: `r = Sqrt[($X-$XS)^2+($Y-$YS)^2]`
- `3D`: `r = Sqrt[($X-$XS)^2+($Y-$YS)^2+($Z-$ZS)^2]`

The triplets of values given in the definitions below correspond to the `1D`, `2D` and `3D` cases.

*green-function-id*:

`Laplace` `[]{`*expression-cst*`}`

`r/2`, `1/(2*Pi)*ln(1/r)`, `1/(4*Pi*r)`.

`GradLaplace`
`[]{`*expression-cst*`}`

Gradient of `Laplace` relative to the destination point (`$X`, `$Y`, `$Z`).

`Helmholtz`
`[]{`*expression-cst*`, `*expression-cst*`}`

`exp(j*k0*r)/(4*Pi*r)`, where `k0` is given by the second parameter.

`GradHelmholtz`
`[]{`*expression-cst*`, `*expression-cst*`}`

Gradient of `Helmholtz` relative to the destination point (`$X`, `$Y`, `$Z`).

### 6.2.4 Type manipulation functions

*type-function-id*:

`Complex` `[`*expression-list*`]`

Creates a (multi-harmonic) complex expression from an number of real-valued expressions. The number of expressions in *expression-list* must be even.

`Complex_MH`
`[`*expression-list*`]{`*expression-cst-list*`}`

Not documented yet.

`Re` `[`*expression*`]`

Takes the real part of a complex-valued expression.

`Im` `[`*expression*`]`

Takes the imaginary part of a complex-valued expression.

`Conj` `[`*expression*`]`

Computes the conjugate of a complex-valued expression.

`Cart2Pol` `[`*expression*`]`

Converts the cartesian form (reale, imaginary) of a complex-valued expression into polar form (amplitude, phase [radians]).

`Vector` `[`*expression*`,`*expression*`,`*expression*`]`

Creates a vector from 3 scalars.

`Tensor` `[`*expression*`,`*expression*`,`*expression*`,`*expression*`,`*expression*`,`*expression*`,`
*expression*`,`*expression*`,`*expression*`]`

Creates a second-rank tensor of order 3 from 9 scalars.

`TensorV` `[`*expression*`,`*expression*`,`*expression*`]`

Creates a second-rank tensor of order 3 from 3 vectors.

`TensorSym`
`[`*expression*`,`*expression*`,`*expression*`,`*expression*`,`*expression*`,`*expression*`]`

Creates a symmetrical second-rank tensor of order 3 from 6 scalars.

`TensorDiag`
`[`*expression*`,`*expression*`,`*expression*`]`

Creates a diagonal second-rank tensor of order 3 from 3 scalars.

`SquDyadicProduct`
`[`*expression*`]`

Dyadic product of the vector given by *expression* with itself.

`CompX` `[`*expression*`]`

Gets the X component of a vector.

`CompY` `[`*expression*`]`

Gets the Y component of a vector.

`CompZ` `[expression]`
Gets the Z component of a vector.

`CompXX` `[expression]`
Gets the XX component of a tensor.

`CompXY` `[expression]`
Gets the XY component of a tensor.

`CompXZ` `[expression]`
Gets the XZ component of a tensor.

`CompYX` `[expression]`
Gets the YX component of a tensor.

`CompYY` `[expression]`
Gets the YY component of a tensor.

`CompYZ` `[expression]`
Gets the YZ component of a tensor.

`CompZX` `[expression]`
Gets the ZX component of a tensor.

`CompZY` `[expression]`
Gets the ZY component of a tensor.

`CompZZ` `[expression]`
Gets the ZZ component of a tensor.

`Cart2Sph` `[expression]`
Gets the tensor for transformation of vector from cartesian to spherical coordinates.

`Cart2Cyl` `[expression]`
Gets the tensor for transformation of vector from cartesian to cylindric coordinates. E.g. to convert a vector with (x,y,z)-components to one with (radial, tangential, axial)-components: Cart2Cyl[XYZ[]] * vector

`UnitVectorX`
`[]`
Creates a unit vector in x-direction.

`UnitVectorY`
`[]`
Creates a unit vector in y-direction.

`UnitVectorZ`
`[]`
Creates a unit vector in z-direction.

### 6.2.5 Coordinate functions

*coord-function-id*:

`X` `[]`
: Gets the X coordinate.

`Y` `[]`
: Gets the Y coordinate.

`Z` `[]`
: Gets the Z coordinate.

`XYZ` `[]`
: Gets X, Y and Z in a vector.

### 6.2.6 Miscellaneous functions

*misc-function-id*:

`Printf` `[`*expression*`]`
: Prints the value of *expression* when evaluated. (`MPI_Printf` can be use instead, to print the message for all MPI ranks.)

`Rand` `[`*expression*`]`
: Returns a pseudo-random number in [0, *expression*].

`Normal` `[]`
: Computes the normal to the element.

`NormalSource`
`[]`
: Computes the normal to the source element (only valid in a quantity of Integral type).

`Tangent` `[]`
: Computes the tangent to the element (only valid for line elements).

`TangentSource`
`[]`
: Computes the tangent to the source element (only valid in a quantity of Integral type and only for line elements).

`ElementVol`
`[]`
: Computes the element's volume.

`SurfaceArea`
`[]{`*expression-cst-list*`}`
: Computes the area of the physical surfaces in *expression-cst-list* or of the actual surface if *expression-cst-list* is empty.

`GetVolume`
`[]`

Computes the volume of the actual physical group.

`CompElementNum`
`[]`

Returns 0 if the current element and the current source element are identical.

`GetNumElements`
`[]{`*`expression-cst-list`*`}`

Counts the elements of physical numbers in *expression-cst-list* or of the actual region if *expression-cst-list* is empty.

`AtIndex` `[`*`expression`*`]{`*`expression-cst-list`*`}`

Returns the i-th entry of *expression-cst-list*. This can be used to get an element in a list, using an index that is computed at runtime.

`InterpolationLinear`
`[`*`expression`*`]{`*`expression-cst-list`*`}`

Linear interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`dInterpolationLinear`
`[`*`expression`*`]{`*`expression-cst-list`*`}`

Derivative of linear interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`InterpolationBilinear`
`[`*`expression`*`,`*`expression`*`]{`*`expression-cst-list`*`}`

Bilinear interpolation of a table based on two variables.

`dInterpolationBilinear`
`[`*`expression`*`,`*`expression`*`]{`*`expression-cst-list`*`}`

Derivative of bilinear interpolation of a table based on two variables. The result is a vector.

`InterpolationAkima`
`[`*`expression`*`]{`*`expression-cst-list`*`}`

Akima interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`dInterpolationAkima`
`[`*`expression`*`]{`*`expression-cst-list`*`}`

Derivative of Akima interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`Order` `[`*`quantity`*`]`

Returns the interpolation order of the *quantity*.

`Field` `[`*`expression`*`]`

Evaluate the last one of the fields ("views") loaded with `GmshRead` (see Section 6.8 [Types for Resolution], page 58), at the point *expression*. Common usage is thus `Field[XYZ[]]`.

`Field` `[`*expression*`]{`*expression-cst-list*`}`

Idem, but evaluate all the fields corresponding to the tags in the list, and sum all the values. A field having no value at the given position does not produce an error: its contribution to the sum is simply zero.

`ScalarField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only real-valued scalar fields. A second optional argument is the value of the time step. A third optional argument is a boolean flag to indicate that the interpolation should be performed (if possible) in the same element as the current element.

`VectorField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only real-valued vector fields. Optional arguments are treated in the same way as for `ScalarField`.

`TensorField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only real-valued tensor fields. Optional arguments are treated in the same way as for `ScalarField`.

`ComplexScalarField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only complex-valued scalar fields. Optional arguments are treated in the same way as for `ScalarField`.

`ComplexVectorField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only complex-valued vector fields. Optional arguments are treated in the same way as for `ScalarField`.

`ComplexTensorField`
`[`*expression*`]{`*expression-cst-list*`}`

Idem, but consider only complex-valued tensor fields. Optional arguments are treated in the same way as for `ScalarField`.

`GetCpuTime`
`[]`

Returns current CPU time, in seconds (total amount of time spent executing in user mode since GetDP was started).

`GetWallClockTime`
`[]`

Returns the current wall clock time, in seconds (total wall clock time since GetDP was started).

`GetMemory`
`[]`

Returns the current memory usage, in megabytes (maximum resident set size).

`SetNumberRunTime`
`[`*expression*`]{`*char-expression*`}`

Sets the *char-expression* ONELAB variable at run-time to *expression*.

`GetNumberRunTime`
`[ <`*expression*`> ]{`*char-expression*`}`

Gets the value of the *char-expression* ONELAB variable at run-time. If the optional *expression* is provided, it is used as a default value if ONELAB is not available.

`SetVariable`
`[ `*expression* `<,...> ]{ $`*variable-id* `}`

Sets the value of the runtime variable `$`*variable-id* to the value of the first *expression*, and returns this value. If optional *expression*s are provided, they are appended to the variable name, separated by `_`.

`GetVariable`
`[ <`*expression*`> <,...> ]{ $`*variable-id* `}`

Gets the value of the runtime variable `$`*variable-id*. If the optional *expression*s are provided, they are appended to the variable name, separated by `_`.

## 6.3 Types for `Constraint`

*constraint-type*:

`Assign` To assign a value (e.g., for boundary condition).

`Init` To give an initial value (e.g., initial value in a time domain analysis). If two values are provided (with `Value [ `*expression*`, `*expression*` ]`), the first value can be used using the `InitSolution1` operation. This is mainly useful for the Newmark time-stepping scheme.

`AssignFromResolution`
To assign a value to be computed by a pre-resolution.

`InitFromResolution`
To give an initial value to be computed by a pre-resolution.

`Network` To describe the node connections of branches in a network.

`Link` To define links between degrees of freedom in the constrained region with degrees of freedom in a "reference" region, with some coefficient. For example, to link the degrees of freedom in the contrained region `Left` with the degrees of freedom in the reference region `Right`, located Pi units to the right of the region `Left` along the X-axis, with the coeficient `-1`, one could write:

```
{ Name periodic;
  Case {
    { Region Left; Type Link ; RegionRef Right;
```

```
        Coefficient -1; Function Vector[$X+Pi,$Y,$Z] ;
      }
    }
  }
```

In this example, `Function` defines the mapping that translates the geometrical elements in the region `Left` by Pi units along the X-axis, so that they correspond with the elements in the region `Right`. For this mapping to work, the meshes of `Left` and `Right` must be identical.

`LinkCplx` To define complex-valued links between degrees of freedom. The syntax is the same as for constraints of type `Link`, but `Coeficient` can be complex.

## 6.4 Types for `FunctionSpace`

*function-space-type*:

`Form0` 0-form, i.e., scalar field of potential type.

`Form1` 1-form, i.e., curl-conform field (associated with a curl).

`Form2` 2-form, i.e., div-conform field (associated with a divergence).

`Form3` 3-form, i.e., scalar field of density type.

`Form1P` 1-form perpendicular to the $z$=0 plane, i.e., perpendicular curl-conform field (associated with a curl).

`Form2P` 2-form in the $z$=0 plane, i.e., parallel div-conform field (associated with a divergence).

`Scalar` Scalar field.

`Vector` Vector field.

*basis-function-type*:

`BF_Node` Nodal function (on `NodesOf`, value `Form0`).

`BF_Edge` Edge function (on `EdgesOf`, value `Form1`).

`BF_Facet` Facet function (on `FacetsOf`, value `Form2`).

`BF_Volume`
Volume function (on `VolumesOf`, value `Form3`).

`BF_GradNode`
Gradient of nodal function (on `NodesOf`, value `Form1`).

`BF_CurlEdge`
Curl of edge function (on `EdgesOf`, value `Form2`).

`BF_DivFacet`
Divergence of facet function (on `FacetsOf`, value `Form3`).

`BF_GroupOfNodes`
Sum of nodal functions (on `GroupsOfNodesOf`, value `Form0`).

`BF_GradGroupOfNodes`
: Gradient of sum of nodal functions (on `GroupsOfNodesOf`, value `Form1`).

`BF_GroupOfEdges`
: Sum of edge functions (on `GroupsOfEdgesOf`, value `Form1`).

`BF_CurlGroupOfEdges`
: Curl of sum of edge functions (on `GroupsOfEdgesOf`, value `Form2`).

`BF_PerpendicularEdge`
: 1-form (0, 0, `BF_Node`) (on `NodesOf`, value `Form1P`).

`BF_CurlPerpendicularEdge`
: Curl of 1-form (0, 0, `BF_Node`) (on `NodesOf`, value `Form2P`).

`BF_GroupOfPerpendicularEdge`
: Sum of 1-forms (0, 0, `BF_Node`) (on `NodesOf`, value `Form1P`).

`BF_CurlGroupOfPerpendicularEdge`
: Curl of sum of 1-forms (0, 0, `BF_Node`) (on `NodesOf`, value `Form2P`).

`BF_PerpendicularFacet`
: 2-form (90 degree rotation of `BF_Edge`) (on `EdgesOf`, value `Form2P`).

`BF_DivPerpendicularFacet`
: Div of 2-form (90 degree rotation of `BF_Edge`) (on `EdgesOf`, value `Form3`).

`BF_Region`
: Unit value 1 (on `Region` or `GroupOfRegionsOf`, value `Scalar`).

`BF_RegionX`
: Unit vector (1, 0, 0) (on `Region`, value `Vector`).

`BF_RegionY`
: Unit vector (0, 1, 0) (on `Region`, value `Vector`).

`BF_RegionZ`
: Unit vector (0, 0, 1) (on `Region`, value `Vector`).

`BF_Global`
: Global pre-computed quantity (on `Global`, value depends on parameters).

`BF_dGlobal`
: Exterior derivative of global pre-computed quantity (on `Global`, value depends on parameters).

`BF_NodeX` Vector (`BF_Node`, 0, 0) (on `NodesOf`, value `Vector`).

`BF_NodeY` Vector (0, `BF_Node`, 0) (on `NodesOf`, value `Vector`).

`BF_NodeZ` Vector (0, 0, `BF_Node`) (on `NodesOf`, value `Vector`).

`BF_Zero` Zero value 0 (on all regions, value `Scalar`).

`BF_One` Unit value 1 (on all regions, value `Scalar`).

*global-quantity-type*:

`AliasOf` Another name for a name of coefficient of basis function.

`AssociatedWith`
: A global quantity associated with a name of coefficient of basis function, and therefore with this basis function.

## 6.5 Types for `Jacobian`

*jacobian-type*:

`Vol`
: Volume Jacobian, for $n$-D regions in $n$-D geometries, $n = 1$, 2 or 3.

`Sur`
: Surface Jacobian, for ($n$-1)-D regions in $n$-D geometries, $n = 1$, 2 or 3.

`Lin`
: Line Jacobian, for ($n$-2)-D regions in $n$-D geometries, $n = 2$ or 3.

`VolAxi`
: Axisymmetrical volume Jacobian (1st type: $r$), for 2-D regions in axisymmetrical geometries.

`SurAxi`
: Axisymmetrical surface Jacobian (1st type: $r$), for 1-D regions in axisymmetrical geometries.

`VolAxiSqu`
: Axisymmetrical volume Jacobian (2nd type: $r^2$), for 2-D regions in axisymmetrical geometries.

`VolSphShell`
: Volume Jacobian with spherical shell transformation, for $n$-D regions in $n$-D geometries, $n = 2$ or 3.

  *Parameters*: *radius-internal*, *radius-external* `<`, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolCylShell`
: Volume Jacobian with cylindrical shell transformation, for $n$-D regions in $n$-D geometries, $n = 2$ or 3. For $n$=2, `VolCylShell` is identical to `VolSphShell`. For $n$=3, the axis of the cylinder is supposed to be along the $z$ axis.

  *Parameters*: *radius-internal*, *radius-external* `<`, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolAxiSphShell`
: Same as `VolAxi`, but with spherical shell transformation.

  *Parameters*: *radius-internal*, *radius-external* `<`, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolAxiSquSphShell`
: Same as `VolAxiSqu`, but with spherical shell transformation.

  *Parameters*: *radius-internal*, *radius-external* `<`, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolRectShell`
: Volume Jacobian with rectangular shell transformation, for $n$-D regions in $n$-D geometries, $n = 2$ or 3.

