GetDP

GetDP Reference Manual

The documentation for GetDP 1.0
A General environment for the treatment of Discrete Problems

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Introduction

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.

Research and collaboration activities

The internal structure of the software is very close to the structure used to define discrete problems in the input data files. As a result, a unicity and conciseness of both development and application levels is obtained without any interface between them, which facilitates work of any kind—particularly validations. GetDP permits to rapidly develop tools for the comparison of methods and the exchange of solutions between research teams, which is one of the main aims of collaboration. Moreover, after a short training, GetDP could be used by teams as a basis for their own developments, while allowing a large freedom in the latter.

Education and training activities

The software environment consists of modeling tools applicable to various physical problems. Education and training can therefore be offered in various domains and at different levels. The closeness between the definition of discrete problems and their symbolic mathematical expressions entails that the theory and mathematical bases of numerical methods, which are essential to anyone who wants to tackle the solving of discrete problems, can be directly followed by their practical applications. These applications can be evolutionary, in the sense that the offered tools are of various levels of complexity. Everyone can tackle, step by step, according to his apprenticeship level, the tools adapted to the solving of more and more complex problems, as well as various methods for the solving of the same problem.

Industrial studies

The treatment of industrial problems can also be facilitated because GetDP is adapted to the study of a wide range of physical problems using various numerical methods. In particular, adapted made to measure and ready-to-use software could be rapidly developed for given problems.

How to read this manual

After reading Chapter 1 [Overview], page 5, and Chapter 2 [Expressions], page 9, which depict the general concepts and the way to construct simple expressions in GetDP, you can safely (during a first reading) skip Chapter 3 [Objects], page 17 and Chapter 4 [Types for objects], page 29 and directly go to Chapter 5 [Short examples], page 47. This chapter gives simple examples of the problem definition syntax used to define the discrete problems. For each example, you should then go back to Chapter 3 [Objects], page 17, and Chapter 4 [Types for objects], page 29, and have a detailed view of the syntax of the objects appearing in it. Note that indexes for many concepts and for all the syntax elements are available at the end of this manual.

Once the examples presented in Chapter 5 [Short examples], page 47, are understood, you may start to use GetDP on your computer (see Chapter 7 [Running GetDP], page 81), for example by solving the complete examples presented in Chapter 6 [Complete examples], page 63.

1 Overview

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 treatments of defined problems.

1.2 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 113, 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.

1.3 Comments

Both C and C++ style comments are supported and can be used in the input data file 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.

These commands won't have the described effects inside double quotes or inside GetDP keywords.

1.4 Includes

Files can be included by placing one of the following commands (*expression-char* represents a file name) on a separate line, and outside any GetDP object. Any text placed after an include command on the same line is ignored.

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

See Section 2.2 [Constants], page 9, for the definition of the character expression *expression-char*.

1.5 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
- eigen value problems (experimental)

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.

2 Expressions

2.1 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 1.2 [Syntactic rules], page 6):

expression:
  integer |
  real |
  constant-id |
  quantity |
  argument |
  current-value |
  register-value-set |
  register-value-get |
  operator-unary expression |
  expression operator-binary expression |
  expression operator-ternary-left expression operator-ternary-right expression |
  built-in-function-id `[ <` *expression-list* `> ] < {` *expression-cst-list* `} > |`
  function-id `[ <` *expression-list* `> ]`

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-value-set*, *register-value-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*). List of expressions are defined as:

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

2.2 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:
  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* `> ]`

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* `]` |
`ListAlt[` *constant-id*`,` *constant-id* `]`

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 last 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 2.4 [Functions], page 13).

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* `> <,...> ];` |
constant-id `=` *constant-def*;

with

constant-id:
string

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

Notes:

1. Five constants are predefined in GetDP: `Pi` (3.1415926535897932), `0D` (0), `1D` (1), `2D` (2) and `3D` (3).
2. 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).

See Section 5.1 [Constant expression examples], page 47, as well as Section 5.3 [Function examples], page 47, for some examples.

Constant character strings can also be defined. The syntax for their definition is the following:

string-id `=` `"`*string*`";`

with

string-id:
  string

Character expressions can be defined, using these constant strings:

expression-char:
  `"`*string*`"` `|`
  string-id `|`
  `StrCat[` *expression-char* `,` *expression-char* `]`

The third case in this definition permits to concatenate two character expressions.

2.3 Operators

2.3.1 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.

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.

2.3.2 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), !`
`/\`

`*, /, %`

`+, -`

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

`&&, ||`

`?:`

2.4 Functions

Two types of functions coexist in GetDP: user-defined functions (*function-id*, see Section 3.2 [Function], page 18) 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 2.6 [Arguments], page 14). 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 4.2 [Types for Function], page 30.
2. Classical mathematical functions (see Section 4.2.1 [Math functions], page 30) are the only functions allowed in a constant definition (see the definition of *expression-cst* in Section 2.2 [Constants], page 9).

2.5 Current values

Current values are a special kind of arguments (see Section 2.6 [Arguments], page 14) which return the current integer or 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.

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

`$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 4.10 [Types for PostOperation], page 42).

Note:

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

2.6 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 3.2 [Function], page 18, and Section 5.3 [Function examples], page 47, for more details.

2.7 Registers

In many situations, identical parts of expressions are used more than once. If this is not a problem with constant expressions (since *expression-cst*s are evaluated only once during the analysis of the problem definition structure, cf. Section 2.2 [Constants], page 9), it may introduce some important overhead while evaluating complex *expression*s (which are evaluated at runtime, thanks to an internal stack mechanism). In order to circumvent this problem, the evaluation result of any part of an *expression* can be saved in a register: a memory location where this partial result will be accessible without any costly reevaluation of the partial expression.

Registers have the following syntax:

register-value-set:
  expression`#`*integer*

register-value-get:
  `#`*integer*

Thus, to store any part of an 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 5.3 [Function examples], page 47, for an example.

2.8 Fields

A discretized quantity (defined in a function space, cf. Section 3.4 [FunctionSpace], page 20) is represented between braces `{}`, and can only appear in well-defined expressions in `Formulation` (see Section 3.7 [Formulation], page 23) and `PostProcessing` (see Section 3.9 [PostProcessing], page 26) objects:

quantity:
`<` *quantity-dof* `>` `{` `<` *quantity-operator* `>` *quantity-id* `}`

with

quantity-id:
string

and

quantity-dof:

`Dof` Defines a vector of discrete quantities (vector of `D`egrees `o`f `f`reedom), 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.

`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.

`dInv` d^(-1): applied to a p-form, gives a (p-1)-form.

`GradInv` Inverse grad: applied to a gradient field, gives a scalar.

`CurlInv`
`RotInv` Inverse curl: applied to a curl field, gives a vector.

`DivInv` Inverse div: applied to a divergence field.

Note:

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.

3 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 1.2 [Syntactic rules], page 6). Please refer to Chapter 4 [Types for objects], page 29, for this.

3.1 `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 8.1 [Input file format], page 85, 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 2.2 [Constants], page 9.

The syntax for the definition of groups is:

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

with

group-id:
  string

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 | OnOneSideOf | 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 8.1 [Input file format], page 85). Ranges of integers can be specified in the same way as ranges of constant expressions in an *expression-cst-list-item* (see Section 2.2 [Constants], page 9). 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. Multidefinition: *group-id*`{#`*n*`} =` *group-def* defines the groups *group-id*`{`*i*`}`, *i*=1, . . . , *n*, by replacing for each *i* any *group-id*`{}` in *group-def* with *group-id*`{`*i*`}`.
4. `#`*group-list* is an abbreviation of `Region[`*group-list*`]`.