  *Parameters*: *radius-internal*, *radius-external* `<`, *direction*, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolAxiRectShell`
: Same as `VolAxi`, but with rectangular shell transformation.

  *Parameters*: *radius-internal*, *radius-external* `<`, *direction*, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

`VolAxiSquRectShell`
: Same as `VolAxiSqu`, but with rectangular shell transformation.

  *Parameters*: *radius-internal*, *radius-external* `<`, *direction*, *center-X*, *center-Y*, *center-Z*, *power*, *1/infinity* `>`.

## 6.6 Types for `Integration`

*integration-type*:

`Gauss` Numerical Gauss integration.

`GaussLegendre`
: Numerical Gauss integration obtained by application of a multiplicative rule on the one-dimensional Gauss integration.

*element-type*:

`Line` Line (2 nodes, 1 edge, 1 volume) (#1).

`Triangle` Triangle (3 nodes, 3 edges, 1 facet, 1 volume) (#2).

`Quadrangle`
: Quadrangle (4 nodes, 4 edges, 1 facet, 1 volume) (#3).

`Tetrahedron`
: Tetrahedron (4 nodes, 6 edges, 4 facets, 1 volume) (#4).

`Hexahedron`
: Hexahedron (8 nodes, 12 edges, 6 facets, 1 volume) (#5).

`Prism` Prism (6 nodes, 9 edges, 5 facets, 1 volume) (#6).

`Pyramid` Pyramid (5 nodes, 8 edges, 5 facets, 1 volume) (#7).

`Point` Point (1 node) (#15).

Note:

1. *n* in (#*n*) is the type number of the element (see Section A.1 [Input file format], page 111).

## 6.7 Types for `Formulation`

*formulation-type*:

`FemEquation`
: Finite element method formulation (all methods of moments, integral methods).

*local-term-type*:

`Galerkin` Integral of Galerkin type.

`deRham` deRham projection (collocation).

*quantity-type*:

`Local` Local quantity defining a field in a function space. In case a subspace is considered, its identifier has to be given between the brackets following the `NameOfSpace` *`function-space-id`*.

`Global` Global quantity defining a global quantity from a function space. The identifier of this quantity has to be given between the brackets following the `NameOfSpace` *`function-space-id`*.

`Integral` Integral quantity obtained by the integration of a `LocalQuantity` before its use in an `Equation` term.

*term-op-type*:

`Dt` Time derivative applied to the whole term of the equation. (Not implemented yet.)

`DtDof` Time derivative applied only to the `Dof{}` term of the equation.

`DtDt` Time derivative of 2nd order applied to the whole term of the equation. (Not implemented yet.)

`DtDtDof` Time derivative of 2nd order applied only to the `Dof{}` term of the equation.

`JacNL` Nonlinear part of the Jacobian matrix (tangent stiffness matrix) to be assembled for nonlinear analysis.

`DtDofJacNL`
Nonlinear part of the Jacobian matrix for the first order time derivative (tangent mass matrix) to be assembled for nonlinear analysis.

`NeverDt` No time scheme applied to the term (e.g., Theta is always 1 even if a theta scheme is applied).

## 6.8 Types for `Resolution`

*resolution-op*:

`Generate` [*`system-id`*]

Generate the system of equations *system-id*.

`Solve` [*`system-id`*]

Solve the system of equations *system-id*.

`SolveAgain`
[*`system-id`*]

Save as `Solve`, but reuses the preconditionner when called multiple times.

`GenerateJac`
[*`system-id`*]

Generate the system of equations *system-id* using a jacobian matrix (of which the unknowns are corrections $dx$ of the current solution $x$).

`SolveJac` [*system-id*]

Solve the system of equations *system-id* using a jacobian matrix (of which the unknowns are corrections $dx$ of the current solution $x$). Then, Increment the solution ($x$=$x$+$dx$) and compute the relative error $dx/x$.

`GenerateSeparate`
[*system-id*]

Generate matrices separately for `DtDtDof`, `DtDof` and `NoDt` terms in *system-id*. The separate matrices can be used with the `Update` operation (for efficient time domain analysis of linear PDEs with constant coefficients), or with the `EigenSolve` operation (for solving generalized eigenvalue problems).

`GenerateOnly`
[*system-id*, *expression-cst-list*]

Not documented yet.

`GenerateOnlyJac`
[*system-id*, *expression-cst-list*]

Not documented yet.

`GenerateGroup`
Not documented yet.

`GenerateRightHandSideGroup`
Not documented yet.

`Update` [*system-id*]

Update the system of equations *system-id* (built from sub-matrices generated separately with `GenerateSeparate`) with the `TimeFunction`(s) provided in `Assign` constraints. This assumes that the problem is linear, that the matrix coefficients are independent of time, and that all sources are imposed using `Assign` constraints.

`Update` [*system-id*, *expression*]

Update the system of equations *system-id* (built from sub-matrices generated separately with `GenerateSeparate`) with *expression*. This assumes that the problem is linear, that the matrix coefficients are independent of time, and that the right-hand-side of the linear system can simply be multiplied by *expression* at each step.

`UpdateConstraint`
[*system-id*, *group-id*, *constraint-type*]

Recompute the constraint of type *constraint-type* acting on *group-id* during processing.

`GetResidual`
[*system-id*, $*variable-id*]

Compute the residual `r = b - A x` and store its L2 norm in the run-time variable $*variable-id*.

`GetNormSolution | GetNormRightHandSide | GetNormResidual | GetNormIncrement`
`[`*system-id*`, $`*variable-id*`]`

Compute the norm of the solution (resp. right-hand-side, residual or increment) and store its L2 norm in the run-time variable $*variable-id*.

`SwapSolutionAndResidual`
`[`*system-id*`]`

Swap the solution `x` and residual `r` vectors.

`SwapSolutionAndRightHandSide`
`[`*system-id*`]`

Swap the solution `x` and right-hand-side `b` vectors.

`InitSolution`
`[`*system-id*`]`

Creates a new solution vector, adds it to the solution vector list for *system-id*, and initializes the solution. The values in the vector are initialized to the values given in a `Constraint` of `Init` type (if two values are given in `Init`, the second value is used). If no constraint is provided, the values are initialized to zero if the solution vector is the first in the solution list; otherwise the values are initialized using the previous solution in the list.

`InitSolution1`
`[`*system-id*`]`

Same as `InitSolution`, but uses the first value given in the `Init` constraints.

`CreateSolution`
`[`*system-id*`]`

Creates a new solution vector, adds it to the solution vector list for *system-id*, and initializes the solution to zero.

`CreateSolution`
`[`*system-id*`, `*expression-cst*`]`

Same as `CreateSolution`, but initialize the solution by copying the *expression-cst*th solution in the solution list.

`Apply` `[`*system-id*`]`

`x <- Ax`

`SetSolutionAsRightHandSide`
`[`*system-id*`]`

`b <- x`

`SetRightHandSideAsSolution`
`[`*system-id*`]`

`x <- b`

`Residual` `[`*system-id*`]`

`res <- b - Ax`

`CopySolution`
: `[system-id, char-expression | constant-id() ]`

  Copy the current solution `x` into a vector named *char-expression* or into a list named *constant-id*.

`CopySolution`
: `[char-expression | constant-id(), system-id]`

  Copy the vector named *char-expression* or the list named *constant-id* into the current solution `x`.

`CopyRightHandSide`
: `[system-id, char-expression | constant-id() ]`

  Copy the current right-hand side `b` into a vector named *char-expression* or into a list named *constant-id*.

`CopyRightHandSide`
: `[char-expression | constant-id(), system-id]`

  Copy the vector named *char-expression* or the list named *constant-id* into the current right-hand-side `b`.

`CopyResidual`
: `[system-id, char-expression | constant-id() ]`

  Copy the current residual into a vector named *char-expression* or into a list named *constant-id*.

`CopyResidual`
: `[char-expression | constant-id(), system-id]`

  Copy the vector named *char-expression* or the list named *constant-id* into the current residual.

`SaveSolution`
: `[system-id]`

  Save the solution of the system of equations *system-id*.

`SaveSolutions`
: `[system-id]`

  Save all the solutions available for the system of equations *system-id*. This should be used with algorithms that generate more than one solution at once, e.g., `EigenSolve` or `FourierTransform`.

`RemoveLastSolution`
: `[system-id]`

  Removes the last solution (i.e. associated with the last time step) associated with system *system-id*.

`TransferSolution`
: `[system-id]`

  Transfer the solution of system *system-id*, as an `Assign` constraint, to the system of equations defined with a `DestinationSystem` command. This is used with the `AssignFromResolution` constraint type (see Section 6.3 [Types for Constraint], page 53).

`TransferInitSolution`
`[`*system-id*`]`

Transfer the solution of system *system-id*, as an `Init` constraint, to the system of equations defined with a `DestinationSystem` command. This is used with the `InitFromResolution` constraint type (see Section 6.3 [Types for Constraint], page 53).

`Evaluate` `[`*expression* `<,` *expression*`>]`

Evaluate the *expression*(s).

`SetTime` `[`*expression*`]`

Change the current time.

`SetTimeStep`
`[`*expression*`]`

Change the current time step number (1, 2, 3, ...)

`SetDTime` `[`*expression*`]`

Change the current time step value (dt).

`SetFrequency`
`[`*system-id*`,` *expression*`]`

Change the frequency of system *system-id*.

`SystemCommand`
`[`*expression-char*`]`

Execute the system command given by *expression-char*.

`Error` `[`*expression-char*`]`

Output error message *expression-char*.

`Test` `[`*expression*`] {` *resolution-op* `}`

If *expression* is true (nonzero), perform the operations in *resolution-op*.

`Test` `[`*expression*`] {` *resolution-op* `} {` *resolution-op* `}`

If *expression* is true (nonzero), perform the operations in the first *resolution-op*, else perform the operations in the second *resolution-op*.

`While` `[`*expression*`] {` *resolution-op* `}`

While *expression* is true (nonzero), perform the operations in *resolution-op*.

`Break` `[]`

Aborts an iterative loop, a time loop or a While loop.

`Sleep` `[`*expression*`]`

Sleeps for *expression* seconds;

`Print` `[ {` *expression-list* `} <, File` *expression-char* `> <, Format` *expression-char* `> ]`

Print the expressions listed in *expression-list*. If `Format` is given, use it to format the (scalar) expressions like `Printf`.

`Print` `[ system-id <, File expression-char > <, { expression-cst-list } > <, TimeStep { expression-cst-list } >]`

Print the system *system-id*. If the *expression-cst-list* is given, print only the values of the degrees of freedom given in that list. If the `TimeStep` option is present, limit the printing to the selected time steps.

`EigenSolve`

`[system-id, expression-cst, expression-cst, expression-cst < , expression > ]`

Eigenvalue/eigenvector computation using Arpack or SLEPc. The parameters are: the system (which has to be generated with `GenerateSeparate[]`), the number of eigenvalues/eigenvectors to compute and the real and imaginary spectral shift (around which to look for eigenvalues). The last optional argument allows to filter which eigenvalue/eigenvector pairs will be saved. For example, `($EigenvalueReal > 0)` would only keep pairs corresponding to eigenvalues with a striclty positive real part.

`Lanczos` `[system-id, expression-cst, { expression-cst-list } , expression-cst]`

Eigenvalue/eigenvector computation using the Lanczos algorithm. The parameters are: the system (which has to be generated with `GenerateSeparate[]`), the size of the Lanczos space, the indices of the eigenvalues/eigenvectors to store, the spectral shift. This routine is deprecated: use `EigenSolve` instead.

`FourierTransform`

`[system-id, system-id, { expression-cst-list }]`

On-the-fly computation of a discrete Fourier transform. The parameters are: the (time domain) system, the destination system in which the result of the Fourier tranform is to be saved (it should be declared with `Type Complex`), the list of frequencies to consider in the discrete Fourier transform.

`TimeLoopTheta`

`[expression-cst,expression-cst,expression,expression-cst] { resolution-op }`

Time loop of a theta scheme. The parameters are: the initial time, the end time, the time step and the theta parameter (e.g., 1 for implicit Euler, 0.5 for Crank-Nicholson).

Warning: GetDP automatically handles time-dependent constraints when they are provided using the `TimeFunction` mechanism in an `Assign`-type `Constraint` (see Section 5.3 [Constraint], page 31). However, GetDP cannot automatically transform general time-dependent source terms in weak formulations (time-dependent functions written in a `Galerkin` term). Such source terms will be correctly treated only for implicit Euler, as the expression in the `Galerkin` term is evaluated at the current time step. For other schemes, the source term should be written explicitly, by splitting it in two (`theta f_n+1 + (1-theta) f_n`), making use of the `AtAnteriorTimeStep[]` for the second part, and specifying `NeverDt` in the `Galerkin` term.

`TimeLoopNewmark`
`[`*expression-cst*`,`*expression-cst*`,`*expression*`,`*expression-cst*`,`*expression-cst*`]`
`{` *resolution-op* `}`

Time loop of a Newmark scheme. The parameters are: the initial time, the end time, the time step, the beta and the gamma parameter.

Warning: same restrictions apply for time-dependent functions in the weak formulations as for `TimeLoopTheta`.

`TimeLoopAdaptive`
`[`*expression-cst*`,`*expression-cst*`,`*expression-cst*`,`*expression-cst*`,`*expression-cst*`,`*integration-method*`,<`*expression-cst-list*`>,`
`System { {`*system-id*`,`*expression-cst*`,`*expression-cst*`,`*norm-type*`} ... }`
`|`
`PostOperation { {`*post-operation-id*`,`*expression-cst*`,`*expression-cst*`,`*norm-type*`} ... } ]`
`{` *resolution-op* `}`
`{` *resolution-op* `}`

Time loop with variable time steps. The step size is adjusted according the local truncation error (LTE) of the specified Systems/PostOperations via a predictor-corrector method.
The parameters are: start time, end time, initial time step, min. time step, max. time step, integration method, list of breakpoints (time points to be hit). The LTE calculation can be based on all DOFs of a system and/or on a PostOperation result. The parameters here are: System/PostOperation for LTE assessment, relative LTE tolerance, absolute LTE tolerance, norm-type for LTE calculation.
Possible choices for *integration-method* are: `Euler, Trapezoidal, Gear_2, Gear_3, Gear_4, Gear_5, Gear_6`. The Gear methods correspond to backward differentiation formulas of order 2..6.
Possible choices for *norm-type*: `L1Norm, MeanL1Norm, L2Norm, MeanL2Norm, LinfNorm`.
`MeanL1Norm` and `MeanL2Norm` correspond to `L1Norm` and `L2Norm` divided by the number of degrees of freedom, respectively.
The first *resolution-op* is executed every time step. The second one is only executed if the actual time step is accepted (LTE is in the specified range). E.g. `SaveSolution[]` is usually placed in the 2nd *resolution-op*.

`IterativeLoop`
`[`*expression-cst*`,`*expression*`,`*expression-cst*`<,`*expression-cst*`>]` `{` *resolution-op* `}`

Iterative loop for nonlinear analysis. The parameters are: the maximum number of iterations (if no convergence), the relaxation factor (multiplies the iterative correction $dx$) and the relative error to achieve. The optional parameter is a flag for testing purposes.

`IterativeLoopN`
`[`*expression-cst*`,`*expression*`,`
`System { {`*system-id*`,`*expression-cst*`,`*expression-cst*`,` *assessed-object* *norm-type*`} ... } |`
`PostOperation { {`*post-operation-id*`,`*expression-cst*`,`*expression-cst*`,` *norm-type*`} ... } ]`
`{` *resolution-op* `}`

Similar to `IterativeLoop[]` but allows to specify in detail the tolerances and the type of norm to be calculated for convergence assessment.
The parameters are: the maximum number of iterations (if no convergence), the relaxation factor (multiplies the iterative correction $dx$). The convergence assessment can be based on all DOFs of a system and/or on a PostOperation result. The parameters here are: System/PostOperation for convergence assessment, relative tolerance, absolute tolerance, assessed object (only applicable for a specified system), norm-type for error calculation.
Possible choices for *assessed-object*: `Solution, Residual, RecalcResidual`. `Residual` assesses the residual from the last iteration whereas `RecalcResidual` calculates the residual once again after each iteration. This means that with `Residual` usually one extra iteration is performed, but `RecalcResidual` causes higher computational effort per iteration. Assessing the residual can only be used for Newton's method.
Possible choices for *norm-type*: `L1Norm, MeanL1Norm, L2Norm, MeanL2Norm, LinfNorm`.
`MeanL1Norm` and `MeanL2Norm` correspond to `L1Norm` and `L2Norm` divided by the number of degrees of freedom, respectively.