See Section 4.1 [Types for Group], page 29, for the complete list of options and Section 5.2 [Group examples], page 47, for some examples.

3.2 `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 > ] = expression; > ...
```

```
}
```

with

function-id:
  string

Note:

1. The optional *group-def* in brackets must be of `Region` type, and indicates on which region the (piecewise) function is defined. 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.

See Section 4.2 [Types for Function], page 30, for the complete list of built-in functions and Section 5.3 [Function examples], page 47, for some examples.

3.3 `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 {
  { Name constraint-id <{#integer}>; Type constraint-type;
    Case {
      { Region group-def; < Type constraint-type; >
        < SubRegion group-def; > < TimeFunction expression; >
        constraint-val; } ...
    }
  | Case constraint-case-id {
      { Region group-def; < Type constraint-type; >
        constraint-case-val; } ...
    } ...
  } ...
}
```

with

constraint-id:
constraint-case-id:
  string

constraint-type:
  `Assign | Init | Network |` *etc*

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

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

Notes:

1. Multidefinition: `Name` *constraint-id*`{#`*n*`}` defines the constraints *constraint-id*`{`*i*`}`, *i*=1, ..., *n*, replacing for each *i* any *group-id*`{}` in *group-def*s of `Case` fields with *group-id*`{`*i* `}`.
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 4.3 [Types for Constraint], page 35, for the complete list of options and Section 5.4 [Constraint examples], page 49, for some examples.

3.4 `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 5.5 [FunctionSpace examples], page 50).

The syntax for the definition of function spaces is:

```
FunctionSpace {
  { Name function-space-id <{#integer}>;
    Type function-space-type;
    BasisFunction {
     { Name basis-function-id; NameOfCoef coef-id;
       Function basis-function-type
         < { Quantity quantity-id;
             Formulation formulation-id {#integer};
             Group group-def; Resolution resolution-id {} } >;
       Support group-def; Entity group-def; } ...
    }
```

```
    < SubSpace {
       { 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 group-type; < EntitySubType group-sub-type; >
         NameOfConstraint constraint-id <{}>; } ...
      } >
    } ...
  }
```

with

function-space-id:
basis-function-id:
coef-id:
sub-space-id:
global-quantity-id:
formulation-id:
resolution-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. Multidefinition: `Name` *function-space-id*`{#`*n*`}` defines the function spaces *function-space-id*`{`*i*`}`, *i*=1, ..., *n*, replacing for each *i* any `{}` in *group-def*s of `BasisFunction` field and in *constraint-id*`{}` of `Constraint` field with `{`*i*`}`.
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. Piecewise defined basis functions: the same `Name` for several `BasisFunction` fields permits to define piecewise basis functions; separate `NameOfCoef`s must be defined for those fields.
4. Constraint: a constraint is associated with geometrical entities defined by an automatically created `Group` of type *group-type*, 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. Function: 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.

See Section 4.4 [Types for FunctionSpace], page 35, for the complete list of options and Section 5.5 [FunctionSpace examples], page 50, for some examples.

3.5 `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 {
  { 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 default case of a `Jacobian` object is defined by `Region All` and must follow all the other cases.

See Section 4.5 [Types for Jacobian], page 37, for the complete list of options and Section 5.6 [Jacobian examples], page 54, for some examples.

3.6 `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 {
  { 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*

See Section 4.6 [Types for Integration], page 38, for the complete list of options and Section 5.7 [Integration examples], page 55, for some examples.