`IterativeLinearSolver`
Generic iterative linear solver. To be documented.

`PostOperation`
`[`*post-operation-id*`]`

Perform the specified `PostOperation`.

`GmshRead` `[`*expression-char*`]`

When GetDP is linked with the Gmsh library, read a file using Gmsh. This file can be in any format recognized by Gmsh. If the file contains one or multiple post-processing fields, these fields will be evaluated using the built-in `Field[]`, `ScalarField[]`, `VectorField[]`, etc., functions (see Section 6.2.6 [Miscellaneous functions], page 50).

(Note that `GmshOpen` and `GmshMerge` can be used instead of `GmshRead` to force Gmsh to do classical "open" and "merge" operations, instead of trying to "be intelligent" when reading post-processing datasets, i.e., creating new models on the fly if necessary.)

`GmshRead` `[`*expression-char*`,` *expression-cst*`]`

Same thing as the `GmshRead` command above, except that the field is forced to be stored with the given tag. The tag can be used to retrieve the given field

with the built-in `Field[]`, `ScalarField[]`, `VectorField[]`, etc., functions (see Section 6.2.6 [Miscellaneous functions], page 50).

`GmshWrite`
`[`*expression-char*`,` *expression-cst*`]`
Writes the a Gmsh field to disk. (The format is guessed from the file extension.)

`GmshClearAll`
`[]`
Clears all Gmsh data (loaded with `GmshRead` and friends).

`DeleteFile`
`[`*expression-char*`]`
Delete a file.

`RenameFile`
`[`*expression-char*`,` *expression-char*`]`
Rename a file.

`CreateDir | CreateDirectory`
`[`*expression-char*`]`
Create a directory.

`MPI_SetCommSelf`
`[]`
Changes MPI communicator to self.

`MPI_SetCommWorld`
`[]`
Changes MPI communicator to world.

`MPI_Barrier`
`[]`
MPI barrier (blocks until all processes have reached this call).

`MPI_BroadcastFields`
`[ <` *expression-list* `> ]`
Broadcast all fields over MPI (except those listed in the list).

`MPI_BroadcastVariables`
`[]`
Broadcast all runtime variables over MPI.

## 6.9 Types for `PostProcessing`

*post-value*:

`Local` `{` *local-value* `}`
To compute a local quantity.

`Integral` `{` *integral-value* `}`
To integrate the expression over each element.

## 6.10 Types for `PostOperation`

*print-support*:

`OnElementsOf`
*group-def*

To compute a quantity on the elements belonging to the region *group-def*, where the solution was computed during the processing stage.

`OnRegion` *group-def*

To compute a global quantity associated with the region *group-def*.

`OnGlobal` To compute a global integral quantity, with no associated region.

`OnSection`
`{ {` *expression-cst-list* `} {` *expression-cst-list* `} {` *expression-cst-list* `} }`

To compute a quantity on a section of the mesh defined by three points (i.e., on the intersection of the mesh with a cutting a plane, specified by three points). Each *expression-cst-list* must contain exactly three elements (the coordinates of the points).

`OnGrid` *group-def*

To compute a quantity in elements of a mesh which differs from the real support of the solution. `OnGrid` *`group-def`* differs from `OnElementsOf` *`group-def`* by the reinterpolation that must be performed.

`OnGrid` `{` *`expression`*`,` *`expression`*`,` *`expression`* `}`
`{` *`expression-cst-list-item`* `|` `{` *`expression-cst-list`* `} ,`
*`expression-cst-list-item`* `|` `{` *`expression-cst-list`* `} ,`
*`expression-cst-list-item`* `|` `{` *`expression-cst-list`* `} }`

To compute a quantity on a parametric grid. The three *expression*s represent the three cartesian coordinates $x$, $y$ and $z$, and can be functions of the current values `$A`, `$B` and `$C`. The values for `$A`, `$B` and `$C` are specified by each *expression-cst-list-item* or *expression-cst-list*. For example, `OnGrid {Cos[$A], Sin[$A], 0} { 0:2*Pi:Pi/180, 0, 0 }` will compute the quantity on 360 points equally distributed on a circle in the z=0 plane, and centered on the origin.

`OnPoint` `{` *expression-cst-list* `}`

To compute a quantity at a point. The *expression-cst-list* must contain exactly three elements (the coordinates of the point).

`OnLine` `{ {` *expression-cst-list* `} {` *expression-cst-list* `} } {` *expression-cst* `}`

To compute a quantity along a line (given by its two end points), with an associated number of divisions equal to *expression-cst*. The interpolation points on the line are equidistant. Each *expression-cst-list* must contain exactly three elements (the coordinates of the points).

`OnPlane` `{ {` *expression-cst-list* `} {` *expression-cst-list* `} {` *expression-cst-list* `} }`
`{` *`expression-cst`*`,` *`expression-cst`* `}`

To compute a quantity on a plane (specified by three points), with an associated number of divisions equal to each *expression-cst* along both generating directions. Each *expression-cst-list* must contain exactly three elements (the coordinates of the points).

`OnBox` `{ {` *expression-cst-list* `} { ` *expression-cst-list* `} { ` *expression-cst-list* `}`
`{` *expression-cst-list* `} } { ` *expression-cst*`, ` *expression-cst*`,`
*expression-cst* `}`

To compute a quantity in a box (specified by four points), with an associated number of divisions equal to each *expression-cst* along the three generating directions. Each *expression-cst-list* must contain exactly three elements (the coordinates of the points).

*print-option*:

`File` *expression-char*

Outputs the result in a file named *expression-char*.

`File` `>` *expression-char*

Same as `File` *expression-char*, except that, if several `File >` *expression-char* options appear in the same `PostOperation`, the results are concatenated in the file *expression-char*.

`File` `>>` *expression-char*

Appends the result to a file named *expression-char*.

`AppendToExistingFile`
*expression-cst*

Appends the result to the file specified with `File`. (Same behavior as `>` if *expression-cst* = 1; same behavior as `>>` if *expression-cst* = 2.)

`Name` *expression-char*

For formats that support it, sets the label of the output field to *expression-char*.

`Depth` *expression-cst*

Recursive division of the elements if *expression-cst* is greater than zero, definement if *expression-cst* is smaller than zero. If *expression-cst* is equal to zero, evaluation at the barycenter of the elements.

`Skin` Computes the result on the boundary of the region.

`Smoothing`
`<` *expression-cst* `>`

Smoothes the solution at the nodes.

`HarmonicToTime`
*expression-cst*

Converts a harmonic solution into a time-dependent one (with *expression-cst* steps).

`Dimension`
*expression-cst*

Forces the dimension of the elements to consider in an element search. Specifies the problem dimension during an adaptation (h- or p-refinement).

`TimeStep` *`expression-cst-list-item | { expression-cst-list }`*

Outputs results for the specified time steps only.

`TimeValue`
*`expression-cst-list-item | { expression-cst-list }`*

Outputs results for the specified time value(s) only.

`TimeImagValue`
*`expression-cst-list-item | { expression-cst-list }`*

Outputs results for the specified imaginary time value(s) only.

`LastTimeStepOnly`
Outputs results for the last time step only (useful when calling a `PostOperation` directly in a `Resolution`, for example).

`AppendExpressionToFileName`
*expression*

Evaluate the given *expression* at run-time and append it to the filename.

`AppendExpressionFormat`
*expression-char*

C-style format string for printing the *expression* provided in `AppendExpressionToFileName`. Default is `"%.16g"`.

`AppendTimeStepToFileName`
`<` *expression-cst* `>`

Appends the time step to the output file; only makes sense with `LastTimeStepOnly`.

`AppendStringToFileName`
*expression-char*

Append the given *expression-char* to the filename.

`OverrideTimeStepValue`
*expression-cst*

Overrides the value of the current time step with the given value.

`NoMesh` `<` *expression-cst* `>`

Prevents the mesh from being written in the output file (useful with new mesh-based solution formats).

`SendToServer`
*expression-char*

Send the value to the Onelab server, using *expression-char* as the paramater name.

`SendToServer`
*expression-char* `{` *expression-cst-list* `}`
Send the requested harmonics of the value to the Onelab server, using *expression-char* as the paramater name.

`Color` *expression-char*
Used with `SendToServer`, sets the color of the parameter in the Onelab server.

`Units` *expression-char*
Used with `SendToServer`, sets the units of the parameter in the Onelab server.

`Frequency`
*expression-cst-list-item* `|` `{` *expression-cst-list* `}`
Outputs results for the specified frequencies only.

`Format` *post-operation-fmt*
Outputs results in the specified format.

`Adapt` `P1 | H1 | H2`
Performs p- or h-refinement on the post-processing result, considered as an error map.

`Target` *expression-cst*
Specifies the target for the optimizer during adaptation (error for `P1|H1`, number of elements for `H2`).

`Value` *expression-cst-list-item* `|` `{` *expression-cst-list* `}`
Specifies acceptable output values for discrete optimization (e.g. the available interpolation orders with `Adapt P1`).

`Sort` `Position | Connection`
Sorts the output by position (x, y, z) or by connection (for `LINE` elements only).

`Iso` *expression-cst*
Outputs directly contour prints (with *expression-cst* values) instead of elementary values.

`Iso` `{` *expression-cst-list* `}`
Outputs directly contour prints for the values specified in the *expression-cst-list* instead of elementary values.

`NoNewLine`
Suppresses the new lines in the output when printing global quantities (i.e., with `Print OnRegion` or `Print OnGlobal`).

`ChangeOfCoordinates`
`{` *expression*`,` *expression*`,` *expression* `}`
Changes the coordinates of the results according to the three expressions given in argument. The three *expression*s represent the three new cartesian coordinates $x$, $y$ and $z$, and can be functions of the current values of the cartesian coordinates `$X`, `$Y` and `$Z`.

`ChangeOfValues`
`{ expression-list }`

Changes the values of the results according to the expressions given in argument. The *expression*s represent the new values (*x*-compoment, *y*-component, etc.), and can be functions of the current values of the solution (*$Val0*, *$Val1*, etc.).

`DecomposeInSimplex`
Decomposes all output elements in simplices (points, lines, triangles or tetrahedra).

`StoreInVariable`
`$expression-char`

Stores the result of a point-wise evaluation or an `OnRegion` post-processing operation in the run-time variable $code[$]*expression-char*.

`StoreInRegister`
`expression-cst`

Stores the result of point-wise evaluation or an `OnRegion` post-processing operation in the register *expression-cst*.

`StoreMinInRegister`
`StoreMaxInRegister`
`expression-cst`

Stores the minimum or maximum value of an `OnElementsOf` post-processing operation in the register *expression-cst*.

`StoreMinXinRegister`
`StoreMinYinRegister`
`StoreMinZinRegister`
`StoreMaxXinRegister`
`StoreMaxYinRegister`
`StoreMaxZinRegister`
`expression-cst`

Stores the X, Y or Z coordinate of the location, where the minimum or maximum of an `OnElementsOf` post-processing operation occurs, in the register *expression-cst*.

`StoreInField`
`expression-cst`

Stores the result of a post-processing operation in the field (Gmsh list-based post-processing view) with tag *expression-cst*.

`StoreInMeshBasedField`
`expression-cst`

Stores the result of a post-processing operation in the mesh-based field (Gmsh mesh-based post-processing view) with tag *expression-cst*.

`TimeLegend`
`< { expression, expression, expression } >`

Includes a time legend in Gmsh plots. If the three optional expressions giving the position of the legend are not specified, the legend is centered on top of the plot.

`FrequencyLegend`
`< { expression, expression, expression } >`

Includes a frequency legend in Gmsh plots. If the three optional expressions giving the position of the legend are not specified, the legend is centered on top of the plot.

`EigenvalueLegend`
`< { expression, expression, expression } >`

Includes an eigenvalue legend in Gmsh plots. If the three optional expressions giving the position of the legend are not specified, the legend is centered on top of the plot.

*post-operation-fmt*:

`Gmsh`
`GmshParsed`

Gmsh output. See Section A.1 [Input file format], page 111 and the documentation of Gmsh (`http://gmsh.info`) for a description of the file formats.

`Table` Space oriented column output, e.g., suitable for Gnuplot, Excel, Caleida Graph, etc. The columns are: *element-type element-index x-coord y-coord z-coord* <*x-coord y-coord z-coord*> ... *real real real values*. The three *real* numbers preceding the *values* contain context-dependent information, depending on the type of plot: curvilinear abscissa for `OnLine` plots, normal to the plane for `OnPlane` plots, parametric coordinates for parametric `OnGrid` plots, etc.

`SimpleTable`

Like `Table`, but with only the *x-coord y-coord z-coord* and *values* columns.

`TimeTable`

Time oriented column output, e.g., suitable for Gnuplot, Excel, Caleida Graph, etc. The columns are: *time-step time x-coord y-coord z-coord* <*x-coord y-coord z-coord*> ... *value*.

`NodeTable`

Table of node values. The first value corresponds to the number of listed nodes. The columns of the following lines are: *node-number node-value*(s)

`Gnuplot` Space oriented column output similar to the `Table` format, except that a new line is created for each node of each element, with a repetition of the first node if the number of nodes in the element is greater than 2. This permits to draw unstructured meshes and nice three-dimensional elevation plots in Gnuplot. The columns are: *element-type element-index x-coord y-coord z-coord real real real values*. The three *real* numbers preceding the *values* contain context-dependent information, depending on the type of plot: curvilinear abscissa for `OnLine` plots, normal to the plane for `OnPlane` plots, parametric coordinates for parametric `OnGrid` plots, etc.

`Adaptation`
: Adaptation map, suitable for the GetDP `-adapt` command line option.

# 7 Short examples

## 7.1 Constant expression examples

The simplest constant expression consists of an *integer* or a *real* number as in

```
21
-3
```

or

```
-3.1415
27e3
-290.53e-12
```

Using operators and the classic math functions, *constant-id*s can be defined:

```
c1 = Sin[2/3*3.1415] * 5000^2;
c2 = -1/c1;
```

## 7.2 `Group` examples

Let us assume that some elements in the input mesh have the region numbers 1000, 2000 and 3000. In the definitions

```
Group {
  Air = Region[1000]; Core = Region[2000]; Inductor = Region[3000];
  NonConductingDomain = Region[{Air, Core}];
  ConductingDomain    = Region[{Inductor}];
}
```

`Air`, `Core`, `Inductor` are identifiers of elementary region groups while `NonConductingDomain` and `ConductingDomain` are global region groups.

Groups of function type contain lists of entities built on the region groups appearing in their arguments. For example,

```
NodesOf[NonConductingDomain]
```

represents the group of nodes of geometrical elements belonging to the regions in `NonConductingDomain` and

```
EdgesOf[DomainC, Not SkinDomainC]
```

represents the group of edges of geometrical elements belonging to the regions in `DomainC` but not to those of `SkinDomainC`.

## 7.3 `Function` examples

A physical characteristic is a piecewise defined function. The magnetic permeability `mu[]` can for example be defined in the considered regions by

```
Function {
  mu[Air] = 4.e-7*Pi;
  mu[Core] = 1000.*4.e-7*Pi;
}
```

A nonlinear characteristic can be defined through an *expression* with arguments, e.g.,

```
Function {
  mu0 = 4.e-7*Pi;
  a1 = 1000.; b1 = 100.; // Constants
  mu[NonlinearCore] = mu0 + 1./(a1+b1*Norm[$1]^6);
}
```

where function `mu[]` in region `NonLinearCore` has one argument `$1` which has to be the magnetic flux density. This function is actually called when writing the equations of a formulation, which permits to directly extend it to a nonlinear form by adding only the necessary arguments. For example, in a magnetic vector potential formulation, one may write `mu[{Curl a}]` instead of `mu[]` in `Equation` terms (see Section 7.8 [Formulation examples], page 83). Multiple arguments can be specified in a similar way: writing `mu[{Curl a},{T}]` in an `Equation` term will provide the function `mu[]` with two usable arguments, `$1` (the magnetic flux density) and `$2` (the temperature).

It is also possible to directly interpolate one-dimensional functions from tabulated data. In the following example, the function $f(x)$ as well as its derivative $f'(x)$ are interpolated from the $(x,f(x))$ couples (0,0.65), (1,0.72), (2,0.98) and (3,1.12):

```
Function {
  couples = {0, 0.65 , 1, 0.72 , 2, 0.98 , 3, 1.12};
  f[] = InterpolationLinear[$1]{List[couples]};
  dfdx[] = dInterpolationLinear[$1]{List[couples]};
}
```

The function `f[]` may then be called in an `Equation` term of a `Formulation` with one argument, $x$. Notice how the list of constants `List[couples]` is supplied as a list of parameters to the built-in function `InterpolationLinear` (see Section 4.4 [Constants], page 16, as well as Section 4.6 [Functions], page 22). In order to facilitate the construction of such interpolations, the couples can also be specified in two separate lists, merged with the alternate list `ListAlt` command (see Section 4.4 [Constants], page 16):

```
Function {
  data_x = {0, 1, 2, 3};
  data_f = {0.65, 0.72, 0.98, 1.12};
  f[] = InterpolationLinear[$1]{ListAlt[data_x, data_f]};
  dfdx[] = dInterpolationLinear[$1]{ListAlt[data_x, data_f]};
}
```

In order to optimize the evaluation time of complex expressions, registers may be used (see Section 4.9 [Run-time variables and registers], page 24). For example, the evaluation of `g[] = f[$1]*Sin[f[$1]^2]` would require two (costly) linear interpolations. But the result of the evaluation of `f[]` may be stored in a register (for example the register 0) with

```
g[] = f[$1]#0 * Sin[#0^2];
```

thus reducing the number of evaluations of `f[]` (and of the argument `$1`) to one.

The same results can be obtained using a run-time variable `$v`:

```
g[] = ($v = f[$1]) * Sin[$v^2];
```

A function can also be time dependent, e.g.,

```
Function {
  Freq = 50.; Phase = 30./180.*Pi; // Constants
```

```
  TimeFct_Sin[] = Sin [ 2.*Pi*Freq * $Time + Phase ];
  TimeFct_Exp[] = Exp [ - $Time / 0.0119 ];
  TimeFct_ExtSin[] = Sin_wt_p [] {2.*Pi*Freq, Phase};
}
```

Note that `TimeFct_ExtSin[]` is identical to `TimeFct_Sin[]` in a time domain analysis, but also permits to define phasors implicitely in the case of harmonic analyses.

## 7.4 `Constraint` examples

Constraints are referred to in `FunctionSpace`s and are usually used for boundary conditions (`Assign` type). For example, essential conditions on two surface regions, `Surf0` and `Surf1`, will be first defined by

```
Constraint {
  { Name DirichletBoundaryCondition1; Type Assign;
    Case {
      { Region Surf0; Value 0.; }
      { Region Surf1; Value 1.; }
    }
  }
}
```

The way the `Value`s are associated with `Region`s (with their nodes, their edges, their global regions, ...) is defined in the `FunctionSpace`s which use the `Constraint`. In other words, a `Constraint` defines data but does not define the method to process them. A time dependent essential boundary condition on `Surf1` would be introduced as (cf. Section 7.3 [Function examples], page 75 for the definition of `TimeFct_Exp[]`):

```
      { Region Surf1; Value 1.; TimeFunction 3*TimeFct_Exp[] }
```

It is important to notice that the time dependence cannot be introduced in the `Value` field, since the `Value` is only evaluated once during the pre-processing.

Other constraints can be referred to in `Formulation`s. It is the case of those defining electrical circuit connections (`Network` type), e.g.,

```
Constraint {
  { Name ElectricalCircuit; Type Network;
    Case Circuit1 {
      { Region VoltageSource; Branch {1,2}; }
      { Region PrimaryCoil; Branch {1,2}; }
    }
    Case Circuit2 {
      { Region SecondaryCoil; Branch {1,2}; }
      { Region Charge; Branch {1,2}; }
    }
  }
}
```

which defines two non-connected circuits (`Circuit1` and `Circuit2`), with an independent numbering of nodes: region `VoltageSource` is connected in parallel with region `PrimaryCoil`, and region `SecondaryCoil` is connected in parallel with region `Charge`.

## 7.5 `FunctionSpace` examples

Various discrete function spaces can be defined in the frame of the finite element method.

### 7.5.1 Nodal finite element spaces

The most elementary function space is the nodal finite element space, defined on a mesh of a domain $W$ and denoted *S0(W)* (associated finite elements can be of various geometries), and associated with essential boundary conditions (Dirichlet conditions). It contains 0-forms, i.e., scalar fields of potential type:

$$v = \sum_{n \in N} v_n s_n \quad v \in S^0(W)$$

where $N$ is the set of nodes of $W$, *sn* is the nodal basis function associated with node $n$ and *vn* is the value of $v$ at node $n$. It is defined by

```
FunctionSpace {
  { Name Hgrad_v; Type Form0;
    BasisFunction {
      { Name sn; NameOfCoef vn; Function BF_Node;
        Support Domain; Entity NodesOf[All]; }
    }
    Constraint {
      { NameOfCoef vn; EntityType NodesOf;
        NameOfConstraint DirichletBoundaryCondition1; }
    }
  }
}
```

Function `sn` is the built-in basis function BF_Node associated with all nodes (`NodesOf`) in the mesh of $W$ (`Domain`). Previously defined `Constraint DirichletBoundaryCondition1` (see Section 7.4 [Constraint examples], page 77) is used as boundary condition.

In the example above, `Entity NodesOf[All]` is preferred to `Entity NodesOf[Domain]`. In this way, the list of all the nodes of `Domain` will not have to be generated. All the nodes of each geometrical element in `Support Domain` will be directly taken into account.

### 7.5.2 High order nodal finite element space

Higher order finite elements can be directly taken into account by `BF_Node`. Hierarchical finite elements for 0-forms can be used by simply adding other basis functions (associated with other geometrical entities, e.g., edges and facets) to `BasisFunction`, e.g.,

```
...
BasisFunction {
  { Name sn; NameOfCoef vn; Function BF_Node;
    Support Domain; Entity NodesOf[All]; }
  { Name s2; NameOfCoef v2; Function BF_Node_2E;
    Support Domain; Entity EdgesOf[All]; }
}
...
```

### 7.5.3 Nodal finite element space with floating potentials

A scalar potential with floating values *vf* on certain boundaries *Gf*, *f* in *Cf*, e.g., for electrostatic problems, can be expressed as

$$v = \sum_{n \in N_v} v_n s_n + \sum_{f \in C_f} v_f s_f \quad v \in S^0(W)$$

where *Nv* is the set of inner nodes of *W* and each function *sf* is associated with the group of nodes of boundary *Gf*, *f* in *Cf* (`SkinDomainC`); *sf* is the sum of the nodal basis functions of all the nodes of *Cf*. Its function space is defined by

```
FunctionSpace {
  { Name Hgrad_v_floating; Type Form0;
    BasisFunction {
      { Name sn; NameOfCoef vn; Function BF_Node;
        Support Domain; Entity NodesOf[All, Not SkinDomainC]; }
      { Name sf; NameOfCoef vf; Function BF_GroupOfNodes;
        Support Domain; Entity GroupsOfNodesOf[SkinDomainC]; }
    }
    GlobalQuantity {
      { Name GlobalElectricPotential; Type AliasOf; NameOfCoef vf; }
      { Name GlobalElectricCharge; Type AssociatedWith;
        NameOfCoef vf; }
    }
    Constraint { ... }
  }
}
```

Two global quantities have been associated with this space: the electric potential `GlobalElectricPotential`, being an alias of coefficient `vf`, and the electric charge `GlobalElectricCharge`, being associated with coefficient `vf`.

### 7.5.4 Edge finite element space

Another space is the edge finite element space, denoted *S1(W)*, containing 1-forms, i.e., curl-conform fields:

$$\mathbf{h} = \sum_{e \in E} h_e \mathbf{s}_e \quad \mathbf{h} \in S^1(W)$$

where *E* is the set of edges of *W*, *se* is the edge basis function for edge *e* and *he* is the circulation of *h* along edge *e*. It is defined by

```
FunctionSpace {
  { Name Hcurl_h; Type Form1;
    BasisFunction {
      { Name se; NameOfCoef he; Function BF_Edge;
        Support Domain; Entity EdgesOf[All]; }
    }
    Constraint { ... }
```

```
    }
  }
```

### 7.5.5 Edge finite element space with gauge condition

A 1-form function space containing vector potentials can be associated with a gauge condition, which can be defined as a constraint, e.g., a zero value is fixed for all circulations along edges of a tree (`EdgesOfTreeIn`) built in the mesh (`Domain`), having to be complete on certain boundaries (`StartingOn Surf`):

```
Constraint {
  { Name GaugeCondition_a_Mag_3D; Type Assign;
    Case {
      { Region Domain; SubRegion Surf; Value 0.; }
    }
  }
}

FunctionSpace {
  { Name Hcurl_a_Gauge; Type Form1;
    BasisFunction {
      { Name se; NameOfCoef ae; Function BF_Edge;
        Support Domain; Entity EdgesOf[All]; }
    }
    Constraint {
      { NameOfCoef ae;
        EntityType EdgesOfTreeIn; EntitySubType StartingOn;
        NameOfConstraint GaugeCondition_a_Mag_3D; }
      ...
    }
  }
}
```

### 7.5.6 Coupled edge and nodal finite element spaces

A 1-form function space, containing curl free fields in certain regions $WcC$ (`DomainCC`) of $W$, which are the complementary part of $Wc$ (`DomainC`) in $W$, can be explicitly characterized by

$$\mathbf{h} = \sum_{k \in E_c} h_k \mathbf{s}_k + \sum_{n \in N_c^C} \phi_n \mathbf{v}_n \quad \mathbf{h} \in S^1(W)$$

where $Ec$ is the set of inner edges of $W$, $NcC$ is the set of nodes inside $WcC$ and on its boundary $dWcC$, $sk$ is an edge basis function and $vn$ is a vector nodal function. Such a space, coupling a vector field with a scalar potential, can be defined by

```
FunctionSpace {
  { Name Hcurl_hphi; Type Form1;
    BasisFunction {
      { Name sk; NameOfCoef hk; Function BF_Edge;
```

```
          Support DomainC; Entity EdgesOf[All, Not SkinDomainC]; }
        { Name vn; NameOfCoef phin; Function BF_GradNode;
          Support DomainCC; Entity NodesOf[All]; }
        { Name vn; NameOfCoef phic; Function BF_GroupOfEdges;
          Support DomainC; Entity GroupsOfEdgesOnNodesOf[SkinDomainC];}
      }
      Constraint {
        { NameOfCoef hk;
          EntityType EdgesOf; NameOfConstraint MagneticField; }
        { NameOfCoef phin;
          EntityType NodesOf; NameOfConstraint MagneticScalarPotential; }
        { NameOfCoef phic;
          EntityType NodesOf; NameOfConstraint MagneticScalarPotential; }
      }
    }
  }
```

This example points out the definition of a piecewise defined basis function, e.g., function `vn` being defined with `BF_GradNode` in `DomainCC` and `BF_GroupOfEdges` in `DomainC`. This leads to an easy coupling between these regions.

### 7.5.7 Coupled edge and nodal finite element spaces for multiply connected domains

In case a multiply connected domain $WcC$ is considered, basis functions associated with cuts (`SurfaceCut`) have to be added to the previous basis functions, which gives the function space below:

```
Group {
  _TransitionLayer_SkinDomainC_ =
    ElementsOf[SkinDomainC, OnOneSideOf SurfaceCut];
}

FunctionSpace {
  { Name Hcurl_hphi; Type Form1;
    BasisFunction {

      ... same as above ...

      { Name sc; NameOfCoef Ic; Function BF_GradGroupOfNodes;
        Support ElementsOf[DomainCC, OnOneSideOf SurfaceCut];
        Entity GroupsOfNodesOf[SurfaceCut]; }
      { Name sc; NameOfCoef Icc; Function BF_GroupOfEdges;
        Support DomainC;
        Entity GroupsOfEdgesOf
                 [SurfaceCut,
                  InSupport _TransitionLayer_SkinDomainC_]; }
    }
    GlobalQuantity {
```

```
      { Name I; Type AliasOf       ; NameOfCoef Ic; }
      { Name U; Type AssociatedWith; NameOfCoef Ic; }
    }
    Constraint {

      ... same as above ...

      { NameOfCoef Ic;
        EntityType GroupsOfNodesOf; NameOfConstraint Current; }
      { NameOfCoef Icc;
        EntityType GroupsOfNodesOf; NameOfConstraint Current; }
      { NameOfCoef U;
        EntityType GroupsOfNodesOf; NameOfConstraint Voltage; }
    }
  }
}
```

Global quantities associated with the cuts, i.e., currents and voltages if $h$ is the magnetic field, have also been defined.

## 7.6 `Jacobian` examples

A simple Jacobian method is for volume transformations (of $n$-D regions in $n$-D geometries; $n = 1$, 2 or 3), e.g., in region `Domain`,

```
Jacobian {
  { Name Vol;
    Case {
      { Region Domain; Jacobian Vol; }
    }
  }
}
```

`Jacobian VolAxi` would define a volume Jacobian for axisymmetrical problems.

A Jacobian method can also be piecewise defined, in `DomainInf`, where an infinite geometrical transformation has to be made using two constant parameters (inner and outer radius of a spherical shell), and in all the other regions (`All`, being the default); in each case, a volume Jacobian is used. This method is defined by:

```
Jacobian {
  { Name Vol;
    Case {
      { Region DomainInf; Jacobian VolSphShell {Val_Rint, Val_Rext}; }
      { Region All; Jacobian Vol; }
    }
  }
}
```

## 7.7 `Integration` examples

A commonly used numerical integration method is the `Gauss` integration, with a number of integration points (`NumberOfPoints`) depending on geometrical element types (`GeoElement`), i.e.

```
Integration {
  { Name Int_1;
    Case { {Type Gauss;
            Case { { GeoElement Triangle   ; NumberOfPoints 4; }
                   { GeoElement Quadrangle ; NumberOfPoints 4; }
                   { GeoElement Tetrahedron; NumberOfPoints 4; }
                   { GeoElement Hexahedron ; NumberOfPoints 6; }
                   { GeoElement Prism      ; NumberOfPoints 9; } }
          }
         }
  }
}
```

The method above is valid for both 2D and 3D problems, for different kinds of elements.

## 7.8 `Formulation` examples

### 7.8.1 Electrostatic scalar potential formulation

An electrostatic formulation using an electric scalar potential $v$, i.e.

$$(\epsilon \operatorname{grad} v, \operatorname{grad} v')_W = 0 \quad \forall v' \in S^0(W)$$

is expressed by

```
Formulation {
  { Name Electrostatics_v; Type FemEquation;
    Quantity {
      { Name v; Type Local; NameOfSpace Hgrad_v; }
    }
    Equation {
      Galerkin { [ epsr[] * Dof{Grad v} , {Grad v} ];
                 In Domain; Jacobian Vol; Integration Int_1; }
    }
  }
}
```

The density of the `Galerkin` term is a copy of the symbolic form of the formulation, i.e., the product of a relative permittivity function `epsr[]` by a vector of degrees of freedom (`Dof{.}`); the scalar product of this with the gradient of test function `v` results in a symmetrical matrix.

Note that another `Quantity` could be defined for test functions, e.g., `vp` defined by `{ Name vp; Type Local; NameOfSpace Hgrad_v; }`. However, its use would result in the computation of a full matrix and consequently in a loss of efficiency.

### 7.8.2 Electrostatic scalar potential formulation with floating potentials and electric charges

An extension of the formulation above can be made to take floating potentials and electrical charges into account (the latter being defined in `FunctionSpace Hgrad_v_floating`), i.e.

```
Formulation {
  { Name Electrostatics_v_floating; Type FemEquation;
    Quantity {
      { Name v; Type Local; NameOfSpace Hgrad_v_floating; }
      { Name V; Type Global;
        NameOfSpace Hgrad_v_floating [GlobalElectricPotential]; }
      { Name Q; Type Global;
        NameOfSpace Hgrad_v_floating [GlobalElectricCharge]; }
    }
    Equation {
      Galerkin { [ epsr[] * Dof{Grad v} , {Grad v} ];
                 In Domain; Jacobian Vol; Integration Int_1; }
      GlobalTerm { [ - Dof{Q}/eps0 , {V} ]; In SkinDomainC; }
    }
  }
}
```

with the predefinition `Function { eps0 = 8.854187818e-12; }`.