3.7 `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 {
  { Name formulation-id <{#integer}>; 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; } > ...
     < GlobalEquation
         { Type Network; NameOfConstraint constraint-id;
           { Node expression; Loop expression; Equation expression;
             In group-def; } ...
         } > ...
    }
  } ...
}
```

with

formulation-id:
  string

formulation-type:
  `FemEquation` | *etc*

local-term-type:
  `Galerkin` | `deRham`

quantity-type:
  `Local` | `Global` | `Integral`

term-op-type:
`Dt | DtDt | JacNL |` *etc*

Note:

1. Multidefinition: `Name` *formulation-id*`{#`*n*`}` defines the formulations *formulation-id*`{`*i*`}`, *i* =1, ..., *n*, replacing for each *i* any `{}` in *function-space-id*`{}` of `Quantity` field and in *group-def*s of `Equation` field with `{`*i*`}`.
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 3.8 [Resolution], page 25).
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.
4. A `GlobalEquation` defines a global equation to be assembled in the matrix of the system.

See Section 4.7 [Types for Formulation], page 39, for the complete list of options and Section 5.8 [Formulation examples], page 55, for some examples.

3.8 `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 {
  { Name resolution-id <{#integer}>;
    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 > } ...
    }
    Operation { < resolution-op; > ... }
  } ...
}
```

with

resolution-id:
system-id:
  string

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

system-type:
  `Real | Complex`

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

Notes:

1. Multidefinition: `Name` *resolution-id*`{#`*n*`}` defines the resolutions *resolution-id*`{`*i*`}`, *i*=1, ..., *n*, replacing for each *i* any `{}` in *formulation-id*`{}` of `System` field with `{`*i*`}`.
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 4.8 [Types for Resolution], page 39).
6. `OriginSystem` permits to specify the systems from which ambiguous quantity definitions can be solved (see Section 3.7 [Formulation], page 23).

See Section 4.8 [Types for Resolution], page 39, for the complete list of options and Section 5.9 [Resolution examples], page 58, for some examples.

3.9 `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 {
  { Name post-processing-id <{#integer}>;
    NameOfFormulation formulation-id <{}>; < NameOfSystem system-id; >
    Quantity {
      { Name post-quantity-id; Value { post-value ... } } ...
    }
```

```
    } ...
  }
```

with

post-processing-id:
post-quantity-id:
  string

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. Multidefinition: `Name` *post-processing-id*`{#`*n*`}` defines the post-processings *post-processing-id*`{`*i*`}`, *i*=1, ..., *n*, replacing for each *i* any `{}` in *formulation-id*`{}` with `{`*i*`}`.
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 3.10 [PostOperation], page 27).
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 4.9 [Types for PostProcessing], page 42, for the complete list of options and Section 5.10 [PostProcessing examples], page 60, for some examples.

3.10 `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 {
  { Name post-operation-id; NameOfPostProcessing post-processing-id;
    < Format post-operation-fmt; >
    Operation { < post-operation-op; > ... }
  } ...
} |
PostOperation post-operation-id UsingPost post-processing-id {
  < post-operation-op; > ...
} ...
```

with

post-operation-id:
  string

post-operation-op:
  `Print[` *post-quantity-term*`,` *print-support* `<,`*print-option*`> ... ] |`
  etc

post-quantity-term:
  post-quantity-id `<[`*group-def*`]> |`
  post-quantity-id post-quantity-op post-quantity-id`[`*group-def*`] |`
  post-quantity-id`[`*group-def*`] post-quantity-op post-quantity-id`

post-quantity-op:
  `+ | - | * | /`

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. Both `PostOperation` syntaxes are equivalent. The first one conforms to the overall interface, but the second one is more concise.
2. 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 4.10 [Types for PostOperation], page 42). The default format is `Gmsh`.
3. 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 3.9 [PostProcessing], page 26). In this case, the sum of all elementary integrals is performed over the region *group-def*.
4. The *post-quantity-op* allows the simple combination of space-dependent quantities (*post-quantity-id*) with global integral quantities (*post-quantity-id*`[`*group-def*`]`).

See Section 4.10 [Types for PostOperation], page 42, for the complete list of options and Section 5.11 [PostOperation examples], page 61, for some examples.

4 Types for objects

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

4.1 Types for `Group`

Types in

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

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

`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*) `>`.

`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*) `>`.

`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*.