### 7.8.3 Magnetostatic 3D vector potential formulation

A magnetostatic 3D vector potential formulation

$$(\nu \operatorname{curl} \mathbf{a}, \operatorname{curl} \mathbf{a}')_W = (\mathbf{j}_s, \mathbf{a}')_{W_s} \quad \forall \mathbf{a}' \in S^1(W), \text{ with gauge condition}$$

with a source current density *js* in inductors *Ws*, is expressed by

```
Formulation {
  { Name Magnetostatics_a_3D; Type FemEquation;
    Quantity {
      { Name a; Type Local; NameOfSpace Hcurl_a_Gauge; }
    }
    Equation {
      Galerkin { [ nu[] * Dof{Curl a} , {Curl a} ];
                 In Domain; Jacobian Vol; Integration Int_1; }
      Galerkin { [ - SourceCurrentDensity[] , {a} ];
                 In DomainWithSourceCurrentDensity;
                 Jacobian Vol; Integration Int_1; }
    }
  }
}
```

Note that *js* is here given by a function `SourceCurrentDensity[]`, but could also be given by data computed from another problem, e.g., from an electrokinetic problem (coupling of formulations) or from a fully fixed function space (constraints fixing the density, which is usually more efficient in time domain analyses).

### 7.8.4 Magnetodynamic 3D or 2D magnetic field and magnetic scalar potential formulation

A magnetodynamic 3D or 2D *h-phi* formulation, i.e., coupling the magnetic field $h$ with a magnetic scalar potential *phi*,

$$\partial_t(\mu\,\mathbf{h},\mathbf{h}')_W + (\rho\,\mathrm{curl}\,\mathbf{h},\mathrm{curl}\,\mathbf{h}')_{W_c} = 0 \quad \forall \mathbf{h}' \in S^1(W)$$

can be expressed by

```
Formulation {
  { Name Magnetodynamics_hphi; Type FemEquation;
    Quantity {
      { Name h; Type Local; NameOfSpace Hcurl_hphi; }
    }
    Equation {
      Galerkin { Dt [ mu[] * Dof{h} , {h} ];
                 In Domain; Jacobian Vol; Integration Int_1; }
      Galerkin { [ rho[] * Dof{Curl h} , {Curl h} ];
                 In DomainC; Jacobian Vol; Integration Int_1; }
    }
  }
}
```

### 7.8.5 Nonlinearities, Mixed formulations, . . .

In case nonlinear physical characteristics are considered, arguments are used for associated functions, e.g., `mu[{h}]`. Several test functions can be considered in an `Equation` field. Consequently, mixed formulations can be defined.

## 7.9 `Resolution` examples

### 7.9.1 Static resolution (electrostatic problem)

A static resolution, e.g., for the electrostatic formulation (see Section 7.8 [Formulation examples], page 83), can be defined by

```
Resolution {
  { Name Electrostatics_v;
    System {
      { Name Sys_Ele; NameOfFormulation Electrostatics_v; }
    }
    Operation {
      Generate[Sys_Ele]; Solve[Sys_Ele]; SaveSolution[Sys_Ele];
    }
  }
}
```

The generation (`Generate`) of the matrix of the system `Sys_Ele` will be made with the formulation `Electrostatics_v`, followed by its solving (`Solve`) and the saving of the solution (`SaveSolution`).

### 7.9.2 Frequency domain resolution (magnetodynamic problem)

A frequency domain resolution, e.g., for the magnetodynamic *h-phi* formulation (see Section 7.8 [Formulation examples], page 83), is given by

```
Resolution {
  { Name Magnetodynamics_hphi;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetodynamics_hphi;
        Frequency Freq; }
    }
    Operation {
      Generate[Sys_Mag]; Solve[Sys_Mag]; SaveSolution[Sys_Mag];
    }
  }
}
```

preceded by the definition of constant `Freq`, e.g.,

```
Function {
  Freq = 50.;
}
```

### 7.9.3 Time domain resolution (magnetodynamic problem)

A time domain resolution, e.g., for the same magnetodynamic *h-phi* formulation (see Section 7.8 [Formulation examples], page 83), is given by

```
Resolution {
  { Name Magnetodynamics_hphi_Time;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetodynamics_hphi; }
    }
    Operation {
      InitSolution[Sys_Mag]; SaveSolution[Sys_Mag];
      TimeLoopTheta[Mag_Time0, Mag_TimeMax, Mag_DTime[], Mag_Theta[]] {
        Generate[Sys_Mag]; Solve[Sys_Mag]; SaveSolution[Sys_Mag];
      }
    }
  }
}
```

If, e.g., the `Resolution` above is preceded by the constant and function definitions below

```
Function {
  Tc = 10.e-3;
  Mag_Time0 = 0.; Mag_TimeMax = 2.*Tc; Mag_DTime[] = Tc/20.;
  Mag_Theta[] = 1./2.;
}
```

the performed time domain analysis will be a Crank-Nicolson scheme (theta-scheme with `Theta = 0.5`) with initial time 0 ms, end time 20 ms and time step 1 ms.

### 7.9.4 Nonlinear time domain resolution (magnetodynamic problem)

In case a nonlinear problem is solved, an iterative loop has to be defined in an appropriate level of the recursive resolution operations, e.g., for the magnetodynamic problem above,

```
...
    Operation {
      InitSolution[Sys_Mag]; SaveSolution[Sys_Mag];
      TimeLoopTheta[Mag_Time0, Mag_TimeMax, Mag_DTime[], Mag_Theta[]] {
        IterativeLoop[NL_NbrMax, NL_Eps, NL_Relax] {
          GenerateJac[Sys_Mag]; SolveJac[Sys_Mag];
        }
        SaveSolution[Sys_Mag];
      }
    }
...
```

preceded by constant definitions, e.g.,

```
Function {
  NL_Eps = 1.e-4; NL_Relax = 1.; NL_NbrMax = 80;
}
```

### 7.9.5 Coupled formulations

A coupled problem, e.g., magnetodynamic (in frequency domain; `Frequency Freq`) - thermal (in time domain) coupling, with temperature dependent characteristics (e.g., `rho[{T}]`, ...), can be defined by:

```
Resolution {
  { Name MagnetoThermalCoupling_hphi_T;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetodynamics_hphi;
        Frequency Freq; }
      { Name Sys_The; NameOfFormulation Thermal_T; }
    }
    Operation {
      InitSolution[Sys_Mag]; InitSolution[Sys_The];
      IterativeLoop[NL_NbrMax, NL_Eps, NL_Relax] {
        GenerateJac[Sys_Mag]; SolveJac[Sys_Mag];
        GenerateJac[Sys_The]; SolveJac[Sys_The];
      }
      SaveSolution[Sys_Mag]; SaveSolution[Sys_The];
    }
  }
}
```

Two systems of equations, `Sys_Mag` and `Sys_The`, will be solved iteratively until convergence (`Criterion`), using a relaxation factor (`RelaxationFactor`).

It can be seen through these examples that many resolutions can be linked or nested directly by the user, which gives a great freedom for coupled problems.

## 7.10 PostProcessing examples

The quantities to be post-computed based on a solution of a resolution are defined, e.g., for the electrostatic problem (see Section 7.8 [Formulation examples], page 83; see Section 7.9 [Resolution examples], page 85), for the solution associated with the formulation `Electrostatics_v`, by

```
PostProcessing {
  { Name EleSta_v; NameOfFormulation Electrostatics_v;
    Quantity {
      { Name v; Value { Local { [ {v} ]; In Domain; } } }
      { Name e; Value { Local { [ -{Grad v} ]; In Domain; } } }
      { Name d; Value { Local { [ -eps0*epsr[] *{Grad v} ];
                                In Domain; } } }
    }
  }
}
```

The electric scalar potential $v$ (`v`), the electric field $e$ (`e`) and the electric flux density $d$ (`d`) can all be computed from the solution. They are all defined in the region `Domain`.

The quantities for the solution associated with the formulation `Electrostatics_v_floating` are defined by

```
PostProcessing {
  { Name EleSta_vf; NameOfFormulation Electrostatics_v_floating;
    Quantity {

      ... same as above ...

      { Name Q; Value { Local { [ {Q} ]; In SkinDomainC; } } }
      { Name V; Value { Local { [ {V} ]; In SkinDomainC; } } }
    }
  }
}
```

which points out the way to define post-quantities based on global quantities.

## 7.11 PostOperation examples

The simplest post-processing operation is the generation of maps of local quantities, i.e., the display of the computed fields on the mesh. For example, using the `PostProcessing` defined in Section 7.10 [PostProcessing examples], page 88, the maps of the electric scalar potential and of the electric field on the elements of the region `Domain` are defined as:

```
PostOperation {
  { Name Map_v_e; NameOfPostProcessing EleSta_v ;
     Operation {
       Print [ v, OnElementsOf Domain, File "map_v.pos" ];
       Print [ e, OnElementsOf Domain, File "map_e.pos" ];
     }
  }
```

```
}
```

It is also possible to display local quantities on sections of the mesh, here for example on the plane containing the points (0,0,1), (1,0,1) and (0,1,1):

```
Print [ v, OnSection { {0,0,1} {1,0,1} {0,1,1} }, File "sec_v.pos" ];
```

Finally, local quantities can also be interpolated on another mesh than the one on which they have been computed. Six types of grids can be specified for this interpolation: a single point, a set of points evenly distributed on a line, a set of points evenly distributed on a plane, a set of points evenly distributed in a box, a set of points defined by a parametric equation, and a set of elements belonging to a different mesh than the original one:

```
Print [ e, OnPoint {0,0,1} ];
Print [ e, OnLine { {0,0,1} {1,0,1} } {125} ];
Print [ e, OnPlane { {0,0,1} {1,0,1} {0,1,1} } {125, 75} ];
Print [ e, OnBox { {0,0,1} {1,0,1} {0,1,1} {0,0,2} } {125, 75, 85} ];
Print [ e, OnGrid {$A, $B, 1} { 0:1:1/125, 0:1:1/75, 0 } ];
Print [ e, OnGrid Domain2 ];
```

Many options can be used to modify the aspect of all these maps, as well as the default behaviour of the `Print` commands. See Section 6.10 [Types for PostOperation], page 67, to get the list of all these options. For example, to obtain a map of the scalar potential at the barycenters of the elements on the boundary of the region `Domain`, in a table oriented format appended to an already existing file `out.txt`, the operation would be:

```
Print [ v, OnElementsOf Domain, Depth 0, Skin, Format Table,
        File >> "out.txt" ];
```

Global quantities, which are associated with regions (and not with the elements of the mesh of these regions), are displayed thanks to the `OnRegion` operation. For example, the global potential and charge on the region `SkinDomainC` can be displayed with:

```
PostOperation {
  { Name Val_V_Q; NameOfPostProcessing EleSta_vf ;
     Operation {
       Print [ V, OnRegion SkinDomainC ];
       Print [ Q, OnRegion SkinDomainC ];
     }
  }
}
```

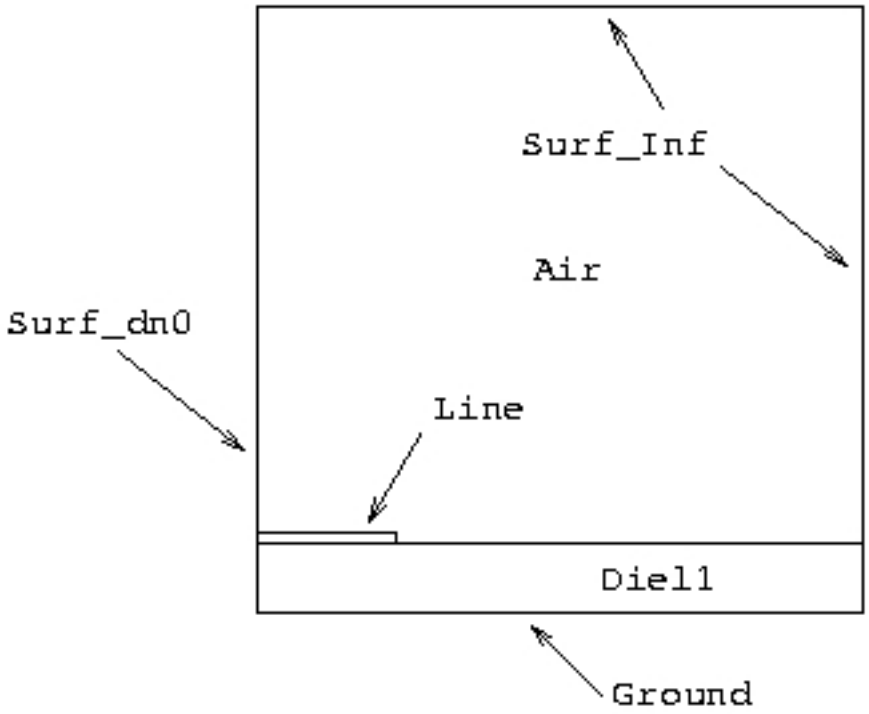
# 8 Complete examples

This chapter presents complete examples that can be run "as is" with GetDP (see Chapter 3 [Running GetDP], page 11).

Many other ready-to-use examples are available on the website of the ONELAB project: `http://onelab.info`.

## 8.1 Electrostatic problem

Let us first consider a simple electrostatic problem. The formulation used is an electric scalar potential formulation (file '`EleSta_v.pro`', including files '`Jacobian_Lib.pro`' and '`Integration_Lib.pro`'). It is applied to a microstrip line (file '`mStrip.pro`'), whose geometry is defined in the file '`mStrip.geo`' (see Appendix B [Gmsh examples], page 115). The geometry is two-dimensional and by symmetry only one half of the structure is modeled.