4.2 Types for `Function`

4.2.1 Math functions

The following functions are the equivalent of the functions of the C math library, and always return real-valued expressions. These are the only functions allowed in constant expressions (*expression-cst*, see Section 2.2 [Constants], page 9).

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].

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

`Acos` `[`*expression*`]`
: Arc cosine (inverse cosine) of *expression* in [0,Pi], *expression* in [-1,1].

`Tan` `[`*expression*`]`
: Tangent of *expression*.

`Atan` [*expression*]

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

`Atan2` [*expression*,*expression*]

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

`Sinh` [*expression*]

Hyperbolic sine of *expression*.

`Cosh` [*expression*]

Hyperbolic cosine of *expression*.

`Tanh` [*expression*]

Hyperbolic tangent of *expression*.

`Fabs` [*expression*]

Absolute value of *expression*.

`Fmod` [*expression*,*expression*]

Remainder of the division of the first *expression* by the second, with the sign of the first.

4.2.2 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.

`TTrace` [*expression*]

Trace; *expression* must be a tensor.

`F_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[w],Sin[w]]`.

`F_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[w],-Cos[w]]`.

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

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

4.2.3 Green functions

The Green functions are only used in integral quantities (see Section 3.7 [Formulation], page 23). 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`).

4.2.4 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.

`Re` [*expression*]

Takes the real part of a complex-valued expression.

`Im` [*expression*]

Takes the imaginary part of a complex-valued expression.

`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.

`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.

4.2.5 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.

4.2.6 Miscellaneous functions

misc-function-id:

`Printf` [*expression*]
Prints the value of *expression* when evaluated.

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

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

`F_CompElementNum`
[]
Returns 0 if the current element and the current source element are identical.

`InterpolationLinear`
[]{*expression-cst-list*}
Linear interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`dInterpolationLinear`
`[]{`*expression-cst-list*`}`
Derivative of linear interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`InterpolationAkima`
`[]{`*expression-cst-list*`}`
Akima interpolation of points. The number of constant expressions in *expression-cst-list* must be even.

`dInterpolationAkima`
`[]{`*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*.

4.3 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 analysis).

`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. This is not documented yet.

`LinkCplx` To define complex-valued links between degrees of freedom. This is not documented yet either.

4.4 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`, 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.

4.5 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* `>`.

`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* `>`.

4.6 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 8.1 [Input file format], page 85).

4.7 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.

`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.

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

`JacNL` Jacobian term to be assembled in the Jacobian matrix for nonlinear analysis.

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

4.8 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*.

`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 iteration matrices separately for system *system-id*. It is destined to be used with `Update` in order to create more efficiently the actual system to solve (this is only useful in linear transient problems with one single excitation) or with `Lanczos` in order to generate the matrices of a (generalized) eigen value problem.

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

Update the system of equations *system-id* (built from iteration matrices generated separately with `GenerateSeparate`) with *expression*

`InitSolution`
[*system-id*]

Initialize the solution of *system-id* to zero (default) or to the values given in a `Constraint` of `Init` type.

`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. `Lanczos` or `FourierTransform`.

`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 4.3 [Types for Constraint], page 35).

`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 4.3 [Types for Constraint], page 35).

`SetTime` [*expression*]

Change the current time.

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

Change the frequency of system *system-id*.

`SystemCommand`
[*expression-char*]

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

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

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

`If` [*expression*] { *resolution-op* }
`Else` { *resolution-op* }

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

`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.

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

Print the current values of the expressions listed in *expression-list*.

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

Eigen value computation by 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 eigen values/vectors to store, the spectral shift.

`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).

`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.

`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.

4.9 Types for `PostProcessing`

post-value:

`Local` `{` *local-value* `}`

To compute a local quantity.

`Integral` `{` *integral-value* `}`

To integrate the expression over each element.

4.10 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*.

`Depth` *expression-cst*

Recursive division of the elements if *expression-cst* is greater than zero, derefinement 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`

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.

`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.).

post-operation-fmt:

`Gmsh`
`GmshParsed`

Gmsh output. See the documentation of Gmsh (`http://www.geuz.org/gmsh/`) 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.

`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*.

`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.

5 Short examples

5.1 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;
```

5.2 `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`.

5.3 `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 5.8 [Formulation examples], page 55). 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 2.2 [Constants], page 9, as well as Section 2.4 [Functions], page 13). 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 2.2 [Constants], page 9):

```
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 2.7 [Registers], page 14). 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.

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[] = F_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.

5.4 `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 5.3 [Function examples], page 47 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`.

5.5 `FunctionSpace` examples

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

5.5.1 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 5.4 [Constraint examples], page 49) 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.

5.5.2 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]; }
}
...
```

5.5.3 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`.

5.5.4 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 { ... }
  }
}
```

5.5.5 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; }
      ...
    }
  }
}
```

The same gauge could also be defined in the BasisFunction field itself, by limiting the set of entities supporting the unknowns: `Entity EdgesOf[All]` would then be replaced by `Entity EdgesOfTreeIn[Domain, StartingOn Surf]`.

5.5.6 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.

5.5.7 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.

5.6 `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; }
    }
  }
}
```

5.7 `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.

5.8 `Formulation` examples

5.8.1 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.

5.8.2 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; }`.

5.8.3 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).

5.8.4 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*,

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

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; }
    }
  }
}
```

5.8.5 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.

5.9 `Resolution` examples

5.9.1 Static resolution (electrostatic problem)

A static resolution, e.g. for the electrostatic formulation (see Section 5.8 [Formulation examples], page 55), 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`).

5.9.2 Frequency domain resolution (magnetodynamic problem)

A frequency domain resolution, e.g. for the magnetodynamic *h-phi* formulation (see Section 5.8 [Formulation examples], page 55), 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.;
}
```

5.9.3 Time domain resolution (magnetodynamic problem)

A time domain resolution, e.g. for the same magnetodynamic *h-phi* formulation (see Section 5.8 [Formulation examples], page 55), 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 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.

5.9.4 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;
```

```
}
```

5.9.5 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.

5.10 `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 5.8 [Formulation examples], page 55; see Section 5.9 [Resolution examples], page 58), 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.

5.11 `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 5.10 [PostProcessing examples], page 60, 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 4.10 [Types for PostOperation], page 42, 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 ];
     }
  }
}
```

6 Complete examples

6.1 Electrostatic problem

An elementary electrostatic problem is first considered. 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`'), of which the geometry is defined in the file '`mStrip.geo`': see Appendix C [Gmsh examples], page 99. The geometry is two-dimensional; one half of the structure is considered by symmetry.

The structure of the following files points out the separation of the data describing the particular problem and the method used to solve it, and therefore how it is possible to build black boxes adapted to well defined categories of problems. The files are commented (see Section 1.3 [Comments], page 6) 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 ; } }
          }
         }
  }
}
```

6.2 Magnetostatic problem

A magnetostatic problem is considered. 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`'), of which the geometry is defined in file '`Core.geo`' (see Appendix C [Gmsh examples], page 99). The geometry is two-dimensional; one fourth of the structure is considered by symmetry.

The jacobian and integration methods used are the same as for the electrostatic problem presented in Section 6.1 [Electrostatic problem], page 63.

```
/* -------------------------------------------------------------------
   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; }
        }
      }
    }
  }
}
```

6.3 Magnetodynamic problem

A magnetodynamic problem is considered. 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 the previous section). It is applied to a core-inductor system (defined in file '`CoreMassive.pro`'), of which the geometry has already been defined in file '`Core.geo`' (giving file '`Core.msh`' with Gmsh; see Section 8.1 [Input file format], page 85).

The jacobian and integration methods used are defined in the same file as in the electrostatic problem in Section 6.1 [Electrostatic problem], page 63.