Note that the structure of the following files points out the separation of the data describing the particular problem and the method used to solve it (see Section 1.1 [Numerical tools as objects], page 5), and therefore how it is possible to build black boxes adapted to well defined categories of problems. The files are commented (see Section 4.1 [Comments], page 15) and can be run without any modification.

```
/* ------------------------------------------------------------------
   File "mStrip.pro"
```

```
   This file defines the problem dependent data structures for the
   microstrip problem.

   To compute the solution:
       getdp mStrip -solve EleSta_v

   To compute post-results:
       getdp mStrip -pos Map
    or getdp mStrip -pos Cut
   ---------------------------------------------------------------------- */

Group {

  /* Let's start by defining the interface (i.e. elementary groups)
     between the mesh file and GetDP (no mesh object is defined, so
     the default mesh will be assumed to be in GMSH format and located
     in "mStrip.msh") */

  Air = Region[101]; Diel1 = Region[111];
  Ground = Region[120]; Line = Region[121];
  SurfInf = Region[130];

  /* We can then define a global group (used in "EleSta_v.pro",
     the file containing the function spaces and formulations) */

  DomainCC_Ele = Region[{Air, Diel1}];

}

Function {

  /* The relative permittivity (needed in the formulation) is piecewise
     defined in elementary groups */

  epsr[Air] = 1.;
  epsr[Diel1] = 9.8;

}

Constraint {

  /* Now, some Dirichlet conditions are defined. The name
     'ElectricScalarPotential' refers to the constraint name given in
     the function space */

  { Name ElectricScalarPotential; Type Assign;
    Case {
```

```
      { Region Region[{Ground, SurfInf}]; Value 0.; }
      { Region Line; Value 1.e-3; }
    }
  }

}

/* The formulation used and its tools, considered as being
   in a black box, can now be included */

Include "Jacobian_Lib.pro"
Include "Integration_Lib.pro"
Include "EleSta_v.pro"

/* Finally, we can define some operations to output results */

e = 1.e-7;

PostOperation {
  { Name Map; NameOfPostProcessing EleSta_v;
     Operation {
       Print [ v, OnElementsOf DomainCC_Ele, File "mStrip_v.pos" ];
       Print [ e, OnElementsOf DomainCC_Ele, File "mStrip_e.pos" ];
     }
  }
  { Name Cut; NameOfPostProcessing EleSta_v;
     Operation {
       Print [ e, OnLine {{e,e,0}{10.e-3,e,0}} {500}, File "Cut_e" ];
     }
  }

}

/* ------------------------------------------------------------------
   File "EleSta_v.pro"

   Electrostatics - Electric scalar potential v formulation
   ------------------------------------------------------------------

   I N P U T
   ---------

   Global Groups :  (Extension '_Ele' is for Electric problem)
   -------------
   Domain_Ele               Whole electric domain (not used)
   DomainCC_Ele             Nonconducting regions
   DomainC_Ele              Conducting regions (not used)
```

```
   Function :
   --------
   epsr[]                   Relative permittivity

   Constraint :
   ----------
   ElectricScalarPotential  Fixed electric scalar potential
                            (classical boundary condition)

   Physical constants :
   ------------------                                          */

   eps0 = 8.854187818e-12;

Group {
  DefineGroup[ Domain_Ele, DomainCC_Ele, DomainC_Ele ];
}

Function {
  DefineFunction[ epsr ];
}

FunctionSpace {
  { Name Hgrad_v_Ele; Type Form0;
    BasisFunction {
      // v = v  s   ,  for all nodes
      //      n  n
      { Name sn; NameOfCoef vn; Function BF_Node;
        Support DomainCC_Ele; Entity NodesOf[ All ]; }
    }
    Constraint {
      { NameOfCoef vn; EntityType NodesOf;
        NameOfConstraint ElectricScalarPotential; }
    }
  }
}


Formulation {
  { Name Electrostatics_v; Type FemEquation;
    Quantity {
      { Name v; Type Local; NameOfSpace Hgrad_v_Ele; }
    }
    Equation {
      Galerkin { [ epsr[] * Dof{d v} , {d v} ]; In DomainCC_Ele;
                 Jacobian Vol; Integration GradGrad; }
```

```
    }
  }
}


Resolution {
  { Name EleSta_v;
    System {
      { Name Sys_Ele; NameOfFormulation Electrostatics_v; }
    }
    Operation {
      Generate[Sys_Ele]; Solve[Sys_Ele]; SaveSolution[Sys_Ele];
    }
  }
}


PostProcessing {
  { Name EleSta_v; NameOfFormulation Electrostatics_v;
    Quantity {
      { Name v;
        Value {
          Local { [ {v} ]; In DomainCC_Ele; Jacobian Vol; }
        }
      }
      { Name e;
        Value {
          Local { [ -{d v} ]; In DomainCC_Ele; Jacobian Vol; }
        }
      }
      { Name d;
        Value {
          Local { [ -eps0*epsr[] * {d v} ]; In DomainCC_Ele;
                                              Jacobian Vol; }
        }
      }
    }
  }
}

/* ------------------------------------------------------------------
   File "Jacobian_Lib.pro"

   Definition of a jacobian method
   ------------------------------------------------------------------

   I N P U T
```

```
   ---------

   GlobalGroup :
   -----------
   DomainInf                Regions with Spherical Shell Transformation

   Parameters :
   ----------
   Val_Rint, Val_Rext       Inner and outer radius of the Spherical Shell
                            of DomainInf
*/

Group {
  DefineGroup[ DomainInf ] ;
  DefineVariable[ Val_Rint, Val_Rext ] ;
}

Jacobian {
  { Name Vol ;
    Case { { Region DomainInf ;
             Jacobian VolSphShell {Val_Rint, Val_Rext} ; }
           { Region All ; Jacobian Vol ; }
    }
  }
}

/* ------------------------------------------------------------------
   File "Integration_Lib.pro"

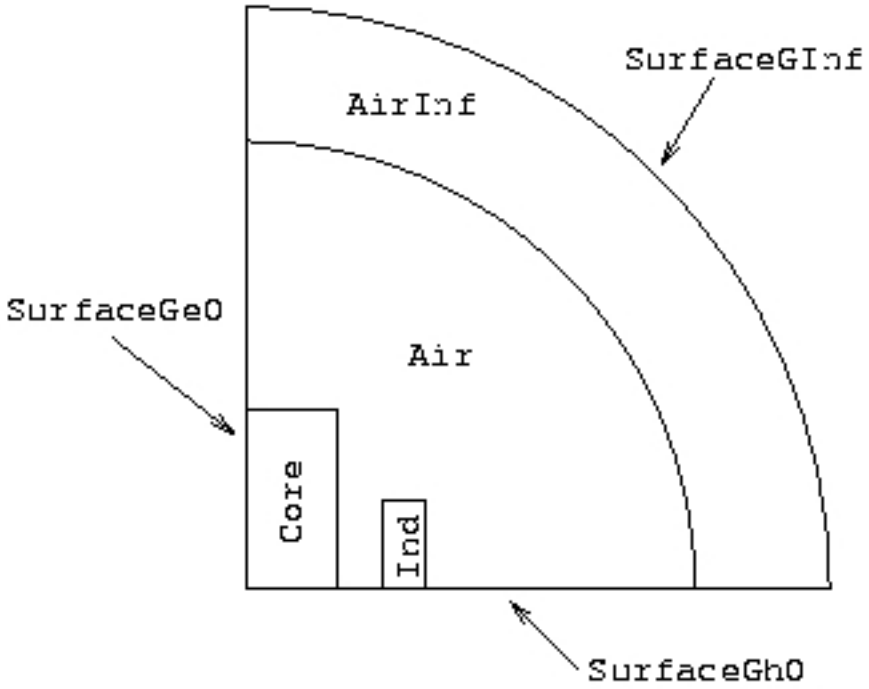
   Definition of integration methods
   ------------------------------------------------------------------ */

Integration {
  { Name GradGrad ;
    Case { {Type Gauss ;
            Case { { GeoElement Triangle    ; NumberOfPoints  4 ; }
                   { GeoElement Quadrangle  ; NumberOfPoints  4 ; }
                   { GeoElement Tetrahedron ; NumberOfPoints  4 ; }
                   { GeoElement Hexahedron  ; NumberOfPoints  6 ; }
                   { GeoElement Prism       ; NumberOfPoints  9 ; } }
          }
         }
  }
  { Name CurlCurl ;
    Case { {Type Gauss ;
            Case { { GeoElement Triangle    ; NumberOfPoints  4 ; }
                   { GeoElement Quadrangle  ; NumberOfPoints  4 ; }
```

```
                    { GeoElement Tetrahedron ; NumberOfPoints  4 ; }
                    { GeoElement Hexahedron  ; NumberOfPoints  6 ; }
                    { GeoElement Prism       ; NumberOfPoints  9 ; } }
            }
          }
  }
}
```

## 8.2 Magnetostatic problem

We now consider a magnetostatic problem. The formulation used is a 2D magnetic vector potential formulation (see file '`MagSta_a_2D.pro`'). It is applied to a core-inductor system (file '`CoreSta.pro`'), whose geometry is defined in theh file '`Core.geo`' (see Appendix B [Gmsh examples], page 115). The geometry is two-dimensional and, by symmetry, one fourth of the structure is modeled.




The jacobian and integration methods used are the same as for the electrostatic problem presented in Section 8.1 [Electrostatic problem], page 91.

```
/* -------------------------------------------------------------------
   File "CoreSta.pro"

   This file defines the problem dependent data structures for the
   static core-inductor problem.

   To compute the solution:
       getdp CoreSta -msh Core.msh -solve MagSta_a_2D

   To compute post-results:
       getdp CoreSta -msh Core.msh -pos Map_a
   ------------------------------------------------------------------- */

Group {
```

```
  Air    = Region[ 101 ];   Core   = Region[ 102 ];
  Ind    = Region[ 103 ];   AirInf = Region[ 111 ];

  SurfaceGh0  = Region[ 1100 ];  SurfaceGe0 = Region[ 1101 ];
  SurfaceGInf = Region[ 1102 ];

  Val_Rint = 200.e-3;
  Val_Rext = 250.e-3;

  DomainCC_Mag = Region[ {Air, AirInf, Core, Ind} ];
  DomainC_Mag  = Region[ {} ];
  DomainS_Mag  = Region[ {Ind} ]; // Stranded inductor
  DomainInf    = Region[ {AirInf} ];
  Domain_Mag   = Region[ {DomainCC_Mag, DomainC_Mag} ];

}

Function {

  mu0 = 4.e-7 * Pi;
  murCore = 100.;

  nu [ Region[{Air, Ind, AirInf}] ]  = 1. / mu0;
  nu [ Core ]  = 1. / (murCore * mu0);

  Sc[ Ind ] = 2.5e-2 * 5.e-2;

}

Constraint {

  { Name MagneticVectorPotential_2D;
    Case {
      { Region SurfaceGe0 ; Value 0.; }
      { Region SurfaceGInf; Value 0.; }
    }
  }

  Val_I_1_ = 0.01 * 1000.;

  { Name SourceCurrentDensityZ;
    Case {
      { Region Ind; Value Val_I_1_/Sc[]; }
    }
  }
```

```
}

Include "Jacobian_Lib.pro"
Include "Integration_Lib.pro"
Include "MagSta_a_2D.pro"

e = 1.e-5;
p1 = {e,e,0};
p2 = {0.12,e,0};

PostOperation {

  { Name Map_a; NameOfPostProcessing MagSta_a_2D;
    Operation {
      Print[ az, OnElementsOf Domain_Mag, File "CoreSta_a.pos" ];
      Print[ b, OnLine{{List[p1]}{List[p2]}} {1000}, File "k_a" ];
    }
  }

}

/* ------------------------------------------------------------------
   File "MagSta_a_2D.pro"

    Magnetostatics - Magnetic vector potential a formulation (2D)
   ------------------------------------------------------------------

   I N P U T
   ---------

   GlobalGroup :  (Extension '_Mag' is for Magnetic problem)
   -----------
   Domain_Mag               Whole magnetic domain
   DomainS_Mag              Inductor regions (Source)

   Function :
   --------
   nu[]                     Magnetic reluctivity

   Constraint :
   ----------
   MagneticVectorPotential_2D
                            Fixed magnetic vector potential (2D)
                            (classical boundary condition)
   SourceCurrentDensityZ    Fixed source current density (in Z direction)
*/
```

```
Group {
  DefineGroup[ Domain_Mag, DomainS_Mag ];
}

Function {
  DefineFunction[ nu ];
}

FunctionSpace {

  // Magnetic vector potential a (b = curl a)
  { Name Hcurl_a_Mag_2D; Type Form1P;
    BasisFunction {
      // a = a  s
      //      e  e
      { Name se; NameOfCoef ae; Function BF_PerpendicularEdge;
        Support Domain_Mag; Entity NodesOf[ All ]; }
    }
    Constraint {
      { NameOfCoef ae; EntityType NodesOf;
        NameOfConstraint MagneticVectorPotential_2D; }
    }
  }

  // Source current density js (fully fixed space)
  { Name Hregion_j_Mag_2D; Type Vector;
    BasisFunction {
      { Name sr; NameOfCoef jsr; Function BF_RegionZ;
        Support DomainS_Mag; Entity DomainS_Mag; }
    }
    Constraint {
      { NameOfCoef jsr; EntityType Region;
        NameOfConstraint SourceCurrentDensityZ; }
    }
  }

}

Formulation {
  { Name Magnetostatics_a_2D; Type FemEquation;
    Quantity {
      { Name a ; Type Local; NameOfSpace Hcurl_a_Mag_2D; }
      { Name js; Type Local; NameOfSpace Hregion_j_Mag_2D; }
    }
    Equation {
      Galerkin { [ nu[] * Dof{d a} , {d a} ]; In Domain_Mag;
                 Jacobian Vol; Integration CurlCurl; }
```

```
      Galerkin { [ - Dof{js} , {a} ]; In DomainS_Mag;
                 Jacobian Vol; Integration CurlCurl; }
    }
  }
}

Resolution {
  { Name MagSta_a_2D;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetostatics_a_2D; }
    }
    Operation {
      Generate[Sys_Mag]; Solve[Sys_Mag]; SaveSolution[Sys_Mag];
    }
  }
}

PostProcessing {
  { Name MagSta_a_2D; NameOfFormulation Magnetostatics_a_2D;
    Quantity {
      { Name a;
        Value {
          Local { [ {a} ]; In Domain_Mag; Jacobian Vol; }
        }
      }
      { Name az;
        Value {
          Local { [ CompZ[{a}] ]; In Domain_Mag; Jacobian Vol; }
        }
      }
      { Name b;
        Value {
          Local { [ {d a} ]; In Domain_Mag; Jacobian Vol; }
        }
      }
      { Name h;
        Value {
          Local { [ nu[] * {d a} ]; In Domain_Mag; Jacobian Vol; }
        }
      }
    }
  }
}
```

## 8.3 Magnetodynamic problem

As a third example we consider a magnetodynamic problem. The formulation is a two-dimensional a-v formulation (see file '`MagDyn_av_2D.pro`', which includes the same jacobian and integration library files as in Section 8.1 [Electrostatic problem], page 91). It is applied to a core-inductor system (defined in file '`CoreMassive.pro`'), whose geometry has already been defined in file '`Core.geo`'.

```
/* -------------------------------------------------------------------
   File "CoreMassive.pro"

   This file defines the problem dependent data structures for the
   dynamic core-inductor problem.

   To compute the solution:
        getdp CoreMassive -msh Core.msh -solve MagDyn_av_2D

   To compute post-results:
        getdp CoreMassive -msh Core.msh -pos Map_a
        getdp CoreMassive -msh Core.msh -pos U_av
   ------------------------------------------------------------------- */

Group {

  Air    = Region[ 101 ];   Core   = Region[ 102 ];
  Ind    = Region[ 103 ];   AirInf = Region[ 111 ];

  SurfaceGh0  = Region[ 1100 ];  SurfaceGe0 = Region[ 1101 ];
  SurfaceGInf = Region[ 1102 ];

  Val_Rint = 200.e-3;
  Val_Rext = 250.e-3;

  DomainCC_Mag = Region[ {Air, AirInf} ];
  DomainC_Mag  = Region[ {Ind, Core} ]; // Massive inductor + conducting core
  DomainB_Mag  = Region[ {} ];
  DomainS_Mag  = Region[ {} ];
  DomainInf    = Region[ {AirInf} ];
  Domain_Mag   = Region[ {DomainCC_Mag, DomainC_Mag} ];

}

Function {

  mu0 = 4.e-7 * Pi;

  murCore = 100.;
```

```
  nu [ #{Air, Ind, AirInf} ]  = 1. / mu0;
  nu [ Core ]  = 1. / (murCore * mu0);
  sigma [ Ind ] = 5.9e7;
  sigma [ Core ] = 2.5e7;

  Freq = 1.;

}

Constraint {

  { Name MagneticVectorPotential_2D;
    Case {
      { Region SurfaceGe0 ; Value 0.; }
      { Region SurfaceGInf; Value 0.; }
    }
  }

  { Name SourceCurrentDensityZ;
    Case {
    }
  }

  Val_I_ = 0.01 * 1000.;

  { Name Current_2D;
    Case {
      { Region Ind; Value Val_I_; }
    }
  }

  { Name Voltage_2D;
    Case {
      { Region Core; Value 0.; }
    }
  }

}

Include "Jacobian_Lib.pro"
Include "Integration_Lib.pro"
Include "MagDyn_av_2D.pro"

PostOperation {
  { Name Map_a; NameOfPostProcessing MagDyn_av_2D;
    Operation {
```

```
      Print[ az, OnElementsOf Domain_Mag, File "Core_m_a.pos" ];
      Print[ j, OnElementsOf Domain_Mag, File "Core_m_j.pos" ];
    }
  }
  { Name U_av;  NameOfPostProcessing MagDyn_av_2D;
    Operation {
      Print[ U, OnRegion Ind ];
      Print[ I, OnRegion Ind ];
    }
  }
}

/* -------------------------------------------------------------------
   File "MagDyn_av_2D.pro"

    Magnetodynamics - Magnetic vector potential and electric scalar
                      potential a-v formulation (2D)
   -------------------------------------------------------------------

   I N P U T
   ---------

   GlobalGroup :  (Extension '_Mag' is for Magnetic problem)
   -----------
   Domain_Mag               Whole magnetic domain
   DomainCC_Mag             Nonconducting regions (not used)
   DomainC_Mag              Conducting regions
   DomainS_Mag              Inductor regions (Source)
   DomainV_Mag              All regions in movement (for speed term)

   Function :
   --------
   nu[]                     Magnetic reluctivity
   sigma[]                  Electric conductivity

   Velocity[]               Velocity of regions

   Constraint :
   ----------
   MagneticVectorPotential_2D
                            Fixed magnetic vector potential (2D)
                            (classical boundary condition)
   SourceCurrentDensityZ    Fixed source current density (in Z direction)

   Voltage_2D               Fixed voltage
   Current_2D               Fixed Current
```

```
   Parameters :
   ----------

   Freq                     Frequency (Hz)

   Parameters for time loop with theta scheme :
   Mag_Time0, Mag_TimeMax, Mag_DTime
                            Initial time, Maximum time, Time step  (s)
   Mag_Theta                Theta  (e.g. 1.  : Implicit Euler,
                                        0.5 : Cranck Nicholson)
*/

Group {
  DefineGroup[ Domain_Mag, DomainCC_Mag, DomainC_Mag,
               DomainS_Mag, DomainV_Mag ];
}

Function {
  DefineFunction[ nu, sigma ];
  DefineFunction[ Velocity ];
  DefineVariable[ Freq ];
  DefineVariable[ Mag_Time0, Mag_TimeMax, Mag_DTime, Mag_Theta ];
}

FunctionSpace {

  // Magnetic vector potential a (b = curl a)
  { Name Hcurl_a_Mag_2D; Type Form1P;
    BasisFunction {
      // a = a  s
      //      e  e
      { Name se; NameOfCoef ae; Function BF_PerpendicularEdge;
        Support Domain_Mag; Entity NodesOf[ All ]; }
    }
    Constraint {
      { NameOfCoef ae; EntityType NodesOf;
        NameOfConstraint MagneticVectorPotential_2D; }
    }
  }

  // Gradient of Electric scalar potential (2D)
  { Name Hregion_u_Mag_2D; Type Form1P;
    BasisFunction {
      { Name sr; NameOfCoef ur; Function BF_RegionZ;
        Support DomainC_Mag; Entity DomainC_Mag; }
    }
    GlobalQuantity {
```

```
      { Name U; Type AliasOf       ; NameOfCoef ur; }
      { Name I; Type AssociatedWith; NameOfCoef ur; }
    }
    Constraint {
      { NameOfCoef U; EntityType Region;
        NameOfConstraint Voltage_2D; }
      { NameOfCoef I; EntityType Region;
        NameOfConstraint Current_2D; }
    }
  }

  // Source current density js (fully fixed space)
  { Name Hregion_j_Mag_2D; Type Vector;
    BasisFunction {
      { Name sr; NameOfCoef jsr; Function BF_RegionZ;
        Support DomainS_Mag; Entity DomainS_Mag; }
    }
    Constraint {
      { NameOfCoef jsr; EntityType Region;
        NameOfConstraint SourceCurrentDensityZ; }
    }
  }

}


Formulation {
  { Name Magnetodynamics_av_2D; Type FemEquation;
    Quantity {
      { Name a ; Type Local ; NameOfSpace Hcurl_a_Mag_2D; }
      { Name ur; Type Local ; NameOfSpace Hregion_u_Mag_2D; }
      { Name I ; Type Global; NameOfSpace Hregion_u_Mag_2D [I]; }
      { Name U ; Type Global; NameOfSpace Hregion_u_Mag_2D [U]; }
      { Name js; Type Local ; NameOfSpace Hregion_j_Mag_2D; }
    }
    Equation {
      Galerkin { [ nu[] * Dof{d a} , {d a} ]; In Domain_Mag;
                 Jacobian Vol; Integration CurlCurl; }

      Galerkin { DtDof [ sigma[] * Dof{a} , {a} ]; In DomainC_Mag;
                 Jacobian Vol; Integration CurlCurl; }
      Galerkin { [ sigma[] * Dof{ur} , {a} ]; In DomainC_Mag;
                 Jacobian Vol; Integration CurlCurl; }

      Galerkin { [ - sigma[] * (Velocity[] *^ Dof{d a}) , {a} ];
                 In DomainV_Mag;
                 Jacobian Vol; Integration CurlCurl; }
```

```
      Galerkin { [ - Dof{js} , {a} ]; In DomainS_Mag;
                 Jacobian Vol;
                 Integration CurlCurl; }

      Galerkin { DtDof [ sigma[] * Dof{a} , {ur} ]; In DomainC_Mag;
                 Jacobian Vol; Integration CurlCurl; }
      Galerkin { [ sigma[] * Dof{ur} , {ur} ]; In DomainC_Mag;
                 Jacobian Vol; Integration CurlCurl; }
      GlobalTerm { [ Dof{I} , {U} ]; In DomainC_Mag; }
    }
  }
}


Resolution {
  { Name MagDyn_av_2D;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetodynamics_av_2D;
        Type ComplexValue; Frequency Freq; }
    }
    Operation {
      Generate[Sys_Mag]; Solve[Sys_Mag]; SaveSolution[Sys_Mag];
    }
  }

  { Name MagDyn_t_av_2D;
    System {
      { Name Sys_Mag; NameOfFormulation Magnetodynamics_av_2D; }
    }
    Operation {
      InitSolution[Sys_Mag]; SaveSolution[Sys_Mag];
      TimeLoopTheta[Mag_Time0, Mag_TimeMax, Mag_DTime, Mag_Theta] {
        Generate[Sys_Mag]; Solve[Sys_Mag]; SaveSolution[Sys_Mag];
      }
    }
  }

}


PostProcessing {
  { Name MagDyn_av_2D; NameOfFormulation Magnetodynamics_av_2D;
    Quantity {
      { Name a;
        Value {
          Local { [ {a} ]; In Domain_Mag; Jacobian Vol; }
```

```
      }
    }
    { Name az;
      Value {
        Local { [ CompZ[{a}] ]; In Domain_Mag; Jacobian Vol; }
      }
    }
    { Name b;
      Value {
        Local { [ {d a} ]; In Domain_Mag; Jacobian Vol; }
      }
    }
    { Name h;
      Value {
        Local { [ nu[] * {d a} ]; In Domain_Mag; Jacobian Vol; }
      }
    }
    { Name j;
      Value {
        Local { [ - sigma[]*(Dt[{a}]+{ur}) ]; In DomainC_Mag;
                Jacobian Vol; }
      }
    }
    { Name jz;
      Value {
        Local { [ - sigma[]*CompZ[Dt[{a}]+{ur}] ]; In DomainC_Mag;
                Jacobian Vol; }
      }
    }
    { Name roj2;
      Value {
        Local { [ sigma[]*SquNorm[Dt[{a}]+{ur}] ]; In DomainC_Mag;
                Jacobian Vol; }
      }
    }
    { Name U; Value { Local { [ {U} ]; In DomainC_Mag; } } }
    { Name I; Value { Local { [ {I} ]; In DomainC_Mag; } } }
  }
 }
}
```

# Appendix A File formats

This chapter describes the file formats that cannot be modified by the user. The format of the problem definition structure is explained in Chapter 5 [Objects], page 29, and Chapter 6 [Types for objects], page 43. The format of the post-processing files is explained in Section 6.10 [Types for PostOperation], page 67.

## A.1 Input file format

The native mesh format read by GetDP is the mesh file format produced by Gmsh (`http://gmsh.info`). In its "version 1" incarnation, an 'msh' file is divided into two sections, defining the nodes and the elements in the mesh.

```
$NOD
number-of-nodes
node-number x-coord y-coord z-coord
...
$ENDNOD
$ELM
number-of-elements
elm-number elm-type elm-region unused number-of-nodes node-numbers
...
$ENDELM
```

All the syntactic variables stand for integers except *x-coord*, *y-coord* and *z-coord* which stand for floating point values. The *elm-type* value defines the geometrical type for the element:

*elm-type*:

`1` Line (2 nodes, 1 edge).

`2` Triangle (3 nodes, 3 edges).

`3` Quadrangle (4 nodes, 4 edges).

`4` Tetrahedron (4 nodes, 6 edges, 4 facets).

`5` Hexahedron (8 nodes, 12 edges, 6 facets).

`6` Prism (6 nodes, 9 edges, 5 facets).

`7` Pyramid (5 nodes, 8 edges, 5 facets).

`15` Point (1 node).

GetDP can also read more recent versions of the 'msh' format (2.0 and above), as well as binary meshes. See the Gmsh documentation for more information about these formats.

## A.2 Output file format

### A.2.1 File '.pre'

The '.pre' file is generated by the pre-processing stage. It contains all the information about the degrees of freedom to be considered during the processing stage for a given resolution (i.e., unknowns, fixed values, initial values, etc.).

```
$Resolution /* 'resolution-id' */
main-resolution-number number-of-dofdata
$EndResolution
$DofData /* #dofdata-number */
resolution-number system-number
number-of-function-spaces function-space-number ...
number-of-time-functions time-function-number ...
number-of-partitions partition-index ...
number-of-any-dof number-of-dof
dof-basis-function-number dof-entity dof-harmonic dof-type dof-data
...
$EndDofData
...
```

with

```
dof-data:
  equation-number nnz
    (dof-type: 1; unknown) |
  dof-value dof-time-function-number
    (dof-type: 2; fixed value) |
  dof-associate-dof-number dof-value dof-time-function-number
    (dof-type: 3; associated degree of freedom) |
  equation-number dof-value
    (dof-type: 5; initial value for an unknown)
```

Notes:

1. There is one `$DofData` field for each system of equations considered in the resolution (including those considered in pre-resolutions).
2. The *dofdata-number* of a `$DofData` field is determined by the order of this field in the '.pre' file.
3. *number-of-dof* is the dimension of the considered system of equations, while *number-of-any-dof* is the total number of degrees of freedom before the application of constraints.
4. Each degree of freedom is coded with three integer values, which are the associated basis function, entity and harmonic numbers, i.e., *dof-basis-function-number*, *dof-entity* and *dof-harmonic*.
5. *nnz* is not used at the moment.

### A.2.2 File '.res'

The '.res' file is generated by the processing stage. It contains the solution of the problem (or a part of it in case of program interruption).

```
$ResFormat /* GetDP vgetdp-version-number, string-for-format */
```

```
1.1 file-res-format
$EndResFormat
$Solution  /* DofData #dofdata-number */
dofdata-number time-value time-imag-value time-step-number
solution-value
...
$EndSolution
...
```

Notes:

1. A `$Solution` field contains the solution associated with a `$DofData` field.
2. There is one `$Solution` field for each time step, of which the time is *time-value* (0 for non time dependent or non modal analyses) and the imaginary time is *time-imag-value* (0 for non time dependent or non modal analyses).
3. The order of the *solution-value*s in a `$Solution` field follows the numbering of the equations given in the '`.pre`' file (one floating point value for each degree of freedom).

# Appendix B Gmsh examples

Gmsh is a three-dimensional finite element mesh generator with simple CAD and post-processing capabilities that can be used as a graphical front-end for GetDP. Gmsh can be downloaded from http://gmsh.info.

This appendix reproduces verbatim the input files needed by Gmsh to produce the mesh files 'mStrip.msh' and 'Core.msh' used in the examples of Chapter 8 [Complete examples], page 91.

```
/* -------------------------------------------------------------------
   File "mStrip.geo"

   This file is the geometrical description used by GMSH to produce
   the file "mStrip.msh".
   ------------------------------------------------------------------- */

/* Definition of some parameters for geometrical dimensions, i.e.
   h (height of 'Diel1'), w (width of 'Line'), t (thickness of 'Line')
   xBox (width of the air box) and yBox (height of the air box) */

h = 1.e-3 ; w = 4.72e-3 ;  t = 0.035e-3 ;
xBox = w/2. * 6. ;  yBox = h * 12. ;

/* Definition of parameters for local mesh dimensions */

s = 1. ;
p0 = h / 10. * s ;
pLine0 = w/2. / 10. * s ;  pLine1 = w/2. / 50. * s ;
pxBox = xBox / 10. * s ;  pyBox = yBox / 8. * s ;

/* Definition of gemetrical points */

Point(1) = { 0   , 0, 0, p0} ;
Point(2) = { xBox, 0, 0, pxBox} ;
Point(3) = { xBox, h, 0, pxBox} ;
Point(4) = { 0   , h, 0, pLine0} ;
Point(5) = { w/2., h, 0, pLine1} ;
Point(6) = { 0   , h+t, 0, pLine0} ;
Point(7) = { w/2., h+t, 0, pLine1} ;
Point(8) = { 0   , yBox, 0, pyBox} ;
Point(9) = { xBox, yBox, 0, pyBox} ;

/* Definition of gemetrical lines */

Line(1) = {1,2};   Line(2) = {2,3};  Line(3) = {3,9};
Line(4) = {9,8};   Line(5) = {8,6};  Line(7) = {4,1};
Line(8) = {5,3};   Line(9) = {4,5};  Line(10) = {6,7};
```

```
Line(11) = {5,7};

/* Definition of geometrical surfaces */

Line Loop(12) = {8,-2,-1,-7,9};   Plane Surface(13) = {12};
Line Loop(14) = {10,-11,8,3,4,5}; Plane Surface(15) = {14};

/* Definition of Physical entities (surfaces, lines). The Physical
   entities tell GMSH the elements and their associated region numbers
   to save in the file 'mStrip.msh'. For example, the Region
   111 is made of elements of surface 13, while the Region 121 is
   made of elements of lines 9, 10 and 11 */

Physical Surface (101) = {15} ;   /* Air */
Physical Surface (111) = {13} ;   /* Diel1 */

Physical Line (120) = {1} ;       /* Ground */
Physical Line (121) = {9,10,11} ; /* Line */
Physical Line (130) = {2,3,4} ;   /* SurfInf */

/* ------------------------------------------------------------------
   File "Core.geo"

   This file is the geometrical description used by GMSH to produce
   the file "Core.msh".
   ------------------------------------------------------------------ */

dxCore =  50.e-3; dyCore = 100.e-3;
xInd   =  75.e-3; dxInd  =  25.e-3; dyInd  =  50.e-3;
rInt   = 200.e-3; rExt   = 250.e-3;

s       =  1.;
p0      = 12.e-3 *s;
pCorex  =  4.e-3 *s; pCorey0 =  8.e-3 *s; pCorey  =  4.e-3 *s;
pIndx   =  5.e-3 *s; pIndy   =  5.e-3 *s;
pInt    = 12.5e-3*s; pExt    = 12.5e-3*s;

Point(1) = {0,0,0,p0};
Point(2) = {dxCore,0,0,pCorex};
Point(3) = {dxCore,dyCore,0,pCorey};
Point(4) = {0,dyCore,0,pCorey0};
Point(5) = {xInd,0,0,pIndx};
Point(6) = {xInd+dxInd,0,0,pIndx};
Point(7) = {xInd+dxInd,dyInd,0,pIndy};
Point(8) = {xInd,dyInd,0,pIndy};
Point(9) = {rInt,0,0,pInt};
Point(10) = {rExt,0,0,pExt};
```

```
Point(11) = {0,rInt,0,pInt};
Point(12) = {0,rExt,0,pExt};

Line(1) = {1,2};  Line(2) = {2,5};   Line(3) = {5,6};
Line(4) = {6,9};  Line(5) = {9,10};  Line(6) = {1,4};
Line(7) = {4,11}; Line(8) = {11,12}; Line(9) = {2,3};
Line(10) = {3,4}; Line(11) = {6,7};  Line(12) = {7,8};
Line(13) = {8,5};

Circle(14) = {9,1,11};  Circle(15) = {10,1,12};

Line Loop(16) = {-6,1,9,10};                 Plane Surface(17) = {16};
Line Loop(18) = {11,12,13,3};                Plane Surface(19) = {18};
Line Loop(20) = {7,-14,-4,11,12,13,-2,9,10}; Plane Surface(21) = {20};
Line Loop(22) = {8,-15,-5,14};               Plane Surface(23) = {22};

Physical Surface(101) = {21};  /* Air */
Physical Surface(102) = {17};  /* Core */
Physical Surface(103) = {19};  /* Ind */
Physical Surface(111) = {23};  /* AirInf */

Physical Line(1000) = {1,2};       /* Cut */
Physical Line(1001) = {2};         /* CutAir */
Physical Line(202)  = {9,10};      /* SkinCore */
Physical Line(203)  = {11,12,13};  /* SkinInd */
Physical Line(1100) = {1,2,3,4,5}; /* SurfaceGh0 */
Physical Line(1101) = {6,7,8};     /* SurfaceGe0 */
Physical Line(1102) = {15};        /* SurfaceGInf */
```

# Appendix C Compiling the source code

Stable releases and nightly source snapshots are available from http://getdp.info/src/. You can also access the Git repository directly:

1. The first time you want to download the latest full source, type:

   ```
   git clone http://gitlab.onelab.info/getdp/getdp.git
   ```

2. To update your local version to the latest and greatest, go in the getdp directory and type:

   ```
   git pull
   ```

Once you have the source code, you need to run CMake to configure your build (see the README.txt file in the top-level source directory for detailed information on how to run CMake).