```
/* -------------------------------------------------------------------
   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; } } }
    }
  }
}
```

7 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 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 an 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 1.4 [Includes], page 7), 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.

`-ipos` *post-processing-id* ...

[1] If you are looking for a graphical front-end to GetDP, you may consider using Gmsh (available at `http://www.geuz.org/gmsh/`). 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 8.1 [Input file format], page 85, and Section 4.10 [Types for PostOperation], page 42).

Enters an interactive post-processing mode, permetting to manually type `PostOperation`-like commands. These commands are based on the *PostProcessing* object(s) selected by the *post-processing-id*(s). If *post-processing-id* is omitted, the list of available choices is displayed.

`-msh` *filename*

Reads the mesh database (in `.msh` format) from *filename* (see Chapter 8 [File formats], page 85) rather than reading it from the default problem file name (with the '`.msh`' extension appended).

`-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, preprocessing and processing files.

`-restart`

Restarts processing of a transient problem interrupted before being complete.

`-solve` *resolution-id*

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

`-adapt` *file*

Reads adaptation constraints from file.

`-order` *real*

Specifies the maximum interpolation order.

`-bin`

Selects binary format for output files.

`-log`

Saves all processing history in a log file (the input file name with an appended `.log` extension).

`-socket` *string*

Communicates through socket *string*.

`-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.

`-p`
`-progress`
integer

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

`-info`

Displays the version information.

`-version`

Displays the version number.

`-help`

Displays a message listing basic usage and available options.

8 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 3 [Objects], page 17, and Chapter 4 [Types for objects], page 29. The format of the post-processing files is explained in Section 4.10 [Types for PostOperation], page 42.

8.1 Input file format

The native mesh format read by GetDP is the mesh file format produced by Gmsh (`http://www.geuz.org/gmsh/`). The 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).

8.2 Output file format

8.2.1 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.

8.2.2 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 */
getdp-version-number file-res-format
$EndResFormat
$Solution  /* DofData #dofdata-number */
dofdata-number time-value time-step-number
```

solution-value
...
`$EndSolution`
...

Notes:

1. A `$Solution` field contains the solution associated with a `$DofData` field.
2. There is one `$Solution` field for each time step, of which the time is *time-value* (0 for non time dependent analyses).
3. The order of the *solution-value*s in a `$Solution` field follows the numbering of the equations given in the '`.pre`' file (one floating point value for each degree of freedom).

9 Bugs, versions and credits

9.1 Bugs

If you think you have found a bug in GetDP, you can report it by electronic mail to the GetDP mailing list at `getdp@geuz.org`. 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 7 [Running GetDP], page 81 to see how to get this information).

See the '`TODO`' file in the distribution to check the problems we already know about.

9.2 Versions

```
$Id: VERSIONS,v 1.51 2005/02/05 20:38:19 geuzaine Exp $

New since 1.0: Lanczos with GSL+lapack; various small improvements and
bug fixes;

1.0: 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: 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: Updated Gmsh output format; many small bug fixes;

0.85: Upgraded communication interface with Gmsh; New ChangeOfValues
option in PostOperation; Many internal changes;

0.84: 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|K;

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;
```