Each build can be configured using a series of options, to selectively enable optional modules or features. Here is the list of CMake options:

`ENABLE_ARPACK`
: Enable Arpack eigensolver (requires Fortran) (default: ON)

`ENABLE_CONTRIB_ARPACK`
: Enable Arpack eigensolver from GetDP's contrib folder (requires Fortran) (default: OFF)

`ENABLE_BLAS_LAPACK`
: Enable BLAS/Lapack for linear algebra (e.g. for Arpack) (default: ON)

`ENABLE_BUILD_LIB`
: Enable 'lib' target for building static GetDP library (default: OFF)

`ENABLE_BUILD_SHARED`
: Enable 'shared' target for building shared GetDP library (default: OFF)

`ENABLE_BUILD_DYNAMIC`
: Enable dynamic GetDP executable (linked with shared lib) (default: OFF)

`ENABLE_BUILD_ANDROID`
: Enable Android NDK library target (experimental) (default: OFF)

`ENABLE_BUILD_IOS`
: Enable iOS (ARM) library target (experimental) (default: OFF)

`ENABLE_FORTRAN`
: Enable Fortran (needed for Arpack/Sparskit/Zitsol & Bessel) (default: ON)

`ENABLE_GMSH`
: Enable Gmsh functions (for field interpolation) (default: ON)

`ENABLE_GSL`
: Enable GSL functions (for some built-in functions) (default: ON)

`ENABLE_LEGACY`
: Use legacy assembler (required for actual computations) (default: ON)

`ENABLE_MPI`
: Enable MPI parallelization (with PETSc/SLEPc) (default: OFF)

`ENABLE_MULTIHARMONIC`
: Enable multi-harmonic support (default: OFF)

`ENABLE_NR`
: Enable NR functions (if GSL is unavailable) (default: ON)

`ENABLE_NX`
: Enable proprietary NX extension (default: OFF)

`ENABLE_OCTAVE`
: Enable Octave functions (default: ON)

`ENABLE_OPENMP`
: Enable OpenMP parallelization of some functions (experimental) (default: OFF)

`ENABLE_PETSC`
: Enable PETSc linear solver (default: ON)

`ENABLE_PYTHON`
: Enable Python functions (default: ON)

`ENABLE_SLEPC`
: Enable SLEPc eigensolver (default: ON)

`ENABLE_SMALLFEM`
: Enable experimental SmallFem assembler (default: OFF)

`ENABLE_SPARSKIT`
: Enable Sparskit solver instead of PETSc (requires Fortran) (default: ON)

`ENABLE_WRAP_PYTHON`
: Build Python wrappers (default: OFF)

`ENABLE_ZITSOL`
: Enable Zitsol solvers (requires PETSc and Fortran) (default: OFF)

# Appendix D Frequently asked questions

## D.1 The basics

1. What is GetDP?

   GetDP is a scientific software environment for the numerical solution of integro-differential equations, open to the coupling of physical problems (electromagnetic, thermal, mechanical, etc) as well as of numerical methods (finite element method, integral methods, etc). It can deal with such problems of various dimensions (1D, 2D, 2D axisymmetric or 3D) and time states (static, transient or harmonic). The main feature of GetDP is the closeness between the organization of data defining discrete problems (written by the user in ASCII data files) and the symbolic mathematical expressions of these problems.

2. What are the terms and conditions of use?

   GetDP is distributed under the terms of the GNU General Public License. See Appendix H [License], page 131 for more information.

3. What does 'GetDP' mean?

   It's an acronym for a "General environment for the treatment of Discrete Problems".

4. Where can I find more information?

   `http://getdp.info` is the primary site to obtain information about GetDP. You will find a short presentation, a complete reference guide as well as a searchable archive of the GetDP mailing list (`getdp@onelab.info`) on this site.

## D.2 Installation

1. Which OSes does GetDP run on?

   Gmsh runs on Windows, MacOS X, Linux and most Unix variants.

2. What do I need to compile GetDP from the sources?

   You need a C++ and a Fortran compiler as well as the GSL (version 1.2 or higher; freely available from `http://sources.redhat.com/gsl`).

3. How do I compile GetDP?

   You need cmake (`http://www.cmake.org`) and a C++ compiler (and a Fortran compiler depending on the modules/solvers you want to compile). See Appendix C [Compiling the source code], page 119 and the README.txt file in the top-level source directory for more information.

4. GetDP [from a binary distribution] complains about missing libraries.

   Try `ldd getdp` (or `otool -L getdp` on MacOS X) to check if all the required shared libraries are installed on your system. If not, install them. If it still doesn't work, recompile GetDP from the sources.

## D.3 Usage

1. How can I provide a mesh to GetDP?

   The only meshing format accepted by this version of GetDP is the 'msh' format created by Gmsh `http://gmsh.info`. This format being very simple (see the Gmsh reference

manual for more details), it should be straightforward to write a converter from your mesh format to the 'msh' format.

2. How can I visualize the results produced by GetDP?

   You can specify a format in all post-processing operations. Available formats include `Table`, `SimpleTable`, `TimeTable` and `Gmsh`. `Table`, `SimpleTable` and `TimeTable` output lists of numbers easily readable by Excel/gnuplot/Caleida Graph/etc. `Gmsh` outputs post-processing views directly loadable by Gmsh.

3. How do I change the linear solver used by GetDP?

   It depends on which linear solver toolkit was enabled when GetDP was compiled (PETSc or Sparskit).

   With PETSc-based linear solvers you can either specify options directly on the command line (e.g. with `-ksp_type gmres -pc_type ilu`), through a specific option file (with `-solver file`), or through the '`.petscrc`' file located in your home directly.

   With Sparskit-based linear solvers can either specify options directly on command line (e.g. with `-Nb_Fill 200`), specify an option file explicitly (with `-solver file`), or edit the '`solver.par`' file in the current working directory. If no '`solver.par`' file exists in the current directory, GetDP will give create it the next time you perform a linear system solution.

# Appendix E Tips and tricks

- Install the 'info' version of this user's guide! On your (Unix) system, this can be achieved by 1) copying all getdp.info* files to the place where your info files live (usually /usr/info), and 2) issuing the command 'install-info /usr/info/getdp.info /usr/info/dir'. You will then be able to access the documentation with the command 'info getdp'. Note that particular sections ("nodes") can be accessed directly. For example, 'info getdp functionspace' will take you directly to the definition of the FunctionSpace object.
- Use emacs to edit your files, and load the C++ mode! This permits automatic syntax highlighting and easy indentation. Automatic loading of the C++ mode for '`.pro`' files can be achieved by adding the following command in your `.emacs` file: `(setq auto-mode-alist (append '(("\\.pro$" . c++-mode)) auto-mode-alist))`.
- Define integration and Jacobian method in separate files, reusable in all your problem definition structures (see Section 4.2 [Includes], page 15). Define meshes, groups, functions and constraints in one file dependent of the geometrical model, and function spaces, formulations, resolutions and post-processings in files independent of the geometrical model.
- Use `All` as soon as possible in the definition of topological entities used as `Entity` of `BasisFunctions`. This will prevent GetDP from constructing unnecessary lists of entities.
- Intentionally misspelling an object type in the problem definition structure will produce an error message listing all available types in the particular context.
- If you don't specify the mandatory arguments on the command line, GetDP will give you the available choices. For example, 'getdp test -pos' (the name of the PostOperation is missing) will produce an error message listing all available PostOperations.

# Appendix F Version history

2.11.2 (June 23, 2017): minor build system changes.

2.11.1 (May 13, 2017): small bug fixes and improvements.

2.11.0 (January 3, 2017): small improvements (complex math functions, mutual terms, one side of, get/save runtime variables) and bug fixes.

2.10.0 (October 9, 2016): ONELAB 1.3 with usability and performance improvements.

2.9.2 (August 21, 2016): small bug fixes.

2.9.1 (August 18, 2016): small improvements (CopySolution[], -cpu) and bug fixes.

2.9.0 (July 11, 2016): new ONELAB 1.2 protocol with native support for lists; simple C++ and Python API for exchanging (lists of) numbers and strings; extended .pro language for the construction of extensible problem definitions ("Append"); new VolCylShell transformation; new functions (Min, Max, SetDTime, ...); small fixes.

2.8.0 (March 5, 2016): new Parse[], {Set,Get}{Number,String}[] and OnPositiveSideOf commands; added support for lists of strings; various improvements and bug fixes for better interactive use with ONELAB.

2.7.0 (November 7, 2015): new Else/ElseIf commands; new timing and memory reporting functions.

2.6.1 (July 30, 2015): enhanced Print[] command; minor fixes.

2.6.0 (July 21, 2015): new ability to define and use Macros in .pro files; new run-time variables (act as registers, but with user-defined names starting with '$') and run-time ONELAB Get/Set functions; new Append*ToFileName PostOperation options; new GetResdidual and associated operations; fixes and extended format support in MSH file reader; fixed UpdateConstraint for complex-simulated-real and multi-harmonic calculations.

2.5.1 (April 18, 2015): enhanced Python[] and DefineFunction[].

2.5.0 (March 12, 2015): added option to embed Octave and Python interpreters; extended "Field" functions with gradient; extended string and list handling functions; new resolution and postprocessing functions (RenameFile, While, ...); extended EigenSolve with eigenvalue filter and high order polynomial EV problems; small bug fixes.

2.4.4 (July 9, 2014): better stability, updated onelab API version and inline parameter definitions, fixed UpdateConstraint in harmonic case, improved performance of multi-harmonic assembly, fixed memory leak in parallel MPI version, improved EigenSolve (quadratic EVP with SLEPC, EVP on real matrices), new CosineTransform, MPI_Printf, SendMergeFileRequest parser commands, small improvements and bug fixes.

2.4.3 (February 7, 2014): new mandatory 'Name' attribute to define onelab variables in DefineConstant[] & co; minor bug fixes.

2.4.2 (Septembre 27, 2013): fixed function arguments in nested expressions; minor improvements.

2.4.1 (July 16, 2013): minor improvements and bug fixes.

2.4.0 (July 9, 2013): new two-step Init constraints; faster network computation (with new -cache); improved Update operation; better cpu/memory reporting; new -setnumber, -setstring and -gmshread command line options; accept unicode file paths on Windows; small bug fixes.

2.3.1 (May 11, 2013): updated onelab; small bug fixes.

2.3.0 (March 9, 2013): moved build system from autoconf to cmake; new family of Field functions to use data imported from Gmsh; improved list handling; general code cleanup.

2.2.1 (July 15, 2012): cleaned up nonlinear convergence tests and integrated experimental adaptive time loop code; small bug fixes.

2.2.0 (June 19, 2012): new solver interface based on ONELAB; parallel SLEPC eigensolvers; cleaned up syntax for groups, moving band and global basis functions; new Field[] functions to interpolate post-processing datasets from Gmsh; fixed bug in Sur/Lin transformation of 2 forms; fixed bug for periodic constraints on high-order edge elements.

2.1.1 (April 12, 2011): default direct solver using MUMPS.

2.1.0 (October 24, 2010): parallel resolution using PETSc solvers; new Gmsh2 output format; new experimental SLEPc-based eigensolvers; various bug and performance fixes (missing face basis functions, slow PETSc assembly with global quantities, ...)

2.0.0 (March 16, 2010): general code cleanup (separated interface from kernel code; removed various undocumented, unstable and otherwise experimental features; moved to C++); updated input file formats; default solvers are now based on PETSc; small bug fixes (binary .res read, Newmark -restart).

1.2.1 (March 18, 2006): Small fixes.

1.2.0 (March 10, 2006): Windows versions do not depend on Cygwin anymore; major parser cleanup (loops & co).

1.1.2 (September 3, 2005): Small fixes.

1.1.0 (August 21, 2005): New eigensolver based on Arpack (EigenSolve); generalized old Lanczos solver to work with GSL+lapack; reworked PETSc interface, which now requires PETSc 2.3; documented many previously undocumented features (loops, conditionals, strings, link constraints, etc.); various improvements and bug fixes.

1.0.1 (February 6, 2005): Small fixes.

1.0.0 (April 24, 2004): New license (GNU GPL); added support for latest Gmsh mesh file format; more code cleanups.

0.91: Merged moving band and multi-harmonic code; new loops and conditionals in the parser; removed old readline code (just use GNU readline if available); upgraded to latest Gmsh post-processing format; various small enhancements and bug fixes.

0.89 (March 26, 2003): Code cleanup.

0.88: Integrated FMM code.

0.87: Fixed major performance problem on Windows (matrix assembly and post-processing can be up to 3-4 times faster with 0.87 compared to 0.86, bringing performance much closer to Unix versions); fixed stack overflow on Mac OS X; Re-introduced face basis functions mistakenly removed in 0.86; fixed post-processing bug with pyramidal basis functions; new build system based on autoconf.

0.86 (January 25, 2003): Updated Gmsh output format; many small bug fixes.

0.85 (January 21, 2002): Upgraded communication interface with Gmsh; new ChangeOfValues option in PostOperation; many internal changes.

0.84 (September 6, 2001): New ChangeOfCoordinate option in PostOperation; fixed crash in InterpolationAkima; improved interactive postprocessing (-ipos); changed syntax of parametric OnGrid ($S, $T -> $A, $B, $C); corrected Skin for non simplicial meshes; fixed floating point exception in diagonal matrix scaling; many other small fixes and cleanups.

0.83: Fixed bugs in SaveSolutions[] and InitSolution[]; fixed corrupted binary post-processing files in the harmonic case for the Gmsh format; output files are

now created relatively to the input file directory; made solver options available on the command line; added optional matrix scaling and changed default parameter file name to 'solver.par' (Warning: please check the scaling definition in your old SOLVER.PAR files); generalized syntax for lists (start:[incr]end -> start:end:incr); updated reference guide; added a new short presentation on the web site; OnCut -> OnSection; new functional syntax for resolution operations (e.g. Generate X -> Generate[X]); many other small fixes and cleanups.

0.82: Added communication socket for interactive use with Gmsh; corrected (again) memory problem (leak + seg. fault) in time stepping schemes; corrected bug in Update[].

0.81: Generalization of transformation jacobians (spherical and rectangular, with optional parameters); changed handling of missing command line arguments; enhanced Print OnCut; fixed memory leak for time domain analysis of coupled problems; -name option; fixed seg. fault in ILUK.

0.80: Fixed computation of time derivatives on first time step (in post-processing); added tolerance in transformation jacobians; fixed parsing of DOS files (carriage return problems); automatic memory reallocation in ILUD/ILUK.

0.79: Various bug fixes (mainly for the post-processing of intergal quantities); automatic treatment of degenerated cases in axisymmetrical problems.

0.78: Various bug fixes.

0.77: Changed syntax for PostOperations (Plot suppressed in favour of Print; Plot OnRegion becomes Print OnElementsOf); changed table oriented post-processing formats; new binary formats; new error diagnostics.

0.76: Reorganized high order shape functions; optimization of the post-processing (faster and less bloated); lots of internal cleanups.

0.74: High order shape functions; lots of small bug fixes.

0.73: Eigen value problems (Lanczos); minor corrections.

0.7: constraint syntax; fourier transform; unary minus correction; complex integral quantity correction; separate iteration matrix generation.

0.6: Second order time derivatives; Newton nonlinear scheme; Newmark time stepping scheme; global quantity syntax; interactive post-processing; tensors; integral quantities; post-processing facilities.

0.3: First distributed version.

# Appendix G Copyright and credits

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This version of GetDP may contain code (in the contrib/Arpack subdirectory) written by Danny Sorensen, Richard Lehoucq, Chao Yang and Kristi Maschhoff from the Dept. of Computational & Applied Mathematics at Rice University, Houston, Texas, USA. See http://www.caam.rice.edu/software/ARPACK/ for more info.

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# Appendix H License

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