9.3 Credits

```
$Id: CREDITS,v 1.12 2004/09/30 04:58:18 geuzaine Exp $

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                           and

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Thanks to the following folks who have contributed by providing fresh ideas on theoretical or programming topics, who have sent patches, requests for changes or improvements, or who gave us access to exotic machines for testing GetDP: Olivier Adam <o.adam at ulg.ac.be>, Alejandro Angulo <aacusm at yahoo.com>, Geoffrey Deliege <deliege at mailserv.esat.kuleuven.ac.be>, Mark Evans <evans at gte.net>, Philippe Geuzaine <geuzaine at gnat.colorado.edu>, Eric Godard <godard at montefiore.ulg.ac.be>, Sebastien Guenneau <guenneau at liverpool.ac.uk>, Francois Henrotte <fhenrott at esat.kuleuven.ac.be>, Daniel Kedzierski <kedzierski at uol.com.br>, Samuel Kvasnica <kvasnica at iaee.tuwien.ac.at>, Benoit Meys <bmeys at techspace-aero.be>, Uwe Pahner <uwe.pahner at esat.kuleuven.ac.be>, Georgia Psoni and Robert Struijs <gpsoni at free.fr>, Ahmed Rassili <a.rassili at ulg.ac.be>, Thierry Scordilis <t.scordilis at atral.fr> and Herve Tortel <tortel at loe.u-3mrs.fr>, Jose Geraldo A. Brito Neto <jgabrito at terra.com.br>, Matthias Fenner <m.fenner at gmx.net>.

Appendix A 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 1.4 [Includes], page 7). 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 `BasisFunction`s. 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 B Frequently asked questions

```
$Id: FAQ,v 1.9 2004/03/08 05:38:37 geuzaine Exp $

This is the GetDP FAQ

**********************************************************************

Section 1: The basics

* 1.1 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.

* 1.2 What are the terms and conditions of use?

GetDP is distributed under the terms of the GNU General Public
License. See the file doc/LICENSE for more information, or go to the
GNU foundation's web site at http://www.gnu.org.

* 1.3 What does 'GetDP' mean?

General environment for the treatment of Discrete Problems

* 1.4 Where can I find more information?

<http://www.geuz.org/getdp/> 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@geuz.org>) on this site.

**********************************************************************

Section 2: Installation

* 2.1 Which OSes does GetDP run on?

GetDP is known to run on Windows 95/98/NT/2000/XP, Linux, Mac OS X,
```

Compaq Tru64 Unix (aka OSF1, aka Digital Unix), Sun OS, IBM AIX, SGI IRIX, FreeBSD and HP-UX. It should compile on any Unix-like operating system, provided that you have access to a recent C and Fortran 77 compiler.

* 2.2 What do I need to compile GetDP from the sources?

You need a C and a Fortran 77 compiler (e.g. the GNU compilers gcc and g77) as well as the GSL (version 1.2 or higher; freely available from http://sources.redhat.com/gsl/).

Under Windows, you will need the Cygwin tools and compilers (freely available from http://www.cygwin.com).

* 2.3 How to I compile GetDP?

Just type

./configure; make; make install

If you change some configuration options (type ./configure --help to get the list of all available choices), don't forget to do 'make clean' before rebuilding GetDP.

* 2.4 GetDP [from a binary distribution] complains about missing libraries.

Try 'ldd getdp' (or 'otool -L getdp' on Mac OS 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.

****

Section 3: Usage

* 3.1 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://www.geuz.org/gmsh>). This format being very simple (see the reference GetDP manual for more details), it should be straightforward to write a converter from your mesh format to the 'msh' format.

* 3.2 How can I visualize the results produced by GetDP?

You can specify a format in all post-processing operations. Available

formats include 'Table', 'TimeTable' and 'Gmsh'. 'Table' and 'TimeTable' output lists of numbers easily readable by Excel/gnuplot/Caleida Graph/etc. 'Gmsh' outputs post-processing views directly loadable by Gmsh.

* 3.3 How do I change the linear solver used by GetDP?

Edit the 'solver.par' file in the current working directory. You can also remove the file: GetDP will give you the opportunity to create it dynamically next time you perform a linear system solving.

If you don't like the default linear solvers (based on Yousef Saad's Sparskit 2.0), you can configure and compile GetDP to use PETSc (http://www.mcs.anl.gov/petsc) instead: run ./configure --help for more info.

Appendix C 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://www.geuz.org/gmsh/`.

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 6 [Complete examples], page 63.

```
/* -------------------------------------------------------------------
   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 D License

GNU General Public License

Version 2, June 1991

Preamble

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